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Dennis Wichelns
Editors

Wastewater

Economic Asset in an Urbanizing World

IWMI
International Water Management Institute

CGIAR
RESEARCH PROGRAM ON
Water, Land and Ecosystems

UNITED NATIONS UNIVERSITY
UNU-INWEH
Institute for Water, Environment and Health

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Foreword

Urbanization – coupled with improved living standards, population increase, and economic development – is generating ever greater volumes of wastewater. Once stigmatized as a waste, wastewater is increasingly recognized as a valuable source of water, nutrients, organic matter, and energy. When managed safely, wastewater supports agricultural production and industrial needs in urban and peri-urban areas and contributes to the livelihoods of millions of smallholder farmers in many parts of the world. In addition, wastewater has shown its potential for reclaiming potable water, aquifer recharge, sustainable implementation of aquaculture and agroforestry, and the support of various ecosystem services.

It is clear that achieving universal treatment of waste will take many generations and so alternative, more cost effective solutions are needed in parallel. And yet the scale of planned resource recovery from wastewater is currently quite limited, especially in low- and middle-income countries. The public sector and the emerging private sector, which could play important roles in resource recovery, often struggle with operational challenges, inadequate regulatory frameworks, and often the lack of capacity to develop or evaluate business plans pertaining to resource recovery and reuse.

Based on the most up to date information and data, this book showcases wastewater from on-site sanitation as well as sewered systems as an asset that can be valued financially and economically. By changing the paradigm of 'treatment for disposal' to 'treatment for reuse' a variety of value propositions for water, nutrient and energy recovery can support cost savings, cost recovery, or even profit generation, contingent upon management of possible health and environmental risks.

The book editors and chapter authors have undertaken a challenging and exciting task of providing insights into the economics of wastewater use and 'business thinking' in a sector that traditionally relies on public funding. We believe that with continued applied research and technological advances, effective policy messages, private sector involvement, and successful business development, the prospects of achieving national and international sanitation and water reuse targets can be greatly enhanced for the benefit of millions of households. This book offers a pertinent and credible analysis of the challenges and opportunities in transforming wastewater into an economic asset and turning urbanization from a challenge into an opportunity.

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About the Editors

Pay Drechsel is a trained environmental scientist working since 20 years in the domain of applied natural resources management in developing countries. Pay has worked extensively on biophysical, social and economic aspects of safe wastewater use and the recovery of nutrients from solid and liquid waste for urban and peri-urban farming systems. After several years with the International Board for Soil Research and Management, Pay joined in 2001 the International Water Management Institute (IWMI) where he is currently leading the global Theme on 'Resource Recovery, Water Quality and Health'. Under the IWMI-led CGIAR Research Program on Water, Land and Ecosystems, Pay is coordinating the flagship program on 'Recovering and Reusing Resources in Urbanizing Ecosystems'. Pay has worked extensively in West and East Africa, but also South and South-East Asia and is based at IWMI HQ in Sri Lanka.

Manzoor Qadir is water and soil management scientist with focus on water recycling and safe and productive use of wastewater, water quality and environmental health, and amelioration of salt-induced land degradation. Manzoor has implemented multidisciplinary projects and directed research teams in Central and West Asia and North Africa. Before joining the United Nations University Institute for Water, Environment and Health (UNU-INWEH) in Canada in 2012, Manzoor previously held professional positions as Senior Scientist jointly appointed by the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Water Management Institute (IWMI); Visiting Professor at the Justus-Liebig University, Giessen, Germany; and Associate Professor at the University of Agriculture, Faisalabad, Pakistan. He is a fellow of the Alexander-von-Humboldt Foundation and serves on the Editorial Boards of several international journals.

Dennis Wichelns is an agricultural and natural resource economist, with particular interests in water, irrigation, food security, and livelihoods. Dennis has served as a lecturer and researcher for many years, including a 3-year assignment with the International Water Management Institute (IWMI) in Sri Lanka, from where he interacted regularly with colleagues and research partners across Asia and Africa. In the United States, Dennis has served as an economist with the California Water

Institute and also with the Rivers Institute at Hanover College. Dennis serves currently as one of the editors of Agricultural Water Management and as chief editor of Water Resources & Rural Development.

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Part I

Introduction and Background

Chapter 1
Wastewater: Economic Asset in an Urbanizing World

Dennis Wichelns, Pay Drechsel and Manzoor Qadir

> *Wastewater is only wastewater when we choose to waste it*
> *(Michael J. Wilson)*

Abstract The challenge of providing food, water, and nutritional security for households and communities in 2050 will be greater than the challenge today. The increasing demands, especially from urban areas, will place significant pressure on land, water, and energy resources. While water recycling and reuse offer the opportunity to augment water resources, there are other valuable resources that can be recovered, as well. Innovative technologies are available that can transform wastewater and bio-solids into energy, fertilizer and other useful materials. With additional investment in resource recovery and reuse, the potential for achieving cost recovery in the sanitation sector increases. A key step is to introduce 'business thinking' and private sector investments in a sector that traditionally relies on public funding. With continued applied research, effective policies, supportive institutional capacities, private sector involvement, and successful business development and advocacy, the prospects of transforming wastewater from an environmental burden into a safe economic asset are quite promising.

Keywords Wastewater business · Costs and benefits · Water recycling and reuse · Energy · Nutrients · Resource recovery · Value proposition · Urbanization

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1.1 Introduction

The 2013 Global Monitoring Report highlights the unique opportunity that urbanization offers to governments striving to accelerate progress toward achieving their development goals. Rural-urban linkages, in particular, offer notable potential for eradicating poverty, opening new markets, and promoting investments in pro-poor services (World Bank 2013). This message applies also to the global challenges of improving access to clean water and sanitation, and reusing wastewater across the rural-urban corridor. Lazarova et al. (2013) illustrate the water reuse potential in the IWA benchmark publication, “Milestones in Water Reuse: The Best Success Stories.” The authors show that planning for water reuse is gaining significant momentum in discussions of sustainable water resources management, green economies, and urban planning. Increasingly, wastewater use is seen as an essential component of local and national efforts to adapt to climate change, enhance food security, extend potable water supply, and optimize industrial and recreational water use.

Global Water Intelligence is projecting a 271 % increase in the planned reuse of treated municipal wastewater, from about 7 km^3 per year in 2011 to 26 km^3 per year in 2030 (GWI 2014). At present, agriculture accounts for about one-third of the global use of tertiary treated wastewater. This number does not reflect the significantly larger share of untreated or partially treated wastewater, which is supporting irrigated crop production, especially in low- and middle-income countries, where treatment levels are less advanced and overall treatment capacities are not keeping pace with population growth and urbanization (Raschid-Sally and Jayakody 2008). Wastewater irrigation occurs here on an estimated 6–20 million ha around 3 out of 4 cities in the developing world (Fig. 1.1), with the largest, mostly unplanned shares in China and India. Much of that use is indirect, as farmers divert water from streams carrying a commingled blend of untreated wastewater and fresh water.

Wastewater use is gaining momentum for several reasons (GWI 2010; Jimenez et al. 2010):

1. Water scarcity is moving up on the global political agenda, including the Sustainable Development Goals (SDG). Increasing demands for water, due to economic and population growth are placing substantial pressure on the fixed global supply.
2. Environmental concerns are gaining prominence. Historically, the solution to water scarcity was to build a new dam, or transfer water from one basin to another. Both approaches have notable costs and environmental impacts that limit their suitability in the twenty-first century. By comparison, water reuse requires less energy than desalination, and its planned introduction is generally beneficial to the environment, especially if combined with the recovery of non-renewable resources, such as phosphorus.
3. Governments are beginning to realize the ‘double value proposition’ in water reuse. Without reuse, wastewater treatment has an environmental value, but no financial value. Water, nutrient and energy reuse add new value streams to the proposition.

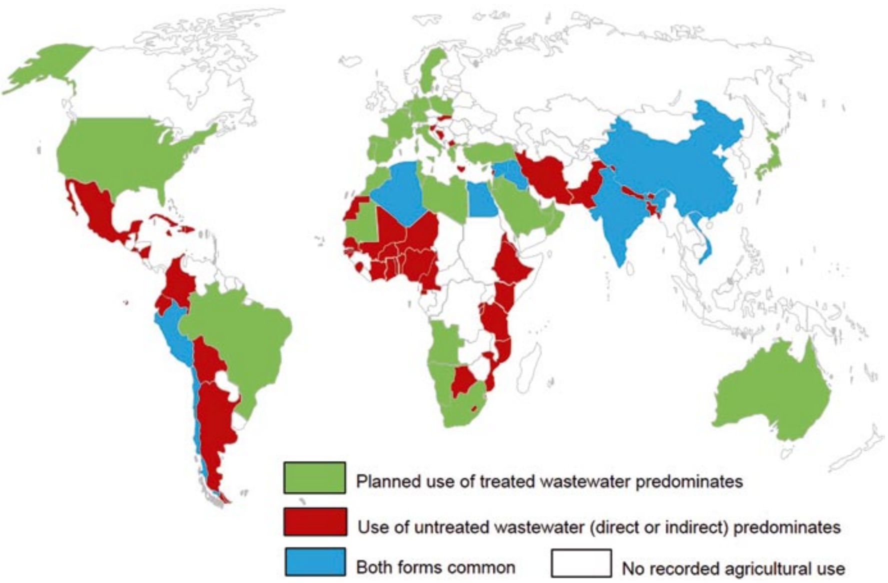

Fig. 1.1 Countries with recorded wastewater use for irrigation. (Source: www.fao.org/nr/water/aquastat/wastewater/index.stm; and IWMI, unpublished)

4. The informal irrigation sector is increasingly recognized as an engine of growth, especially in peri-urban areas of developing countries. The widespread use of unsafe water in these areas has prompted WHO to test on- and off-farm options for safeguarding farmers and public health to support the safe development of this booming sector.

1.2 Changing Demographics and Resource Flows

Although the rate of growth in world population is slowing down, the size of the global population will continue increasing for many decades. Thus, the challenge of providing food and water security for families, households, and communities in 2050 will be greater than the challenge today. By then the global population will likely be in the range of 9–11 billion, as compared with the current 7 billion (UN 2012). Aggregate incomes will be higher in many regions, and the households earning higher incomes will demand more goods and services than their predecessors consume today, especially among the booming urban populations. We expect global demands for meat and vegetables to increase, over time, as households change their consumption patterns, replacing cereals and other staples with more desirable and more nutritious food items (Falkenmark 2012). Feeding future population on more nutritious diets will require much more water use even to supply the same calorie needs.

The increasing demands for food and fiber will place greater pressure on land, water, and energy resources. Universities, research institutes, agricultural companies, and millions of farm families must rise to the challenge of increasing agricultural output, while sustaining and enhancing the natural resources that support agriculture and ecosystems. Advances in agricultural science, innovations in production technology and extraordinary genetic enhancements have enabled farmers to produce sufficient food globally throughout the nineteenth and twentieth centuries. With the notable exception of sub-Saharan Africa, food supply has increased faster than population, such that food availability per person has risen, over time. To maintain and build on this success in future, we must increase food production, improve distribution, and ensure access and affordability for the poor. And we must serve an additional 2–3 billion persons, most of whom will reside in urban areas.

Between now and 2030, the sourcing of water for human needs is expected to change, as the pressure on natural freshwater resources becomes more intense. This pressure is likely to come primarily from agriculture, as increasing demands for higher protein diets and biofuels will require a significant increase in agricultural output, which can only be met through greater water use. This might lead to greater impairment of groundwater resources and over-exploitation of surface water, including a 66 % increase in non-renewable groundwater withdrawals which is likely to affect millions of people by 2030, and billions by the end of the century (GWI 2014). Under these circumstances, there will be limited alternatives to maintaining the balance between water supply and demand. Water reuse, including indirect potable reuse and desalination, will gain prominence, as public agencies seek economically and socially acceptable solutions to water demand and supply imbalances. Matching waters of different qualities with appropriate uses, and implementing helpful reuse incentives, will become an essential component of public agency activities.

The common call to "produce more food with less water," or to obtain "more crop per drop" might sound compelling in this context, but opportunities actually are limited. Water demand is projected to increase by 55 % globally between 2000 and 2050 (OECD 2012), and if we are to produce more food in 2050 than today, crops must transpire more water. The relationship between transpiration and biomass production is mostly linear, such that an increase in crop production requires a proportionate increase in the amount of water consumed by plants. The linear relationship can be shifted with improvements in crop breeding, and such gains certainly have been realized in the past. Yet it seems sensible to plan for larger volumes of transpiration in future, while not taking for granted the prospect of continuous improvements in genetic performance.

Many fast-growing cities face substantial, practical challenges in developing water resources or infrastructure to meet their citizens' needs, and many are consequently sourcing water from distant sources which implies significant pumping costs. Across India, to give an example, urban water sources are as far as 300 km away from the cities or can only be found in a depth of 1000 m (Anon 2011).

Increasing water demands are placing substantial pressure on urban and peri-urban areas, leading to increasing calls for water reuse and inter-sectoral water transfers (Falkenmark 2012), as described, for example in the case of water-wastewater swaps in Spain and Mexico (Winpenny et al. 2010).

Inter-sectoral transfers might look first at agriculture which accounts in many countries for about 70 % of water withdrawals, while industry requires 20 %, and domestic demand is about 10 %. Thus, moving water away from agriculture to uses with higher economic value is widely seen as desirable, especially in view of commonly reported inefficiencies in agricultural water use. In return, cities can offer farmers treated wastewater.

However, Molle and Berkoff (2006) argue that urban growth generally is not constrained by competition with agriculture. In general, rather than using a narrow financial criterion, cities select options that reflect a "path of least resistance," whereby economic, social and political costs are considered together. The authors conclude that the popular perspective that reallocating a small portion of irrigation water to cities would satisfy increasing urban demands is deceptive. In their view, both the arithmetic and the causality are potentially misleading. Much of the water used by irrigation might be diverted at times and places where there is no alternative use, and a large part of the wastewater return flow is already used downstream (Molle and Berkoff 2006).

Given the strong agricultural demand for water, one might still argue that agriculture should be given priority in water reuse strategies. However, the trend in the water reuse industry is toward uses with higher economic value, rather than serving agricultural customers (GWI 2010). GWI also expresses the concern that free or heavily-subsidized 'reclaimed' water will only supplement, rather than substitute, for the water farmers draw from nature.

1.3 Recovering Costs

While the economic analysis of environmental and social benefits will help to decide whether or not wastewater treatment should be carried out, the financial analysis will determine if the project could be financed and how. Reuse offers a variety of means to support financial cost recovery, although the options related to agricultural reuse alone are often limited. There are plenty types of resources that can be recovered such as energy, metals, nutrients, and valuable organics, and some revolutionary technologies have appeared that can transform wastewater or bio-solids into energy and useful materials. Figure 1.2 shows the variety of selected value propositions and options for cost recovery from wastewater treatment to reuse which center around the recovery of water, nutrients and energy which are the thrust of this book.

In many areas, reclaimed water must be priced attractively, relative to potable water, to gain public acceptance. In such cases, motivating reuse takes precedence

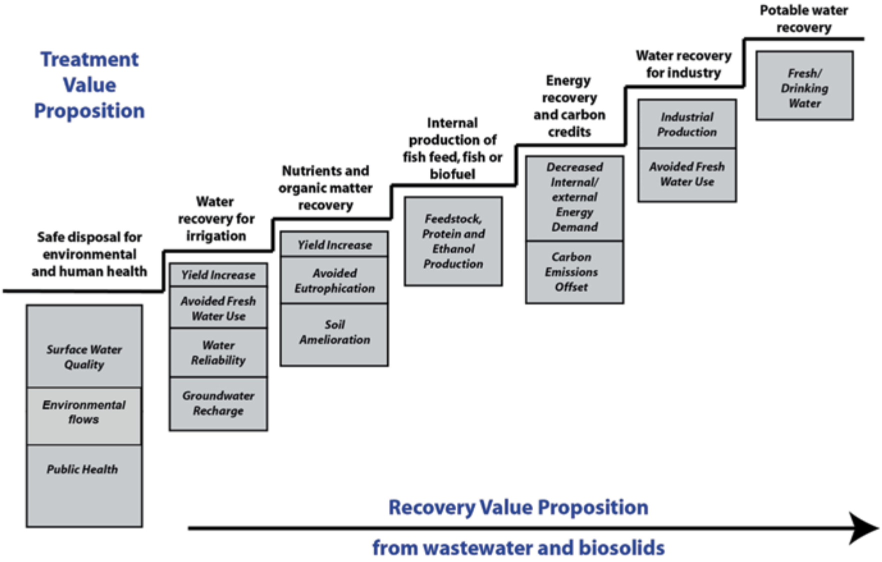

Fig. 1.2 Ladder of increasing value propositions related to wastewater treatment based on increasing investments and cost recovery potential. (Source: IWMI)

over cost recovery, as the rationale for water pricing (Mantovani et al. 2001). A survey of 26 public utilities in the United States found that 29 % recover 100 % of their annual operating costs via sales revenue from reclaimed water. About 43 % of respondents cover less than 25 % of their operating costs, with the remaining respondents covering more than half of their costs. In another survey conducted by the Water Environmental Research Foundation which includes a more diverse sample, only 12 out of 79 projects set reclaimed water rates aimed at full cost recovery (GWI 2010). In a report of the Tunisian Ministry of Agriculture, cost recovery rates from different areas irrigated with treated wastewater range between 13 and 76 % of operational expenses for agricultural supply component (Chenini et al. 2003). In many cases, like this, sales revenues from reclaimed water are not sufficient to cover any substantial amount of the operational and maintenance costs of the water treatment facility itself.

The finance of wastewater recovery and use becomes more favorable when treatment costs are low and the value proposition goes beyond recovering water from wastewater and includes for example the recovery of nutrients and energy (see below). In such cases, the likelihood of recovering both the fixed and variable costs of wastewater use, and parts of the operational and maintenance costs of the treatment process is improved. Technology choice is important, particularly in developing countries. Wastewater use, especially in agriculture, can be supported by relatively simple treatment processes of proven technology, with low investment costs and affordable operation and maintenance. Such processes are particularly suited to countries with warm climates, as biological processes perform better at higher temperatures. The investment costs for such simple or 'appropriate' treatment facilities are in the range of 20–50 % of conventional treatment plants, and more importantly, the operation and maintenance costs are in the range of 5–25 % of conventional activated sludge treatment plants. These cost differentials are substantial from a financial point of view (Libhaber and Orozco-Jaramillo 2013). Appropriate technology processes include (but are not limited to) the following: Lagoon treatment, upflow anaerobic sludge blanket (UASB) reactors, anaerobic baffled reactors (ABRs), constructed wetlands, or stabilisation reservoirs for wastewater use. Various combinations of these processes can be set up.

In view of the significant variations in costs and cost recovery, Lazarova et al. (2013) call for more attention to economic viability also of the reuse component. Yet even where resource recovery and reuse fail to cover their extra costs, investments in reuse generally compare well vis-à-vis dams and other options to increase water supply. Thus, to maximize the net benefits of water reuse, it is important to examine its social, environmental and financial costs and benefits, including the cost of no action, and to compare results to the next-best alternative, like desalination or water transfer.

Based on the social and environmental benefits of wastewater treatment, it is natural that today about 85 % of water utilities are publicly financed and operated, typically by municipal agencies. During the 1990s, there was strong growth in private-sector participation in the international water sector, but this trend was later reversed, due to heavy losses and public opposition to privatizing water utilities (GWI 2010). Rather than supporting large-scale utility concessions, the focus of private finance has shifted to individual projects, such as desalination plants and wastewater treatment plants, including nutrient recovery. The combination of wastewater use's "double value proposition" and the fact that there is little public opposition to private-sector participation in the wastewater industry suggests this market will evolve rapidly, especially where policies and regulations are strongly supporting reuse, like in Australia, India, and Mexico (GWI 2014).

1.4 From Cost Recovery to a Viable Business

Wastewater use is not only about reclaiming water. As urban areas expand and more food is consumed in cities, an increasing portion of the plant nutrients contained in harvested crops will find their way into the waste products of consumers. Depending on the region and local waste management capacity and treatment levels, many of these nutrients will re-appear in human waste streams, including the waste discharged from households into septic tanks and sewers.

The plant nutrient content of wastewater is viewed by many farmers as a positive feature of wastewater irrigation. Indeed, farmers can benefit from the non-priced supplies of nitrogen, phosphorus, and other nutrients. However, unless farmers can access the effluent directly, it will be difficult for them to estimate the concentration of any nutrient in the wastewater. The concentrations will change with distance from a treatment plant, through dilution in the commingled streams and canals from which most farmers withdraw irrigation water.

The increasingly promoted alternative is to capture the nutrients during the treatment process and to make them available to farmers. However, only an estimated 10–20 % of the wastewater generated globally reaches a treatment facility. The current global capacity to treat wastewater to advanced levels is only 4 % of the volume generated (USEPA 2012). This is much less than the capacity needed to sustainably close the rural-urban nutrient loop, which is even more important where commercial fertilizers are not affordable for smallholder farmers. However, there are strong pull and push factors driving nutrient recovery in the treatment industry. On one hand, there are stricter environmental regulations supporting nutrient recovery from sewage and the re-utilization of sewage sludge. And on the other hand, it is financially today more interesting to go for controlled P recovery than the chemical treatment needed to remove unwanted P precipitation in the treatment plant. Finally, with increasing mining costs of rock-phosphate, P recovery generation becomes more cost competitive. Smart subsidies supporting resource recovery can certainly enhance the viability of reuse businesses, whereas subsidies for industrial fertilizers are often a barrier to break even.

While extensive sewer systems require advanced technology to separate nutrients from sewage or sewage sludge, it is technically and financially easier to transform septage from on-site treatment facilities, such as septic tanks and latrines into an organic or organic-mineral fertilizer, which can be sold at market price. The advantage of fecal sludge from septic tanks is the significantly lower risk of chemical contamination than from biosolids produced in the sewage treatment process (Koné et al. 2010).

With more investments in resource recovery and reuse also the potential of cost recovery increases. The next step on the value proposition ladder, in addition to water, nutrient and organic matter recovery, is energy. Many treatment processes, especially aerobic ones, require substantial energy. Yet, energy can be generated from fecal sludge, thus reducing the net energy cost of treatment. Energy recovery improves the benefit-cost ratio of wastewater use, and provides opportunities to serve local energy markets. Related carbon credits can offer another attractive revenue stream.

Another value proposition is based on the products the recovered water or nutrients will be used for. Where for example, nutrient removal in wastewater treatment ponds is based on aquatic plants, such as duckweed, the pond operator-cum-entrepreneur might use the duckweed as fish feed or to produce biofuel. In these cases, the operator can create even more value to recover the operational costs of the business and also the construction of the treatment ponds as the duckweed examples from Peru and Bangladesh show.

1.5 Economic Asset in an Urbanizing World

The existing literature on water reuse shows a strong bias toward technical publications, and those addressing the topic from a water quality guidelines perspective, or describing public perceptions and health risks. There is an increasing number of publications providing frameworks for evaluating the benefits and costs of water reuse, such as Hussain et al. 2001; Morris et al., 2005; Raucher, 2006; Hernandez et al. 2006; and Winpenny et al. 2010. However, a larger gap exists regarding analysis of the trajectory from cost recovery to business opportunities, taking into account options for water, nutrient and energy recovery in sewered and unsewered systems (e.g. Koné 2010; Murray et al. 2011a, 2011b). There are many promising options, particularly in low income countries of "making wastewater an asset" which could motivate public and private sector to stronger engage in sanitation, and ideally feed revenues from reuse back in the sanitation chain (Otoo et al. 2012). However, reuse is not without institutional challenges. The recovery of different value streams could for example involve a single business model and service provider or involve multiple stakeholders through mutually negotiated agreements. The idea that value created through reuse can help maintaining the sanitation service chain will require clearly agreed on benefit sharing mechanism if different entities are responsible for different parts of the service chain.

Given the extensive and increasing interest in the economics of treated and untreated wastewater use, we have tapped into the Resource Recovery & Reuse flagship program of the IWMI led CGIAR Program on Water, Land and Ecosystems (WLE) to assemble key authors within and outside the program working in the field of wastewater finance, economics and business modeling. We have asked them to provide current assessments of key features regarding reuse in agriculture and for other purposes, with a non-exclusive focus on low and middle income countries. The reader will see that a few chapters reference the same reuse cases, partly because of their well-known illustrative value, but also to show different perspectives and motives for wastewater use, as well as different value propositions where more than water is reclaimed.

This resulting book is structured in five sections:

Part I (Introduction and Background) provides with Chapters 1–2 introduction and a general overview of wastewater and fecal sludge generation, treatment, and use in agriculture across the globe. Chapters 3 and 4 address the health and environmental risks of using insufficiently or untreated wastewater, especially for irrigation in developing countries. These risks must be evaluated when fully assessing the potential costs and benefits of wastewater use. We need to know more about those risks, and also about cost effective methods of reducing the probabilities of harmful outcomes.

Part II (Socio-economics of Wastewater Use) describes in Chapters 5 and 6 the social, cultural and institutional aspects of wastewater use and management, with the goal of promoting a better understanding of the policy environment required to initiate interest in wider uses of wastewater at local, regional, and national scales. Our authors look among others at cultural and gender implication drawing from the literature and from their experience in describing how the initial constraints to wastewater use can be overcome, and how sustainability might be achieved. In Chapter 7, we provide a framework for assessing the finance and economics of water related resource recovery and reuse solutions across scales. The framework covers water reuse, energy recovery, carbon credits, and nutrient capture from wastewater as well as fecal sludge and biosolids.

Part III (Costs and Benefits) examines the challenges in applying a cost-benefits framework in Chapter 8, drawing from empirical case studies of wastewater use in agriculture, while Chapters 9 and 10 look at examples related to aquifer recharge, industrial, environmental, recreational and potable purposes. Taken together, these chapters provide a current and comprehensive overview of the economics of wastewater use, while also offering guidance regarding the prospect for reducing costs and enhancing benefits in future.

Part IV (Thinking Business) is perhaps the most innovative and important section of the book. Several authors summarize in Chapters 11 (water recovery), 12 (energy recovery), and 13 (nutrient recovery) recent examples of resource recovery and reuse value propositions that enhance cost recovery and the prospects of financial sustainability and might help to promote water reuse, not only in high-income but also low- and middle-income countries. As the title of our book suggests, wastewater is an asset that has value in many uses. If we can determine how to monetize that value in ways that enable public and private sectors to achieve higher degrees of cost recovery or to generate profits in the delivery of wastewater services, including options for resource recovery, we might greatly enhance the pace of investments in a 'circular economy' (Ellen MacArthur Foundation 2012). Greater water reuse would also enhance social benefits, provided that the well-known health and environmental risks can be managed appropriately.

Part V (Outlook) concludes the book with Chapter 14 with a brief reflection on the potential of urbanization as a positive force for catalyzing the recovery of water, nutrients and energy from wastewater and a summary of the 'take home messages' and challenges discussed in the various chapters.

Our excitement in presenting these chapters builds largely from the opportunity to support 'business thinking' in a sector traditionally relying on public funding, and the goals of a 'circular economy' to revise the common 'take-make-dispose' paradigm. We believe that with continued applied research, effective policy messages, private sector involvement, and successful business development, the prospects of achieving national and international sanitation and reuse targets will be greatly enhanced for the benefit of millions of households in the sanitation—agriculture interface.

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Chapter 2
Global Wastewater and Sludge Production, Treatment and Use

Javier Mateo-Sagasta, Liqa Raschid-Sally and Anne Thebo

Abstract Cities produce large amounts and very diverse types of waste including wastewater. The quality of these wastes depends on their source, the way in which they are collected and the treatment they receive. The final fate of these wastes is also very diverse. To better understand these systems this chapter provides definitions and reuse typologies and describes common reuse patterns and their driving factors. The chapter also shows that, while the prospects for resource recovery from wastewater and sludge are promising the potential is still largely untapped, except in the informal sector. The resources embedded in the approximately 330 km^3/year of municipal wastewater that are globally generated would be theoretically enough to irrigate and fertilize millions of hectares of crops and to produce biogas to supply energy for millions of households. However, only a tiny proportion of these wastes is currently treated, and the portion which is safely reused is significantly smaller than the existing direct and especially indirect use of untreated wastewater, which are posing significant potential health risks. The chapter ends with a call for standardized data collection and reporting efforts across the formal and informal reuse sectors to provide more reliable and updated information on the wastewater and sludge cycles, essential to develop proper diagnosis and effective policies for the safe and productive use of these resources.

Keywords Global wastewater production · Treatment options · Sludge production · Water reuse patterns

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2.1 Introduction

The worlds' population is increasing and concentrating in urban centres. This trend is particularly intense in developing countries, where an additional 2.1 billion people are expected to be living in cities by 2030 (United Nations 2012). These cities produce billions of tons of waste every year, including sludge and wastewater. The fate of these wastes is very different depending on the local context: they can be collected or not, treated or not and finally used directly, indirectly or end without beneficial use. In literature, data on these waste streams is scarce and scattered and comprehensive reviews and assessments at global level are missing, with only few and partial exceptions. Nevertheless, recent efforts from global organizations such as FAO/IWMI through AQUASTAT, UN-Habitat (2008) and the Global Water Intelligence (GWI 2014) allow to renew these assessments and provide a more updated review.

Municipal wastewater and sludge contain valuable resources such as water, organic matter, energy, and nutrients (e.g. nitrogen and phosphorus) which can be recovered for many and very diverse economic, social and environmental purposes. However, and as a consequence of the deficient global data on these waste flows, the total amount of resources that is recovered for beneficial uses has not been well quantified so far.

This chapter offers a systematic and synthesized review of urban wastewater and sludge flows and provides definitions and key figures to better understand the subsequent chapters of this book. The chapter also tries to look at the dimension of valuable resources embedded in waste streams and the extent to which these resources are so far being recovered for beneficial uses, making wastewater and fecal sludge economic assets. Where data are weak or scarce, the causes of such data gaps are discussed.

2.2 Typology of Reuse and Definitions

Wastewater use can range from the formal use of ultrapure recycled water for advanced industrial purposes to the informal use of untreated and raw wastewater for vegetable production in a peri-urban area. The diversity of cases is as large as the diversity of types of wastewater and sludge, types of reuse and types of users (Box 2.1 and 2.2).

Box 2.1: Types of Wastewater Treatment

Before being treated, sewage usually goes through *pre-treatment* to remove grit, grease and gross solids that could hinder subsequent treatment stages.

Later, *primary treatment* aims to settle and remove suspended solids, both organic and inorganic. The most common primary treatments are primary settlers, septic and imhoff tanks.

In *secondary treatment* soluble biodegradable organics are degraded and removed by bacteria and protozoa through (aerobic or anaerobic) biological processes. Typical secondary treatments include aerated lagoons, activated sludge, trickling filters, oxidation ditches and other extensive processes such as constructed wetlands.

Tertiary treatment aims at effluent polishing before being discharged or reused and can consist the removal of nutrients (mainly nitrogen and phosphorous), toxic compounds, residual suspended matter, or microorganisms (disinfection with chlorine, ozone, ultraviolet radiation or others). Nevertheless this third stage/level is rarely employed in low-income countries. Tertiary treatment process can include membrane filtration (micro-, nano-, ultra- and reverse osmosis), infiltration/percolation, activated carbon, disinfection (chlorination, ozone, UV).

Finally, *water reclamation* refers to the treatment of wastewater to make it suitable for beneficial use with no or minimal risk.

2.2.1 Types of Wastewater, Treatment and Uses

Wastewater can be defined as 'used water discharged from homes, businesses, industry, cities and agriculture' (Asano et al 2007). According to this definition there are as many types of wastewater as water uses (e.g. urban wastewater, industrial wastewater, or agricultural wastewater). Where the wastewater is collected in a municipal piped system (sewerage) it is also called sewage. The term 'wastewater' as used in this book is basically synonymous with urban (or municipal) wastewater which is usually a combination of one or more of the following:

- Domestic effluent consisting of blackwater (from toilets) and greywater (from kitchens and bathing)
- Water from commercial establishments and institutions, including hospitals
- Industrial effluent where present
- Stormwater and other urban runoff

Wastewater can be collected or not, treated or not, and finally used directly or discharged to a water body, and then, be either reused indirectly downstream or support environmental flow (Fig. 2.1).

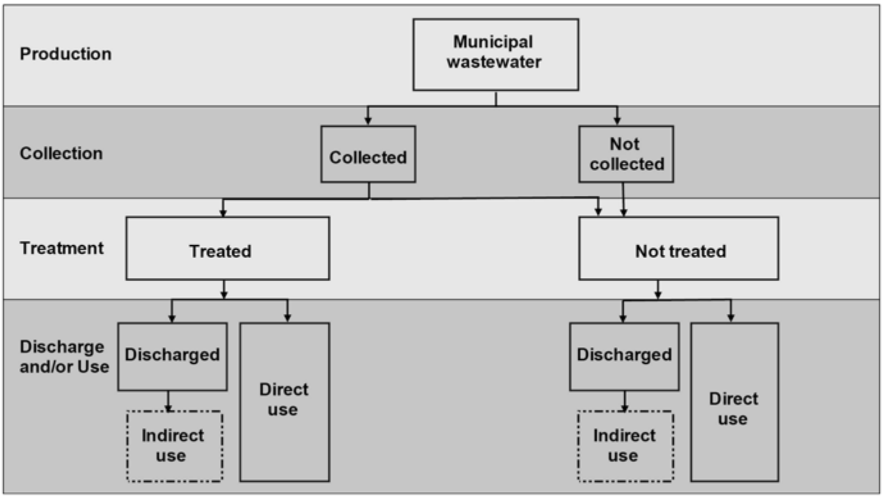

Fig. 2.1 Municipal wastewater chain, from production to use. (Source: Adapted from Mateo-Sagasta and Salian 2012)

Box 2.2: Types and Examples of (Treated or Untreated) Wastewater Usages (GWI 2009):

Agricultural Irrigation: Crop Irrigation, Commercial Nurseries

Landscape Irrigation: Parks, School Yards, Freeway Medians, Golf Course, Cemeteries, Greenbelts, Residential

Industrial Recycling and Reuse: Cooling Water, Boiler Feed, Process Water, Heavy Construction

Groundwater Recharge: Groundwater Replenishment, Saltwater Intrusion Control, Subsidence Control

Recreational/Environmental Uses: Lakes and Ponds, Marsh Enhancement, Stream-Flow Augmentation, Fisheries, Snowmaking

Non-potable Urban Uses: Fire Protection, Air Conditioning, Toilet Flushing

Potable reuse: Blending in Water Supply Reservoirs, Pipe-To-Pipe Water Supply

The direct use of wastewater implies that treated or untreated wastewater is used for different purposes (such as crop production, aquaculture, forestry, industry, gardens, golf courses) with no or little prior dilution. When it is used indirectly, the wastewater is first discharged into a water body where it undergoes dilution prior to use downstream (Fig. 2.2).

Finally reuse can be planned or unplanned. Planned use of wastewater refers to the deliberate and controlled use of raw or treated wastewater for example for

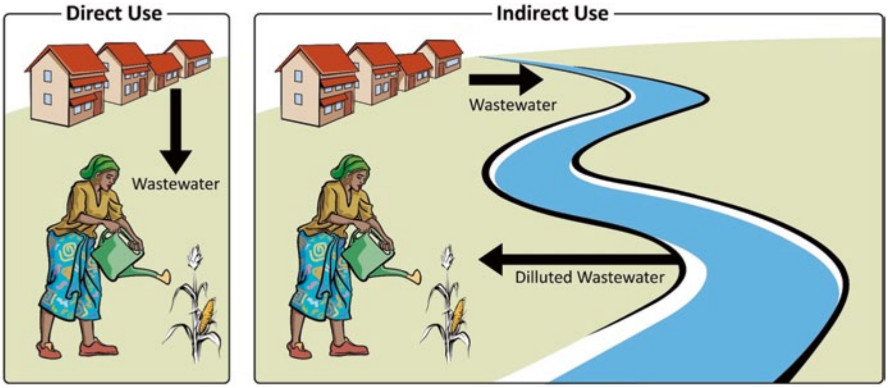

Fig. 2.2 Simplified example of direct and indirect reuse. (Source: Authors)

irrigation. Most indirect use, i.e. after dilution, occurs without planning. Aquifer recharge might be an exception (see also Chap. 9).

2.2.2 Types of Sludge, Treatment and Uses

Excreta which gets collected in a toilet remain either on-site (e.g. in a pit latrine or septic tank) or is transported off-site in sewer systems. When collected on-site, excreta is commonly called fecal sludge which is usually pumped and transported through trucks to fecal sludge treatment ponds or if there are no treatment facilities discharged untreated. The combination of sludge, scum and liquid pumped from septic tanks is called septage, although, many times the terms “septage” and “fecal sludge” are interchangeably used. Sewage treatment plants also produce sludge, called sewage sludge, when suspended solids are removed from the wastewater and when soluble organic substances are converted to bacterial biomass which also become part of the sludge (Fig. 2.3).

The characteristics of sludge depend on the origin and quantity of flushing water (public toilet, private toilet), its collection type (on-site, off-site) and subsequent treatment level, for example digestion (Table 2.1). Fresh and untreated sludge will have many pathogens, a high proportion of water, high biochemical oxygen demand (BOD) and is normally putrid and odorous. Nevertheless, sludge also contains essential nutrients for plants (e.g. nitrogen and phosphorus) and is potentially a very beneficial fertilizer. The organic carbon in the sludge, once stabilized, has also potential as a soil conditioner because it improves soil structure for plant roots, or can be transformed into energy through bio-digestion or incineration. As sewage may receive harmful pollutants (e.g. heavy metals, pharmaceuticals) from industries and other activities which may accumulate in its sludge, the sludge collected from

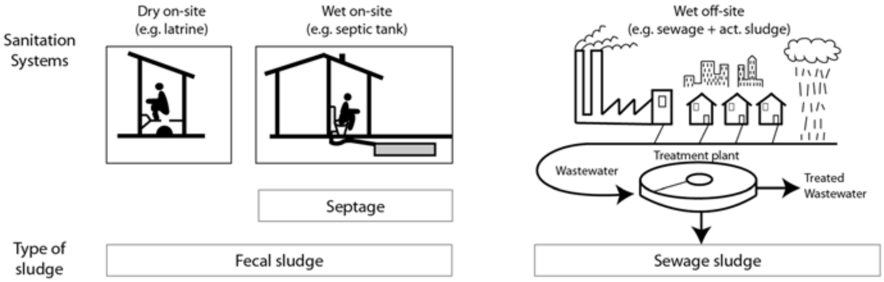

Fig. 2.3 Sludge types. (Source: Authors)

Table 2.1 Typical properties of untreated and digested sewage sludge. (Source: Metcalf and Eddy 2003, modified)

Item (% dry weight)	Untreated primary sludge		Digested primary sludge	
	Range	Typical	Range	Typical
Total dry solids	2–8	5	6–12	10
Volatile solids	60–80	65	30–60	40
N	1.5–4.0	2.5	1.6–6.0	3.0
P_2O_5	0.8–2.8	1.6	1.5–4.0	2.5
K_2O	0–1	0.4	0–3	1
pH	5–8	6	6.5–7.5	7

on-site systems is normally considered safer in view of reuse unless households use their toilets for general waste disposal.

The treatment required will be dependent on the initial characteristics of the sludge and its final use. The main purposes of treatment are to reduce the water content, BOD, pathogens and any bad odors. Options for sludge treatment include thickening, dewatering/drying as well as stabilization/composting (Strauss et al 2003; Koné et al 2010).

Water content in raw sludge is as high as 98 % which makes it unsuitable for composting and makes handling and transport difficult and costly. With sludge thickening in a sedimentation pond water content can be lowered up to 90 %. Dewatering and drying reduce the water content further so that the solid part of the sludge remains about 20 % (UNEP 2001). Dewatering is faster but requires energy to press-filter or centrifuge while drying takes more time (even weeks) but does not require energy as water is lost through evaporation and drainage.

Both aerobic and anaerobic processes can be used for sludge stabilization. Aerobic stabilization is typically done through composting at higher temperatures (55 °C) which imitates an accelerated natural process that takes place on a forest floor where the organic material (leaf litter, animal wastes) is broken down, resulting in an overall reduction of volume, or converted to more stable organic materials. In anaerobic stabilization, bacterial decomposition through anaerobic processes, reduces BOD in organic wastes and produces a mixture of methane and carbon dioxide gas (biogas).

Once properly treated, sewage sludge is called biosolids and if safe can be marketed for beneficial uses e.g. in landscaping. The application of biosolids on land can contribute to the generation of new soil, where there was virtually none, or increase the physical and chemical fertility of existing soils, thus reducing the need for other soil ameliorants (see Chap. 13).

Sludge can also be used for energy recovery, if sufficiently dry directly, through incineration or, indirectly, through anaerobic digestion, pyrolysis or gasification, which produce bio-fuels such as methane-rich biogas, bio-oil and syngas (Kalogo and Monteith 2012). Anaerobic digestion is the cheapest option as there is no energy input needed and the residual 'cake' can still be used as soil ameliorant. However, when sludge has high concentrations of heavy metals or persistent pollutants, anaerobic digestion would not be the best option as the resulting digested sludge would not be suitable for agricultural application. In these circumstances incineration, pyrolysis or gasification may be more suitable. A thorough analysis of options is provided in Chap. 12.

2.2.3 Reuse Types and Patterns

As outlined in Chap. 1, the increasing scarcity of water and fertilizers in many parts of the world is one of the motivations of wastewater use, be it treated or not. The physical, economic, social, regulatory and political environments greatly influence the type of wastewater use that takes place, resulting in very heterogeneous situations (Scheierling et al 2011; Raschid-Sally 2013). Yet, common reuse patterns can be identified for wastewater (Mateo-Sagasta and Burke 2010). Generally, in low income countries, where wastewater collection and treatment has limited coverage, wastewater and sludge tend to be used mostly informally, with no prior treatment, while in high income countries, with high health and environmental awareness, wastewater and sludge are generally treated, and their use is regulated and planned. While this does not look surprising, the magnitude of informal wastewater use which is probably ten times higher than formal reuse (Scott et al 2010) appears remarkable, as well as the limited data on the use of sludge.

Direct use of untreated wastewater occurs in low income settings where alternative water sources are scarce, i.e. usually in drier climates but also in wetter climates in the dry season. The reasons for such use can be lack or low quality of alternative water sources (e.g. groundwater salinity), or the unaffordable costs of accessing freshwater (e.g. costs of pumping). Although officially disapproved in most countries direct use of untreated wastewater takes place in many urban and peri-urban areas of the developing world (Raschid-Sally and Jayakody 2008; WHO 2006). The most common reuse form is in agriculture. For example, untreated wastewater is used on farms located downstream of many cities in Pakistan, because treated wastewater and groundwater are too saline for irrigation (Ensink et al 2002). In the semi-arid climate of the twin city of Hubli–Dharwad in Karnataka, India, farmers irrigate with untreated wastewater from open sewers (locally known as sewage nallas) and underground sewer pipes (Bradford et al 2002) because it is cheaper than using groundwater from boreholes, for which farmers have no capacity to pay. In other cases, such as Cochabamba in Bolivia, or Accra and Tamale in Ghana, farmers use wastewater from malfunctioning treatment plants or sewers, taking advantage of the already collected resource (Huibers et al 2004; Abdul-Ghaniyu et al 2002). In Haroonabad, Pakistan, and Hyderabad, India, wastewater is the only water flowing in irrigation canals in the dry season and at the tail-ends of irrigation schemes (Ensink 2006). In some extreme cases, farmers rupture or plug sewage lines to access the wastewater. This practice has been reported in Nairobi in Kenya, Bhaktapur in the Katmandu Valley in Nepal, and for example Dakar in Senegal (Hide et al 2001; Rutkowski et al 2007; Faruqui et al 2004). At Maili Saba in Kenya, as well as Addis Ababa in Ethiopia, farmers have removed sewage line inspection covers to block the sewer, causing raw sewage to rise up the manholes and flow out over the farm land (Hide et al 2001; own observation).

Indirect use of untreated wastewater is by far the most extensive type of use (Jimenez and Asano 2008; Keraita et al 2008; Scott et al 2010). It occurs in drier and wetter climates, when untreated wastewater is discharged into freshwater streams where it becomes diluted and is subsequently used—mostly unintentionally—by downstream users (e.g. farmers, households or industries). Untreated wastewater discharge occurs more frequently in low and middle income countries with little or no capacity for collecting and treating wastewater effectively. Additionally, the opportunity to sell crops into urban food markets encourages farmers to seek irrigation water in the city vicinity.

Several examples of indirect use of untreated wastewater have been reported in sub-Saharan Africa, Nepal, India, and around many cities in Brazil, Argentina, and Colombia, which lack adequate sanitation facilities (Keraita et al 2008; Jimenez 2008; Raschid-Sally and Jayakody 2008). In West Africa, there is extensive irrigation of vegetables in city vicinity with highly polluted water. Up to 90 % of vegetables consumed in the cities are grown within or near the same urban areas (Drechsel et al 2006).

Planned use of reclaimed water occurs more frequently in high income countries where the main motivation for water reclamation and reuse is water scarcity, although in many countries with no scarcity problems but with high environmental awareness, wastewater is also being reclaimed and used to preserve freshwater ecosystems. Reclaimed water can be used directly for many purposes such as agricultural irrigation, for city landscaping, golf courses, toilet flushing, washing of vehicles, groundwater recharge, and also as a source of potable water supply, like the case of Windhoek in Namibia testifies (Lahnsteiner et al 2013). Within industries wastewater may be purified to industrial standards and recycled within the system. In all of these cases reclaimed water is seen as vital resource, essentially for its “water” value (see also chap. 10). Planed use of reclaimed water is today a common pattern in countries of the Middle East and North Africa, Australia, the Mediterranean, and the United States of America (AQUASTAT 2014; Global Water Intelligence 2010). In all these cases, highly effective sanitation and treatment technology supports water reclamation, while the main challenge for reuse is public acceptability (see Chap. 5).

Informal use of untreated sludge. While sludge can be used on farm if safety precautions are followed, the enforcement of regulations (if they exist) is weak in many low-income countries. Although reuse is usually disapproved in such conditions, it can be a thriving business. As any use of untreated sludge happens in a very informal way, there are however only few data available. Many farmers consider sludge, even untreated, to be a valuable nutrient source similar to farmyard manure and prefer that septic trucks discharge their content onto their farms to use it after drying as fertilizer. This has been reported in West Africa and South Asia (Kvarnström et al 2012; Cofie et al 2005). The delivery of sludge from on-site sanitation facilities via septic trucks to farmers who pay for it is an interesting model of resource recovery if the on-farm treatment is able to reduce the obvious health risks (Keraita et al 2014; see also Chap. 13).

There can also be indirect reuse of sludge, but probably not in a planned way. Fact is that in many cities in developing countries, septage haulers empty waste into sewers, vacant land, landfill sites or water bodies, simply due to the lack of designated treatment facilities. When untreated sludge is discharged to water bodies it becomes diluted and might find its way back into the food chain where the water is used in farming.

Formal use of biosolids in agriculture is strictly regulated in developed countries but can be encouraged like in Michigan's biosolid and septage programs. Reuse is driven by the intention of closing nutrient loops to ensure that nutrients are returned to agricultural land to improve soil fertility while reducing the pressure on final deposal sites. Nevertheless, in many industrialized countries, there is a growing opposition to the use of biosolids in agriculture, due to concerns regarding the potential content of persistent and toxic pollutants such as heavy metals. In these countries energy recovery from sludge, mainly through bio-digestion and incineration, is gaining momentum.

2.3 Wastewater and Sludge Production and Treatment

2.3.1 Wastewater

Information describing current levels of wastewater generation and treatment is globally important for the post—2015 discussion as well as national policy makers, researchers, practitioners, and public institutions, to develop national policy and action plans aiming at wastewater treatment and productive use of wastewater (e.g. in agriculture, aquaculture, and agroforestry systems, or industry). Nevertheless this information is frequently not systematically monitored or not reported in many countries as stressed by Sato et al 2013, with a significant paucity of data on the rural sector.

In 2010, global annual domestic water withdrawals modeled by WaterGAP3 accounted for 390 km^3 (Flörke et al 2013) compared to 477 km^3 estimated time back by Shiklomanov 2000. The WaterGAP model further estimated a global production of wastewater in the domestic and manufacturing sectors of 450 km^3 in 2010, approximately 70% (315 km^3) of which was accounted for by the domestic sector (Flörke et al 2013).

Empirical records compiled from a variety of sources for example by AQUASTAT and Sato et al 2013 suggest that globally more than 330 km^3 year^{-1} of (mostly) municipal wastewater are produced. The countries in Table 2.2 alone, which account for more than 80 % of the global urban population, produce an estimated volume of 261 km^3 of wastewater annually, and this is a conservative figure, as some of the national data appear outdated. Together, China, India, United States, Indonesia, Brazil, Japan and Russia produce more than 167 km^3 of wastewater, which represents half of global municipal wastewater production.

Globally, on average, and according to the data available from AQUASTAT, 60 % of the produced municipal wastewater is treated. Nevertheless, this figure needs to be taken with caution. First, actual treatment figures are likely to be lower, as many wastewater treatment plants, particularly in middle and low income countries are functioning below expectation if at all (Oliviera and von Sperling 2008; Murray and Drechsel 2011) which means that actual treatment capacities are below the installed and usually reported capacity. Secondly, data from some low-income countries with large urban populations, such as Nigeria, are not available and therefore not reported in AQUASTAT. And thirdly, while most countries report only secondary and tertiary treated wastewater as "treated wastewater" some countries also include primary treated wastewater, thus making country data aggregation and comparisons difficult. Relatively well documented is the small global tertiary treatment and advanced reuse capacity, which has been estimated for 2014 as about 24 km^3/year globally (GWI 2009). On the other hand and for obvious reasons, treatment capacity is strongly correlated with the countries' income: in lower-middle-income countries on average 28 % of the generated wastewater is reported to be treated, and in low-income countries, only 8 % is treated, while in high income countries the ratio is closer to 70 % (Sato et al 2013).

The cross-city comparison reported by Raschid-Sally and Jayakody (2008) highlighted the contrast between cities in developed and developing countries. In the latter, the capacity for collection and treatment is notably limited, as is the degree of treatment. Figure 2.4 provides a snapshot of the situation which is representative of much of the developing world and flags in particular that collection does not mean treatment. In fact, many sewers end in natural water bodies, not to speak about dysfunctional treatment plants.

2.3.2 Sludge

With wastewater treatment increasing, many countries are solving one problem, but creating a new challenge: managing or disposing sewage sludge. While, thanks to wastewater treatment, cleaner water is discharged to seas, rivers and lakes, large amounts of sewage sludge are produced in the process (Table 2.3) especially in high and middle income countries with high treatment coverage. This sludge has the added drawback that it tends to accumulate heavy metals and other persistent toxic compounds coming from industrial discharges, traffic related pollution and other commercial activities which is limiting its reuse potential.

Table 2.2 Municipal wastewater production, collection and treatment in countries with the largest urban populations. (Sources: Data from AQUASTAT 2014; GWI 2014)

Country	Municipal wastewater (km^3)			
	Produced	(Year)	Treated	(Year)
United States	60.40	2008	40.89	2008
China	37.98	2010	26.61	2009
Japan	16.93	2011	11.56	2011
India	15.44	2011	4.42	2011
Indonesia	14.28	2012	NA	–
Russian Federation	12.32	2011	NA	–
Brazil	9.73	2009	2.51	2009
Korea, Rep.	7.84	2011	6.58	2011
Mexico	7.46	2011	3.08	2011
Egypt, Arab Rep.	7.08	2012	3.71	2012
Canada	6.61	2009	3.55	2009
Germany	5.30	2007	5.18	2007
Thailand	5.11	2012	1.17	2012
Malaysia	4.22	2009	2.60	2009
United Kingdom	4.09	2011	4.05	2011
Italy	3.93	2007	3.9	2007
France	3.79	2008	3.77	2008
Turkey	3.58	2010	2.72	2010
Iran, Islamic Rep.	3.55	2010	0.89	2012
South Africa	3.54	2009	1.92	2009
Spain	3.18	2004	3.16	2004
Pakistan	3.06	2011	0.55	2011
Venezuela, RB	2.90	1996	NA	–
Argentina	2.46	2010	0.29	2000
Colombia	2.40	2010	0.60	2010
Poland	2.27	2011	1.36	2011
Vietnam	1.97	2012	0.20	2012
Netherlands	1.93	2010	1.88	2010
Australia	1.83	2007	2.00	2013
Saudi Arabia	1.55	2010	1.06	2010
Philippines	1.26	2011	NA	–
Peru	1.00	2011	0.28	2012
Algeria	0.82	2012	0.32	2012
Bangladesh	0.73	2000	NA	–
Iraq	0.58	2012	0.10	2012

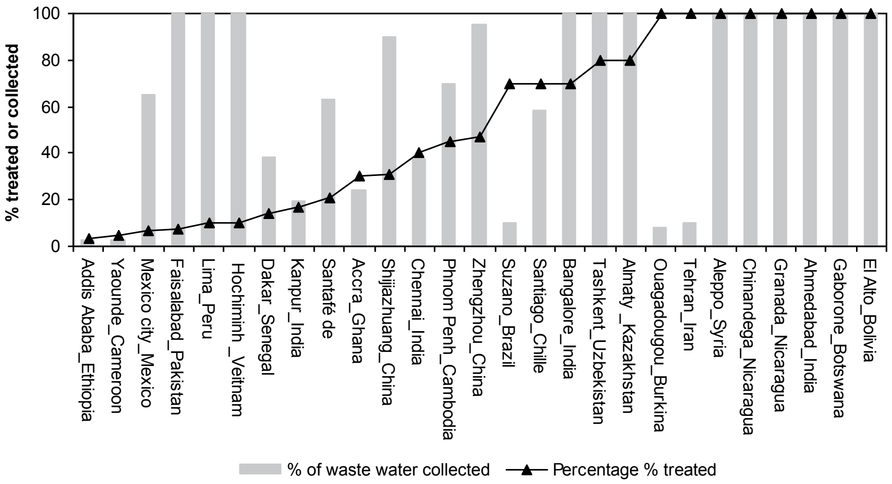

Fig. 2.4 Proportion of waste water collected and proportion of the collected wastewater that is treated. (Source: Raschid-Sally and Jayakody 2008)

Table 2.3 Estimated sewage sludge production in selected countries

Country	Sewage sludge (thousands of dry metric tons)	Year
EU-27[b]	8909	2010
USA[a]	6514	2004
China[a]	2966	2006
Japan[a]	2000	2006
Korea Rep[c]	1900	–
Iran[a]	650	2008
Jordan[a]	300	2008
Turkey[a]	580	2004
Canada[a]	550	2008
Brazil[a]	372	2005
Australia and New Zeland[a]	360	2008
Norway[a]	87	2008

[a] UN-Habitat 2008
[b] EUROSTAT 2014
[c] Asian Development Bank 2012

In low income countries, wastewater and sludge treatment systems, if they exist, are minimal, and therefore sewage sludge from wastewater treatment plants is not a pressing issue. In these countries, the accumulation of fecal sludge in household based onsite systems is the larger challenge as both, collection services and designated treatment sites are seldom developed (USAID 2010; WSP 2014). It is

Table 2.4 Septage collection and treatment in selected countries of South and Southeast Asia. (Source: USAID 2010)

Country	Known population connected to septic tanks (in %)	Known % of septage treated
Indonesia	62 (urban)	4 (national)
Malaysia	27 (national)	100 (national)
Philippines	40 (national) 85 (Metro Manila)	5 (Metro Manila)
Thailand	All except for highly urbanized areas	30 (national)
Vietnam	77 (urban)	< 4 (national)
India	29 (urban)	< 1 (national)
Sri Lanka	89 (national)	< 1 (national)

estimated that billions of residents in urban and peri-urban areas of Africa, Asia, and Latin America are served by onsite sanitation systems (e.g. various types of latrines and septic tanks) while related septage treatment capacity is in many countries nearly inexistent. Table 2.4 provides some examples of septage collection and treatment coverage for South and Southeast Asia.

Until recently, the management of fecal sludge from onsite systems has been largely neglected, partly because they have been viewed as temporary solutions until sewer-based systems will be implemented. Thus many countries lack legislation addressing fecal sludge management and septage haulers have been emptying raw septage into water bodies, vacant land, drains, and landfills. These have become major sources of groundwater and surface water pollution, with significant environmental, public health, and economic impacts (Narain 2012).

However, the perception on the need for onsite or decentralized sanitation technologies for urban areas is gradually changing, and they are increasingly being considered as a long-term, sustainable option in urban areas, especially in low–and middle-income countries that lack sewer infrastructure (WSP 2014). The guidance note on septage management developed by the Indian Government has been an important recent milestone.

Despite the increasing recognition of on-site sanitation, data availability remains a key challenge. There is a lack of data on the location and condition of onsite systems, on the amounts of waste those systems accumulate, and what is most important, about the fate of these wastes after collection, particularly in developing countries.

2.4 Potential for Resource Recovery and Reuse

Both wastewater and sludge contain valuable resources, mainly water, nutrients (nitrogen, phosphorus, potassium, etc.), organic carbon and related energy, which can be recovered for many uses. Water is the most important and abundant asset in wastewater and can be used as a substitute for freshwater if appropriately treated.

Table 2.5 Typical nutrient production (in kg/cap/year) in human excreta (after Drangert 1998)

Nutrient	In urine (500 l/year)	In feces (50 l/year)	Total
Nitrogen (as N)	4.0	0.5	4.5
Phosphorus (as P)	0.4	0.2	0.6
Carbon (as C)[a]	2.9	8.8	11.7

[a] Indicative of the potential for soil conditioning or energy generation

Table 2.6 Typical composition of raw municipal wastewater of different strengths. (Source: Metcalf and Eddy 2003)

Contaminants/resources	Unit	Concentration		
		Weak	Medium	Strong
Nitrogen (total as N)	mg L^{-1}	20	40	85
Phosphorus (total as P)	mg L^{-1}	4	8	15
Total organic carbon (TOC)	mg L^{-1}	80	160	290

Table 2.7 Resources potentially embedded in the globally produced municipal wastewater for different strengths of wastewater. (Source: IWMI)

Strength of wastewater	N (Tg/yr)	P (Tg/yr)	C (Tg/yr)
Weak	6.6	1.3	26.4
Medium	13.2	2.6	52.8
Strong	28.1	5.0	95.7

Note: *Tg* Teragram = 10^9 kg

Nutrients are valuable in agriculture and aquaculture; and organic carbon can be used as a soil conditioner or to generate energy.

Water in municipal wastewater comes from households, from the rainwater that drains our cities and, in less proportion, from industries and commercial activities. Most of the nutrients in wastewater come from human excreta. The excretion of nutrients per capita is highly dependent on diets (e.g. protein consumption) which differ with countries, wealth status and cultures. Table 2.5 provides average values, showing that most nutrients are in urine. In wastewater, phosphorus does not come only from human excreta but also from detergents used in laundry and dish washing, although this share decreased with the introduction of P-free washing powder in countries, like the USA. As a result of these material flows, municipal wastewater concentrates valuable resources (Table 2.6). The concentration of these resources depends very much on the sanitation system, household water use and rainfall entering sewage systems (dilution).

Based on a typical composition of a weak, medium and strong wastewater (Table 2.6) it is possible to estimate ranges of nitrogen, phosphorus and organic carbon potentially contained in municipal wastewater globally. This would be the maximum theoretical amount of resources that could be recovered from wastewater (Table 2.7) disregarding technical and economic limitations. Unlike wastewater, sludge concentrates nutrients and organic matter, which results in a higher efficiency for nutrient and energy extraction (see Chaps. 12 and 13). However, the global resource recovery potential from sludge is hard to assess due to severe data limitations, particularly with respect to fecal sludge production and collection.

The potential energy value from carbon in wastewater could be estimated assuming an anaerobic conversion factor for organic carbon to methane of 0.14 m^3 CH_4 per m^3 of wastewater, at 20°C, (Frinjs et al 2013; Verstraete et al 2009) considering that the caloric value of methane is 35.9 MJ/m^3 CH_4. Therefore, the 330 km^3 of municipal wastewater estimated to be produced globally, assuming a medium strength wastewater, could potentially produce 46.2 km^3CH_4 with a global caloric value of $1660 \cdot 10^9$ MJ, which, if fully recovered, would be enough to provide electricity for about 130 million households, considering an average electricity consumption of 3500 kWh/household (World Energy Council 2013).

The 330 km^3 of municipal wastewater could theoretically irrigate more than 40 million hectares, even if we assume a relatively high application rate of 8000 m^3/ha/yr (FAO 2012). The related ‘free’ fertilizer application would be in the order of 322 kg N/ha/yr and 64 kg P/ha/yr assuming a medium strength wastewater. While such figures might help to raise awareness of wastewater as an asset, they are far from reality for various reasons like the assumption of 100 % system efficiency. On the other hand, these prospective figures only capture the generation of resources in municipal settings, not rural areas.

With increasing population growth, also the global demand for fertilizer is increasing and has reached in 2008/2009 more than 130 million t of N and almost 38 million t of P_2O_5 (16 million t of P) (FAO 2008). Nutrient recovery from wastewater, sludge and other wastes (such as food waste) can regionally and locally help to meet this demand and is particularly interesting in and around cities, close to where these wastes are produced, and where intensive agriculture is expanding in an attempt to feed the increasingly hungry cities. Moreover, for an essential nutrient like phosphorous, its recovery from waste is decreasingly an option but a necessity as it is a non-renewable resource obtained from mining of finite deposits in a few countries (Mihelcic et al 2011).

2.5 Actual Use of Wastewater and Sludge

Despite the apparent opportunities for resource recovery from wastewater and sludge the potential is still untapped and only a small proportion of these wastes is treated and reused in a planned and sustainable manner. The most promising cases and models of safe resource recovery and reuse which achieve cost recovery or even profits are discussed in Chaps. 11–13, while informal agricultural reuse of wastewater (and to smaller extent of sludge) remain popular in many low and middle income countries.

2.5.1 Wastewater

Describing the present use of wastewater, particularly in developing countries, is challenging, due to the lack of reliable and sufficient information. In addition, much of the available information does not use uniform terms and units when describing wastewater use, making it difficult to compare data or establish global inventories. The lack of data is due partly to the informal character of the majority of wastewater irrigation or even, in some cases, to the intention not to disclose data. This may be done because farmers fear difficulties when trading their produce or when governments do not want to acknowledge what could be perceived as a malpractice (Jimenez et al 2010).

Assuming an average farm size of 0.1 ha, an estimated 200 million farmers irrigate with treated and untreated wastewater, on an estimated 20 million ha (Hussain et al 2001; Scott et al 2004; Raschid-Sally and Jayakody 2008). Although these figures have been reported in several publications and scientific presentations, there is no comprehensive study that reveals the basis or verifies the number of farmers using wastewater, the area under wastewater irrigation, or the volumes of wastewater used at the global scale. Based on empirical information from research and country reports, at least 6 million ha are irrigated with wastewater or polluted water (Jimenez et al 2010) with China ranking highest (Scott et al 2010).

AQUASTAT is currently making an attempt to collect, analyze and validate data on direct use of wastewater for irrigation per country. Nevertheless, as illustrated by the data gaps in Table 2.8, which describes countries with the largest urban

Table 2.8 Direct use of wastewater in countries with the largest urban populations (data from the last 15 years). (Source: AQUASTAT 2014; GWI 2014; van der Hoek 2004)

Country	Direct use of treated municipal wastewater			Direct use of untreated wastewater
	All uses (year)	Use in irrigation (year)	Use in irrigation (year)	Use in irrigation (year)
	km^3	km^3	1000 ha	1000 ha
China	3.37 (2010)	0.48 (2008)	N A	N A
India	N A	N A	N A	N A
USA	2.77 (2008)	0.33 (2004)	15 (2004)	N.A
Brazil	0.009 (2008)	0.008 (2008)	N A	N A
Indonesia	N A	N A	N A	N A
Japan	0.19 (2006)	0.012 (2009)	N A	N A
Russian Federation	N A	N A	N A	N A
Mexico	0.68 (2010)	0.40 (2010)	70 (2008)	220 (2000)
Nigeria	N A	N A	N A	N A
Pakistan	N A	N A	N A	33 (2005)

NA not available

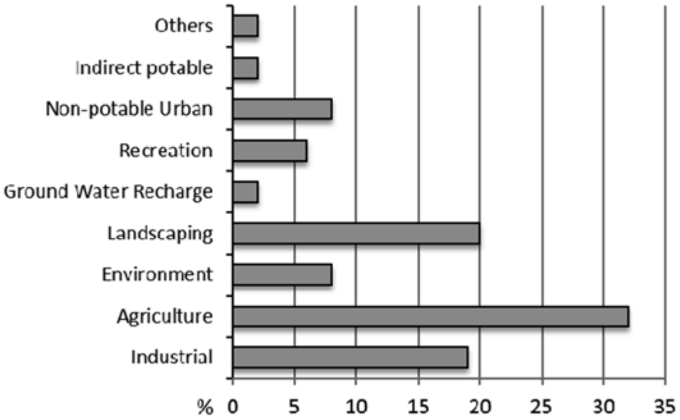

Fig. 2.5 Global water reuse after advanced (usually tertiary) treatment: Market share by application. (Adapted and modified from GWI 2009)

populations, there is still an important lack of information, even of direct use of treated wastewater, which is normally a planned practice and should thus be well documented.

It is interesting to note that agricultural reuse also ranks highest if we compare different reuse options of advanced treated wastewater (Global Water Intelligence 2009) while groundwater recharge and indirect potable reuse are still relatively small uses (Fig. 2.5)

The unplanned use of untreated wastewater is much more extensive than the planned use of treated wastewater (Scott et al 2004; Jimenez et al 2010; Raschid-Sally and Jayakody 2008). Where wastewater treatment does not exist, the direct and indirect use of untreated wastewater for irrigation are common place. Most of the use of untreated wastewater occurs in an informal to semi-formal manner, with little government intervention. Thus, data describing this practice consists primarily of case studies rather than official statistics (Ensink et al 2002; Raschid-Sally and Jayakody 2008; van der Hoek 2004). Given the extent of the direct and indirect use of untreated wastewater, alternative assessment approaches of wastewater generation (e.g. via population densities) and water quality are being explored, using 'earth observations, novel data collection and data integration' (UNEP, WHO, UN-Habitat 2014). An example is an ongoing study in partnership between IWMI and University of California, Berkeley, which is implementing a Remote Sensing and GIS supported spatial model to obtain estimates on the use of polluted water in farming at a global scale. The spatial model identifies areas equipped for irrigation within a certain distance downstream of an urban center in regions with low levels of wastewater treatment. Early results show globally 24 Mha of irrigated croplands located within urban agglomerations and 130 Mha of irrigated croplands within 20 km of urban areas (Thebo et al. 2014).

Refinements of this model will include consideration of irrigation water source, the size of upstream populations, and consideration of differential downstream distances. The results will provide a reasonable upper bound of areas where there is a high probability of the indirect use of wastewater for irrigation. Given the combination of high population densities and large areas equipped for irrigation, India and Eastern China are dominating the global extent of probable areas of indirect use of untreated wastewater both in total area and as a proportion of total irrigated area which corresponds well with empirical data on the use of diluted wastewater or highly polluted water (Thebo et al. 2014).

2.5.2 Sludge

The global extent of sludge use refers mostly to sewage sludge and biosolids, and is only documented in developed countries (UN-Habitat 2008). Many of these countries experienced difficulties in disposing their sewage sludge from treatment plants realizing that the traditional sewage sludge disposal in open waters or landfills is not sustainable. Policies and guidelines were developed which are supporting sludge valorization e.g. by the EU and USEPA (see also Chap. 13). As a result increasing shares of sewage sludge are being processed and used for beneficial purposes, such as land application and energy recovery. Extensive research has examined the possible biochemical impacts of such sludge use for soil amelioration and guidelines on regulating acceptable amounts. Emerging economies are starting to be aware of these challenge as also here policies and regulations are changing (Harper 2013) although so far most of the sewage sludge is still disposed of in landfills. Figure 2.6 illustrates these differences using the cases of Europe, United States and China.

The beneficial uses of sludge vary between countries. In countries where there is a deficit of soil organic matter, agricultural use is most common. For example in Spain almost 100 % of biosolids are valorized in agriculture. In those industrial economies where heavy metals are of concern and soil organic matter content is high, energy generation is the preferred option. For example in the Netherlands almost 100 % of sewage sludge is incinerated (Fig. 2.7).

Globally, the use of treated sewage sludge is still low. In countries such as Brazil, Jordan, Mexico and Turkey the use of biosolids in agriculture is so far modest (<5 %) but growing, while in Japan, the Netherlands, Switzerland, Austria and

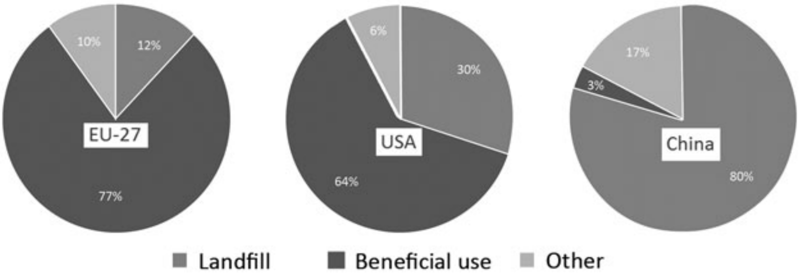

Fig. 2.6 Sewage sludge use and landfill disposal in EU-27, USA and China. (Source: Authors based on Eurostat 2014, UN-Habitat 2008 and Asian Development Bank 2012)

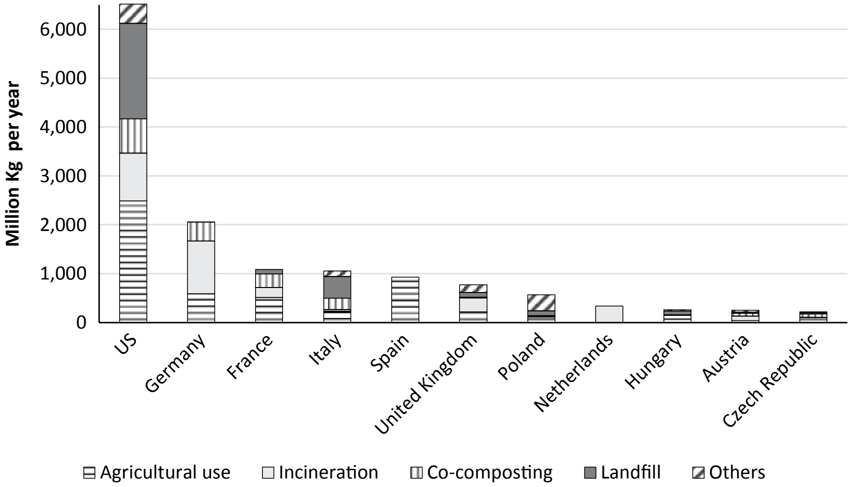

Fig. 2.7 Annual sewage sludge use/disposal in the United States and Europe (selected countries). (Source: Authors based on UN-Habitat 2008; Eurostat 2014)

Germany their use in agriculture is decreasing due to environmental concerns related to pollutants (UN Habitat 2008).

In contrast, in low income countries, where more septage than sewage sludge is produced, disposal remains a priority while formal resource recovery, like through co-composting, is only emerging. Cases of agricultural reuse of biosolids (e.g. Senegal, Uganda) or raw fecal sludge from septic trucks (e.g. Ghana, India) occur in the informal sector with limited information on extent and location of these types of reuse which limits the implementation of required safety measures (see Chap. 13).

Traditional areas of excreta use in rural settings include backyards and home gardens. In Vietnam, fecal sludge after some stabilization, has been applied to fields regularly for centuries. Today an estimated 30,000–40,000 t of well composted human feces are applied annually to vegetable crops (Khoa et al 2005). Cash crop and aquaculture production systems in and around cities also are popular for their ability to utilize significant quantities of fecal sludge and other waste, as reported from Vietnam, the Philippines, China, Nepal, India, Mexico and Peru (Strauss 2000; Midmore and Jansen 2003).

2.6 Conclusions

Although cities produce large amounts of wastewater and sludge the global extent of the production, collection, treatment, use and disposal of these wastes is not well known. Even less known is the proportion of the valuable resources (i.e. water, organic matter, energy, nitrogen and phosphorus) embedded in these waste streams that is recovered and safely reused for beneficial uses, including agriculture.

Few global organizations such FAO/IWMI (AQUASTAT: from wastewater generation to use), UN-Habitat (Sludge management atlas), UNEP (Global water quality assessment), the Water and Sanitation Program (WSP) of the World Bank (IBNET: Water and sanitation utility performance), and Global Water Intelligence (Wastewater treatment and reuse market reports), are trying to systematically collect, select and harmonize the best available data around water quality, wastewater and sludge production, treatment, and/or use. But the task is challenging as much of the available information from the countries does not use uniform terms when describing for example wastewater and its use, thus making it difficult to compare data or establish homogenous global inventories. Furthermore, particularly in developing countries, the systems for data collection along the water—wastewater cycle are not in place and data is not generated. With fecal sludge the situation is worse as septage management is only now gaining attention while data are still scarce and unreliable, and there is no global monitoring system so far.

Data on the use (e.g. in agriculture) of wastewater and sludge are particularly deficient, which makes it difficult to analyze and support the trajectory from unsafe informal to a more safe and formal reuse. In fact, without reliable data the diagnosis of the health and environmental risks associated to the disposal or use of wastewater and sludge, and the potential for resource recovery from these wastes cannot be adequately quantified, nor can the opportunties be modeled across regions, and their possible impact assessed. Therefore, it is advisable to invest in increasing the countries' capacities to generate comparable data on the wastewater and sludge cycles supported by standard definitions and methodologies for data generation. This will help public authorities to design well targeted policies while improving international comparability and global monitoring efforts, which will be crucial to assess progress towards the Sustainable Development Goals (SDGs).

The rough estimates presented in this chapter suggest that wastewater has a significant potential to support those in need of water, nutrients and energy. These resources can be regionally very important, particularly in periurban areas, close to where these wastes are produced, and where food and energy are massively consumed. Despite the opportunities for resource recovery from wastewater and sludge the existing potential of resource recovery and reuse is largely untapped and only a small portion of these wastes is so far used in a planned and safe manner.

Take Home Messages

- Standardized data collection and reporting efforts are needed at national and global level, to provide reliable and updated information on the wastewater and sludge cycles, vital to develop proper diagnosis and monitoring mechanism for effective policies supporting the safe and productive use of these resources.
- The available information suggests that the role of wastewater and sludge as a source of water, energy and nutrients can be regionally and locally

important, particularly near cities, where wastewater and sludge are produced, and where demand for resources is growing.

- The potential for resource recovery from wastewater and sludge is largely untapped and in developing countries only a small portion of these wastes is used in a planned and safe manner, while the majority remains untreated or partially treated, and is more commonly used in the informal (unregulated) than formal irrigation sector.

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Chapter 3
Health Risks and Cost-Effective Health Risk Management in Wastewater Use Systems

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Abstract The increasing extent and diversity of wastewater use, even without appropriate treatment, present public health risks. We describe existing approaches and options to managing health risks in various wastewater uses. Traditionally, regulators have used water quality standards achieved through wastewater treatment for health protection. The chapter presents some of the treatment technologies, including membrane filtration, which is increasing popular and effective in removing pathogens and other pollutants. However, the high investment, operation and maintenance costs of these technologies limit their use in resource constrained settings. In these settings, the use of health-based targets achieved through placing multiple barriers along the food chain is recommended. In this approach, firms, farmers, and public agencies have flexibility to choose from a range of low-cost risk management options which in combination can achieve the health targets. Returns on Investment (ROI) of these interventions are high (US$ 4.9 per US$ invested), if incentive systems and institutional arrangements are in place to support the application and adoption of these risk management measures.

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3.1 Introduction

Wastewater contains pathogens and pollutants, which may pose health risks if not well managed. These pollutants include salts, metals, metalloids, residual drugs, organic compounds, endocrine disruptor compounds, and active residues of personal care products (WHO 2006). The kind and extent of health risks depends on many factors including the treatment level, types and concentrations of contaminants, human exposure, and regional risk relevance. For example, in low-income countries, where access to safe drinking water and improved sanitation remain challenging, risks from pathogens receive most attention. Residents are mostly affected with diarrhoeal diseases and helminthic infections, and high loads of pathogenic microorganisms are common in their wastewater systems (Prüss-Ustün and Corvalan 2006). The situation is different in transitional and high-income economies, where microbiological risks are largely under control. In this context, chemical pollution from the industrial sectors and emerging pollutants such as pharmaceuticals, are of a major concern to public health.

The health risk posed also depends on how the wastewater is used. Asano (2001) considers seven categories of wastewater use. Arranged in order of decreasing extent of wastewater use, these are (i) agricultural irrigation, (ii) landscape irrigation, (iii) groundwater recharge, (iv) industrial use, (v) environmental and recreational uses, (vi) non-potable urban uses, and (vii) indirect or direct potable use. In Europe, Bixio et al. (2006) identify four major wastewater uses (i) agriculture (ii) industry (iii) urban, recreational and environmental uses, including aquifer recharge; and (iv) combinations of the above (mixed uses). In many low and middle income countries, there is limited wastewater treatment and most wastewater is used in agriculture, either directly or indirectly after dilution in surface water bodies (Keraita et al. 2010). An example of the specific health risks associated wastewater irrigation is shown in Table 3.1.

Risk management is an important component of wastewater use. Public health can be protected through three measures: (i) reducing or eliminating concentrations of pathogenic bacteria, parasites, and enteric viruses in wastewater; (ii) controlling chemical constituents in wastewater, and (iii) limiting public exposure (contact, inhalation, or ingestion) to wastewater (EPA 2012). There exist a number of risk management approaches. Commonly used is the water quality approach which associates water quality levels with different degrees of health risks, implying wastewater has to be treated to meet particular water quality criteria to avoid the corresponding risks (WHO 1989; EPA 2012). In recent revisions of the WHO

Table 3.1. Simplified presentation of the main human health risks from wastewater irrigation. (Modified from Abaidoo et al. 2010)

Type of risk	Health risk	Who is at risk	Exposure pathway
Occupational risks (contact)	Parasitic worms such as *A. lumbricoides* and hookworm infections Bacterial and viral infections Skin irritations caused by infectious and non-infectious agents—itching and blister on the hands and feet Nail problems such as koilonychias (spoon-formed nails)	Farmers/field workers Marketers of wastewater-grown produce	Contact with irrigation water and contaminated soils Contact with irrigation water and contaminated soils Contact with contaminated soils during harvesting Exposure through washing vegetables in wastewater
Consumption-related risks (eating)	Mainly bacterial and viral infections such as cholera, typhoid, ETEC, Hepatitis A, viral enteritis which mainly cause diarrhoeas Parasitic worms such as ascaris	Vegetable consumers	Eating contaminated vegetables, especially those eaten raw
Environmental risks	Similar risks as those exposed to occupational and consumption risks, but decreasing with distance from farm	Children playing in wastewater-irrigated fields People walking on or nearby fields	Soil particle intake Aerosols

guidelines, the Stockholm Framework, which uses health-based targets, has been used (WHO 2006). It encourages countries to take into consideration their social, cultural, economic and environmental circumstances, so as to develop and implement the locally most sustainable and cost-effective risk management interventions (Bos et al. 2010). Even in the water quality based approach, there is increasing understanding that the level of treatment must fit the purpose of reuse (Murray and Buckley 2010; NRC 2012). It is therefore important to assess the cost-effectiveness of risk management options, including treatment, to support decision making on the choice of options and resource allocation priorities, especially in low-income settings with constrained public budgets (WHO 2003).

3.2 Water Quality Guidelines Vary with Wastewater Use

To protect public health without unnecessarily discouraging wastewater use, regulatory approaches stipulate water quality standards (Asano 2001). However, there are no universal water quality guidelines for wastewater use. The US-EPA Guidelines provide the most comprehensive water quality guidelines (Table 3.2). In the European Union, substantial pan-European guidelines for wastewater recycling and use have been proposed for selected applications, but no action has yet been taken (AQUAREC 2006; Bixio and Wintgens 2006).

The WHO guidelines, which focus on pathogenic contamination, have been adopted in many in low-income countries (Keraita et al. 2010). The 1989 edition of the WHO Guidelines relied primarily on water quality thresholds; i.e., critical pathogen levels in the irrigation water. The Guidelines provide specific recommendations on treating wastewater to achieve these quality standards (Havelaar et al. 2001). For example, the WHO 1989 Guidelines recommend fecal coliform levels of ≤ 1000 per 100 ml and ≤ 1 nematode egg per litre for unrestricted irrigation. However, the 2006 revision of the Guidelines adopts a different approach, which moves the control point from the water to a health-based target of a tolerable additional disease burden of $\leq 10^{-6}$ DALYs per person per year (see text box 3.1 for explanation on DALYs). The Guidelines translate the health based target into a performance target of 6–7 log units of pathogen reduction at the point of exposure, however and wherever it can be achieved, between wastewater treatment and food intake. A lower health based target of $\leq 10^{-4}$ or $\leq 10^{-5}$ DALYs per person per year might be appropriate as suggested by Mara et al. (2010).

Box 3.1: Disability-Adjusted Life Years (DALYs)

DALYs are a measure of population health expressed as burden of disease due to specific diseases or risk factors. DALYs attempt to measure the time lost because of disability or death from a disease compared with a long life free of disability in the absence of the disease. DALYs are calculated by adding the years of life lost to premature death (YLL) to the years lived with a disability (YLD). Years of life lost are calculated from age-specific mortality rates and the standard life expectancies of a given population. YLD are calculated from the number of cases multiplied by the average duration of the disease and a severity factor ranging from 1 (death) to 0 (perfect health) based on the disease (e.g., watery diarrhoea has a severity factor from 0.09 to 0.12 depending on the age group) (Prüss and Havelaar 2001). DALYs are an important tool for comparing health outcomes because they account for not only acute health effects but also for delayed and chronic effects, including morbidity and mortality (Bartram et al. 2001). Thus, when risk is described in DALYs, different health outcomes (e.g., cancer vs giardiasis) can be compared and risk management decisions prioritized. More details and explanations on the relationship between DALYs and log pathogen reduction are in the WHO wastewater Guidelines (WHO 2006).

Table 3.2 Water quality guidelines for wastewater use as used in USA. (Adapted from: Environmental Protection Agency (EPA 2012))

		pH	BOD (mg/l)	Turbidity (NTU)	TSS (mg/l)	Fecal coliform (/100 ml)	Residual Cl_2 (mg/l)
Urban use	*Unrestricted*	6.0–9.0	≤10	≤2	–	No detectable	1
	Restricted	6.0–9.0	≤30	–	30	≤200	1
Agricultural use	*Food crops*	6.0–9.0	≤10	≤2	–	No detectable	1
	Processed food/Non-food crops	6.0–9.0	≤30	–	30	≤200	1
Impoundments	*Unrestricted*	6.0–9.0	≤10	≤2	–	No detectable	1
	Restricted	–	≤30	–	30	≤200	1
Environmental use	*Environmental reuse*	–	≤30	–	30	≤200	1
Industrial use	*Once-through cooling*	–	≤30	–	30	≤200	1
	Recirculating cooling towers	–	≤30	–	30	≤200	1
Groundwater recharge	Non-potable reuse	Site specific and use dependent					
	Indirect potable use—Spreading/injection into potable aquifers/augmentation of surface supply systems	6.5–8.5	Meet drinking water standards	≤2	≤2 TOC of wastewater origin	No detectable	1

3.3 Options for Cost-Effective Risk Management

There are many options for managing risks from wastewater use. The best option in a given setting will vary with the end use application, socio-cultural acceptance, and economic, institutional, biophysical and technological factors (Balkema et al. 2002). Whenever human exposure (via food or direct contact) is more likely, more stringent risk management measures will be required. For example, when wastewater used is for irrigation of non-food crops on a restricted farming site less stringent management measures could be used compared to when wastewater is used for landscape irrigation at a public park or school, while much more stringent measures will be required when wastewater is used to augment potable supplies. Cost efficiencies can be gained by matching levels of risk management to intended uses, while considering likely exposure, rather than applying same risk management levels across board. However, while this sounds fine in theory, it is seldom that all water will be absorbed by the designated reuse. There might be seasonally lower demand (winter, rainy season) or just more effluent available than what crops can transpire. The implication is that the treatment level also has to consider possible unintended uses downstream of any designated reuse. An example of one of the risk management measures, wastewater treatment, is given on Table 3.3.

Table 3.3 Wastewater uses and appropriate treatment levels

	Increasing Levels of Treatment →			
Treatment Level	**Primary**	**Secondary**	**Tertiary – Filtration and Disinfection**	**Advanced**
Processes	Sedimentation	Biological oxidation and disinfection	Chemical coagulation,biological or chemical nutrient removal, media filtration, and disinfection	Activated carbon, reverse osmosis, advanced oxidation processes, soil aquifer treatment, etc.
End Use	No uses recommended	Surface irrigation of orchards and vineyards	Landscape and golf course irrigation	Indirect potable use, including groundwater recharge and surface water reservoir augmentation
		Non-food crop irrigation	Food crop irrigation	
		Restricted landscape impoundments	Vehicle washing	
		Groundwater recharge (for non-potable uses)	Toilet flushing	
		Wetlands, wildlife habitat, stream augmentation	Unrestricted recreational impoundment	
		Industrial cooling processes	Industrial systems	
Acceptance	→ Increasing Acceptable levels of Human Exposure			
Cost	→ Increasing Levels of Cost			

Source: Environmental Protection Agency (EPA, 2012).

Treatment-Based Options for Improving Water Quality Many options exist for reducing microbial and chemical contaminants to achieve wastewater quality goals (NRC 2012; EPA 2012). Removal rates of pathogens and chemicals vary with the degree of treatment and the treatment technology (Table 3.4). The cost of treatment varies substantially with the choice of technology and location. In general, treatment costs increase with treatment levels. However, it is possible to remove microbial and chemical contaminants using land-intensive treatment methods such as waste stabilization ponds that are less costly than capital-intensive options (Scheierling et al. 2010; Libhaber and Orozco-Jaramillo 2013).

Biodegradable organics and pathogens are removed during secondary treatment. Yet more advanced treatment is needed when wastewater is used to augment drinking water supplies or used in the food preparation industry. Tertiary and advanced treatment involves filtration with either media filters (sand, charcoal) or membranes (citations). Recent advances in membrane filtration include the use of microfiltration, ultrafiltration, nanofiltration and reverse osmosis, (van der Bruggen et al. 2003; Jacob et al. 2010; EPA 2005). Reverse osmosis is the most extensively used process in desalination of wastewater for industrial and domestic uses (Al-Sahali and Ettouney 2007). Singapore's NEWater is produced from treated wastewater that is purified further using advanced membrane filtration technologies and ultraviolet (UV) disinfection, making the water ultra-clean and safe to drink (Seah 2012). Though membrane filtration may be cost-effective (US$/m^3) for industrial and potable water use, its high investment and operation costs limit its application potential e.g. in irrigation (Lazarova et al. 1999).

Combined Treatment and Non-treatment Based Options in Agricultural Irrigation Irrigation is one of the most extensively studied uses of wastewater. Several authors have shown that wastewater treatment, coupled with strict implementation of water quality standards should be sufficient to safeguard public health when wastewater is used for irrigation. (Norton-Brandão et al. 2013: WHO 2006; Amoah et al. 2011). However, in many low-income countries, such as those in sub-Saharan Africa where less than 1 % of wastewater is treated, this approach is not feasible in preventing pathogens from entering the food chain or getting in contact with farmers.

The 2006 WHO guidelines propose a multi-barrier approach in which wastewater treatment is just one of several treatment and non-treatment options to protect public health (WHO 2006). The advantage of the multi-barrier perspective is that it goes beyond irrigation water quality and can address e.g. post-harvest contamination concerns, giving particular protection to consumers. Hence, treatment, where possible, is combined with other health protection measures at farmer, trader and consumer levels. Barriers are placed at critical control points along the food chain from production to consumption, aiming to minimise risk and build a cascade of barriers which can be effective even if one fails. For example, barriers can be placed at wastewater generation points, on farms, at markets, and at the consumer level (Fig. 3.1). While this approach appears to be more applicable in low-income countries, where irrigation with untreated wastewater is common, and

Table 3.4 Removal rates (in log units) of microorganisms and chemicals, by wastewater treatment option. (Adapted from multiple sources reviewed and reported by EPA (2012))

		Secondary treatment	Media filtration	Membrene filtration	Aquifer storage	Ozonation	UV disinfection	Advanced oxidation	Chlorination
Indicator microorganisms (log units)	*E. coli (for bacteria)*	1–3	0–1	4–>6	1–5	2–6	2–>6	>6	2–>6
	Clostridium perfringens	0.5–1	0–1	>6	N/A	0–0.5	N/A	N/A	1–2
	Phage (virus)	0.5–2.5	1–4	2–>6	1–4	2–6	3–>6	>6	0–2.5
Pathogenic microorganisms (log units)	Enteric bacteria	1–3	0–1	>6	1–5	2–6	2–>6	>6	2–>6
	Enteric viruses	0.5–1	0.5–3	2–>6	1–4	3–6	1–>6	>6	1–3
	Giardia lamblia	0.5–2.5	1–3	>6	3–4	2–4	3–>6	>6	0.5–1.5
	Cryptosporidium parvum	0.5–1	1.5–2.5	4–>6	1–3.5	1–2	3–>6	>6	0–0.5
	Helminths	0–2	2–3	>6	1.5–>3	N/A	N/A	N/A	0–1
Organic chemicals (% removal)	B(a)p	nd	nd	>80	nd	>80	–	–	>80
	Antibiotics	10–50	<20	50–>95	50–90	>95	20–>80	50–80	>80
	Pharmaceuticals—DZP	nd	<20	50–>95	10–50	50–80	<20	50–80	20–50
	Hormones- steroid	>90	<20	50–>95	>90	>95	>80	>80	>80

UV is ultra-violet

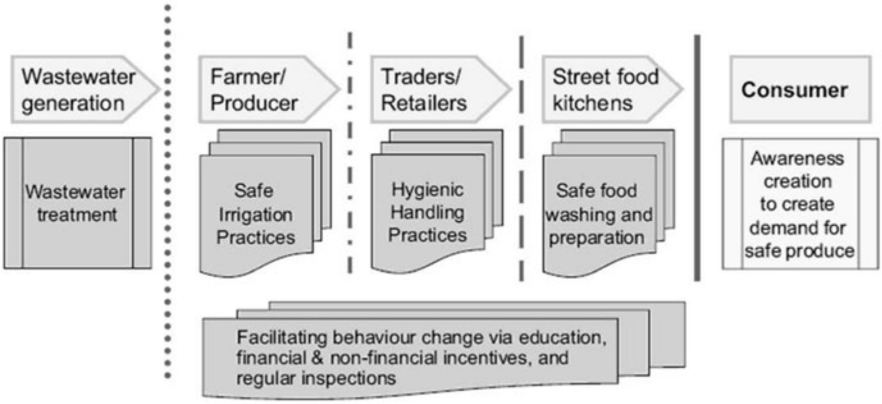

Fig. 3.1 The multi-barrier approach for reducing consumption-related risks along the food chain, as applied in wastewater irrigation. (Source: Amoah et al. 2011)

wastewater treatment is limited, the approach already is institutionalized in most developed countries which have adopted the hazard analysis and critical control points (HACCP) principles (Ilic et al. 2010).

Table 3.5 provides examples of some of the risk management measures and their pathogen reduction potential, based on reviews by the WHO and fieldwork from Ghana (WHO 2006; Amoah et al. 2011). For example, combining a minimal (low-cost) wastewater treatment (1–2 log units pathogen reduction) with drip irrigation (2–4 log units pathogen reduction) and washing vegetables after harvesting (1 log units pathogen reduction) can achieve a 4–7 log unit pathogen reduction. However, some challenges remain, including (i) verification of the cumulative risk reduction (ii) field testing and implementation of the suggested measures (iii) how to monitor, at low cost, the acceptance and effectiveness of combined measures and (iv) how to translate the flexibility of the multi-barrier approach into specific policies as policy makers prefer unambiguous regulations. So far, the concept of health-based targets and performance targets expressed as log reductions remains challenging for policy makers and practitioners in developing countries who are the primary audience of the guidelines. Specialists preparing the next revision of the WHO guidelines will consider expressing the rather complex health based targets in a simpler way and entry points where compliance is easier to monitor.

Cost effectiveness of Combined Options Used in Irrigation Systems in Ghana Drechsel and Seidu (2011) assessed for selected treatment and post-treatment or non-treatment options their cost-effectiveness in terms of the costs of preventing one DALY at the end of the consumer. The interventions included two wastewater treatment options i.e. (i) construction of smaller new wastewater treatment plants (WWTPs with capacity: 6400 m^3/day), (ii) rehabilitation of five currently dysfunctional smaller WWTP, and sets of non-treatment options to be implemented (iii) as farm-based interventions to improve water quality and reduce vegetable contamination, and (iv) as post-harvest interventions focusing on vegetable-washing

Table 3.5 Effectiveness of treatment and non-treatment options in pathogen removal. (Sources: EPHC-NRMMC-AHMC 2006; WHO 2006; Amoah et al. 2011)

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 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 h
(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 surfaces 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	5–6	Option depends on local diet and preference for cooked food

practices in kitchens. For farm and post-harvest based (non-treatment) interventions, a comparison was done for adoption rates of 25, 50, 75 and 100 %. As presented in Table 3.6, the CERs range from US$ 13 to 352/DALY, on average. Based on the Ghana's Gross Domestic Product (GDP) benchmark, all these interventions could be considered cost-effective. However, only a few meet the combined criteria of high DALY aversion, low absolute cost, and high cost-effectiveness.

Drechsel and Seidu (2011) conclude that among the treatment interventions, the rehabilitation of existing treatment plants appears to be both, a low-cost and cost-effective way to avoid most of the wastewater irrigation related DALYs. However, this requires that farmers move to sites with safer (treated) water, which requires well accepted incentives, closure of current sites, and enforced monitoring, which might not be possible in every country and situation. Among the non-treatment options, the most effective and cost-effective low-cost interventions include a combination of on- and off-farm interventions, reaching at least an on- or off-farm adoption rate of 75 %. A higher impact can be achieved if broader adoption is attained. However, it is challenging to identify appropriate incentives for behaviour change (Karg and Drechsel 2011). Finally, combining either WWTP rehabilitation or construction and the non-treatment options would offer farmers and authorities more choices, and probably less risk (multi-barrier approach) against non-compliance on- or off-farm. Such combinations have a high positive impact on averting DALYs, and can still be considered cost-effective, according to the GDP related threshold.

From an investment perspective the high cost-effectiveness of US$ 20–80 per averted DALY through farm-based and postharvest safety options indicate a return of US$ 4.9 per dollar invested, using an economic DALY value for low-income countries according to John and Ross (2010).

In the larger context of safeguarding public health, pathogen exposure through wastewater irrigation is only one of many health threats that household members face. Additional barriers for the prevention of diarrhea should be put in place in other areas of water, sanitation and hygiene. The estimated CERs for interventions related to wastewater irrigation are among the most cost-effective ones (Table 3.7), especially when compared to improved urban water supply and sewerage systems. The CER of treatment plants would be even more attractive if environmental benefits also were considered.

While cost-effectiveness of safeguarding potential consumers of contaminated food is important, given the complexity of outreach to the target group, it is usually easier to protect farmers' health. A factor often overlooked is this context is the absolute cost of risk mitigation. Irrigating farmers who, for example, produce exotic vegetables for urban markets face mostly occupational contact risks, not consumption risks. These risks concern their contact with different types of helminthes, such as hook- and roundworms. While estimating the costs of being sick is a significant challenge given that farmers do not know the (rather unspecific) symptoms of worm infections, and tend to over-estimate health impacts resulting in costs between US$ 50 and 350 (see Chap. 8) which can create a significant distortion in any cost-benefit analysis, a simple chemical deworming would cost less than US$ 1 per person per year (Hall and Horton 2009).

Table 3.6 Effectiveness and cost-effectiveness ratios of interventions. (Source: Drechsel and Seidu 2011)

Interventions	DALYs averted (%)	CER (US$ per DALY)	
		Mean	CI (5–95 %)
Wastewater treatment plants (WWTP) options			
Basic rehabilitation of five urban WWTPs, without work on sewer and household connections	82	41	35–47
Construction of five new WWTPs (waste stabilization ponds), without sewer and household connections	93	338	278–402
Farm- and postharvest options			
100 % adoption rate (AR) on-farm	92	13	11–15
75 % AR on-farm (best realistic on-farm case)	69	17	14–20
25 % AR on-farm	23	51	43–60
100 % AR postharvest	88	20	17–24
75 % AR postharvest (best realistic off-farm case)	66	27	23–32
25 % AR postharvest	22	81	68–96
100 % AR on-farm + 100 % AR postharvest	99	30	25–35
75 % AR on-farm + 75 % AR postharvest	75	40	33–47
50 % AR on-farm + 50 % AR postharvest	49	59	49–70
75 % AR on-farm + 25 % AR postharvest	70	42	35–49
25 % AR on-farm + 75 % AR postharvest	68	43	36–51
25 % AR on-farm + 25 % AR postharvest	24	123	103–145
Combined options			
Rehabilitation + on farm (75 % AR)	86	43	37–49
Rehabilitation + postharvest (75 % AR)	83	52	45–60
Rehabilitation + on farm + postharvest (each 75 % AR)	90	61	52–70
Construction + on-farm (75 % AR)	98	339	279–403
Construction + postharvest (75 % AR)	97	339	279–403
Construction + on farm + postharvest (each 75 % AR)	99	352	289–417

DALY is disability adjusted life years (see Box 3.1)

Table 3.7 Cost effectiveness ratios of interventions for diarrhoea disease reduction. (Source: Various studies referenced by Drechsel and Seidu 2011)

Intervention	CER (US$ per DALY)		Country/Region
	Mean	Range	
Hygiene behavior-change campaign		3–20	Developing
Chlorination at household level		46–266	Africa
Solar disinfection	54	40–74	Africa
Ceramic filtration	125	83–159	Africa
Basic sanitation (pit latrine) construction and promotion	≤270	–	Developing
Basic sanitation (promotion only)	11	–	Developing
Water supply via hand pumps/stand posts	94	–	Developing
Water supply via house connection	223	–	Developing
Oral rehydration therapy	988	4–1972	Sub-Saharan Africa
Rotavirus immunization	2478	1402–8357	Developing
Cholera immunization	2945	1658–8274	Developing
Improved rural water supply and sanitation	1974	–	Developing
Improved urban water supply and sanitation	6396	–	Developing
Safer irrigation and vegetable-washing practices adopted by every second farmer and trader	59	49–70	Ghana

DALY is disability adjusted life years (WHO 2006)

3.4 Conclusion

Wastewater use is seen as one of the alternatives to address global water scarcity. By far, agricultural and landscape irrigation are the largest users of wastewater although in industrialized countries, industrial applications and groundwater recharge have high reuse portfolios as well. However, untreated wastewater can have many pathogens and chemical pollutants, which if not well treated and managed, pose human health and environmental risks. In low-income countries, contamination from pathogens resulting from inadequate sanitation (poor excreta disposal) and low coverage of wastewater treatment poses greatest health risks to farmers and consumers benefiting from irrigated crop production (the most common reuse option). In middle and high income countries, where sewer systems serve domestic and industrial areas, pathogenic hazards are largely controlled, and the discussion is focusing on heavy metals or other chemical contaminants, like those deriving from pharmaceutical and personal care products. Regardless the possible complexity of conventional or emerging contaminants, safeguarding public health remains an integral pillar of any reuse system.

To protect public health without unnecessarily discouraging wastewater use, regulatory approaches need to stipulate water quality standards and other health protection measures. There is also in increasing global understanding of "treating to fit the purpose" and many treatment options exist to meet specific wastewater uses and related water quality objectives. Advances in membrane filtration enable the treatment of wastewater to meet standards sufficient for potable water use. However, more cost-effective technologies need to be developed, especially for irrigation, which is globally represents the largest use of wastewater.

The water standards approach might be more pertinent in middle to high income countries where wastewater receives adequate treatment and where strong institutions exist for regulating wastewater use. The approach will also remain a pillar of risk reduction in low and middle income countries aiming to use wastewater for potable purposes and in the food industry. However, as low and middle income countries work towards improving sanitation and wastewater treatment, the WHO (2006) promoted approach of health-based targets, which relies on a combination of treatment and non-treatment options, might be more feasible and offer more flexibility of compliance, especially if operationalized through the WHO promoted Sanitation Safety Plans. Research from Ghana has shown that such combined barriers can be cost-effective with a high ROI. However, more research is needed in other countries to develop a catalogue of risk mitigation options with verified risk reduction, limited costs in set-up and operations, and thus high cost effectiveness in terms of disease prevention in resource constrained settings.

Take Home Messages

- With food production being the most widespread water reuse application and potable use the financially most attractive, public health concerns will be an important component of any reuse discussion.
- Depending on treatment coverage and quality, different types of contaminants are of priority concern.
- Water quality based guidelines and health-based targets are the most widely discussed approaches in health risk mitigation.
- Many options and treatment technologies exist for risk mitigation, but more focus should be placed on cost-effective options, especially in resource constrained settings.

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Chapter 4
Environmental Risks and Cost-Effective Risk Management in Wastewater Use Systems

Manzoor Qadir, Javier Mateo-Sagasta, Blanca Jiménez, Christina Siebe, Jan Siemens and Munir A. Hanjra

Abstract Wastewater use in agriculture has many potential benefits, yet it also poses environmental risks. In particular, the use of untreated or partially treated wastewater over the long run may result in negative impacts on irrigated crops, soils, and groundwater through the addition of excessive levels of metals and metalloids, nutrients, salts and specific ionic species, and micro- pollutants. The environmental risk reduction strategies for wastewater can be categorized into: (1) treatment of wastewater to a desired effluent quality; (2) on-farm wastewater treatment options; and (3) farm-based measures to reduce risks in areas irrigated by untreated or

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partially treated wastewater. However, the number of strategies that have been economically assessed and have proven to be cost-effective is rather limited, although all mention a positive impact. Despite limited examples, the economics of risk management reveal that cost-effective options for improving water quality by removing undesirable constituents are available at the treatment plant level and beyond.

Keywords Wastewater and environment · On-farm treatment · Metals and metalloids · Salinity · Micro-pollutants

4.1 Introduction

Wastewater is used increasingly to irrigate crops in urban and peri-urban areas. Yet, irrigation with untreated or partially treated wastewater poses chemical and pathogenic risks to farmers, consumers, and ecosystems (Pescod 1992; Qadir et al. 2007; Keraita et al. 2010). Wastewater contains different types and levels of undesirable constituents, depending on the source from which it is generated and the level of its treatment. The non-pathogenic components of wastewater include organic and inorganic chemicals that can be harmful or beneficial, depending on their concentrations, solubility, and inherent toxicity. For example, some of the elements in wastewater are essential plant nutrients, such as nitrogen and phosphorus. Among the undesirable compounds are salts, metals and metalloids, pesticides, organic toxic compounds and micro-pollutants (Siemens et al. 2008; Simmons et al. 2010). The pathogenic components include viruses, bacteria, protozoa, and multicellular parasites (Bos et al. 2010). The concentrations of these constituents above the permissible limits have bearing on human and environmental health (WHO 2006).

Past research has been restricted mainly to assessing situation-specific environmental risks and risk management (Stevens and McLaughlin 2006; Abaidoo et al. 2010; Qadir and Scott 2010). Environmental risk is different from economic, social or health risk (Hanjra et al. 2011), as it focuses on environmental capital; i.e. ecosystems. It may refer to a pollutant concentration exceeding the carrying capacity of an ecosystem receiving the pollution load or the over recharge of an upper aquifer that leads to waterlogging in agricultural land, thus leading to its degradation and reducing its productivity. In addition to environmental risk assessment stemming from the use of untreated or partially treated wastewater, studies have also addressed economic valuation of the environmental benefits from wastewater treatment processes and the use of treated wastewater for irrigation (Tziakis et al. 2009; Hernández-Sancho et al. 2010; Ganoulis 2012; Molinos-Senante et al. 2012).

We describe the environmental risks resulting from the use of untreated or partially treated wastewater and provide insight into cost-effective risk management, through economic valuation of the environmental benefits from safe and productive approaches leading to water recycling and reuse. Health risks related to untreated or partially treated wastewater and cost-effective risk management are addressed in the previous Chap. 3.

4.2 Environmental Risks Stemming from Wastewater

Several constituents of wastewater are essential for human needs, but even these 'essential' constituents can become undesirable and considered environmental pollutants when their concentrations exceed the carrying capacity of an ecosystem (Corcoran et al. 2010). Based on these environmental thresholds and the specific use of wastewater (irrigation, aquaculture, or groundwater recharge), a maximum allowable pollutant concentration in wastewater is usually specified in environmental quality standards or guidelines (WHO 2006). In addition to concentration of a specific constituent, its pollution loads over time are also important. Therefore, continuous use of wastewater having concentration of a specific pollutant over and above the maximum allowable concentration would lead to the pollutant-specific environmental risk.

With the potential for environmental risks due to concentrations and loads above the maximum allowable levels, the constituents that need to be addressed in wastewater-irrigated environments can be broadly grouped into: (1) Metals and metalloids, such as cadmium, chromium, nickel, zinc, lead, arsenic, selenium, mercury, copper, manganese, among others (Römkens et al. 2001; Hamilton et al. 2005; Rai 2012); (2) Nutrients such as nitrogen, phosphorous, and magnesium, which in high concentrations might suppress other nutrients or affect plant growth otherwise negatively (Nhapi et al. 2002; Lazarova and Bahri 2005; Simmons et al. 2010); (3) Salts and specific ionic species such as sodium, boron, and chloride (Oster et al. 1999; Tanji and Kielen 2002; Money et al. 2009); and (4) Micropollutants also known as persistent organic pollutants, such as pesticides as well as residual pharmaceuticals, endocrine disruptor compounds, active residues of personal care products, among others (Boxall et al. 2006; Dalkmann et al. 2012; Durán-Álvarez et al. 2012).

4.2.1 Toxic Metals and Metalloids

All of the potentially toxic metals and metalloids are naturally present in the environment in trace amounts and are ingested with food, water, and air. Several of these metals and metalloids are of particular concern due to their adverse effects on agricultural productivity as well as environment (Römkens et al. 2001; Gupta et al. 2012). For example, metals such as cadmium, mercury, and lead do not have essential function but they are detrimental, even in small quantities, to plants, animals and humans, and accumulate because of their long biological half-life. Other metals and metalloids, such as manganese, zinc, and copper are essential micronutrients in small concentrations, but harmful to crops when they reach above maximum allowable concentrations (Table 4.1; Hamilton et al. 2005; Simmons et al. 2010).

Table 4.1 Four distinct groups of selected metal ions based on their bioavailability, phytotoxicity, and risks. (Modified from Hamilton et al. 2005)

Group	Metal[a]	Soil adsorption	Phytotoxicity and risks
1	Ag, Cr, and Ti	Low solubility and strong retention in soil	Low
2	As, Hg, and Pb	Strongly adsorbed by soil colloids	Plant roots may take up but not translocate to shoots; generally not phytotoxic except at very high concentrations
3	B, Cu, Mn, Ni, and Zn	Less strongly adsorbed by soil colloids than Groups 1 and 2	Readily taken up by plants and phytotoxic at concentrations that pose little risk to human health
4	Cd, Co, Mo, and Se	Least adsorbed of all metals	Pose human and animal health risks at plant tissue concentrations that are not generally phytotoxic

[a] Abbreviations for metals refer to *Ag* Silver, *As* Arsenic, *B* Boron, *Cd* Cadmium, *Co* Cobalt, *Cr* Chromium, *Cu* Copper, *Hg* Mercury, *Mn* Manganese, *Mo* Molybdenum, *Ni* Nickel, *Pb* Lead, *Se* Selenium, *Ti* Titanium, *Zn* Zinc

4.2.2 Excess Nutrients

Wastewater usually contains valuable plant nutrients, such as nitrogen, phosphorous, potassium, and magnesium, among other elements. Although availability of these nutrients is one benefit of wastewater irrigation in developing countries, maintaining appropriate levels of nutrients in wastewater is a challenging task. The nutrient concentrations vary significantly in wastewater due to wastewater source and treatment level, and may reach levels that are in excess of crop needs (Lazarova and Bahri 2005).

Continued irrigation with wastewater having nutrient concentrations and loads over and above the crop requirement would result in nutrient leaching, such as nitrates, to groundwater and subsequent groundwater pollution (Tang et al. 2004). In addition, disposal of nutrient-rich wastewater to surface water bodies may cause water quality deterioration in the form of algal blooms (particularly excess of some phosphates) and eutrophication (excess of total phosphorus and total nitrogen). Once a water body is eutrophicated, it loses its primary functions and/or subsequently influences sustainable development of economy and society (Mayer et al. 2013).

4.2.3 Salts and Specific Ionic Species

Wastewater contains more soluble salts than freshwater because salts are added to it from different sources. The amount and type of salts used in an industry and the relevant treatment affect the quality of wastewater. For example, in the tannery industry, skins are usually salted with 50–100 % salt by weight and hides with 40–50 % salt (Money et al. 2009). These values suggest that each ton of salted skins contributes 500 kg of salt to the environment if wastewater treatment is not in place. Wastewater from tanneries contains salt in the range of 10–50 g L^{-1} while domestic wastewater contains salt 0.3–0.5 g L^{-1} (Qadir and Drechsel 2010). There are no economically viable means to remove salts from wastewater. Cation exchange and reverse osmosis, which are only used to produce high-quality recycled water, are too expensive for most applications of wastewater (Toze 2006).

Salt management is complicated when industrial or commercial brine waste streams are not discharged into separate waste sewers, rather into main urban sewers that convey wastewater to the treatment plants or to disposal channels leading to farmers' fields. Compared to other wastewater constituents, there are indeed no restrictions on salt concentrations wastewater to be discharged into urban sewers (Lazarova and Bahri 2005).

The adverse effects of salts from wastewater irrigation on crop growth and soil stem from: (1) increasing the osmotic pressure and thereby rendering the water in the soil less available for the plants; and (2) specific effects of some elements present in excess concentrations, such as sodium, which exhibit structural problems as a result of certain physical processes (slaking, swelling, and dispersion of clay) and specific conditions (surface crusting and hard-setting); and (3) imbalances in plant nutrition (Qadir and Schubert 2002).

4.2.4 Micro-Pollutants

The continuous release of micro-pollutants such as pharmaceutical and personal care products (PPCPs) into the environment through wastewater is an emerging concern. The environmental risk assessments for micro-pollutants are regulated by the European Medicines Agency in their guidelines on the environmental risk assessment of medicinal products for human use (European Medicines Agency 2006). These risk assessments begin with an estimation of the exposure by calculating a predicted environmental concentration (PEC), based on dosage of pharmaceuticals or consumption data. These PECs are then compared to predict no effect concentrations (PNEC) to assess potential risks.

Although pharmaceuticals and other emerging pollutants can accumulate in soil as a result of long-term irrigation with wastewater (Dalkmann et al. 2012; Durán-Álvarez et al. 2012) and may transfer from soils to crops, the amounts taken up by plants seem too small to cause acute toxic effects to humans (Boxall et al. 2006). However, little is known regarding health risks arising from the long-term uptake of small concentrations of mixtures of micro-pollutants in food and drinking water.

4.3 Environmental Risk Management

Several research-based options are available for environmental risk management with regard to the use of wastewater in agriculture (WHO 2006). Yet, the number of risk reduction strategies that have been economically assessed and have proven to be cost-effective is limited. The risk reduction strategies can be categorized into: (1) treatment of wastewater to a desired quality as many wastewater treatment options with a proven track record are available and produce a range of effluent quality; (2) treatment beyond wastewater treatment plants such as on-farm wastewater treatment options; and (3) farm-based measures to reduce environmental risk in areas where untreated or partially treated wastewater is used for irrigation.

4.3.1 Wastewater Treatment Systems and Technologies

Appropriate, effective and low-cost wastewater treatment technologies are needed to increase the coverage of wastewater treatment in developing countries. These can be simple treatment processes that provide required effluent quality with low investment costs and, in particular, low operational and maintenance costs (Jiménez 2011; Libhaber and Orozco-Jaramillo 2013). Such processes exist and are particularly suited to countries with warm climates, as biological processes perform better at higher temperatures. Most developing countries are in warm climates.

Many wastewater treatment options are available to generate a range of effluent quality (Libhaber and Orozco-Jaramillo 2013) and include: preliminary treatment by rotating micro screens; vortex grit chambers; lagoon treatment (anaerobic, facultative and polishing), including recent developments in improving lagoon performance (using upgraded lagoons); anaerobic treatment processes of various types, mainly anaerobic lagoons, up-flow anaerobic sludge blanket (UASB) reactors, anaerobic filters, piston anaerobic reactors (PARs), anaerobic baffled reactors (ABRs), and activated sludge treatment; physicochemical processes of various types, mainly chemically enhanced primary treatment (CEPT) or advanced primary treatment (APT); constructed wetlands; stabilization reservoirs for wastewater use and other purposes; overland flow; infiltration-percolation; septic tanks; and submarine and large river outfalls. Various combinations of these processes can be set up. Combinations can also include some other simple processes such as sand filtration and dissolved air flotation (DAF). Table 4.2 presents the treatment capacities and costs of some technology units and combined processes for wastewater treatment.

A number of methodologies can be used to evaluate the benefits from wastewater treatment, which can be integrated in a broader cost-benefit analysis (CBA) to appraise wastewater treatment options. Undertaking CBA of actions with environmental impacts is complex because many environmental resources, including most water resources, have public good dimensions and do not trade in markets that determine prices (Hernández Sancho et al. 2010).

Table 4.2 Treatment capacity and costs of some wastewater treatment units and combined processes. (Adapted from Libhaber and Orozco-Jaramillo 2013)

Process	Total BOD removal capacity (%)	TSS removal capacity (%)	Investment cost		Operation and maintenance cost	
			US$ per capita	% of activated sludge cost	US$ per capita	% of activated sludge cost
Conventional activated sludge[a]	80–90	80–90	100–150[b]	100	4–8	100
Rotating micro screens	0–30	0–30	3–10	4–10	0.1–0.15	1.9–2.5
Conventional lagoon systems	70–90	70–90	20–40	25–40	0.2–0.4	5–8
Mixer aided lagoon systems	70–95	80–90	20–40	25–40	0.2–0.4	5
Covered anaerobic + mixer lagoons[c]	80–95	80–90	20–50	25–50	0.2–0.4	5
UASB Reactors	60–75	60–70	20–40	25–50	1.0–1.5	19–25
Anaerobic filters	70–80	70–80	10–25	10–25	0.8–1.0	13–20
CEPT	70–75	80–90	20–40	20–40	1.5–2.0	25–38
Constructed wetlands	80–90	80–90	20–30	20–30	1.0–1.5	19–25
Stabilization reservoir systems	75–95	75–90	30–50	30–50	0.2–0.4	5
Submarine outfalls	99.9	99.9	3–30	3–30	0.1–0.15	1.9–2.5
Overland flow	70–80	70–80	15–30	15–30	0.8–1.5	19–20
UASB-anaerobic filter combination	80–90	80–90	20–40	20–40	1.0–1.5	19–25
UASB-lagoon combination	80–90	70–80	30–50	30–50	1.0–1.5	19–25
CEPT-sand filtration combination	80–90	80–90	40–50	40–50	1.5–2.0	25–38
UASB-sand filtration combination	80–90	80–90	30–50	30–50	1.0–1.5	19–25
UASB-dissolved air flotation combination	80–90	80–90	30–40	30–40	1.0–1.5	19–25

[a] Conventional activated sludge is used for reference. It is not an appropriate process

[b] The investment cost of an activated sludge plant used for the calculation is $ 100 per capita

[c] Covered anaerobic lagoons, followed by mixer-aided facultative lagoons

Table 4.3 Reference price of treated wastewater and shadow prices for undesirable outputs revealing environmental benefits (environmental damage avoided) from disposal of treated wastewater into wetlands, rivers, or the sea. (Modified from Hernández-Sancho et al. 2010)

Destination	Reference price of wastewater (€ m^{-3})[a]	Shadow prices for undesirable outputs (€ kg^{-1})[a]				
		N	P	SS	BOD	COD
Wetlands	0.9	−65.21	−103.42	−0.010	−0.117	−0.122
River	0.7	−16.35	−30.94	−0.005	−0.033	−0.098
Sea	0.1	−4.61	−7.53	−0.001	−0.005	−0.010

[a] 1.00 € in 2010 = 1.31 US$

Hernández-Sancho et al. (2010) evaluate the benefits of wastewater treatment through the removal of pollutants and estimated shadow prices for each pollutant, depending on disposal of effluent into a river, sea, or wetland. The pollutants investigated include nitrogen (N), phosphorus (P), suspended solids (SS), biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The shadow price of each of the pollutant is helpful in estimating the costs avoided by removing the pollutant during wastewater treatment. These avoided costs represent the economic value of the minimal environmental benefits obtained from the treatment process.

The estimated shadow prices of disposing wastewater into wetlands are greater in absolute value than those of disposing wastewater into rivers or the sea (Table 4.3). This ordering of incremental damages might reflect the limited dilution and the environmental vulnerability and importance of wetlands (Hernández-Sancho et al. 2010). The estimated shadow prices, which reflect the incremental benefits of wastewater treatment, are highest in absolute value for phosphorus and nitrogen (Table 4.3). Both nutrients are essential, but excessive concentrations in water bodies cause eutrophication and reduce biodiversity by causing algal blooms in water bodies (Mayer et al. 2013).

Wastewater treatment options are available to substantially decrease or even eliminate micro-pollutants such as PPCPs in spite of their low concentrations. Molinos-Senante et al. (2013) estimate environmental shadow prices for five PPCPs (diclofenac, later referred to as DCF; tonalide, AHTN; galaxolide, HHCB; sulfamethoxazole, SMX; and ethynilestradiol, EE2). Shadow prices represent the environmental benefits from treating effluent using a pilot-scale ozonation reactor. These estimated benefits are equivalent to the incremental values of avoiding the discharge of these PPCPs into water bodies. Molinos-Senante et al. (2013) consider two scenarios: (1) sensitive areas where in case the wastewater is treated, the damage avoided is significantly greater; and (2) non-sensitive areas where the damage avoided with wastewater treatment is significantly smaller than sensitive areas. In the first scenario, the values obtained for eliminating PPCPs from wastewater, expressed in € kg^{-1} of material, are higher than non-sensitive areas (Table 4.4). Estimates of the environmental benefits stemming from wastewater treatment are useful in developing feasibility studies for wastewater management projects, justifying the implementation of technologies aimed to increase the level of environmental protection.

Table 4.4 Average values of shadow prices for undesirable outputs (€ kg^{-1})[a] and their standard deviation in parenthesis. (Adapted from Molinos-Senante et al. 2013)

Scenario	DCF	AHTN	HHCB	SMX	EE2
Non-sensitive	−42.20 (−4.63)	−10.98 (4.33)	−8.67 (−3.97)	−34.95 (−17.76)	−73.73 (−24.13)
Sensitive	−53.47 (−5.21)	−13.98 (5.88)	−11.06 (−4.85)	−44.46 (−23.06)	−93.76 (−28.57)

DCF diclofenac, *AHTN* tonalide, *HHCB* galaxolide, *SMX* sulfamethoxazole, *EE2* ethynilestradiol

[a] 1.00 € in 2013 = 1.38 US$

Wastewater treatment generates value also by providing useful water in water-short areas. In a field survey involving 32 wastewater treatment plants using different treatment options in Nicaragua, Jiménez et al. (2011) find that irrigation with treated wastewater, even in this humid country, increases crop yields, due to year round availability of water. The range of crops cultivated is also extended (21 instead of 14 under rainfed conditions), and there is less dependence on fertilizers. Irrigation with treated water caused a two-fold increase in farmers' income (from US$ 340 ha^{-1} to US$ 680 ha^{-1}). Although the increase in net income in Nicaragua is lower than that reported for arid or semi-arid regions (Keraita et al. 2008), the increase is significant for a humid area. In economic terms, the nutrients contained in the effluent from just 5 stabilization ponds resulted in yearly savings for farmers of US$ 265,170 for nitrogen and US$ 167,636 for phosphorus (Jiménez et al. 2011). In another example, Jiménez et al. (2014) highlight the importance of both nutrients and the water content in wastewater, in an economic assessment of irrigating 90,000 ha with untreated wastewater in the Mezquital Valley, Mexico. The farmers realized benefits (and damages avoided) due to nutrients in water, increases in crop yields, increase in land rental prices, provision of water, and the avoided costs for treatment.

Risk management in the wastewater-irrigated area in the Mezquital Valley primarily involves crop restrictions. Only fodder crops and large stem grains or vegetables are allowed, but all vegetables that are either produced in direct contact with wastewater and soil, and particularly those that are consumed raw, are prohibited. The risk of soil degradation through the accumulation of soluble salts is limited, as most farmers over-irrigate, which provides groundwater recharge. To minimize environmental and health risks, a large wastewater treatment plant is under construction and expected to begin operating in 2015 (Conagua 2014). The plant is expected to treat urban wastewater from Mexico City at the rate of 23 $m^3\ s^{-1}$ (2 million $m^3\ d^{-1}$ or 725 million $m^3\ yr^{-1}$) using a biological activated sludge system. During the rainy season, the plant will also treat 12 $m^3\ s^{-1}$ of surface runoff by advanced physico-chemical treatment. The investment costs are US$ 751.1 million (49 % from the government and 51 % from a private investor), and the annual estimated operation costs are US$ 85.3 million. This is equivalent to US$ 0.12 m^{-3} of biologically treated wastewater and US$ 0.07 m^{-3} of physical and chemically treated wastewater.

These costs will be charged to consumers in Mexico City, through their potable water bills (Ariel Flores Robles, personal communication).

4.3.2 On-Farm Wastewater Treatment Options

Current estimates suggest that low-income countries on average treat 8 % of the generated wastewater (Sato et al. 2013). There are several reasons for the low levels of wastewater treatment in developing countries, including: (1) allocation of limited financial resources to wastewater treatment; (2) weakness of governance at central and local government levels; (3) limited institutional and technical capacity at utility level; (4) priority for expanding water supply and sewerage in advance of expanding wastewater collection and treatment; (5) inadequate planning for wastewater treatment coverage; (6) poor quality planning that does not match wastewater treatment plant capacity with anticipated population growth and urbanization; and (7) tendency to construct new treatment plants based on cutting-edge technology, rather than relying on low-cost and affordable treatment options.

Given these issues and challenges, it is unlikely that the low levels of wastewater treatment in developing countries will increase substantially in near future unless some innovative and affordable strategies for expanding wastewater treatment coverage are adopted. Driven by the lack of wastewater treatment capacity in low-income countries, some on-farm options for wastewater treatment have been used for environmental and health risk reduction (WHO 2006; Keraita et al. 2008; Bino et al. 2008; Reymond et al. 2009).

Using sedimentation as the treatment process, affordable pond-based on-farm treatment systems such as dugouts, drums or concrete tanks are used in many countries (Keraita et al. 2008; Reymond et al. 2009). Primary sedimentation through on-farm ponds, and systems of interconnected ponds, can remove 60 % of suspended solids, 35 % of BOD, and reduce the concentrations of pathogens and toxic compounds attached to the sediments. Part of heavy metals and other toxic chemicals can adsorb to the sediments carried in wastewater, and thus reducing the concentration of undesirable metals and toxic chemicals. Ponding of wastewater also is helpful in reducing such concentrations, as some organic pollutants and pathogens degrade photochemically in ponds and reservoirs (Keraita et al. 2008; Reymond et al. 2009). For example, a pond system constructed in a peri-urban agricultural area in Accra, Ghana, enhanced fecal coliform removal from 10^6–10^7 MPN 100 mL^{-1} by at least 2 log units from the first to the last pond. Individual ponds showed a removal of 1–1.5 log units over 2 days. Helminth eggs were not frequently found in the source water (up to 2 eggs L^{-1}) but when present, decreased to ≤ 1 egg L^{-1} in the first pond (Reymond et al. 2009).

The costs of on-farm ponds include labor for construction for simple land pond systems, and machinery cost for more sophisticated ponds (Reymond et al. 2009). The cost of constructing the simple on-farm pond in Accra includes the wages for

2 days of labor and $ 50 for construction materials. These systems, although robust and simple, need maintenance (e.g. sediments dredging) and have opportunity costs associated with the loss of crop production on the piece of land that is allocated to on-farm ponds (Reymond et al. 2009).

Wastewater treatment can be achieved through filtration systems at farm level using a range of media such as sand, gravel or soil. Sand filters (sand size: 0.15–0.40 mm) can be used in water containers feeding drip irrigation systems where untreated wastewater tends to clog the outlets. These filters can remove 0–3 log units for bacteria and 1–3 log units for helminth (WHO 2006). The sand filters need frequent cleaning to avoid clogging of the filtration medium.

Gravel sand filters are used to treat greywater from small streams or households before irrigating crops, flowers, and fruit trees. The gravel under anaerobic conditions facilitates biological treatment with retention times of 2–3 days. Pathogens and total suspended solids can be reduced to 50 %. The filters need cleaning to prevent odors and with time clogging of the gravel media (Bino et al. 2008). Based on the economics of greywater treatment systems in Jordan, the capital cost of one unit may range between US$ 260 to 300 for site preparation, gravel media, plastic sheets, and PVC pipes. The average annual operation and maintenance cost would be US$ 39. Based on the Net Present Values, interest rates of 3 and 5 %, and lifespan of the system for 5 and 10 years, the system proves to be economically feasible with benefit-cost ratios of 1.76 and 1.83 for 5 years at 3 and 5 % interest rates, respectively; for 10 years period at 3 and 5 % interest rates, the respective benefit-cost ratios would be 2.58 and 2.75 (Bino et al. 2008).

Some components of irrigation infrastructure such as weirs and water storage tanks in irrigation schemes can also be used to improve the microbiological quality of domestically polluted water. For example, in the case of Musi River which passes Hyderabad in India, the natural remediation efficiency of the river system, aided by the construction of irrigation infrastructure, particularly weirs can reduce fecal coliforms, helminth eggs, BOD, and nitrogen at rates comparable with the treatment efficiency of a well-designed waste stabilization pond system. The improvement in water quality over a distance of 40 km with 13 weirs is due to the combined effects of different remediation processes such as sedimentation, dilution, aeration, natural die-off, and exposure to UV-light (Ensink et al. 2010).

4.3.3 Farm-Based Measures While Irrigating with Untreated Wastewater

Under conditions where untreated or partially treated wastewater is used for irrigation, some specific farm-based measures can reduce environmental risk stemming from toxic metals and metalloids, excess nutrient, salts and specific ionic species, and micro-pollutants.

4.3.3.1 Toxic Metals and Metalloids

The risk management steps for metals and metalloids may consist of: (1) identifying farms with elevated risks from specific metal sources; (2) testing soil and plant samples to verify levels of risk from specific metals; (3) developing irrigation, fertilization, and residue management strategies that reduce metal uptake by plants; (4) recommending crops with less risk as some crops are more prone than others to contamination with metals and metalloids or pose a greater risk to human health, due to levels of dietary intake; and (5) identifying varieties of a specific crop that take up less of the metal or convert the toxin to less toxic forms when grown in high-risk areas, if such varieties are available (Hamilton et al. 2007; Simmons et al. 2010). The available techniques that have been applied to remediate metal and metalloid contaminated soils include *in-situ* and *ex-situ* engineering options, *in-situ* soil based immobilization, phytoremediation, chelate enhanced phytoextraction, and the use of transgenic crops (Salt et al. 1996; Qadir et al. 2000; Römkens et al. 2001; Rai 2012).

4.3.3.2 Excess Nutrients

As long as untreated or partially treated wastewater is used informally, the issue of disproportional application of nutrients will remain pertinent since wastewater seldom contains nutrients in optimal ratios. However, to minimize the effects of excessive or unbalanced additions of nutrients to wastewater-irrigated soils and crops, farmers can select crops less sensitive to high nutrient levels or which utilize high amounts of major nutrients, such as nitrogen and phosphorous. For example, leafy vegetables can accommodate higher levels of nitrogen. Some grasses and fodder crops are well suited to wastewater irrigation, as they safely accumulate the nutrients added via wastewater. For example, reduction efficiencies of 84 % for nitrogen and 54 % for phosphorus have been reported from wastewater irrigated pastures in Zimbabwe (Nhapi et al. 2002).

Soil based options also can be used to reduce nutrient impacts. For example, medium to fine textured soils may hold more nutrients than sandy soils, thereby releasing fewer amounts in the water percolating through the soil and adding to groundwater (Simmons et al. 2010). However, there is a need for groundwater quality monitoring when groundwater is shallow and used for drinking. In areas where farmers do not have the option to grow crops which benefit from high nutrient levels, the irrigation water might first be passed through other systems that transform some of the nutrient load into biomass.

To regulate nutrient input to wastewater-irrigated soils, guidelines are needed to optimize wastewater irrigation and nutrient input (Lazarova and Bahri 2005). In addition, nutrient loads at different stages of crop growth should be considered in the guidelines. For example, most nutrient input occurring at early crop development stages is taken up by the crop, but most nutrient input at later stages of crop development is not taken up by the crop due to less nutrient requirement at maturity.

4.3.3.3 Salts and Specific Ionic Species

Irrigation with saline wastewater needs specific on-farm preventive measures and management strategies, which may include: (1) appropriate selection of crops or crop varieties capable of producing profitable yield with saline wastewater (Maas and Hoffman 1977; Maas and Grattan 1999); (2) selection of saline wastewater irrigation methods reducing crop exposure to salts (Oster et al. 1999); (3) application of saline wastewater in excess of crop water requirement (evapotranspiration) to leach excess salts from the root zone (Qadir and Drechsel 2010); (4) saline wastewater irrigation in conjunction with freshwater, if available, through cyclic applications or blending interventions (Tanji and Kielen 2002); (5) use of agronomic interventions such as sowing on relatively less saline parts of ridges, raising seedlings with freshwater and their subsequent transplanting and irrigation with saline wastewater, mulching of furrows to minimize salinity buildup and maintain soil moisture for longer period, and increasing plant density to compensate for possible decrease in growth (Tanji and Kielen 2002; Hassan et al. 2013); and (6) application of calcium supplying amendments, such as gypsum, to the soils in case of irrigation with highly sodic or saline-sodic wastewater to mitigate the negative effects of sodium on soils and crops (Oster et al. 1999; Murtaza 2014).

4.3.3.4 Micro-Pollutants

Chemical stability and slow natural attenuation of some micro-pollutants makes remediation of these pollutants a particularly intractable environmental challenge. The degree to which wastewater containing persistent organic pollutants needs to be treated depends on (1) pollutant loads, i.e. concentration in wastewater × wastewater volume over time; (2) behavior of these compounds in the soil, which can be assessed through bioavailability tests to be performed before costly remediation strategies are undertaken The toxic effects of some compounds begin diminishing soon after they are added to soil, due to diffusion and sorption processes that sequester harmful compounds and reduce their toxicity; (3) soil properties, as soils with large buffer capacities (adequate pH, high soil organic matter content, loamy clay texture, high cation exchange capacity, and medium to deep profile) can receive and filter larger pollutant loads. For the sites already contaminated with these compounds, the approach usually taken is to isolate the affected sites, and either remove the contaminated soil or rely on phytoremediation. However, it remains crucial to ensure that industrial wastewater is treated at source and/or separated from other wastewater streams used for irrigation.

Pesticide contamination is more likely to reach significant levels through direct on-site application. Thus, farm based measures such as the use of alternative pesticides or integrated pest management are important for risk reduction. Pesticide entry into streams can be reduced by constructing buffer zones, reducing run-off, and using wetlands for remediation (Simmons et al. 2010). Containment of contaminated water in dams or wetlands may provide time for pesticides to be removed by sedimentation or through degradation. Farming practices that reduce runoff such as cover crops or vegetative buffer strips can reduce environmental impacts. The key removal mechanisms for most organic substances are sorption and biodegradation (WHO 2006). Removal efficiencies for pesticides are usually greater in soils rich in silt, clay and organic matter.

4.3.3.5 Trade-Offs

The major environmental challenge stemming from irrigation with untreated or partially treated wastewater is maintaining suitable salt balance in the root zone by applying water in excess of crop water requirement for salt leaching vis-à-vis managing metal ions, metalloids, and other undesirable constituents that also move with salts. The generation of drainage water by saline wastewater irrigation is a necessity to maintain root zone salinity at acceptable levels for crop growth. However, it is no longer sufficient to set leaching requirement objectives based solely on irrigation water salinity, soil salinity, and crop salt tolerance. There are crucial implications when irrigating with untreated or partially treated wastewater, over the long-term, which may cause adverse effects on groundwater quality in terms of accumulation of microbiological, inorganic, and organic contaminants.

Monitoring of groundwater quality is essential while irrigating with untreated or partially treated wastewater, particularly in areas where soils are coarse- to medium-textured, and groundwater is shallow and used for drinking. In the case of irrigation with highly polluted water, water, crop and soil quality evaluations are necessary to determine potential negative implications for farmers, their families, and consumers.

4.4 Conclusions

The constituents of major concern with regard to environmental risks from untreated or inadequately treated wastewater include metals and metalloids, nutrients, salts and specific ionic species, and micro- pollutants. The environmental risk reduction strategies can be categorized into: (1) treatment of wastewater to a desired effluent quality; (2) on-farm wastewater treatment options; and (3) farm-based measures to reduce environmental risks in areas irrigated by untreated or partially treated wastewater.

The costs and efficiency of wastewater treatment systems at the treatment plant level differ widely both in terms of cost and efficiency. For example, the cost of establishing wastewater treatment unit using conventional activated sludge is US$ 100–150 per capita and BOD and total TSS removal capacity is 80–90 %. Once established, its annual operation and maintenance cost is US$ 4–8 per capita. With the same level of treatment efficiency, the constructed wetland system would cost US$ 20–30 per capita along with annual operation and maintenance cost of US$ 1.0–1.5 per capita. In addition to cost and efficiency aspects, the choice of wastewater treatment systems depends on the availability of relevant skilled human resources, local conditions, and targeted use or disposal options for the treated wastewater.

Evaluating the economics of wastewater treatment options for environmental risk reduction is not simple and straight forward because many environmental commodities have public good dimensions and do not trade in markets that determine prices. Alternatively, shadow prices of pollutants can be used in estimating the costs avoided by removing the pollutants during wastewater treatment, i.e. economic value of the environmental benefits.

With only 8 % of wastewater treated, low-income countries can benefit from some affordable on-farm treatment options such as ponds, dugouts, drums, concrete tanks, or filtration systems. For example, primary sedimentation through on-farm ponds, and systems of interconnected ponds, can remove 60 % of suspended solids, 35 % of BOD, and reduce the concentrations of pathogens and toxic compounds attached to the sediments. Under conditions where untreated or partially treated wastewater is used for irrigation, certain farm-based measures can reduce environmental risks from pollutants. However, there may be adverse effects on groundwater quality in the long run, necessitating monitoring of groundwater quality.

Take Home Messages

- The constituents of major concern with regard to environmental risks from untreated or inadequately treated wastewater include metals and metalloids, nutrients, salts and specific ionic species, and micro- pollutants.
- The number of strategies that have been economically assessed and proven to be cost-effective for environmental risk reduction when irrigating with wastewater is rather limited, but all mention a positive impact.
- In addition to cost and efficiency aspects, the choice of wastewater treatment systems depends on the availability of relevant skilled human resources, local conditions, and targeted use or disposal options for the treated wastewater.
- There is a need to design and implement tools and models for the evaluation of risks and risk reduction approaches to help policy makers decide on available treatment options under specific environmental, social, and economic conditions.

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Part II
Socio-economics of Wastewater Use

Chapter 5
Social and Cultural Dimensions in Wastewater Use

Pay Drechsel, Olfa Mahjoub and Bernard Keraita

Abstract Even when wastewater use projects are technically well-planned, appear financially viable, and have incorporated appropriate health protection measures, reuse can fail if planners do not adequately account for the dynamics of social acceptance. Drawing from practical cases of project failure or success, we present a number of factors that commonly influence the introduction or improvement of wastewater use for potable and non-potable purposes. While water scarcity supports a discussion about reuse, decisive factors might be the level of direct exposure, availability of alternative water sources, education levels and perceptions of health risks, extent of public participation and buy-in, religious concerns, and the means and messages used in knowledge sharing and communication. Overall, acceptance of (safe) wastewater use varies with the development stage of the society, and can be a very dynamic process which makes social feasibility studies, close participation of target groups, and trust building essential components of successful reuse programs.

Keywords Wastewater acceptance · Potable water · Religion · Risk awareness · Gender · Perceptions

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5.1 Introduction

Globally, Australia, the United States, Namibia and Israel are among the most successful countries in introducing planned wastewater use for different purposes. Scholars and public officials in those countries have gained substantial experience in addressing public perceptions and attitudes toward the reuse of reclaimed water, be it for direct, indirect, potable and non-potable uses (Dolnicar and Schafer 2009; Higgins et al. 2002; Hurlimann 2009; Hurlimann and McKay 2006; USEPA 2012). Since the first reuse projects, it became clear that acceptance of reuse is not straightforward even when key factors like high levels of water scarcity, education and treatment capacities are in place, although there can be exceptions like in Israel (Dishman et al. 1989).

In general, for social acceptance of wastewater use, public and private concerns and benefits must be aligned. Concerns about real or perceived risks are weighed against the benefits of using treated (reclaimed) water. Given the many determinants of social acceptance and the need to improve wastewater management and use in many areas, a comprehensive approach including educational, policy, and management strategies is needed to support public acceptance (Keremane 2007).

Especially discussions around the introduction of direct and indirect potable reuse sparked public interest and research on social acceptance. However, also recreational or agricultural reuse requires stakeholder buy-in (Wegner-Gwidt 1991; Po et al. 2004, 2005; Marks 2004; Marks et al. 2006; McKay and Hurlimann 2003; WHO 2006; USEPA 2012). Failure to gain public acceptance can result in program stalling or becoming unviable (Keremane 2007; Friedler and Lahav 2006; Wegner-Gwidt 1991). Depending on the region and case, cultural, religious, educational and/or socio-economic factors can support or constrain the development of wastewater use in a given location (Po et al. 2004). These social acceptance challenges pertain to both the introduction of new wastewater use schemes and also to improvements in existing situations where wastewater is already informally used. This chapter will highlight some key consideration and lessons learnt drawing from examples mostly in the domains of agricultural and potable reuse.

For *agricultural* wastewater use, we have to distinguish two contrasting common situations:

1. First, are those schemes that are planned and formally designed to use treated wastewater as a source of irrigation water. These are common in many water scarce regions of middle and high income countries, where wastewater is promoted as an economic good. Wastewater is treated before being released to irrigation schemes and there are usually strict regulations guiding its use.
2. The second category pertains mostly to low to middle income countries with limited treatment capacity, in which untreated or partially treated wastewater is polluting water bodies which are used for informal irrigation. Thus wastewater is used either in diluted or raw form, largely opportunistically, unregulated and unplanned. In this situation the cultural and social challenge is not the ‘introduction of reuse’ but to prevent it, or better to support a ‘transition to safe reuse’.

Due to the significant scale of water pollution in many low-income countries, and limited capacity to monitor water quality, banning the unsafe practices would be difficult to enforce as the example of for instance Ghana showed (Obuobie et al. 2006). Thus the use of polluted water remains often in a state of "laissez-faire," without ability of authorities to enforce restrictions or assistance to reduce potential risks (Drechsel et al. 2006). Introducing risk reduction efforts would have to rely on occupational safety measures, crop restrictions, safer irrigation practices, and good post-harvest handling, following for example the WHO (2006) multi-barrier approach. In this situation, the conventional 'technical responsibility' of treatment plants to safeguard public health becomes a social task involving various stakeholders along the food chain. Thus, the challenge 'formalizing' informal wastewater, by introducing pathogen barriers, will eventually be as much a cultural and social challenge as the introduction of reuse.

5.2 Factors Influencing Social Acceptance of Wastewater Use

Across the spectrum of reuse purposes, social acceptance of wastewater use is influenced by many factors, ranging from expressions of disgust to calculated costs and benefits, issues of choice, trust and knowledge, attitudes toward the environment, and socio-demographic factors (Po et al. 2004; USEPA 2012). While these criteria appear relevant in many planned wastewater schemes, the situation is obviously different where wastewater irrigation is a common practice and behavior change is needed to improve its safety. However, there are a number of common factors which play an important role in both situations, like knowledge and risk awareness, the availability of alternative water sources, the financial implications for those directly concerned, and the need to progress in mutual agreement. These and other factors will be discussed in the following two section on planned (5.2.1) and unplanned (5.2.2) reuse.

5.2.1 Accepting the Use of Treated Wastewater for Potable and Non-Potable Purposes

The acceptance of planned reuse can vary strongly depending on a range of factors, such as the degree of contact, education and risk awareness, the degree of water scarcity or availability of alternative water sources, economic considerations, involvement in decision making, and experience with treated wastewater. Some of these factors will be looked at in more detail:

Knowledge and Direct Exposure Several authors have investigated the association of socio-demographic descriptors with the acceptance of treated wastewater. The two factors that have been frequently found to be associated with the acceptance

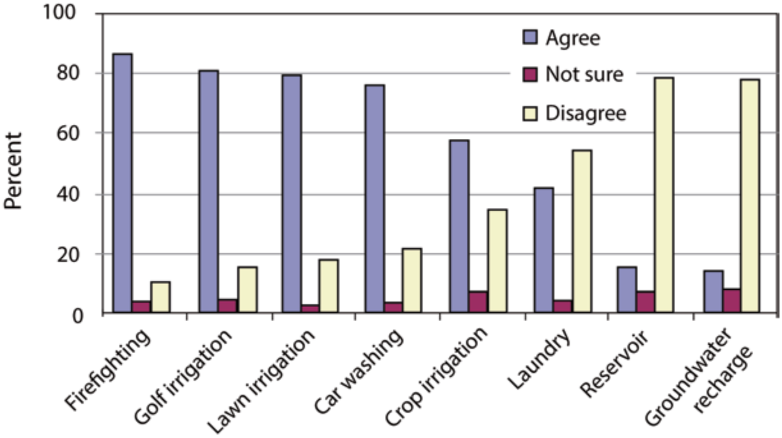

Fig. 5.1 Attitudes towards Wastewater Use Options, as expressed by 303 participants in a telephone survey in southeast United States. (Source: Robinson et al. 2005)

levels are the education/knowledge of the individuals expressing their opinion, and the personal proximity or involvement in the planned reuse. In Kuwait or Greece, for example, the willingness to accept or pay for reuse increased with the educational attainment (Alhumoud and Madzikanda 2010; Tsagarakis and Georgantzís 2003). However, as much as knowledge can support decision making, direct exposure to the water during the intended reuse can strongly influence its acceptance (Po et al. 2005; Hamilton et al. 2007). Positive perceptions towards reuse are usually directly the inverse of the level of physical contact with the reclaimed water. For example, despite significant technical advances, potable use usually is rejected due to health concerns (Higgins et al. 2002; Dolnicar and Saunders 2006). Assuming stakeholders have the choice, then wastewater use in agriculture generally is preferred to potable use, while more distant uses, such as landscape irrigation, are the most preferred (Fig. 5.1). A similar perspective has been reported for Kuwait, Israel, UK, USA and Australia (Po et al. 2004; Friedler et al. 2006; Hartley 2006; Alhumoud and Madzikanda 2010; USEPA 2012).

Availability of Alternative Water Sources Even when advanced processes are used to treat wastewater and known health risks are well managed, negative public perception can prevent well-planned projects from moving forward, especially if it concern potable use and there are still alternative water sources. The case of Singapore is such an example where the produced NEWater is technically safe but the public remains hesitant to accept it, even for indirect potable use. As a result, only a small portion (2.5 % in 2011) of NEWater has been injected into Singapore's freshwater reservoirs (Lim and Seah 2013). In Windhoek, Namibia, which lacks affordable water alternatives, up to 35 % of the city's wastewater is treated and blended with other potable sources to increase the drinking water supply. The success of Windhoek is supported by the fact that since the wastewater use program began in 1968, no health problems have been reported (Lahnsteiner et al. 2013). The Windhoek example shows that absolute water scarcity is an important factor in support of wastewater treatment for reuse. Where an alternative freshwater source is a crucial disincentive to the adoption of reuse, as it was reported e.g. for Jordan, Spain, and Tunisia (Molinos-Senante et al. 2010; Ben Brahim and Duckstein 2011), restrictions on the use of freshwater, especially if it concerns agricultural use, can be set and enforced; in contrast to potable reuse (Box 5.1).

Box 5.1: Resistance to Re-use

Queensland's Toowoomba in Australia is an often cited case illustrating the strength of public opinion regarding wastewater use. A plan to turn wastewater into drinking water failed in Toowoomba at a referendum in 2006, although water scarcity in the community was severe, to the point that water use for gardening was completely prohibited in the "Garden City". With no major river nearby, the community water supply had to be pumped uphill. During several years of drought, the 140,000 residents of Toowoomba and surrounding areas endured tough water restrictions. Local officials considered that the city had no choice but to treat and use parts of its wastewater for drinking water, and given the water crisis, they expected the program would be acceptable. However, the proposal met with fierce opposition from the community. In 2006, the residents of Toowoomba voted strongly against treating and using 25 % of the city's wastewater. They relied instead on water piped from Brisbane's Wivenhoe Dam, at a cost to ratepayers of nearly $ 100 million more than the reuse program would have cost.

The Toowoomba proposal was an indirect wastewater use program, in which highly treated wastewater would be passed through an environmental buffer before being treated again, as part of the drinking water system. The public poll was accompanied by two dynamic campaigns building on the "yuck" and "fear" factors on one side, and social and financial arguments on the other. In the end, 62 % of those polled opposed the project.

Sources: The Source (2006), Wikipedia (2013), SBS (2013)

Financial Feasibility If we assume that the reuse, be it for potable or non-potable purposes, is legally supported and has been suggested for sound economic reasons, it is still important for the concerned (direct or indirect) user to know if the change is financially viable from his/her perspective. In the case of wastewater irrigation, for example, crop acceptance by the consumer remains the most crucial criterion. Assuming the source of the crop is known to the consumer, his/her decision to buy or not to buy a crop produced with reclaimed water is determined by public views, knowledge and perceptions. To identify the actual consumer and to understand consumer's views, the crop marketing channels needs to be analyzed before assessing the perceptions (Amoah et al. 2007; Abu-Madi et al. 2008). In many countries, not only those with planned reuse schemes but in particular those where informal wastewater irrigation is a common reality, the existing marketing system does not differentiate between different farms or water sources, and wastewater irrigated

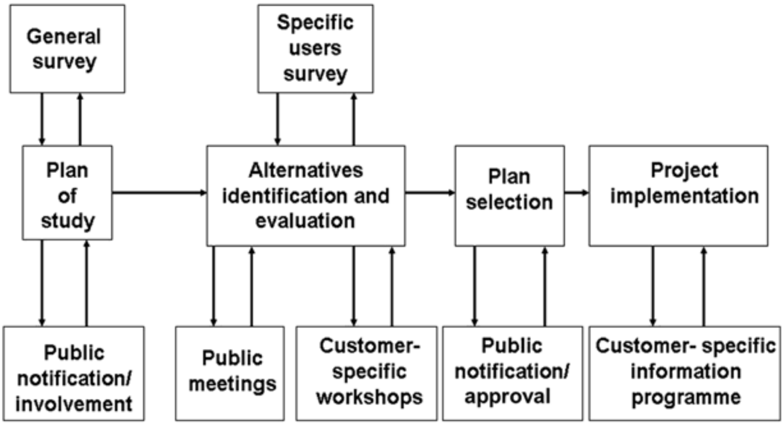

Fig. 5.2 Strategy for public participation in planned wastewater use. (Modified from WHO 2006; based on Crook et al. 1992 and Helmer and Hespanhol 1997)

crops are on offer together with freshwater irrigated crops. This could be an incentive to farmers but not to consumers with high risk awareness who would prefer dedicated marketing channels showing in the situation of planned reuse the crops produced with reclaimed water, and in the situation of common unplanned reuse the crops produced under safe conditions. However, unless consumers clearly articulate their preference there will not be much advantage for traders to separate and display produce according to its source.

Public Involvement and Buy-in A general consensus across many cases is that to achieve general acceptance of planned wastewater use schemes, especially in a social environment with the power to influence the implementation process, it is important to ensure active public involvement from the planning phase to full implementation (USEPA 2012; WHO 2006). Public involvement begins with early contact with potential users, and can involve the forming of an advisory committee, and public workshops on reasons, benefits and risks of reuse (Fig. 5.2). The exchange of information between authorities and public representatives should ensure that concerns from perceived health or environmental impacts to lower property values have been shared and addressed (Crook et al. 1992; Helmer and Hespanhol 1997). The dialogue should build on mutual trust to provide the right climate for negotiation and conflict resolution. Timing might be an important factor. Gaining public acceptance is easier once water scarcity is affecting the public and the need to conserve high quality water sources for domestic purposes is established. In a sense, the use of wastewater becomes a solution to a problem, rather than a problem (Fawell et al. 2005). However, good timing alone is not a guarantee of success, as the Toowoomba example showed (Box 5.1). It will also require a sensitive approach to avoid a polarization of stakeholders in favour and against reuse.

Results from Australia indicate that actual exposure (see above) and practical experience can positively influence trust building in water authorities and community acceptance of reclaimed water, indicating the importance of demonstration projects (Hurliman 2008). Dolnicar and Saunders (2006) propose reuse pilots in high-status communities first, as socio-demographic characteristics of the population can influence wider acceptance rates.

Jordan has succeeded in informing and convincing its population about the importance of wastewater use in agriculture, by implementing an active educational campaign with strong community outreach (EMWATER 2004). Program component included the distribution of newsletters, guidebooks, coverage of water issues in newspapers and on television and radio, websites, public educational places, and the education of land-use decision makers. Additionally, educational materials were distributed in schools, universities, and libraries (Al-Momani 2011).

In Jordan, like for example also in Tunisia or Kuwait, also religious concerns were expressed (Box 5.2) but not among the top reasons for farmers' rejection or hesitation to use reclaimed wastewater for irrigation (Abu-Madi et al. 2008; Alhumoud and Madzikanda 2010). Also in view of potable water reuse, no fundamental religious objections appear to exist either internationally or locally, as a multi-level survey in Durban showed (Wilson and Pfaff 2008).

Box 5.2: Religious Concerns

Religious concerns were mentioned in surveys carried out in Islamic countries. However, the attitudes of Islam can actually be considered as an incentive for irrigation with reclaimed wastewater although some farmers and rural dwellers might not be aware of this (Abu-Madi et al. 2008). In 1978, the Council of Leading Islamic Scholars (CLIS) in Saudi Arabia stated that treated wastewater can be used if its treatment included advanced technical procedures that remove impurities with regard to taste, colour and smell (Faruqui et al. 2001). According to Farooq and Ansari (1983), there are three ways in which impure water may be transformed into pure water:

- self-purification of the water (for example, removal of the impurities by sedimentation);
- addition of pure water in sufficient quantity to dilute the impurities; and
- removal of the impurities by the passage of time or physical effects (for example, sunlight and filtration).

It is notable that the first and third of these transformations are essentially similar to those achieved by wastewater treatment processes (WHO 2006).

In any community outreach program, care must be taken that the use of negative language and images does not stigmatize the wastewater use. Negative branding, especially by some media, including such headlines as "Toilet to Tap" or "Recycled Sewage" prevents unbiased thinking and can generate fear, stigma, and disgust (Gunderson 2008). Also, technical terms might not be convincing, as learned in a study in the United States (Fig. 5.3). While inadequate and negative terminology

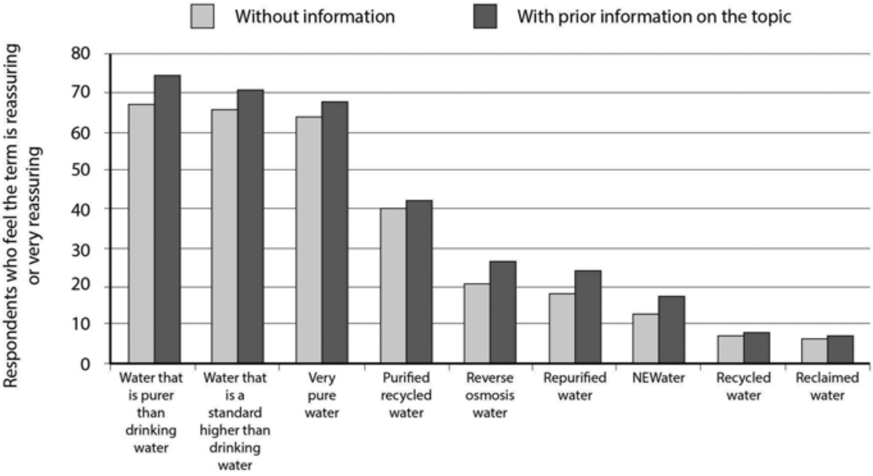

Fig. 5.3 Water reclamation terms in order of declining public reassurance. (USEPA 2012, based on data from the Water Reuse Association www.watereuse.org/product/07-03)

can impede clear communication, positive images and terms that enhance knowledge and understanding of water and wastewater can enhance the likelihood of success (Macpherson 2010).

5.2.2 Accepting Safety Interventions for Raw or Diluted Wastewater Use in Agriculture

Where the use of untreated or partially treated wastewater, either directly or indirectly from receiving streams, is common, and any enforcement to limit or regulate this practice is weak, the adoption of safety interventions and any related behaviour change will largely depend on (i) personal risk awareness and perceptions, which inter-link with educational standards, cultural and social factors, and (ii) financial benefits and cost for those whose livelihoods depend directly on using wastewater. Some of these factors appear similar to those discussed above for the introduction of reuse, such as the availability of alternative water sources, while experienced responses might be very different.

Risk Awareness In many low-income countries, health-related risks are commonplace and many poor households face numerous risk factors daily. The risks include insufficient food and water, inadequate or missing sanitation facilities, and exposure to malaria and other diseases. In such a setting, food safety hazards which would concern consumers in developed countries do usually not merit special attention or a priority claim on the households' financial resources as we are experiencing it in a more developed environment (Whittington et al. 2013). Thus, the normal living environment in large parts of for example Africa is characterized by several notable health hazards, such that the health risks of producing or consuming vegetables irrigated with unsafe water is usually not a primary concern of farmers, traders, or consumers, and also only one of many challenges authorities are facing.

Typically, farmers rank other farming constraints (crop pests, input supply, etc.) higher than any health related challenges. In addition, whenever health risks are identified, farmers link them more to off-farm activities such as sanitation and drinking water than to farm based activities (Ouedraogo 2002; Obuobie et al. 2006; Weldesilassie et al. 2010; Chaudhuri 2008; Kilelu 2004). Thus, there are often no significant differences in risk perception between farmers using safe and unsafe water from a scientific perspective (Gbewonyo 2007; Gerstl 2001), even when risk assessments predict or confirm likely health impacts (Seidu et al. 2008; Niang 2002).

A limited risk awareness applies in particular to the most common situation in which wastewater is diluted (indirect use), compared to the use of raw sewage or where chemical contamination is visually evident (Binns et al. 2003). The invisibility of pathogens and the lack of connection made between symptoms of potential illnesses and exposure show the need for mutually agreed on risk indicators (Box 5.3).

Box 5.3: The Challenge of Visualizing Invisible Risks

A significant challenge for the introduction of safety options for wastewater use is getting farmers and traders to understand health risks stemming from 'invisible' contamination, such as from pathogens or chemicals in water and soil, and their possible transmission to crops and consumers (e.g. with UV fluorescent powders; www.glitterbug.com). Especially where farm households do not consume the (exotic) vegetables they produce, only occupational exposure problems, such as skin rashes appear to be suitable indicators. However, the common measures to avoid water contact, for example through the use of rubber boots, will not protect the consumer.

Studies in West Africa of traders and consumers show a generally low risk perception which is limited to visible quality characteristics, such as the colour, size and cleanliness of produce (Hope et al. 2008; Obuobie et al. 2006; Acheampong et al. 2012). Thus it is important to identify also other risk indicators to increase awareness (Knudsen et al. 2008). In Kano, Nigeria, for example, severe chemical contamination from tanneries resulted in different water colors well known and distinguished by local farmers in terms of possible risks (Binns et al. 2003).

Source: Keraita et al. (2008; modified).

Economic Benefit Studies show that farmers in West and East Africa, South-East Asia and the MENA region generally are concerned about the quality of their irrigation water, yet they consider the potential gains from irrigating with wastewater to be greater than their occupational risks and the risks to consumers. The common lack of safer (and equally beneficially) alternatives makes the use of polluted water an accepted, hardly avoidable professional trade-off (Kilelu 2004; Keraita et al. 2008; Gbewonyo 2007; Gerstl 2001; Abu-Madi et al. 2008; Knudsen et al. 2008).

A challenge related to some of the recommended safer irrigation practices, such as drip irrigation, furrow irrigation, or cessation of water application, is that these practices do not only reduce microbial contamination, but can also reduce crop yields if they are not well adapted to local conditions (Amoah et al. 2011). For example, introducing drip kits with too wide spacing in Ghana, was counterproductive to the space constrains urban farmers face. Participatory research helped to understand farmers' constraints and adjust the technology to farmer's particular crops and farming conditions.

In general, health risk reduction measures will be adopted more easily if they appeal to farmers' priority challenges. For example, drip kits reduce pathogen exposure for farmers and crops, and they also enable farmers to save water and labor (Keraita et al. 2010). Mixing saline water with wastewater reduces pathogen concentration in the commingled irrigation water, while also transforming two unsuitable resources into a valuable asset (Keraita et al. 2010). In Ghana, Keraita et al. (2008) concluded that cost/labour savings and market incentives are the main factors which would motivate farmers to adopt best practices in the long term. However, marketing channels or an institutional framework to promote safer vegetable production and marketing are missing. To build such value chains, gender related work distribution will have to be addressed. In Ghana, for example, the marketing of most exotic vegetables is only done by women, while vegetable farming is mostly the domain of men (Drechsel et al. 2013). These gender roles prevent farmers from direct marketing, and result in 'safe' vegetables usually becoming mixed with unsafe vegetables in markets.

In general, the net beneficiaries of safe vegetables are the urban consumers, who might pay more for safe produce and dedicated marketing channels (Ngigi et al. 2011). So far only specialist markets for more wealthy population groups show interest to pay for safety (Danso et al. 2002; Acheampong et al. 2012; Lagerkvist et al. 2013). A challenge will be how to make safe produce accessible for the most vulnerable, who have the lowest ability to pay a premium.

Availability of Alternative Water Sources In contrast to the planned introduction of reuse, where the availability of freshwater can be a strong disincentive for accepting reclaimed water, stakeholder preference can be very different in informal irrigation, especially if the driver of choice is income and not personal safety. Where wastewater is highly concentrated, farmers are often also aware of its fertilizer value (Van der Hoek et al. 2002). There are many cases described where farmers actively seek the wastewater, and preferably untreated wastewater. In Pakistan, for example, treated wastewater did not find the same acceptance among farmers than untreated wastewater given its increase in salinity in treatment ponds (Ensink et al. 2004). In Mexico, farmers protested against treatment to maintain the fertilizer value of the water (Scott et al. 2000; Silva-Ochoa and Scott 2004). In Bangladesh, farmers appeared to be well aware of actual and possible risks but still preferred wastewater for its fertilizer value or due to lack of alternative or equally (year round) reliable water sources (Mojid et al. 2010). A rather indifferent view was observed when reuse was indirect from streams carrying diluted wastewater. In this situation, the nutrient value of wastewater can be negligible (Erni et al. 2010).

In the Mezquital Valley, Mexico, the possibility of irrigating with wastewater instead of (only) rainwater caused land rents to increase many times as the additional water enabled three crops to be harvested per year instead of one (Jimenez 2005). Only where wastewater use was actively banned, like in Tunisia, its use became unattractive (Al Atiri et al. 2002).

Trust Building Participatory research has shown high potential to facilitate the adoption of innovations among farmers (Chambers and Ghildyal 1985; Drechsel and Gyiele 1998). Participatory research allows for a mutual diagnosis of farmers' constraints and the identification of appropriate solutions to those constraints. The goal is to minimize the required behavior change (and possible discomfort), while maximizing risk reduction, based on mutual learning loops and modifications (Martin and Sherington 1997; Collinson 2000). Offering for example an alternative water source, such as safer groundwater would enhance safety without demanding new skills, although there can be additional pumping costs. A lesson from Benin showed that such safer water source should ideally be identified on the existing farm, as any site further away could jeopardize farmers' competitive advantage of market proximity and not be accepted (Drechsel et al. 2006).

Trust is important for participatory research, particularly in the domain of food safety, as farmers and traders might feel a threat for their business and use denial or defensive strategies, which can greatly hinder risk communication and are difficult to separate from low risk perception (Siegrist 2000). Alternatively, farmers might exaggerate possible risks if they perceive a likelihood of external support. These examples show that these types of perception studies require naturally a very high degree of professionalism in the design and execution of questionnaire based interviews, also in view of the often low degree of literacy.

Facilitating the Adoption of Safer Behavior Behavior change is a particular challenge where wastewater irrigation is common, and safety measures are required to facilitate a transition from informal to formal use. Such safety measures can be introduced along the food chain (from "farm to fork") as described e.g. by Amoah et al. (2011) and WHO (2006). Where risk awareness is low, and not easy to develop, research is needed to determine how best to motivate and trigger adoption of risk mitigation measures. Gender specific roles can be an important factor in this context (Box 5.4).

Measures to support behavior change can include economic or social incentives, such as access to credit, labelling, dedicated marketing chains, tax exemptions, and institutional support, like the provision of extension services, awards, or tenure security, but also restrictive regulations if they can be enforced (Drechsel and Karg 2013). Labeling of food products in a manner that reveals safe or unsafe irrigation methods will be needed to support a market response to changing consumer behavior.

Box 5.4: Gender Roles

Thoughtful safety interventions must be gender sensitive. In many cultures, women carry the main responsibility for hygiene and health, also vis-à-vis greywater or wastewater use as reported for example from Jordan (Boufaroua et al. 2013), Vietnam (Knudsen et al. 2008) and Tunisia (Mahjoub 2013). The strong connection between water use at a household level and women, offers a significant potential for innovative training approaches to improve the social acceptance of safe water reuse as recently demonstrated in Jordan (Boufaroua et al. 2013). Also the acceptance and use of protective clothing can be gender specific. In Vietnam, women were observed wearing with more consistency than men protective gloves and boots. The differences was attributed to the gender specific work separation on the farm, with men walking around the farms much more than women, where protective clothing constrained men's movements (Knudsen et al. 2008).

In many cases, increased education and risk awareness will not be sufficient to motivate the desired changes in behavior. Economic incentives might be helpful in motivating wastewater farmers who are usually engaged in cash crop production, while consumers might respond better to social marketing which aims to respond to inner desires, fears and motivations (Scott et al. 2007). Successes with social marketing have been reported from promoting latrine use and hand washing (Box 5.5).

Where regulations and monitoring are weak, media publicity can encourage farmers to adopt safety practices including safer water sources, in the same way that negative media exposure can harm business activity (Obuobie et al. 2006).

Box 5.5: Social-Marketing Studies in the West African Context

"Health in your hands": A marketing approach was applied in a nationwide hand-washing campaign in Ghana ("Health in your hands"), involving the use of professional marketing techniques facilitated through a private–public partnership to promote "socially useful products" (in this case, hand washing with soap) through generation of demand. The underlying research revealed two main drivers for hand washing with soap: disgust of dirt (yuck factor) and caring for a child, whereas health (protection from disease) was a weak motivator. The communication campaign was thus designed to evoke the feeling of disgust without mentioning health or sickness. The campaign was fairly successful: soap use after toilet use increased by 13 % and soap use before eating increased 41 % (Scott et al. 2007).

"A wanted latrine is a used latrine": Many sanitation projects in developing countries have failed because they relied only on subsidized latrine construction and health education without generating demand. Thus the

target community did not change established habits (like open defecation) and the latrines remained unused. In Benin, the social marketing approach was applied to improve sanitation. Research was conducted to determine what triggers people to invest in a latrine and to use it. Health benefits did not appear in the top ten triggers, whereas safety, dignity and prestige were among the top five (Martinsen 2008).

5.3 Conclusion

The documented experience on the social and cultural dimension of wastewater was grouped into two contrasting scenarios: those where the use of treated wastewater is being promoted in societies largely aware of potential risks, and those where risk perceptions are low and public health is potentially challenged by the common use of untreated, partially treated or diluted wastewater in the informal irrigation sector.

Commonalities between both situations concern for example the need to gain trust and work closely with those of whom a behavior change is expected. Another commonality is that the availability of an alternative water source, might in both situations function as a disincentive to change.

While for potable reuse, individual and group perceptions related to risks and disgust and the possibility of alternatives appear to be the main decisive criteria for potential users of reclaimed water, farmers' main arguments for or against changing their water source or behavior was usually related to economic arguments, like market perceptions affecting sales and revenues or cost and benefits in general (saving on fertilizer, extra harvest, reliability of supply). Even when own health impacts were experienced, these were perceived as controllable, or as an acceptable professional challenge, balanced by economic gains.

The review showed that the need to change behaviour, be it for using treated wastewater or assisting in making informal wastewater irrigation safer calls for a strong integration of social science research and related strategic partners and stakeholders in the strongholds of engineering and epidemiology to address possible adoption barriers and opportunities. These concern in particular:

- Public perceptions and group dynamics which can easily jeopardize any reuse project,
- Educational levels which might be too low to understand risks and related responsibility;
- The lack of economic or social incentives for changing practices.

Compared to the significant body of references on each of the two discussed situations, there is comparatively little information on strategies and achievements along the trajectory from unplanned to planned reuse, or informal to formal, like in Peru, Mexico or several MENA countries where both systems co-exist. The reason might be that there are only a few developing countries, like Tunisia which started early in the 1980s to combine in one program and from the planning stage on wastewater treatment and use needs (Bahri 2009). Of the treated 97 % of its wastewater, 72 % is used for agricultural and landscape irrigation, supported by well-enforced regulations that are reviewed to encompass new fields of reuse (ONAS 2012). Most other success stories derive from well-resourced developed countries with own reuse regulations. These regulations are however seldom transferable to other countries due to differences in institutional and technical capacities.

Locally adapted and applied regulations and reuse guidelines are essential to support reuse project. The global WHO (2006) guidelines provide this flexibility for local adaptation and are particularly strong in supporting the transition from informal to formal reuse even where treatment plants are not yet able to safeguard public health. They are building on the adoption of multiple barriers (safety options) along the contamination pathway from farm to fork, similar to the well accepted Hazard Analysis and Critical Control Points (HACCP) concept of the food industry. However, the guidelines fall short in explaining how the behavior change towards their adoption could be facilitated and sustained.

So far, the 2006 guidelines face limited acceptance probably due to their loss of simplicity by moving away from irrigation water quality thresholds to more flexible, human exposure based targets based on local risk assessments. This shift in itself requires a behavior change among those familiar with the previous WHO guidelines (Scott et al. 2010).

Take Home Messages

- Public acceptance of water reuse is more likely when wastewater is sufficiently treated and in locations which have water scarcity. However, both criteria are not necessarily sufficient reason for the acceptance of reuse.
- Social and cultural dimensions are critical factors for successful introduction or improvement of safe water reuse practices. Stakeholder participation and trust building at the earliest stages of any reuse project are crucial.
- For many of the world's poor, wastewater exposure is a common reality and an issue of no choice. Education, awareness creation and incentives will be required to facilitate behavior-based safety measures unless treatment systems gain sufficient coverage.
- To move from informal to formal reuse, social sciences will have an important role including the development of culturally acceptable and locally feasible guidelines and regulations.

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Chapter 6
Policy and Institutional Determinants of Wastewater Use in Agriculture

Dennis Wichelns and Manzoor Qadir

Abstract We describe policies, interventions, and institutions pertaining to wastewater use in agriculture, with particular emphasis on low and middle income countries. Designing policies and implementing interventions are challenging in such countries, where most of the wastewater used for irrigation is untreated and much of the use is informal and unintentional. Farmers, communities, and consumers are at risk from harmful constituents in the untreated wastewater, yet each group also obtains important benefits. There are no simple or easily affordable policy choices regarding the use of untreated wastewater in developing countries, particularly where the institutional support for wastewater collection, treatment, and reuse also is not yet well developed. In many countries, the responsibilities for wastewater management are shared among several ministries or agencies, and there is too little coordination regarding policies and programs pertaining to wastewater. Legislation alone is not sufficient in motivating or enabling greater use of wastewater in agriculture. Guidelines or regulations regarding specific water quality criteria, monitoring programs, and enforcement plans also are needed to provide farmers and consumers with the information and assurances needed to engender widespread support for wastewater irrigation.

Keywords Wastewater policies · Institutions · Legislation · Regulations · Costs

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6.1 The Rationale

Many farmers in developing countries use untreated wastewater for irrigation, often because it is the only source of water available. Many small-scale farmers obtain irrigation water from streams or ditches that are polluted with effluent from a nearby city, industry, or housing development. Polluted waterways are common in many developing countries, as wastewater treatment is not yet widely practiced. The average estimated rates of wastewater treatment are just 8 % in low-income countries and 28 % in lower-middle-income countries (Sato et al. 2013).

Most farmers irrigating with untreated wastewater likely would prefer higher quality water, but in most cases they have no alternative source. There can be agronomic value in the nitrogen and phosphorus in the untreated wastewater, but there are also pathogens and chemicals that threaten the health of farmers, food vendors, and consumers. Irrigating with untreated wastewater is risky business in developing countries, yet it generates household income for families with limited livelihood alternatives. Many farmers irrigating with untreated wastewater likely would vote to continue using the wastewater, even if they understood the risks, in the absence of an alternative, higher quality source.

In a sense, farmers using untreated wastewater provide a public service by removing effluent from polluted streams and applying it to soils, thus reducing the pollutant load in downstream locations. However, wastewater irrigation also generates risk for farm communities and consumers of farm products. Polluted canals and ditches, and wastewater-irrigated fields create hazards in which children and other residents are exposed to harmful pathogens and chemicals (Grangier et al. 2012). Consumers of farm produce also are at risk of illness when they handle and ingest contaminated vegetables, particularly when the food is eaten raw or prepared with inadequate care toward reducing contamination risk.

In this chapter, we describe the important roles of policies and institutions in motivating and assuring the safe use of wastewater in agriculture, with particular emphasis on low and middle income countries. The policy issues in higher income countries are somewhat straightforward and mature, as public agencies have largely determined appropriate water quality criteria and implemented treatment protocols to support wastewater use in irrigation. Future issues will include refining those standards and protocols and evaluating the costs and benefits of alternative levels of wastewater treatment and use in agriculture and other activities. There will also be discussions of who should pay for wastewater treatment and who should have priority in receiving limited supplies of treated wastewater. Those issues involve costs, returns, and the allocation of economic rents, but they generally do not involve decisions that can support or destroy livelihood opportunities, either intentionally, or as the unintended consequences of seemingly beneficial policy choices.

Policy issues are more challenging in developing countries, where most of the wastewater used for irrigation is untreated and much of the use is informal and unintentional (Wichelns and Drechsel 2011). In addition, institutional arrangements are unclear and few specialists are trained to manage wastewater collection and treatment. Farmers, communities, and consumers are at risk from harmful constituents in the untreated wastewater, yet each group also obtains important benefits (Scheierling et al. 2011). Farmers generate financial returns that enhance their livelihoods and improve the economic status of farm communities. Consumers gain nutritional value by having affordable access to locally grown fresh vegetables (Weldesilassie et al. 2011). The public, more generally, benefits also when farmers divert effluent for use in irrigation, rather than allowing it to continue flowing downstream.

Public funding for treating all wastewater will not be available in many regions within the foreseeable future. Lacking the treatment alternative, public agencies must identify measures that will reduce the risks of using untreated wastewater, while maintaining the benefits that accrue to farmers, consumers, and the larger community (Drechsel and Seidu 2011). The best policies and programs will address both farm-level and societal concerns regarding the costs and benefits of wastewater irrigation. Farmers will seek assurances that they can maintain their access to wastewater for irrigation, while consumers will need assurances that the crops irrigated with wastewater are safe to consume. Crafting policies that address both sets of concerns will be challenging in some settings. Yet the potential rewards of implementing successful risk reduction measures that will enable the safe and profitable use of wastewater in agriculture are substantial.

6.2 A Conceptual Framework

From a policy perspective, the use of wastewater in agriculture provides opportunities and challenges that require public intervention. In one sense wastewater is an effluent requiring treatment or disposal, subject to regulations that protect public health. In the absence of regulations, private generators of wastewater would have little incentive to reduce volume or to manage the flow of wastewater beyond their property line. Because wastewater generation is a negative externality in most settings, regulations and incentives are needed to minimize the potential harm from wastewater in the environment.

Wastewater management has public good characteristics in that once it is provided, many members of society benefit. At the same time, it is difficult to exclude individuals from enjoying the benefits of a cleaner, healthier environment once the decision has been made to collect and treat all wastewater in a community. The non-rival nature of the benefits and the difficulty of exclusion provide the basis for managing wastewater treatment within the public sector.

The public goods perspective is appropriate when viewing wastewater as an effluent requiring treatment or disposal. However, when viewing wastewater as a resource, there are notable private benefits for which individuals will be willing to invest time, effort, and funding to enhance their opportunities. The private goods perspective pertains to both treated and untreated wastewater. Several water agencies in Australia, Israel, and the United States sell treated wastewater (directly or through an aquifer recharge program) to farmers and golf course owners who obtain private benefits through irrigation (Mills et al. 2004; van Roon 2007). Often there is a price differential between treated wastewater and fresh water, thus providing a financial incentive for irrigators to select the treated wastewater (Hurlimann and McKay 2007).

Farmers in developing countries also obtain private benefits, but the distribution of wastewater among them is much less formal and the wastewater generally has not been treated. An estimated 80 % of the sewage generated in developing countries is discharged untreated into the environment, and half the population is exposed to polluted water sources (UNESCO 2003; Drechsel and Evans 2010). Many farmers acquire untreated wastewater when they divert irrigation water from a stream or ditch that carries effluent from a nearby city or from households in an urban, peri-urban, or rural area. Water diversions and the use of wastewater in such settings generate private benefits for the farmers. The public gains also as the farmers remove the low-quality water from streams and ditches. However, the primary motivation for farmers is to boost their productivity and increase their net returns. By doing so, they risk the health of their families through exposure to untreated wastewater and they create situations in which consumers also are at risk of eating harmful produce. Public policies are needed to reduce these risks and to optimize the management of wastewater from the public's perspective.

6.3 Policy Challenges in Low and Middle Income Countries

Policy issues pertaining to wastewater irrigation in developing countries are notably challenging, in part, because much of the wastewater irrigation takes place in decentralized, informal settings in which individual farmers gain access to wastewater simply by diverting polluted water from a stream or ditch. Property rights to the water are not defined and there is no communal agency or water user association that coordinates irrigation activities. Millions of individual farmers will be reluctant to stop diverting polluted water for use in irrigation, given that their livelihoods depend on the sale of irrigated farm produce. In addition, financial resources are limited in developing countries and there are many competing demands on public funds. Thus, it is unlikely that large gains will be made in treating wastewater in the near future.

Public officials in developing countries must determine how to minimize the risks to farmers and consumers, while not destroying or severely diminishing the livelihoods of those farmers who currently irrigate with wastewater. This will not be easily achieved. Public officials will be mindful of the benefits that farmers provide by diverting and using polluted water for irrigation. If not for that activity, larger volumes of wastewater would continue flowing downstream in many watercourses, creating greater risk for downstream residents and causing environmental harm over a larger area. Farmers who irrigate with wastewater generate one set of risks for their families and consumers, while reducing another set of risks to residents downstream.

In summary, farmers generate both private and public benefits when they divert polluted water from streams and ditches to irrigate crops in urban areas. Public officials in developing countries must determine how to sustain these beneficial aspects of wastewater irrigation and the livelihoods of farm families, while minimizing risks to those same families and the consumers of their produce.

6.4 Interventions Include Treatment and Non-treatment Alternatives

The interventions available to public officials for reducing the risks associated with wastewater irrigation in developing countries, while sustaining livelihood benefits, might be placed in four categories:

1. Improve and extend centralized wastewater treatment
2. Improve and extend de-centralized wastewater treatment
3. Regulate (with enforcement) the use of untreated wastewater in agriculture
4. Complement existing wastewater use patterns with risk reduction interventions to protect farm families, communities, and consumers

The first category is likely the most costly and the least likely to be implemented along a reasonable timeline. There might be affordable opportunities in some settings within developing countries, in which new, large-scale wastewater treatment plants can be constructed to improve the quality of water available for agriculture. Yet it seems that if such opportunities were affordable, if they compared favorably with alternative public investments, and if an affordable source of finance were available, then such efforts would already be underway. It is difficult to imagine that the pace of investments in large, centralized wastewater treatment plants will be sufficient to improve water quality for many of the farmers who currently use wastewater for irrigation in developing countries.

Some developing countries are beginning to invest in wastewater collection, treatment, and reuse systems. For example, in the Mezquital Valley, Mexico where about 90,000 ha are irrigated largely with untreated wastewater, the government has invested in wastewater treatment. Initiated in 2010 on the basis of a build-operate-transfer contract, a large wastewater treatment plant is under construction, and is expected to be completed in 2015 (see also Chap. 9 of this book).

The second category includes interventions that should be more affordable than building large, centralized wastewater treatment plants. The goal within this category is to identify opportunities for enhancing irrigation water quality at an appropriate scale and within a meaningful distance from the point of wastewater use. Small-scale wastewater treatment plants might be designed with the expressed purpose of making higher quality water available for irrigation. The construction costs and operating criteria for such plants might be different—and less expensive—than those pertaining to centralized wastewater treatment plants that discharge water intended for uses outside agriculture (van Lier and Huibers 2010). For example, it is important to remove solids, salts, and pathogens from water intended for use in irrigation, but farmers can accommodate higher nutrient levels than wastewater users in municipal and industrial settings.

The third category likely will be challenging in many developing country settings, given the decentralized, informal nature of wastewater use and the strong dependency of farm households on wastewater. Regulations will be politically unpopular and enforcement will be difficult to achieve. In Syria, for example, the government disallows the irrigation of vegetables with wastewater, but compliance with the restriction is not complete. Syrian officials resort to destroying vegetable crops irrigated with wastewater when they find such situations. As a result, less than 7 % of the area irrigated with wastewater near the city of Aleppo is in vegetable production (Qadir et al. 2010). The opportunity costs involved in planting and cultivating crops, only to have them destroyed by the government, can be substantial for farm households with limited sources of income.

The financial burden of treating wastewater in developing countries and the challenge of regulating wastewater use by farmers will remain substantial for the foreseeable future. Hence, many farmers will continue using wastewater and their workers and families will remain at risk of infection while applying irrigation water. Consumers will remain susceptible to sickness caused by handling and consuming the irrigated produce. Given this near-term outlook, public agencies in developing countries should seek opportunities to reduce the risks of infection and sickness by intervening at selected stages of the process that includes wastewater generation, capture, irrigation, crop production, harvest and handling, and food preparation and consumption. Thus we focus on the fourth category of policy options—reducing risk to farm households, communities, and consumers.

6.5 Interventions Should Focus on Reducing Risk

Conventional wastewater treatment might be viewed as the ultimate risk reduction measure when considering the use of wastewater in irrigation (Keraita et al. 2010a). Establishing and enforcing water quality standards, in conjunction with a wastewater treatment program, can be effective in removing potentially harmful constituents. However, the cost of treating wastewater and enforcing water quality standards will exceed affordability in many developing countries. Recognizing this challenge, the World Health Organization recommends shifting the policy focus from reliance on wastewater treatment and water quality standards, to establishing health-based targets that might be achieved by implementing a range of risk reducing interventions (WHO 2006a; Keraita et al. 2010a).

The World Health Organization (WHO 2006b) describes three sets of health protection measures pertaining to the three groups most susceptible to health impacts of wastewater irrigation: (1) farmers and their families, (2) agricultural communities, and (3) consumers of farm products. We consider each group in turn.

6.5.1 Farmers and Their Families

When delivering irrigation water or working in fields irrigated with wastewater, farmers, family members, and other farm workers can be exposed to microbial pathogens including viruses, bacteria, helminths (nematodes and tapeworms), and protozoa (Toze 2006). Wastewater also can contain endocrine disrupting chemicals, pharmaceutically active compounds, and residuals of personal care products (Ternes et al. 2007; Lapen et al. 2008; Siemens et al. 2008; Topp et al. 2008). Exposure to wastewater can result in skin irritation and diseases related to pathogens in human waste products. The World Health Organization (WHO 2006b) recommends considering the following measures when designing interventions to protect farmers and their families:

1. Treating wastewater
2. Supporting the use of personal protective equipment
3. Providing access to safe drinking water and sanitation on farms
4. Promoting good health and hygiene practices
5. Providing chemotherapy[1] and immunization
6. Controlling disease vectors and intermediate hosts
7. Reducing contact with disease vectors

One or more of these measures would be helpful in breaking or disrupting the pathway of contamination from wastewater to farm family members and farm workers. However, success will be determined by how effectively the benefits of these measures are communicated to farmers, and how aggressively farm workers adopt them. The farm-level cost of any measure also will be a key determinant of its successful adoption.

6.5.2 Agricultural Communities

In a sense, many residents of agricultural communities are susceptible to the same type of risks as farmers and their families, particularly if they utilize water in irrigation canals or ditches, or they have access to farm fields. In many irrigated areas, community residents use water from irrigation canals or ditches for cleaning clothes, washing livestock, and watering kitchen gardens (Meinzen-Dick and van der Hoek 2001). Young children often swim or play in irrigation ditches, while some residents rely on irrigation canals as a source of household drinking water (Senzanje et al. 2008). The lack of knowledge regarding the potential health risks in many rural and peri-urban settings, and the scarcity of fresh water supplies, create situations in which many residents are at substantial risk. The World Health Organization (WHO 2006b) recommends the following measures to protect members of agricultural communities:

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[1] The term refers in this context to the use of, for example, deworming tablets, i.e. chemical treatment of infections.

1. Treating wastewater
2. Restricting access to irrigated fields and canals and ditches
3. Providing safe recreational water, particularly for adolescents
4. Providing safe drinking water and sanitation facilities to communities
5. Promoting good health and hygiene practices
6. Providing chemotherapy and immunization
7. Controlling disease vectors and intermediate hosts
8. Reducing contact with disease vectors

Several of these measures are similar to those recommended to protect farm families and farm workers, given the similarity in exposure opportunities on farms and in the larger community. Many of the challenges involved in implementing the measures and encouraging sustainable adoption also would be similar.

6.5.3 Consumers of Farm Products

In many settings, in the absence of policy intervention, consumers might be the least informed group regarding the potential health risks due to wastewater irrigation. They might be unaware that farmers using wastewater have produced some of the fruits and vegetables for sale in local markets. They might also be unaware that some of the farm produce carries harmful pathogens and chemicals, or that cooking the produce might reduce the likelihood of damage from infectious pathogens. Given these considerations, the World Health Organization (WHO 2006b) recommends the following measures to reduce the risk to consumers:

1. Treating wastewater
2. Restricting the crops that are irrigated with wastewater
3. Promoting irrigation practices that minimize contamination of plants
4. Implementing withholding periods that allow pathogens to die between the last irrigation and harvest
5. Promoting hygienic practices at food markets and during food preparation
6. Promoting good health and hygiene practices
7. Promoting produce washing, disinfection, and cooking
8. Providing chemotherapy and immunization.

Although enforcement will be difficult, public agencies might consider disallowing wastewater irrigation of vegetables and other crops that consumers often eat without cooking. Leafy vegetables, such as lettuce and spinach, are particularly prone to accumulating pathogens on edible portions of the plant when wastewater is applied directly over the plants and when irrigators splash contaminated soil particles on the leaves (Keraita et al. 2010b). Modifying the spouts of watering cans will reduce contamination by reducing the splashing of soil particles (Keraita et al. 2010b). Drip irrigation on the soil surface or below ground will minimize contamination (Capra and Scicolone 2007), but many poor farmers will not have the funds to invest in such systems.

Withholding periods between the date of last irrigation and harvest are sensible approaches, as well, but monitoring and enforcement might be problematic in areas where wastewater irrigation is prevalent. Some farmers report that irrigating lettuce on the morning of the day of harvest freshens the crop and enhances its appearance in local markets (Keraita et al. 2010b). Encouraging farmers to change such practices will be challenging, particularly given the perishable nature of leafy vegetable crops. Farmers generally want to obtain the highest price possible and to sell their produce quickly, before its appearance and quality begin to fade.

Public efforts to improve hygienic practices and food preparation at homes and in the marketplace also will be challenging. In areas where small-scale farmers sell produce to small-scale vendors who re-sell the produce in a restaurant or fast-food outlet, individuals have little incentive to assume the extra cost of enhanced food treatment. This situation in which information is limited and asymmetric, can be described also an externality involving producers and consumers. The benefits of a cleaner, safer food supply accrue to consumers and communities, rather than to the farmers and food shop owners who will incur higher costs if they implement improved production, washing, and handling practices. Public policy is needed to ensure that farmers and vendors internalize the external costs of their activities.

6.6 Examples of Public Policies

Helpful examples of public policies regarding wastewater use in irrigation are found in the Middle East and North Africa, and other regions where farmers have been using treated and untreated wastewater for many years. In some countries, such as Egypt, the volume of municipal wastewater exceeds the treatment capacity, and large volumes of untreated wastewater enter agricultural drains (Abdel-Dayem et al. 2007). The government attempts to manage the blending of treated and untreated wastewater with agricultural drainage water, and the use of blended water by farmers, but success is limited by the scale of the problem and the strong demand for supplemental water supplies in the Nile Delta. Irrigation with treated wastewater will increase over time, with the expansion of wastewater treatment capacity.

The Palestinian Ministry of Agriculture, which regulates the use of treated wastewater on the West Bank, requires color coding of pipelines carrying fresh water and wastewater, and the posting of lands irrigated with treated wastewater (Mizyed 2013). In addition, farmers irrigating with treated wastewater are required to wear protective clothing, although it is not clear if the monitoring and enforcement of the clothing regulation is effective. The extent of wastewater treatment and use in agriculture on the West Bank is limited partly by the lack of funding for treatment facilities and also by limited public acceptance of wastewater irrigation (McNeill et al. 2009).

Several countries in the region, including Algeria, Cyprus, and Tunisia, do not allow the irrigation of vegetables with treated wastewater. Cyprus also disallows the irrigation of ornamental plants destined for sale in international markets (Angelakis et al.1999). Wastewater policies are well developed in Cyprus and Tunisia, where the governments actively support and regulate wastewater treatment and use. In Cyprus, the government pays for large portions of the cost of water treatment plants in cities and villages, while also paying for the distribution of wastewater to farmers (Bazza 2003). Tunisia requires that industries comply with wastewater discharge standards designed to support reuse on farms, golf courses, and landscapes, and also for aquifer recharge (Bazza 2003). Saudi Arabia plans to use all of its treated wastewater, primarily in agriculture. The city of Muscat in Oman has installed an extensive drip irrigation system for irrigating landscapes with treated municipal wastewater (Bakir 2001).

Several autonomous provinces in Spain have developed legal prescriptions or recommendations regarding wastewater use in agriculture (Angelakis et al. 2003). Wastewater accounts for an estimated 41 % of the irrigation water used on Spanish golf courses (Rodriguez Diaz et al. 2007). Much of the agricultural use of wastewater in Spain occurs along its arid Mediterranean coast and on nearby islands (Pedrero et al. 2010).

In Italy, legislators have acknowledged the potential value of treated wastewater use in irrigation, yet the implementing regulations are not sufficiently accommodative to promote widespread use of wastewater by farmers (Cirelli et al. 2012). In particular, there are many water quality parameters to be considered (54) and there is no allowance made for the impacts of alternative methods of irrigation on the likelihood of harm when applying wastewater. The same regulations apply to farmers using furrow irrigation and to those using sprinklers or drip systems. Yet the likelihood of contaminating vegetables is much smaller with drip irrigation, as less wastewater comes in contact with the plants. The government of Botswana has encouraged greater use of wastewater in irrigation and mining, in part, by ending its policy of providing fresh water supplies at subsidized prices (Swatuk and Rahm 2004). Botswana also is considering how to account for wastewater volumes within its national water accounting framework (Arntzen and Setlhogile 2007).

The city of Beijing, China uses a combination of administrative orders and financial incentives to motivate greater use of wastewater, as part of its strategy to accommodate increasing water demands. Households and industries in Beijing can purchase treated wastewater for 1 RMB per m^3 ($ 0.16), which is much lower than the prices of 4.0 RMB per m^3 for conventional water for household use and 6.2 per m^3 for industrial use (Chang and Ma 2012). Farmers can purchase treated wastewater for 0.05 RMB per m^3 ($ 0.008), which is less than the cost of pumping groundwater in agricultural areas of the city. Since 2003, the proportion of treated wastewater in Beijing's water deliveries has increased from 5.7 to 19.3 % (Chang and Ma 2012).

Beijing's progressive development of wastewater use has been motivated, in part, by a management directive issued by the city in 2009. The directive addresses the sectoral allocation of wastewater and calls for constructing safe distribution channels, as stated in four key points (Chang and Ma 2012):

1. Treated wastewater will be integrated into the city's water allocation system, and will be blended with surface water and groundwater.

2. Treated wastewater will be used primarily in industry and agriculture, and also for landscaping and to supplement lakes and rivers.
3. Wastewater suppliers and users will be guided by contracts they sign for the purchase and delivery of treated wastewater.
4. The delivery channels for wastewater must be constructed to ensure that water quality is maintained.

Not all efforts to implement wastewater treatment and management are successful as the program in Beijing. In the city of Hermosillo, Mexico, farmers lacking access to freshwater supplies continue to irrigate with untreated wastewater, despite several attempts by the city to fund and construct a water treatment plant (Scott and Pineda Pablos 2011). Absent that investment, much of the city's wastewater is discharged into irrigation canals managed by an irrigation district, which charges farmers a fee for the wastewater they divert. The farmers are pleased to have any source of irrigation water, although their production options are constrained to fodder crops, due to uncertainties regarding health effects and the possible deterioration in soil quality, over time.

Also in Mexico, farmers irrigating crops near the city of Durango have increased their production of corn, alfalfa, and oats by using treated wastewater during periods of drought (Heinz et al. 2011). In addition to achieving a 30 % increase in output, the farmers have reduced their fertilizer use by about 50 %. The city benefits, as well, from the reduced demand pressure on its limited groundwater supply.

Public officials in countries with little experience in regulating the use of wastewater in irrigation can gain value by reviewing the examples presented here and by considering ways to engage producers and consumers in active discussion of wastewater issues. As in many regulatory settings, the prospect of new rules and procedures regarding wastewater irrigation and food preparation will be viewed initially as a cost-increasing outcome that will harm the financial performance of individual farmers and food vendors. Hence the rational strategy from an individual's perspective, involves a combination of maintaining a low profile and quietly lobbying against the adoption of any new programs. Yet, in aggregate, net social welfare is decreased if the sum of damages from using wastewater in irrigation exceeds the sum of the benefits.

Perhaps the key to starting policy discussions is to demonstrate the potential gains in aggregate net benefits. Farmers, food vendors, and consumers can gain value together as they work with public officials to develop safe practices in crop production and food preparation. Individual farmers and food vendors will not be disadvantaged if everyone agrees to adopt safe practices, and if consumers are willing to pay higher prices in return for safety assurances. Details regarding policy parameters, and effective monitoring and enforcement programs can be developed over time, once all parties appreciate the potential gains in net benefits made possible through the safe and efficient use of wastewater in agriculture and the preparation of healthful food products.

6.7 Policies and Interventions Differ, But the Goals Are Similar

Policies and interventions regarding the use of wastewater in irrigation are quite different in developed and developing countries. In developed countries, most municipal and industrial wastewater is treated, and thus most of the wastewater used in agriculture is treated. Protective guidelines regarding the quality of wastewater used for irrigation have been in place for many years. Interventions in developed countries pertain largely to financial and economic considerations regarding the improvement and expansion of wastewater treatment facilities. Public officials and water management agencies motivate greater use of wastewater by providing financial incentives and increasing public awareness of the safety and benefits of using treated wastewater on farms, golf courses and urban landscapes.

Public officials in developing countries also consider financial and economic questions regarding investments in wastewater treatment and use. However, in many countries, the pace of such investments will not be sufficient to meet demand, or remains uncoordinated. For instance, national water policy framework and reuse guidelines in India denote the need for wastewater use but with little progress towards specific treatment standards, types of reuse, operation and maintanace issues, and tariff structures for various reuses. Many reuse projects led by various states and cities across India operate in isolation and locally, often with a delink to national policy and programs.

Much of the wastewater generated in cities and rural areas will remain untreated for many years. As a result, farmers will continue to use untreated wastewater for irrigation, and their use will be largely unintentional and informal. Public officials must therefore implement risk reduction programs that protect farm families, communities, food vendors, and consumers from the potentially harmful effects of exposure to the pathogens and chemicals in untreated wastewater.

Public investments and interventions in developing countries will reflect a range of activities along a pathway that includes wastewater generation, irrigation water capture and use, crop production and harvest, food preparation, and consumption. Public officials can implement risk-reducing guidelines and programs at each stage along the wastewater exposure pathway. For example, public officials can support improvements in wastewater treatment at the point of generation, when funds for such improvements are available. Officials also can call for changes in household and industrial production practices that would reduce the loads of harmful constituents in wastewater, thus reducing concentrations of those constituents in the irrigation water diverted from streams and ditches by farmers.

At the farm level, public agencies can provide technical assistance regarding water diversion and irrigation methods that would reduce potential exposure of farm workers to harmful pathogens and chemicals. Technical assistance regarding irrigation methods that reduce contamination of leafy vegetables and other produce consumed without cooking is essential for reducing risks to food vendors and consumers. Although difficult to enforce, regulations that establish a minimum time period between the dates of last irrigation and harvest would be helpful in reducing the risk of contamination from agricultural products.

Public officials in developing countries might also consider implementing certification programs for “consumer safe” farm produce, particularly in markets where local farmers sell their irrigated vegetables. Public agencies can begin such programs, with support from farmers and food vendors, but eventually market forces must arise to sustain them. Consumers must find value in certified produce and they must be willing to pay a small premium that compensates farmers and vendors for their costs in providing the safer produce. Educational and marketing campaigns can be helpful in boosting demand for safe produce among consumers. Box 6.1 presents examples of key policy and institutional drivers of uptake of water reuse in selected counteries.

Box 6.1: Policy and Institutional Factors Driving Wastewater Use in Selected Countries

Global: The World Health Organization guidelines shift the policy focus from reliance on wastewater treatment and water quality standards, to establishing health-based targets that might be achieved by implementing a range of risk reducing interventions (WHO 2006a; WHO 2006b; Keraita et al. 2010a).

Australia: Water scarcity driven policy change is a defining feature of Australian society. Australia launched an extensive program to encourage the use of treated wastewater in agriculture and other sectors, including heavy manufacturing and water intensive industrial customers, such as power plants. This involved policy actions at national and state levels, resulting in National Guidelines for Water Recycling and Reuse (ARMCANZ-ANZECC 2000 2000) for the protection of public and environmental health and community amenities (Hanjra et al. 2012). Many entities now purchase recycled water from water providers. The new policy framework enables third party access to wastewater for recycled water projects. Increasing investments in infrastructure and research have aimed at a broadening the scope of reuse options. National policy has set a target of 30 % of Australia’s wastewater being recycled by 2015 (Marsden Jacob Associates 2012).

Israel: Israel implemented a substantial wastewater use program in irrigation in the 1970s, and today almost all crops are safely irrigated with wastewater. Israel uses about 70 % of its sewage in rrigation, and national water policy describes wastewater as an important asset (Kislev 2011). Key factors that led to the wider uptake of wastewater irrigation include (Lawhon and Schwartz 2006; Dreizin 2007; Kislev 2011):

- State water security concerns
- The National Policy on Sustainable Agriculture and Rural Development, which includes wastewater irrigation
- Collaboration between the Ministry of Agriculture and the Ministry of Environment
- Development of regulations and reuse guidelines through the Inter- Ministerial Committee

- Research and development on reuse, and its uptake into national policy
- The transfer of knowledge from research to farmers, via the government extension service
- Requiring farmers to obtain permits for irrigation with effluent
- Linking environmental and economic sustainability with establishing standards for wastewater use
- Regulating private investments in wastewater use and providing incentives for investments in technology, infrastructure and partnerships.

Singapore: So far Singapore only meets its water needs through water imports from Malaysia. During the past 20 years, policy makers have reduced reliance on outside sources in part by incorporating the best available technology in water supply and wastewater treatment. The Public Utilities Board, which serves as the single entity for managing water supply and wastewater treatment, initiated the NEWater Program, in which municipal wastewater is treated to achieve drinking water standards. Although most NEWater is used for non-potable purposes, it will meet 40 % of Singapore's total water demand by 2020. The Public Utilities Board has adopted a full metering policy, introduced proper accounting of water, and implemented measures to prevent illegal water taps. The success in Singapore is due to strong government support and effective public education and communication (Lim and Seah 2013).

Ghana: Wastewater use is not high on the political agenda in Ghana, even though some areas of the country experience a long dry season, and many urban centers are challenged to provide a continuous water supply. Within the sanitation sector, priority is given to increasing wastewater collection and treatment capacity, rather than increasing wastewater use. However, the National Environmental Sanitation Strategy and Action Plan supports the principles of waste reduction, recovery, use, and recycling. The political motivation for addressing wastewater use is the need to safeguard public health. The National Irrigation Policy, Strategies and Regulatory Measures of 2011 encourage research on safe irrigation practices in urban and peri-urban agriculture and support of best practices for the safe use of marginal quality water, in accordance with the WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture.

USA: Many American cities implement best practices in wastewater use. The US Environmental Protection Agency Guidelines for Reuse (revised in 2012), and state specific standards support wastewater use. Increasing water scarcity and the rising costs of providing water supply and environmental regulations motivate states and cities to implement wastewater use. Four states—Arizona, California, Florida, and Texas account for 90 % of all wastewater use. About 30 states have adopted grey water regulations that vary however in their comprehensiveness (Sheikh 2010).

6.8 Institutional Aspects of Wastewater Use in Agriculture

Many authors have examined wastewater use at different scales and many also have described methods and guidelines for promoting the safe use of wastewater (Ensink and van der Hoek 2009; Keraita et al. 2010a; Qadir et al. 2010; Abdulai et al. 2011). By contrast, there is limited information available regarding institutional aspects of wastewater use in agriculture, particularly in lower-middle-income and low-income countries, where respectively only 28 and 8 % of the wastewater generated is treated (Sato et al. 2013).

A recent assessment of the institutional aspects of wastewater management, undertaken in a UN-Water project addressing capacity assessment and development, examined the safe use of wastewater in agriculture (Raschid-Sally and Jayakody 2008). The project included an inception workshop and five regional workshops, involving representatives from 51 countries in Asia, Africa, Latin America, and the Caribbean. Feedback was collected in the form of responses to questionnaires and workshop discussions. This feedback from the country representatives was given in their personal capacity and views, and provided the basis for an assessment of the institutional aspects of wastewater management.

The representatives report a variety of institutional arrangements regarding the responsibility for wastewater management at the national or central government level. In India, wastewater management is the responsibility of the Ministry of the Environment and Forests, while in Iran, the Ministry of Energy has the responsibility. In Iraq and China, wastewater management falls within the Ministry of Agriculture, while in Jordan, the Ministry of Water and Irrigation is responsible. In some countries, several ministries share responsibility for wastewater management. For example, in Thailand, the Ministries of Industry (industrial wastewater), Interior (community wastewater), Natural Resources and Environment (water quality of natural water resources), and Public Health (human excreta collection, transportation and treatment) share the responsibility. In many countries, the ministry responsible for wastewater management and sanitation is not the ministry responsible for irrigation.

Similar diversity in wastewater management is observed at the municipal level, where a many institutions are responsible for wastewater collection, treatment, use, and disposal. None of the representatives reports excellent inter-ministerial or inter-institutional collaboration in wastewater management. Only 10 countries report adequate collaboration (20 %), 20 countries report inadequate collaboration (40 %) and 18 countries report average collaboration (36 %). Three countries report no inter-ministerial collaboration in managing wastewater.

There is also a lack of coordination between national agencies and local institutions for wastewater management, institutional arrangements are not sufficiently clear, and there are overlapping responsibilities across institutions. As a result, there are bureaucratic limitations in wastewater management at different scales. In terms of rating governments' commitment and budget allocation to wastewater management, a trend similar to inter-ministerial collaboration was reported by the participants of the capacity development workshops. Only 7 countries reported adequate commitment and budget allocation for wastewater management (14 %). Twenty-two countries reported an inadequate level (44 %) and 18 countries reported an average level (36 %). Four countries reported very little budget allocation for wastewater management. In cases in which wastewater treatment is not the primary objective of the responsible authority, the transaction costs of implementing programs can be substantial. In Ghana, for example, the Ministry of Defense manages its own treatment plants, while the Ministry of Health manages the treatment plants in hospitals, and the Ministry of Education manages their plants in universities.

Only seven countries report that farmers in peri-urban areas pay a local institution or organization for the wastewater they use for irrigation. In Tunisia, farmers pay for the volume of irrigation water required, the area to be irrigated, and the number of hours corresponding to the contract, at a rate of TND 0.02–0.03 per m^3 (US$ 0.012 to US$ 0.018 per m^3 in 2013). In some areas of South Africa, such as in eThekwini Metropolitan Municipality, the cost of wastewater is much lower than the cost of potable water. As drinking water often is subsidized, it is difficult to achieve substantial cost recovery for water reuse where wastewater is sold at a very low price.

In some areas of India, treatment is not available or sought for much of the collected wastewater, and it is sold to nearby farmers by the respective Water and Sewerage Board. In areas that lack alternative sources of water, such as Vadodara in Gujarat, one of the most lucrative income-generating activities for the lower social classes is the sale of wastewater and the renting of pumps for lifting wastewater. In Jordan, farmers sign contracts for wastewater with the Water Authority of Jordan, usually at 20 fils per m^3 (US$ 0.028 per m^3 in 2013). In Pakistan, wastewater is auctioned, and the highest bidder in turn sells the water to small farmers on an hourly basis. In Mexico, wastewater irrigators in the Mezquital Valley pay US$ 0.80 per ha.

There are only nine countries where farmer associations or water user associations collaborate with local institutions for wastewater delivery. In the Tula Irrigation District (District 03, Mezquital Valley, in Mexico), there are several farmer associations that have been operating since the 1990s. These associations develop irrigation plans, ensure water distribution, and conduct assessments of farm-level fertilizer and pesticide use, to improve crop yields. In South Africa, there is a private network of local communities for wastewater use in the eThekwini Metropolitan Municipality area. In addition, there are farmer groups in Mauritius that collaborate with the Wastewater Management Authority regarding the amount and quality of wastewater delivered. In general, however, there is a divide between the agriculture and sanitation sectors, and a lack of collaboration between farmer associations or water user associations and institutions responsible for wastewater management.

The subjects of wastewater management and use do not appear in the standard course offerings of many primary or secondary schools. Most countries have yet to introduce the importance of water quality and wastewater management in their standard curriculum. However, in recent years, several universities have added new courses on wastewater management and use.

6.9 Summing Up

The policies and interventions we describe pertain largely to near-term strategies for minimizing the risk of negative health effects, while also enabling farmers to gain the potential benefits of using untreated and partially treated wastewater in agriculture. This approach is appropriate for countries that presently cannot afford to build, operate, and maintain a full complement of modern wastewater treatment facilities. Over time, as the demand for water in agriculture and other uses continues to increase, public officials in all countries should endeavor to provide wastewater treatment that matches end uses, including the irrigation of crops, landscapes, and golf courses. In developing countries, it will be necessary also to ensure that small-scale farmers retain access to a reliable source of irrigation water when the untreated and commingled wastewater they once relied on becomes unavailable, with the expansion of wastewater treatment programs.

Institutional arrangements regarding wastewater collection and reuse are unclear in many countries. In some countries, the responsibility for wastewater management is divided among several ministries or departments, rather than placed within a single agency. This can increase the transaction costs of managing wastewater effectively and delay the pace with which improvements are implemented. In addition, the annual budgets of many countries are not sufficient to support the collection, treatment, and reuse of all wastewater in an environmentally acceptable manner.

In most countries of Asia, Africa, Latin America, and the Caribbean, supportive institutional arrangements are needed to facilitate wastewater collection, treatment, and reuse. These arrangements must be implemented at several levels and may include some of the following components: relevant policies facilitating water recycling and reuse at the local and national scales; strategic campaigns regarding water quality protection and wastewater treatment and productive reuse; and institutional collaboration such as private sector participation. A flexible policy framework, implemented with effective institutional support across sectors, can be helpful in addressing rapid demographic changes and protecting public health and the environment. To champion the concept of a ‘Circular Economy’ where recycling is taken seriously, the right combination of smart policies, effective institutional linkages, and wise financial planning will enable cities, provinces, and countries to achieve the potential private and public benefits made possible by collecting, treating, and using wastewater and its byproducts in agriculture and other sectors.

Take Home Messages

- Limited information is available regarding institutional aspects of wastewater use in agriculture, particularly in lower- and low-income countries.
- Information is limited also regarding the trajectory toward comprehensive regulatory frameworks in high-income countries.

- Future policy issues include refining wastewater use guidelines and protocols, and continually evaluating the costs and benefits for pro-development policy.
- In addition, policy interventions should focus on reducing risks by motivating safer practices by those who use wastewater, consume wastewater irrigated crops and get in contact with parks or landscapes irrigated with wastewater.
- Smart policies, effective institutions, and financial instruments are needed to enhance the public and private benefits of wastewater use programs.

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Chapter 7
Assessing the Finance and Economics of Resource Recovery and Reuse Solutions Across Scales

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Abstract The recovery and reuse of wastewater can contribute to reducing poverty, improving food security, improving nutrition and health, and managing natural resources more sustainability to protect ecosystems and build climate resilient communities. Reusing wastewater generates both private and public benefits, yet care must be taken to minimize environmental harm and risks to human health. Assessing the costs and benefits of wastewater use is challenging for decision making. Financial analysis of wastewater and other reuse options can underpin decision making from a business standpoint, and economic analysis provides the information needed to support public policy decisions. In this chapter, we provide a framework for assessing the finance and economics of wastewater and other reuse options. We examine several components of resource recovery and reuse, including water reuse, energy recovery, and nutrient capture from wastewater as well as fecal sludge and biosolids. We describe the cost-savings and partial cost-recovery made possible by wastewater use and we discuss value propositions for possible business models. Many water reuse solutions do not achieve financial cost recovery but are viable

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from an economic perspective. However, public agencies can enhance revenue streams by supporting more than water recovery and/or by targeting high-end users.

Keywords Resource recovery · Value · Energy · Nutrient capture · Biosolids · Externalities

7.1 Introduction

Wastewater use can be one important component of a wise resource recovery and reuse (RRR) program for sustainable development. Reuse program can contribute to prosperity through the reuse of water in wastewater and other useful constituents. Improved management of wastewater use can offer positive-sum solutions in human health and ecosystem protection. Concern about the sustainability of water use for future food security provides motivation to understand the potential of water reuse and nutrient capture and energy recovery through energy generation from biogas during the treatment process as well as small hydropower to generate energy upstream before the influent enters the plant due to elevation difference and then from the treated effluent before it is discharged downstream to the environment. Wastewater can also be used for aquifer recharge, water swaps with irrigators to deliver more freshwater to urban users, reducing extraction from groundwater through exchange of entitlements, environmental restoration as well as for earning carbon credits and trading in the future markets. Fecal sludge and sludge from wastewater can also contribute to biogas and energy production to help address the future energy resource challenges while reducing emission to the environment and contributing towards climate change adaptation and mitigation. We use the term RRR to refer to the several components of resource recovery and reuse, including water reuse, energy recovery and nutrient capture from wastewater as well as fecal sludge and biosolids—RRR Solutions.

Wastewater use can contribute to reducing rural poverty, improving food security, improving nutrition and health, and managing natural resources more sustainability to protect ecosystems and build climate resilient communities. Securing sustainable water, nutrients, and energy for all is a post-2015 Global Goal for Water (UN-Water 2014). Towards that goal, addressing wastewater use and water quality issues will promote the following development outcomes, among others, via several pathways as shown in Fig. 7.1.

However there are negative externalities of waste water use such as risks to public health and environmental risks due to excess nutrients (Kalavrouziotis et al. 2008), pathogens (Kazmia et al. 2008), saline salts and heavy metals (Li et al. 2009). These can negatively impact human health (Toze 2006), biosafety (Feldlite et al. 2008), soil and groundwater resources (Walker and Lin 2008; Khan et al. 2008), and the natural and built infrastructure (Rong-guang et al. 2008). These can also result in negative consumer attitude and societal back lash towards reuse (Chap. 8). Research findings compiled from studies around the globe (Keraita et al. 2010)

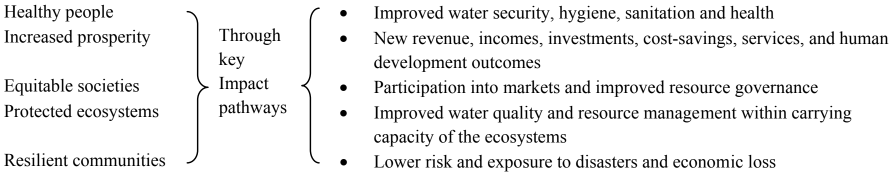

Fig. 7.1 Wastewater use for better development outcomes. (Source: Authors based on UN-Water 2014)

suggest that awareness of health risks is not high among farmers. However, 89 % of the farmers interviewed in two case studies in Nepal linked untreated wastewater use with negative health outcomes, specifically skin irritations (Rutkowski et al. 2007). Wastewater governance issues, due to weak institutions and policy failures in most developing countries, increase these environmental and health risks (Asano and Levine 1996). They may accept the environmental and health risks due to the economic benefits of using wastewater for irrigation (Wichelns and Drechsel 2011).

The socio-economic benefits from wastewater use in agriculture, for instance, have often been inadequately differentiated and quantified. A better understanding of the costs and benefits of reuse in agriculture can improve understanding of the significance of wastewater as a resource and can highlight implications of its use on public health and ecosystems. Economics and finance of other correlated benefits, including groundwater recharge and entitlement trading, water swaps and water transfers across sectors, energy recovery and ecosystem services have generally not been assessed. This chapter will provide a framework for assessing financial and economic costs and benefits of wastewater use at different scales and for different reuse options and also point at useful handbooks.

7.2 Values of Wastewater and Costs and Benefits of Reusing

We examine the empirical evidence on the costs and benefits of water reuse and we place these into a unifying conceptual framework for guiding the financial and economic analysis. In particular, we examine water reuse, nutrient capture, and energy recovery with a special emphasis on options related to water.

Water recovered from wastewater serves as a key resource in the face of water security and climate change issues. Bulk of the water that is diverted for consumption purposes in urban areas is returned back to the sewage network or drains as wastewater. Humans create vast quantities of wastewater through inefficiencies and poor management of water systems. Further, the wastewater is often a more reliable and local source of water supply for reuse in agriculture and other reuse options since wastewater discharge will continue to rise with urbanization and urban use have a higher priority over any other water use. Wastewater has become a strategic asset serving many constituencies including the reuse for economic purposes and its potential commodification as an instrument for exercising economic control and gaining access to lucrative future markets, and for inter-sectoral water transfers (Molle and Berkoff 2006; Winpenny et al. 2010). New approaches are emerging for reusing wastewater in agriculture and beyond and in some cases business propositions have been put forward to promote reuse options including nutrients and energy recovery based on business principles (move from partial to full cost recovery and earning net profits). However, their widespread adoption will require how freshwater is sourced, managed, used, and priced (Grant et al. 2012). The reuse options involving water, nutrients, energy, and carbon credits offer economic value and fresh business opportunities. The details of value propositions, costs and benefits of various RRR Solutions can be found elsewhere in this book (see in particular Chaps. 11–13). In Table 7.1 we summarize the main ideas based on selected empirical evidence (Qadir et al. 2010; Hanjra et al. 2011; Hussain et al. 2002; Weldesilassie et al. 2011).

Potential benefits from RRR Solutions are health and environmental benefits from the averted human exposure to waste that would otherwise be traditionally disposed of into the environment, contaminating water bodies and even groundwater. In specific cases, traditional roles of women are associated with waste management at the household level. This implies that in the instance of status quo (poor waste collection systems), women are exposed to waste first hand. Additionally, in the case where water from water bodies is used directly by women for household activities, they are the most directly exposed to the contamination and pollution. Thus from this perspective, benefits from RRR Solutions that seek to change the status quo can accrue directly to women and children via health cost savings, and improvements in productivity and human capital. This suggests the need for consideration of gender aspects in RRR Solutions. It is important that RRR activities are not assessed in isolation of other subsectors whether in the sanitation, agricultural, energy, or related value chains as the interlinkages between these subsectors have the potential to create benefits or costs to actors outside the sector. Therefore, RRR Solutions must support gender empowerment, ecosystem services and climate resilient development (Table 7.1).

7.3 Assessing the Finance and Economics

Much of the existing literature on wastewater use has focused on the financial analysis (GWI 2009). Yet there is a need also for economic analysis for decision making from a policy perspective. Financial analysis considers the private costs and cash flows of a water reuse project, while economic analysis considers also the public costs and benefits of wastewater use (Fig. 7.2; GWI 2009). If one considers only the financial analysis, the sales revenue must at least equate costs and this is often not the case such that most reuse options have bad financials. This is because the cost of construction, operation, and maintenance is high and prices, e.g., of water reuse, fertilizer from sludge, are generally kept low to encourage uptake. The financials

Table 7.1 Value propositions and costs and benefits of RRR Solutions. (Source: Authors)

Approach	Value proposition	Main ideas	Link to the chapter(s)	Methods commonly used
	Values in wastewater			
Low economic value	Water	Wastewater is being generated by human at all times and its reuse across sectors can help address water security issues, and motivate a behavioral change for efficient use of natural resources	Chapter 8-11	CBA
	Nutrients	Nutrient capture from wastewater streams such as wastewater, fecal sludge, biosolids is the key strategy to recycle NPK, recover precious metals while addressing resource scarcity	Chapter 13	CBA, environmental analysis
	Biogas/energy	Biogas and energy production from fecal sludge, sludge from the wastewater and biogas capture for conversion into thermal power can cut energy cost and enhance cost recovery but might not become net energy neutral with current technology	Chapter 12	CBA, LCA
	Carbon credits	Investments to capture the methane, normally emitted to the environment, for carbon credits can generate new revenue for reuse businesses and provide investment opportunities	Chapter 11, 12, 13	CBA, *ex ante* calculation of emission reductions
	Costs and benefits from reuse			
	For the environment	Reduced discharge of nutrients and gases into the natural environment and better ecosystem health and services	Chapter 9, 10, 13	Environmental and economic analysis
	For farmers	Farmer benefit from a more reliable water supply with better local control, nutrient reuse, fertilizer cost savings, higher crop yield, many crops and year-round production, groundwater recharge, and higher land rent and property values	Chapter 8	CBA
	For the cities	Reuse options save costs of developing new urban supplies, promote tourism industry, protect public health, and attract investment in future reuse markets	Chapter 9-11	CBA, other
	Cross cutting issues			
	Ecosystems	No appreciable harm on the environment and ecosystems and public health must be ensured by reuse businesses	Chapter 3, 4, 9, 10	Environmental and economic analysis
	Gender neutral	Reuse options must at least be Gender Neutral – not disadvantage women and other marginalized social groups due to the nature of the technology, education and low market participation	Chapter 5	Social analysis Institutional analysis
High social value	Climate change	Reuse options must reduce ex ante carbon emissions and improve net carbon balances to ensure long term sustainability, social welfare and inter-generational equity	Chapter 7, and others	CBA , economic modeling

Note: CBA – Cost benefit analysis; LCA – Life cycle assessment; and other include a range of unspecified methods.

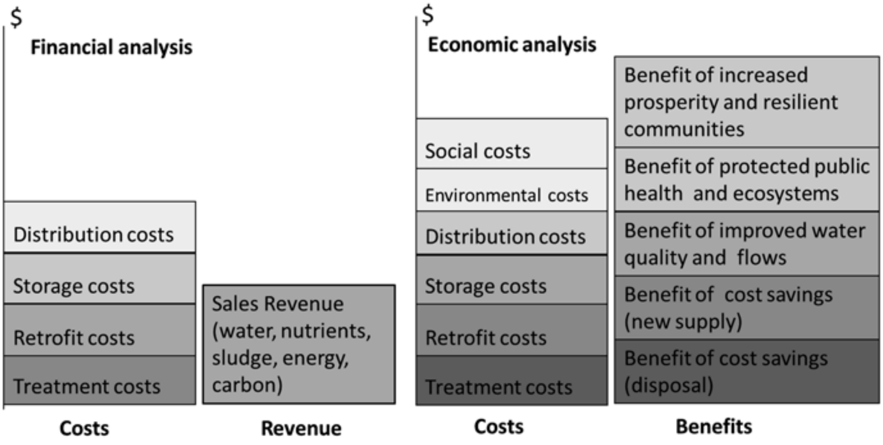

Fig. 7.2 Financial versus economic analysis of RRR Solutions. (Source: Authors modified from GWI 2009)

can improve where multiple resources are recovered, e.g., not just water but also nutrients and energy, supported e.g. by carbon credits.

Multiple resource recovery requires economic analysis which incorporates *all* financial, environmental and social costs and benefits (Table 7.2) for decision

Table 7.2 Economic costs and benefits of wastewater use. (Source: Authors based on the literature survey (GWI 2009; Hanjra et al 2011))

Economic costs	≤	Economic benefits
Financial costs: Include project planning, regulatory approvals, public consultation, building upgrade, O&M, conveyance and distribution, monitoring and compliance, billing, and legal costs of reuse options		**Financial benefits**: Depends on the fee, charges, and prices paid for the reuse options by considering all the outputs where multiple resources are recovered such as water, nutrients, energy and organic matter
Capital expenditure (CAPEX): Includes construction costs of pipes (80 % of all project costs in water reuse), distribution network (200 % higher than construction), and engineering **Operating expenditure (OPEX)**: Includes energy consumption, chemicals, materials, transport (sludge and nutrients), operator training, and salaries cost of treatment plants and reuse facilities		**Subsidies**: Account for the transfer payments received from government and other partners that help incentivize the reuse options, for instance, installation of water reuse systems (rainwater harvesting, reuse of treated wastewater), nutrient recovery (sludge for fertilizer), and energy recovery *Benefits of cost savings*—reuse options offer dual financial benefits, one from subsidies and another from cost savings of not having to invest in new projects for water, nutrients and energy
Environmental costs: Includes cost of land clearing, biodiversity loss, environmental risks, health risks, environmental impact assessment costs, and cost of mitigation measures to minimize the environmental impacts		**Environmental benefits**: *Avoids pollution*—reuse options help reduce the discharges of water, nutrients and gases to the environment with numerous environmental benefits such as better environmental quality and ecosystems. *Avoids aquifer depletion*—through wastewater use for aquifer recharge, reduce abstractions of groundwater, and replacing extraction entitlements with reuse water *Reuse benefits of water, sludge, and nutrients*—nutrients such as N and P from wastewater and sludge as fertilizer, and energy have economic value for farming, domestic and other uses

Table 7.2 (continued)

Economic costs	≤	Economic benefits
Social costs: Includes negative externalities such as noise and environmental health risks that cause disturbance to the community, and result in productivity loss and impose a cost on society. Another example is the loss of property values due to proximity to reuse facilities such that economic value of loss in property values is a cost to the residents		**Social benefits:** *Water security*—Water reuse enhances water security due to a more dependable and continuous water source. Nutrient capture and energy recovery is a renewable source of economic benefits *Healthy people*—reuse options can be implemented anywhere because waste is everywhere, and it also help to protect public health *Increased prosperity*—reuse options enhance community education and environmental awareness. Energy recovery empowers the community and girls are able to study at night and go to school for the first time in some cases, improving human capital and prosperity *Protected ecosystem and recreational benefits*—reuse solutions offer multiple reuse benefits such as reduce waste, protect ecosystems through better environmental quality, stream flow augmentation, wetlands, wildlife and aesthetics
Life cycle costs: Includes the entire costs and benefits from commissioning to eventual disposal of the reuse infrastructure and whole-life carbon costs		**Life cycle benefits:** Environmental benefits from reusing water, nutrients, sludge and energy and reduction in carbon footprint over the life cycle of the reuse options should be included as part of economic analysis

making. It is important to note that while financial costs are higher than financial benefits, the economic and social benefits typically are indicative of investments in different reuse options. Such an analysis can be helpful also in describing how wastewater and other reuse options offer environmental and social benefits that benefit wider community (AQUAREC 2006; Urkiaga et al. 2008).

In the economic analysis it is also important to consider externalities, the costs or benefits that are external to the market transactions and arise due to consumption or production linkages. These external costs are called negative externalities, e.g., environmental risk to general public not directly involved in wastewater use, and the external benefits are called positive externalities, e.g., flow-on benefits in consumption due to less pollution in the environment (AQUAREC 2006). For example, wastewater and sludge disposal into the environment have negative production externalities for downstream users of water and have not just financial implications but the consequences are also environmental and social. For instance, aquaculture farming downstream may be affected due to water pollution; vegetation surrounding the polluted stream might wilt and larger environment affected; dying habitat gives off foul odors affecting the living conditions of the community (GWI 2009)—and investors may shy away from such affected areas—a distinct financial externality. There is no market for externalities to make the transaction to absorb/allocate this cost. Therefore wastewater use must value these externalities in economic terms, but also in qualitative terms, and involve a mechanism for appropriate payments for these costs and internalizing the externalities. Similarly, positive externalities should be valued in economic terms, where possible, and incorporated into the analysis.

The costs and benefits for which there is no market should be assessed by using non-market based approaches such as the contingent valuation method, conjoint analysis, and choice experiments to elicit stated preferences in hypothetical markets that could serve as a proxy for economic valuation of the environmental impacts that cannot be valued through revealed preference or cost-based approaches. Where impacts cannot be valued in monetary units, it must be quantified and reported in non-monetary units and no attempt should be made to conflate monetary and non-monetary indicators. A conceptual framework for assessing the economic costs and benefits of RRR Solutions is given in Fig. 7.3. Further details of these non-market valuation approaches can be found in appropriate sources (Carson et al. 1997; Molinos-Senante et al. 2013; Ko et al. 2004; Tziakis et al. 2009). These approaches are particularly helpful for valuing the environmental impacts.

The economic valuation could also become the basis of mechanisms for dealing with the negative externalities (e.g., taxes on pollution, permits, cap and trade instruments; laws, legislation and guidelines on pollution). Then there is also the need to incorporate opportunity cost of reuse options into the economic analysis. The opportunity cost refers to the economic value of next best alternative foregone due to the decision making (cost of 2nd or 3rd best alternative or cost of no action). It is also important in the economic analysis to incorporate the opportunity cost of not using the reuse options, such as the damages to agriculture of not

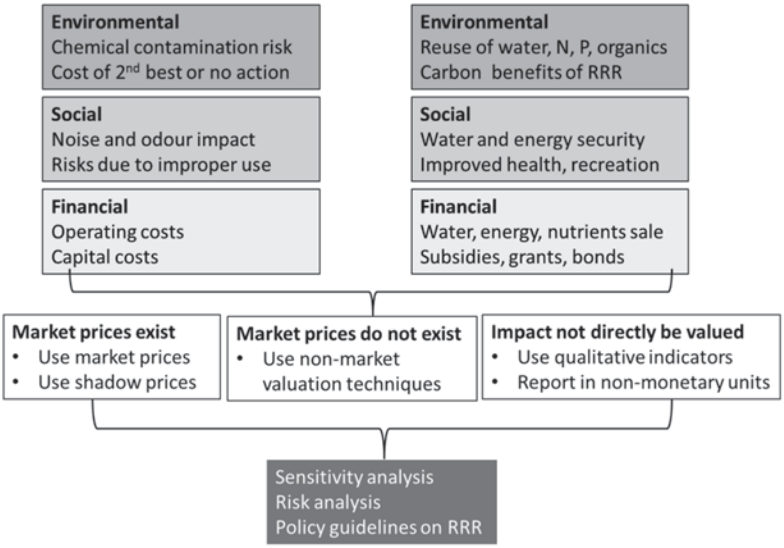

Fig. 7.3 Conceptual framework for economic analysis of RRR Solutions. (Source: Authors)

using the wastewater and nutrients and releasing to the environment. We provide as example an estimate of annual economic cost of damages due to wastewater shortages for irrigated agriculture in Israel in the next section. The opportunity cost of investments is often estimated at real interest rates but the most fundamental aspect is the economic value of next-best alternative. For example, developing water reuse instead of constructing a desalination plant, using sludge for briquettes instead of cutting the trees and causing deforestation; capturing nutrients for reuse in agriculture, aquaculture and forestry instead of discharging wastewater and sludge to the waterways and causing eutrophication damages. The economic value of foregoing these 2nd best alternatives is the opportunity cost of not using reuse options.

Once all financial, environmental and social costs and benefits have been estimated, these must be discounted to the net present value. Then sensitivity analysis must be conducted on water prices, energy, nutrients and interest rates. Further, the supply of materials for RRR solutions is subject to uncertainty and variability. Uncertainty is derived due to the lack of knowledge and understanding on the RRR solutions (e.g., energy prices and chemical cost affect financial costs, new regulations affecting environmental and social costs) whereas variability arises due to natural variation caused by external factors. For instance, demand for and generation of wastewater and sewage sludge is subject to natural variability. Handling uncertainty and variability in the economic analysis requires risk analysis. It considers probability of occurrence of events, i.e., various states of nature, and consequences of the event. For instance, drought have a strong bearing on the water reuse in RRR

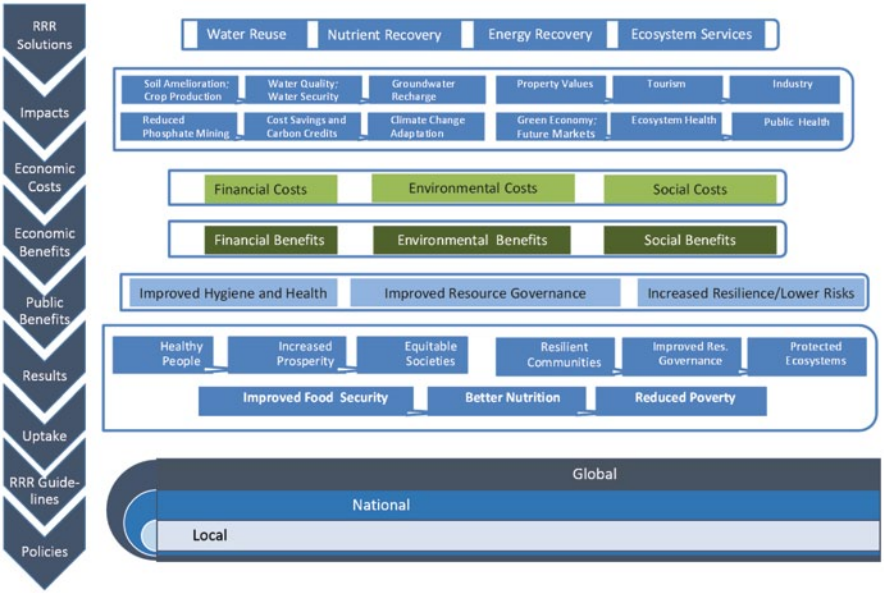

Fig. 7.4 Results Framework for policy analysis of RRR solutions. (Source: Authors)

solutions where as food prices affect nutrient capture decisions via the fertilizer prices and subsidy linkages. The net present value of all costs and benefits along with non-monetary values of some environmental costs and benefits that cannot be valued through market-based approaches must be used for the decision making. Such robust economic analysis on reuse options could then become the basis of decision on funding, policy reforms, and guidelines on reuse options (Fig. 7.4). This framework supports the Results Framework of the World Bank, widely adopted by global development partners. However, a key requirement before the results of economic analysis can be used for decision making is that reuse options must demonstrate the principal of *no appreciable harm* and thus must not pose environmental and human health risk and must be *gender neutral*. That means that from the business model perspective the reuse options must leave no one worse off while generating benefits for some.

The cost benefit analysis remains the most widely used method in the water economics field (Ward 2007) and for reuse options despite methodological limitations (Wichelns and Drechsel 2011). Natural data limitations in most developing countries make any reuse options economics difficult. For instance, the analysis of wastewater use in four countries in Asia and Africa, where research has been conducted for many years, found a significant patch work of results, but almost no robust overall economic assessment to inform policy decisions on reuse (see the following Chap. 8 for related challenges).

7.4 Assessment of Economics of Reuse

This section presents empirical evidence on how different approaches have been used worldwide to assess the economic costs and benefits of not just wastewater use but also nutrient capture, energy recovery and carbon credits. The empirical evidence comes across scale and includes micro level, meso-level and macro level analysis. Detailed guidelines for preparing economic analysis for water recycling projects can be found in other sources (Smith 2011, and those listed in Box 7.1).

At the national or **macro level**, **treated wastewater use** can be an additional source of water, which could be integrated with the national water systems. One country case example of this is the state of Israel, where wastewater is integrated into national water framework. The analysis of costs of treatment in the Emek Hefer area in Israel (Haruvy et al. 2008) shows that average wastewater treatment costs are lower than seawater desalinization, and in particular the infrastructure costs are the lowest (Fig. 7.5). Further, the net present value of the total costs over 100 years (data not shown here) for treating wastewater to an agriculturally acceptable level is lower than seawater desalination (Haruvy et al. 2008). This shows that wastewater use is a cost-effective strategy and better alternative than sea water desalinization. Wastewater management and use is essential since it is being generated and the volume is expected to rise with urban development and hence its management is essential.

Treated wastewater in Israel is used mainly for large scale irrigated farming and value-added agriculture. The plant operators have gained experience in adjusting treatment levels and quality of the effluent to suit land and crops. The treatment costs range from \$ 0.16–0.30/m^3 for the sequencing batch reactor and \$ 0.25–0.45 for tertiary treatment and the effluent is of acceptable quality and within the maximum permissible limits for the main parameters for unlimited irrigation and for

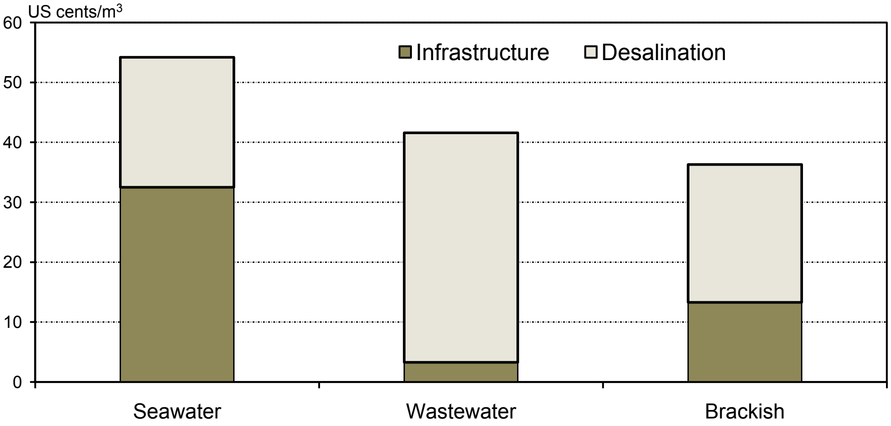

Fig. 7.5 Net present value of the annual cost of water supply to agricultural threshold in the Emek Heffer area in Israel. (Data source: Haruvy et al. 2008)

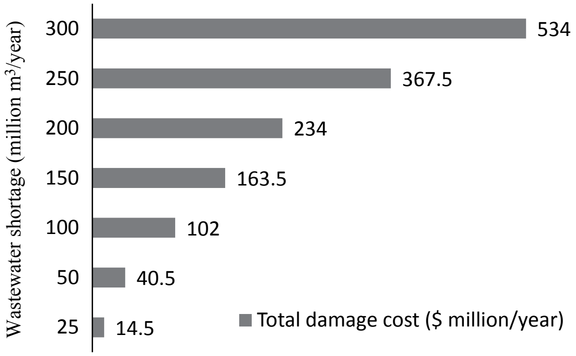

Fig. 7.6 Estimated annual economic cost of damages due to wastewater shortages (million m^3/year) for irrigated agriculture in Israel. (Source: Authors based on the cost-function cited in Dreizin 2007)

river flow restoration. Wastewater irrigation is cost-effective due to high levels of water scarcity and national concerns on water security and is a much cheaper alternative than seawater desalination or abandoning agriculture. Wastewater irrigation is a profitable and booming business across Israel. Although there are no major episodes of disease outbreaks for wastewater irrigated crops, the potential risks include human health risk, environmental risk, and economic risk.

Economic risks include strategic risks due to mismatch between supply and demand and lost investment opportunities in wastewater treatment systems. Israel is a pioneer in the use of wastewater for irrigation at the global level. However, this also exposes the state to a strategic risk due to (Dreizin 2007): reduction in demand—wastewater cycle and its supply are fully managed and controlled whereas agricultural demand is uncertain and fluctuates greatly. Farmers could abandon wastewater irrigated field due to economic losses for numerous factors operating outside the wastewater 'box' such as labor shortages and loss of land to housing, leading to a reduction in demand; cut in wastewater supply—the wastewater suppliers may incur economic losses due to low demand, leading to the closure of the treatment plants and wastewater being discharged to the sea; and wastewater shortage damages—wastewater supply is not enough to meet the demand for cost-effective farming. The economic cost of the damages due to wastewater shortages has been rarely estimated in the literature, although most framework suggest using the ***damages avoided*** **or** ***cost of no action*** if wastewater was not reused in agriculture and discharged to the sea. Figure 7.6 based on the cost-function cited in Dreizin (2007) shows the damage costs. The damage costs could be huge if any emerging environmental, health and public regulations issue prevents the use of wastewater for irrigation. This analysis must also consider the **opportunity cost** of not building the wastewater project, the next alternative foregone. That cost is much higher as the alternatives would be to decrease the irrigated areas or seawater desalination and both of these options are either politically unacceptable or not cost-effective. It must be noted that Israel treated about 350 million m^3 of wastewater in 2010, such that the estimated damages consider the full continuum from lowest to full scale wastewater shortages for agriculture.

Israel has made tremendous efforts in linking environmental and economic sustainability in establishing standards for wastewater re-use (Lawhon and Schwartz 2006) and this had helped reconcile cost-effectiveness goal with environmental and public health protection. Further, private investments in wastewater infrastructure are regulated and protected by the state and this provides incentives for investment in technology, infrastructure and partnerships.

At the micro level, studies on willingness to pay for the provision of wastewater treatment infrastructure (Tziakis et al. 2009; Menegaki et al. 2008; Massoud et al. 2009) and farmer's willingness to pay for recycled wastewater (Tziakis et al. 2009; Dolnicar and Schäfer 2009; Birol et al. 2008) imply that there are significant risks to public health and the socioeconomic benefits associated with wastewater are positively valued by the stakeholder. The above empirical evidence also implies that there is a need for the valuation of environmental and health risks of wastewater by applying a comprehensive conceptual framework. Only then the stakeholder values can be incorporated into policy decisions. A case study by Agunwamba (2001), based on total irrigated area of 5.5 ha and 66 respondent farmers in Nsukka, Niregia estimated the economic impact values as reported in Table 7.3 (Agunwamba 2001).

The results of surveyed farms in MENA region (Jordan and Tunisia) show that irrigation with reclaimed wastewater, especially when blended with fresh surface water, can be as profitable as, if not better than, irrigation with only freshwater (Abu-Madi et al. 2008). This is mainly due to the low water tariff and less use of expensive fertilizers because of the entrained **nutrients** in wastewater, both resulting in net cost savings. For instance, net farm profit/ profitability of using secondary treated wastewater for irrigation of fruit trees averages about US$ 800 (including own labor) and 3430/ha/year (excluding own labor), compared with that using fresh groundwater that averages about US$ 2710 and 3230/ha/year, respectively. Profitability of using reclaimed wastewater that is blended with fresh surface water for irrigation of vegetables averages about US$ 2550 and 4770/ha/year, respectively, compared with that irrigated with fresh groundwater that averages about US$ 370 and 3160/ha/year, respectively (Abu-Madi et al. 2008).

At the **meso level**, beyond the farm economics of wastewater use, studies on **multiple-resource recovery** show that greater benefits become possible when the resource reuse trajectory extends to **energy** and also targets **carbon credits**. For example, data from the As-Samra wastewater treatment shows that the total cost of the plant is $ 223 million, with $ 93 million funding from the Millennium Challenge Corporation; $ 20 million from the Government of Jordan; and the remaining $ 110 million by private debt and equity sources. The total cost of the As-Samra wastewater treatment includes depreciation, salary, electricity, operation and maintenance, chemicals, sludge disposal and contracted testing. The average total cost is about $ 1.51 per m^3, average variable cost is $ 0.53 per m^3 and the marginal cost is $ 1.23 per m^3 (SPC 2012). The plant generates revenues (full cost recovery) from the payments made by the government to cover the operational expenditures plus private capital expenditure. The government pays for the provision of water services which

Table 7.3 Valuation of the impacts of wastewater use in irrigation at Nsukka, Nigeria. (Data source: Authors based on Agunwamba 2001)

Item	Valuation approach	Estimated value
Crop production Nutrient capture	Incremental crop production (gains)	$ 58,890 in output
	Increase in productivity due to adequate water	$ 4710 wastewater value
	Fertilizer cost savings	$ 175 for inorganic fertilizer
Soil resources	Production losses caused by fall in land productivity, estimated as the cost of replacement by fertilizer or humus	$ 16,990 for fertilizer; $ 3740 for humus
Ecology	Destruction of fowl	$ 440
Public health	Medical treatment costs (malaria, typhoid, diarrhea)	Around $ 23,110 for malaria; $ 1430 for diarrhea; $ 900 for typhoid
	Productivity losses caused by illness (forgone earnings) and absenteeism (replacement cost for medical expenses)	
Environment	Improvement costs, estimated as the cost of two training programs	$ 2240
	Effluent quality monitoring costs	$ 770
	Cost of chemicals for odour control	$ 1000
	Onsite facilities for bathing	$ 500
Total economic benefit		$ 63,775
Total cost of improvements		$ 27,620
Benefit: cost ratio		2.4

is currently $ 0.17 per m^3. This represents the unit cost of wastewater treatment only and this is fully recovered by the private consortium from the payment made by the government (Personal communication with As-Samra plant manager, 2013). The government then recovers its costs through tariffs to water users. In sum, the plant generates total revenue of 15 million JD (US$ 1 = 0.71 Jordanian Dinar in March 2014) per year of about 1.3 million JD per month to cover operation and maintenance less government payments (personal communication with plant manager, 2014).

The Phase 2 plant generates 103,000 kWh of green energy per day. The Phase 2 upgrade involves multi-resource recovery strategy to abandon the previous lagoon treatment system, implementing biogas capture and conversion to energy and creating carbon credits through reduction of emissions to the atmosphere, and introducing hydraulic turbines for production of renewable energy to be used onsite. Expected revenue due to greenhouse gas emission reduction (about 300,000 Carbon Credits) is around $ 7.5 million per year with a total of about $ 74 million by 2020. Multiple-resource reuse streams beyond water recovery such as hydraulic energy

Table 7.4 Summary of the *ex-ante* estimates of emission reductions. (Source: Authors based on UNFCCC 2006)

Year	Baseline emissions	Projected emissions	Emission reduction	New revenue, ($ 25/Carbon credit)
2011	327,350	16,740	310,610	USD 7,765,300
2012	337,760	17,320	320,440	USD 8,010,980
2013	348,160	17,900	330,270	USD 8,256,630
2014	358,570	18,480	340,090	USD 8,502,300
2015	368,980	19,060	349,920	USD 8,747,980
2016	378,840	19,610	359,240	USD 8,980,930
2017	242,810	12,030	230,780	USD 5,769,400
2018	248,700	12,360	236,340	USD 5,908,430
2019	254,590	12,690	241,900	USD 6,047,480
2020	260,480	13,020	247,460	USD 6,186,500
Total	3,126,200	159,200	2,967,000	USD 74,175,900
Average	312,600	15,900	296,700	USD 7,417,600

and carbon credits increase the revenue frontier and help the plant move beyond government payments to net profits (Table 7.4; UNFCCC 2006).

At the global level, economic assessments are lacking. Table 7.5 gives the key approaches for assessing the economic feasibility of RRR projects.

The assessment by GWI (2009) shows that the total capacity of global *advanced water reuse* industry is around 32 million m^3/day and the total revenue generated is about $ 700 million. The broader water reuse market including water treated to a lower standard has a global capacity of around 54 million m^3/day and the total revenue is around $ 730 million. Assuming that a switch to advanced wastewater treatment adds about $ 0.20 to the cost of wastewater treatment process, the estimated total operating cost of advanced treatment is about $ 2.3 billion, which means a 30 % cost recovery rate. This estimate does not include the damage cost avoided via the energy recovery pathway and protection afforded to the humans and ecosystem health due to water reuse. Inclusion of carbon credits, ex ante reductions in emissions, has the potential to turn the global market head on and transition from 30 % cost recovery rate to net profit trajectory, due to the huge potential that reuse market offers for generating and trading carbon credits and the expected rise in credit prices (from current about $ 24) in the future. Even if the credit prices fall to $ 10, the reuse credit market will remain competitive due to low investment cost and long-term returns. Where the RRR solutions include wastewater use in agriculture, typical costs of water reuse reflect fairly well on the financial costs and can serve as a proxy for the value of costs avoided in increasing supply (Table 7.6)

A key determinant of the cost of RRR Solutions is the technology used and the scale of operations. Typically costs have a linear relationship with the scale and their extent varies across technologies (Molinos-Senante et al. 2011). Most important cost item is staff (about 1/3rd of total cost) followed by maintenance (21 %) and energy (18 %), while waste management (15 %) and regent costs (14 %) have a

Table 7.5 Key methodologies for assessing the economic feasibility of reuse projects. (Source: IWMI based on the literature survey)

Reuse options	Approach	Remarkable aspects of the approach	References
Wastewater	Asano	*Needs assessment*—assess wastewater treatment needs *Supply and demand*—ascertain the supply and demand of water *Market assessment*—study the market of reclaimed water *Economic analysis*—carry out a technical and economic analysis of the alternatives *Implement*—design the implementation plan based on a financial plan	(Asano 2002; Kampas et al. 2007)
	Standish-Lee	*Legal and social framework*—greater focus on social and legal aspects of wastewater use	(Roma et al. 2013)
	Seguí	*Integrated framework*—includes technical, social, economic, financial, environmental and legal aspects	(Haq and Cambridge 2012)
	Hernandez and others	*Modeling approach*—outlines the mathematical approach examining the environmental, social and financial aspects	(Hernández et al. 2006)
	World Bank	*Expert consultation*—involves consultation with experts from a variety of disciplines such as public health specialists, sociologists and economists	(Karak and Bhattacharyya 2011; Mihelcic et al. 2011)
	IWMI	*Comprehensive economic framework*—includes reuse options, impacts, financial, economic, social, environmental and public costs and benefits to link investments to sustainable development such as reduction in poverty	(Hanjra et al. 2011; Hussain et al. 2002; Hussain et al. 2001)
Nutrients	Mo and Zhang	*Integrated resource recovery*—analysis of available resource recovery approaches of wastewater treatment including onsite energy generation, nutrient recycling, and water reuse, valuation from a life cycle perspective	(Mo and Zhang 2013)

Table 7.5 (continued)

Reuse options	Approach	Remarkable aspects of the approach	References
Sludge	Lundin and others	*Environmental and economic analysis*—analysis of four recycling and disposal options for municipal sewage sludge including: agricultural application; co-incineration with household waste combined; incineration combined with P recovery by the Bio-Con process; and fractionation including phosphorous recovery with the Gambi-KRBPRO process, to showcase the economic and environmental restrictions	(Lundin et al. 2004)
	Tsagarakis and others	*Life cycle approach*—Estimation of life cycle cost functions of WWTPS in Greece. It considers costs of sludge treatment and disposal. Life cycle cost functions are estimated for land usage, construction costs and O&M costs	(Tsagarakis et al. 2001)
	Molinos-Senante and others	*Cost modeling*—estimation of cost functions for sludge and waste management in WWTPs. Costs of sludge and waste management are modelled as a function of the volume of evacuated sludge, sand, solid waste and grease. Shows that costs for sludge management are the most important cost factor in waste management	(Molinos-Senante et al. 2013)
Energy	Jackson and Hanjra	*Risk analysis approach to energy modeling*—models energy savings from conversion of inefficient flood irrigation method to pressurized irrigation systems such as drip and pivot, in the context of climate change and water scarcity scenarios and economic value of water. The model can be used for wastewater irrigation	(Jackson et al. 2011)
	Nogueira and others	*Cost modeling*—Estimation of cost functions of investment and O&M costs of small decentralized energy saving wastewater treatment systems	(Nogueira et al. 2013)
Carbon credits	World Bank	*Ex Ante calculation of emission reductions*—Comprehensive step-wise methodology to estimate emission reduction (CO2e/year) for any given year of the crediting period, which is obtained by subtracting projected emissions (CO2e/year) and leakages from base line emissions (CO2e/year), based on methane conversion factor for domestic wastewater, sludge, and electricity used, as developed by the IPCC	UNFCCC (2006)

Table 7.6 Typical cost/value of water reuse solutions. (Data source: Adapted from GWI 2009)

Reuse solution	Market potential	Reuse price ($/m^3)
Informal reuse of wastewater agriculture, untreated	▮ ▮ ▮	0
Informal reuse of wastewater agriculture, primary treated	▮ ▮ ▮	0.01
Reuse in restricted agriculture after secondary treated	▮	0.02–0.10
Municipal and leisure reuse, tertiary treated	▮ ▮	0.12–0.35
Bulk municipal and industrial reuse at 10 km, tertiary treated	▮ ▮	0.45–0.80
Groundwater recharge, quaternary treated	▮	0.45–1.20
Unrestricted reuse with dual piping system, tertiary treated	▮ ▮ ▮	0.45–0.85
Industrial water recycling with zero discharge	▮ ▮ ▮	0.80–1.50
Urban sewage network for agriculture reuse 50 km away, secondary treated	▮ ▮ ▮	1.50–2.5

similar weight. Cost also depends on if single (water) or multiple resource recovery is involved in the RRR Solution. For instance, data from 22 WWTPs in Spain show that the average cost of plants with **nutrients removal** processes is 0.2149 EUR/m^3 while cost is reduced to 0.1827 EUR/m^3 if plants do not remove nutrients (Molinos-Senante et al. 2011).

Energy cost is the most important cost factor for systems with extended aeration while volume treated is the most relevant cost factor for activated sludge systems without nutrient removal. Based on the estimates of total annual estimated economic costs which includes land use, construction and O&M costs, extended aeration with natural drying is the most economic system, followed by extended air with mechanical dewatering, and conventional secondary treatment have lowest economic performance due mainly to energy costs.

What is more important is that energy costs account for bulk of the cost of RRR solutions such as water reuse, nutrients and energy. Most RRR solutions recovering energy at best can achieve up to 85 % self-sufficiency and save on energy costs. Further, energy cost is the best available indicator of the operating costs of the RRR solutions. For instance, typical energy cost of different treatment options for water reuse is given in Table 7.7. Exiting business cases on energy recovery but also nutrient recovery and water reuse can be found in Chaps. 11–13, this book.

7.5 Conclusion and Policy Implications

National or state level assessments of the costs and benefits of wastewater use are commonly lacking. Such economic analysis could make a stronger business case for investments in reuse solutions for integrated cost recovery and support a move towards overall profitability.

Table 7.7 Typical energy use by treatment process for innovative reuse solutions. (Data source: Adapted from GWI 2009)

Reuse solutions	Energy use (kWh/m^3)
Drinking water supply	
Activated sludge	0.0–1.74
Extended aeration	0.37–1.32
Waste stabilization ponds	4.94–5.41
Biological wastewater treatment for reuse	
Activated sludge	0.43–1.09
Extended aeration	0.49–1.01
Waste stabilization ponds	0.05
Recreational treatment for pathogen removal for reuse	
Direct filtration (pulsed beds) and UV disinfection	0.18
Direct filtration and UV disinfection	0.20–0.63

This chapter presents a framework for that purpose which goes beyond those developed earlier (Hussain et al. 2001, 2002). However, the studies conducted to date reflect only a patchwork of information. In particular, the social benefits of wastewater use have seldom been quantified (Weldesilassie et al. 2011; see also the following Chap. 8). Many frameworks focus mainly on water reuse in agriculture (e.g. Winpenny et al. 2010). Other reuse options such as nutrients, energy, and the link e.g. to carbon credits were not included. Thus there is a need for a validated and agreed framework that considers other reuse options across scales in the face of ever increasing demand for policy relevant economic input. This chapter contributes to filling that gap in the literature and likes also to point at useful handbooks and papers providing guidance for practical application (Box 7.1).

Box 7.1 Recommended References Addressing the Economics of Wastewater Use

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De Souza S, Medellín-Azuara J, Burley N, Lund JR, Howitt RE (2011) Guidelines for preparing economic analysis for water recycling projects, prepared for the State Water Resources Control Board by the Economic Analysis Task Force for Water Recycling in California, University of Califiornia, Davis, Centre for Watershed Sciences, CA, USA.

Hussain I, Raschid L, Hanjra MA, Marikar F, van der Hoek W (2001) A framework for analyzing socioeconomic, health and environmental impacts of wastewater use in agriculture in developing countries, Working Paper 26, Colombo, Sri Lanka, International Water Management Institute.

Otoo M. and Drechsel, P. (2015) Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse. Earthscan, London

WateReuse Research Foundation (2006) An economic framework for evaluating the benefits and costs of water reuse. Final Project Report and User Guidance. WateReuse Research Foundation, Alexandria, VA

Winpenny J., Heinz I., Koo-Oshima S. (2010) The Wealth of Waste: The Economics of Wastewater Use in Agriculture. FAO Water Report 35, Rome, Italy

We argue that wastewater use can contribute towards key social benefits such as reducing rural-urban poverty, improving food security, improving nutrition and health, and managing natural resources more sustainability to protect ecosystems and build climate resilient communities. Wastewater and other reuse options have elements of positive externalities and public goods. The economic feasibility would vary if only market impacts are integrated in the economic assessment such that some reuse projects are not feasible. For instance, in the context of water reuse domain only, most reuse projects such as those supplying water for irrigation and value added farming activities, are unlikely to achieve **financial cost recovery** and might only cover the operation and maintenance costs of supplying the water for reuse and some projects could well only be **cost-saving models**. Full cost recovery remains elusive. However, wastewater use has implications beyond the water domain and include nutrient, organic matter and energy recovery which can support better financials and a higher probability of cost recovery or even profitable revenue streams. The key argument is that while in the short run and purely from the financial perspective, reuse solutions may only achieve second-best results, but when the continuum of activities along the reuse value chain are considered, the economic assessment provides a rationale for investments in reuse options. A stronger rationale for reuse options comes however from the public benefits such as healthy people, increased prosperity, equitable societies, resilient communities, improved resource governance and protected ecosystems. As the opportunities grow and experience accumulates, the trajectory of business models from cost savings and cost recovery towards profitability will improve. Thus, the key to economic sustainability of the reuse options is having a government or stewardship willing to engage for **cost-sharing** and able to cover the rest of the costs through subsidies and incentives for its reuse to generate public goods. There is a need to look at the financial analysis of wastewater use from the business standpoint, and economic analysis of reuse options for a policy perspective. The existing regulations and institutional frameworks are antiquated and not geared to harness the emerging business opportunities in the market place. This is a serious knowledge gap from the institutional perspective. Among the emerging RRR solutions those showing clear results-based outcomes in human development could then underpin the guidelines, uptake, and policy reform.

Take Home Messages

- Wastewater and other reuse options can contribute to reducing poverty, improving food security, improving nutrition and health, and managing natural resources more sustainability to protect ecosystems and build climate resilient communities.
- There is a need to look at the financial analysis of water reuse from the business standpoint, and economic analysis of reuse options for a public policy perspective.
- Reclaiming water, and recovering nutrients and energy can improve cost recovery and pave the way for new investments into wastewater use, based on business principles of profit maximization while supporting a move towards greater sustainability.

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Part III
Costs and Benefits

Chapter 8
Wastewater Use in Agriculture: Challenges in Assessing Costs and Benefits

Pay Drechsel, George Danso and Manzoor Qadir

Abstract Estimating the benefits and costs of planned or unplanned, ongoing or future, water reuse projects is not without challenges. In additional to the common difficulties of applying cost benefits analysis in agriculture or for justifying the use of reclaimed wastewater, the chapter tries to present some particular challenges with respect to the assessment of wastewater irrigation in the developing country context where treatment might be minimal or lacking and irrigation an informal activity along wastewater canals as well as natural streams. Challenges start with the term 'wastewater', and the comparison of crop yields and farm incomes under wastewater and freshwater irrigation and cumulate in the difficulties of assessing and costing likely health and environmental impacts. Bottlenecks related more often to the correct quantification of differences or impacts than their economic valuation.

Keywords Wastewater planning · Farmers · Crops · Quantitative microbial risk assessment

8.1 Introduction

Public agencies and private firms are investing in wastewater use in many water scarce regions and countries. The investments are driven largely by increasingly limited supplies of freshwater, increasing populations, rapid urbanization and increasing amounts of wastewater. In many settings, wastewater is already used informally as a low-cost and reliable alternative to freshwater. Wastewater irrigation and

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wastewater-based aquaculture often support large numbers of livelihoods and generate considerable value in the local economies especially where other water sources are scarce (Scott et al. 2004; Bunting 2004; Van Veenhuizen and Danso 2007).

Estimating the costs and benefits, in particular of planned wastewater collection, treatment, and use program is generally straightforward (Morris et al. 2005) with a clearly outlined methodology (Urkiaga et al. 2008; Winpenny et al. 2010; Condom et al. 2012). Many of such appraisals are carried out as part of feasibility studies (Box 8.1).

Box 8.1. Planning for Reuse

Lienhoop et al. (2013) investigated the likely costs and benefits of introducing decentralized wastewater treatment and use at two locations in Jordan. The cost-benefit analysis included non-market and market benefits associated with the environment, health and irrigation. To monetize the economic value three valuation techniques were applied: (1) the contingent valuation method (CVM) to value environmental benefits, (2) the cost of illness approach (COI) to assess the health benefits, and (3) gross margin analysis to estimate the benefit of additional water made available to agriculture. The findings suggested that it is worthwhile to introduce treatment for reuse, especially if it can be based on low-cost treatment technology.

Haruvy (1997) estimated that the reuse of wastewater in central and southern Israel would generate additional agricultural output with economic value of US\$ 0.14/m^3, benefits of aquifer recharge at US\$ 0.07/m^3, and damage to the aquifer due to nitrogen at US\$ 0.10/m^3, resulting in a net national benefit of US\$ 0.11/m^3 such that water reuse in agriculture is a cost-effective option compared to, for instance, disposal to rivers which has a net cost of US\$ 0.40/m^3 for the society. The study confirmed the importance of evaluating externalities at watershed level for an integrated management of water resources (Winpenny et al. 2010).

Scott et al. (2000) described an interesting scenario where improved wastewater treatment with increased nutrient removal capacity would reduce a key benefit of wastewater for famers resulting in significant expenditures on fertilizers. The improved technology would support local and regional communities and discharge standards related to water eutrophication. Social cost–benefit analysis could help in this case to determine the net welfare effects of reuse, whether reuse could be considered an alternative to treatment, or if the treatment facility should be constructed and, if so, how the costs and benefits of operating the plant could be distributed. Eventually, the impact for farmers was very limited as treated and untreated discharges mix in the river downstream of the plant (Silva-Ochoa and Scott 2004).

However, when farmers use untreated (raw or diluted) wastewater for irrigation or aquaculture, the assessment and valuation especially of potential health benefits and costs along the food chain becomes a particular challenge. The same applies to studies that compare farm performance indicators of freshwater and wastewater irrigation.

In this chapter, we will highlight selected methodological challenges as they are common in the assessment of the benefits and costs of productive wastewater use. As the perspective of the treatment and reuse operator is well covered in the literature (Morris et al. 2005), the chapter will focus on the perspective of the farmers engaged in water reuse and of the public sector in charge of safeguarding public health. Thus, we are looking at empirical examples from both treated and untreated wastewater applications with a bias towards informal wastewater irrigation as it is predominant in low-income countries and poses the larger assessment challenges within the flexible framework as presented in Chap. 7 (this volume).

8.2 Farmers' Perspectives

In many water scarce regions, wastewater—where available—is a valuable asset and often the only source of water for irrigation, or even the preferred one. The reasons are several: reliable supply, high nutrient content unless the water is diluted, usually at no cost, resulting in an increased and/or less variable crop yield, or new opportunities for high value crops, fish or livestock production systems. There is a large number of reports which show that the availability and use of treated or untreated wastewater can be beneficial for farming (Hamilton et al. 2007; Qadir et al. 2007b; Scott et al. 2004; Scheierling et al. 2011) and outweigh possible health impacts if safety guidelines are followed (WHO 2006; Grangier et al. 2012). This is however not the case in the majority of informal reuse situations where compliance with safety measures is uncommon (Drechsel et al. 2010; Raschid-Sally and Jayakody 2008).

A standard approach for assessing benefits and costs of crop production with wastewater is to compare it with similar systems using fresh water, ideally in one and the same community to reduce biophysical and socio-economic variability. This situation is however seldom and more common are studies comparing different communities, each with a particular water source. In a recent and still unpublished[1] study in peri-urban Aleppo, Syria, for example, 6 villages using a mix of untreated and partially treated urban wastewater from Aleppo city and its surroundings carried by the Qweik River were compared with 6 villages depending on freshwater (unpolluted groundwater). The comparative evaluation of wastewater and groundwater irrigation for crop production revealed higher yields from wastewater irrigated fields (Table 8.1).

Similar results are frequently reported as summarized by Qadir et al. (2007a), who showed that yields of wastewater irrigated crops are often about 10–30 % higher than those of freshwater irrigated crops (Table 8.2). The presentation of data like

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[1] As some examples will be used to describe possible traps and shortcomings in economic assessments we tried to focus as much as possible on cases where we can validate the approaches and the assumptions used.

Table 8.1 Comparison of crop yields harvested from wastewater and freshwater irrigated areas in Aleppo region, Syria. (Qadir et al. unpublished data)

Crop	Wastewater	Freshwater	Change
	Mg ha^{-1}	Mg ha^{-1}	%
Wheat	4.49	3.29	36
Cotton	4.24	4.14	2
Faba bean	3.65	1.50	143
Vegetables[a]	35.90	19.20	87

[a] Sum of different vegetables grown in a year, but mostly eggplant

Table 8.2 Comparison of freshwater and wastewater irrigated crop yields in India and Syria. (Qadir et al. 2007a)

Crops	Average Crop Yield (Mg ha^{-1})	
	Wastewater	Freshwater
Carrot	11.75	9.71
Radish	8.33	7.26
Potato	9.33	6.12
Cabbage	12.13	9.27
Tomato	13.38	10.01
Tobacco	1.25	1.12
Rice	3.3	3.8
Wheat	3.1	2.8
Soybean	2.1	1.6
Cauliflower	18.2	16.4
Sugarcane	44.4	42.7
Cotton	4.24	4.14

in Tables 8.1 and 8.2 requires however several additional information on the methodology as we will discuss in Sect. 8.3.

In the study in Syria, the gross income per unit area (US$ ha^{-1}) was tabulated from the market price of the agricultural produce. The cost of production was differentiated into different components:

1. Cost on cultivation, which included seed costs and seed bed preparations, use of farm equipment, insecticides, pesticides, and herbicides, where needed
2. Expenditures on the purchase, transport, and application of fertilizers
3. Labor cost for sowing, cleaning of field, harvesting, and post-harvest management
4. Cost of irrigation based on pumping costs.

The net income was tabulated as the difference between the gross income and total cost (Table 8.3). In case of certain crops irrigated with wastewater, such as vegetables, farmers often received a higher price than for those irrigated with freshwater (groundwater). The reason rests with the greenish and seemingly healthier

Table 8.3 Economic evaluation of wastewater and freshwater irrigated agriculture in Aleppo region, Syria. (Qadir et al. unpublished data)

Crop	Costs					Incomes	
	Cultivation	Fertilizer	Labor	Irrigation	Total	Gross	Net
	(US$ ha^{-1})					(US$ ha^{-1})	
Wastewater irrigated							
Wheat	74	68	36	1	179	951	772
Cotton	85	77	275	4	441	2282	1841
Faba bean	79	0	129	4	212	1123	911
Vegetables	69	96	203	2	370	2767	2397
Freshwater irrigated							
Wheat	74	163	29	4	270	632	362
Cotton	81	154	185	6	426	2228	1802
Faba bean	38	0	96	14	148	433	285
Vegetables	96	96	240	16	448	1474	1026

appearance of the crops harvested from wastewater irrigated fields. Overall, the cost-benefit ratio indicated up to twice the returns on wastewater than groundwater irrigation farms (Qadir et al. unpublished data).

Farmers interviewed in Aleppo preferred wastewater for three reasons: (1) wastewater is available throughout the year (57 % of farmers consider this as the most important reason), (2) wastewater is a source of nutrients (26 % of the farmers), and (3) pumping cost of wastewater is less than that groundwater pumping (17 % of the farmers) (Qadir et al. unpublished data).

The first reason is often the most important, as in many water scarce areas the availability of wastewater can help to convert unproductive land to productive land. A well-known example is the Mezquital Valley in Mexico, where about 75,000 farmers irrigate 90,000 ha using wastewater from Mexico City (Carlos Pailles, personal communication 2013). Also, downstream of several Indian cities up to 33,000 ha of crops depends on urban wastewater (Amerasinghe et al. 2013). The livelihood benefits of these activities extend far beyond the farm (Buechler and Devi 2003).

However, there can also be costs for farmers aside those from potential health issues. A likely cost factor for the farmer is a change in the production potential of the soil, like through increased salinity levels or over-fertilization from frequent wastewater irrigation (Hamilton et al. 2007). There can also be higher expenditures for plant pest control given the higher nutrient load (Amerasinghe et al. 2013). This will force farmers to invest in remediation measures, change crops or accommodate lower yields (McCartney et al. 2008; Zimmermann 2011). These adaptations or changes e.g. in soil productivity can be quantified and their value be estimated (Drechsel et al. 2004). There is a significant body of literature comparing the positive and negative impacts of wastewater irrigation on the soil; however, the conclusions are very site-specific depending on water quality and quantity, soil type and texture, and the cultivated crop which will be reflected in the cost benefit assessment (Hamilton et al. 2007; Qadir et al. 2007b; Chap. 4 this volume).

Table 8.4 Annual monetary value of health cost from intestinal illness among farmers using polluted river water for irrigation in Addis Ababa, Ethiopia. (Weldesilassie et al. 2010)

Variables	Mean	SD
Frequency of illness per year	1.8	1.4
Treatment cost for one short period of illness in Birr	106	168
Treatment cost per year in Birr	203	342
Working days lost per year due to illness	58	223
Wage loss for a typical farmer per year in Birr	231	1052
Monetary cost of intestinal illness per year in Birr	580	1521

1 US$ = 8.62 Ethiopian Birr during the survey period (2006)

Health risk assessments and valuations are particularly challenging. As mentioned in Chap. 5 of this volume, risk perception can vary significantly, ranging from no risk awareness to risk denial or exaggeration, especially among farmers using wastewater or polluted water sources informally, that is not in formal reuse schemes where water is treated and stakeholders are informed about any residual risk. Where health risk assessment cannot be based on official records, a common approach is to use interviews to assess farmer's risk via experienced illness. Weldesilassie et al. (2010), for example, used interviews and an econometric approach to compare the health status of farmers using freshwater ($n = 175$) and wastewater ($n = 240$) in and around Addis Ababa, Ethiopia. The authors quantified treatment costs and wage losses based on symptoms, which can be related to intestinal illness through contact with wastewater. The mean annual total cost for an average household member who works on a wastewater irrigated farm was estimated for the year of the survey (2006) as about Birr 580 or US$ 67 (Table 8.4).

Controlling for observed and unobserved differences in individual behavior and farm location characteristics, the marginal health-related cost for household members working on wastewater irrigation farms was US$ 37 higher compared to those working on freshwater farms. These results varied with the econometric approach and the financial burden was lower using other models (Weldesilassie et al. 2010).

8.3 Challenges in Assessing Farmer's Costs and Benefits

In addition to the often discussed traditional challenges (i.e., no equity considerations and aggregation of values into a single metric, etc.) of valuing the use of water resources or other inputs in agriculture (Turner et al. 2004; Boardman et al. 2010) including the use of reclaimed wastewater (Winpenny et al. 2010), we try to present some particular on-farm challenges with respect to the assessment of wastewater irrigation in the developing country context where treatment might be minimal or lacking and irrigation an informal activity along wastewater canals as well as natural streams (Weldesilassie et al. 2011). The challenges will be illustrated using as far as possible the examples presented above:

a. **Water Quality:** The comparison of 'wastewater' and 'freshwater' irrigation is often missing its basic biophysical justification, which is the difference in water quality. This challenge is common where wastewater is used indirectly from polluted streams or rivers. The term "wastewater" is used in the literature without any stringent definition, and can refer to grey or black water, raw sewage, diluted sewage or polluted stream water, the latter being the most common in publications on informal "wastewater" irrigation in urban and peri-urban areas. However, concentrations of pathogens and beneficial nutrients vary considerably between these different expressions of wastewater, as they can vary between seasons, irrigation methods as well as with increasing distance from the pollution source(s) within the same irrigation area or 'scheme'. In some cases, farmers using wastewater reduced their expenditures for fertilizer (van der Hoek et al. 2002), while in others, the diluted nutrient levels in the wastewater are marginal and did not influence farm-level practices regarding soil-fertility management (Erni et al. 2010). The same variation in possible benefits can be seen in view of potential risk. Thus costs and benefits can vary substantially with location, even along the same river, and sometimes the supposed clean water source might also carry an unacceptable pathogen load. It appears very common that farmers and researchers might have different views of the local water quality, and terms such as 'wastewater' can bias assessments, or when asking farmers to express their willingness to pay for 'safer' water.
b. **Freshwater control group:** In many situations all streams within and around urban areas are polluted and it is difficult to find a control group using continuously safe water. Communities relying on safe groundwater could be an options if soils are comparable (see below). This lack or inability to produce an appropriate control group e.g. for health risk assessment is a common challenge of economic appraisals as also flagged by Weldesilassie et al. (2011). In Addis Ababa, Ethiopia, for example, the control community using freshwater could only be located at a distance of 40 km from the urban wastewater sites. The control farmers had different housing conditions and produced different crops on different soils than farmers in the wastewater-irrigated area. In Ghana, where all urban streams are polluted, the livelihood characteristics of irrigating farmers using unoccupied plots near streams have been compared with those of farmers without access to irrigation water. In this case, both groups had similar living conditions, but the crops and farm sizes differed (Danso et al. 2002). This difference can result in a significant misrepresentation. In Addis Ababa, Ethiopia, for example, the annual average net income from wastewater use is with US$ 1600 per hectare more than twice as high as from freshwater use (US$ 700). However, presenting data per hectare (like in Table 8.3) might hide that e.g. in the Addis Ababa urban wastewater farmers cultivate on average less than half the irrigated area than freshwater farmers, thus the income based on

actual farm sizes did not much differ between both groups (Weldesilassie et al. 2009, 2010).

c. **Spatial heterogeneity** occurs also within much shorter distance e.g. in view of soil fertility, crop varieties, or farm management. The yields presented for example in Tables 8.1 and 8.2 can only be related to differences in water quality if the crops or better crop varieties have been the same and the soils have been of similar initial fertility before irrigation started. This might be the case where wastewater is conveyed and accessed from a canal, and compared with groundwater irrigation nearby, but if one of the two sources is a natural stream or river conveying the water, there is a high probability of fertile soils in the floodplain. These might not be comparable with soils near wells further away. Another more common challenge can be the cultivation history of the plots which might entail different fertilizer rates and irrigation application methods and rates, etc. If these differences are not captured, wrong conclusions on yields, but also farmer's exposure to pathogens are possible. Thus for Tables, like 8.1 and 8.2 details on site conditions, water source, soil quality and crops are needed. With the move from experimental station research to smallholder on-farm research statistical analysis often gets difficult. However, statistical tests are needed to verify if any differences are significant. In an ideal situation, that is if farmers agree and have the available land and capacity to cultivate it, a completely randomized experimental design could be applied, even within a farmer's field, to control e.g. for plot selection effects, or several farmers' field where similar practices are undertaken may be considered as replications. Without such control, we do not know how much of the yield effect might be due to farmer's choice of plots that receive certain input, including irrigation, or residual nutrients, or due to the previous crop sequence.

d. **A too common disease?** As mentioned in Chap. 3 in this volume, irrigating farmers who produce exotic vegetables for urban markets face mostly occupational contact risks, less consumption risks. These risks concern possible skin infections and contact with different types of helminthes, such as hook- and round-worms (WHO 2006). The challenge of assessing the related costs (sick days and treatment costs) is based on the common nature of these infections and their rather unspecific or hidden symptoms. This makes a correct attribution very data demanding. Much better would be a stool test, or to compare (irrespectively of symptoms and disease) the total health expenditures between the wastewater and freshwater irrigating communities, through interviews or hospital records.

   As worm infection signalize poor sanitation in general, it should not surprise if infection are more frequent in the rural control groups than in peri-urban communities using wastewater (Amerasinghe et al. 2009; Weldesilassie et al. 2010).

   In the above reported case of Addis Ababa, Ethiopia, farmers were interviewed and the range of symptoms was kept relatively broad to include also diarrhea. Farmers using water from the polluted river estimated on average 57.8 sick days per year (Table 8.4) which appears exaggerated, if attributed to irrigation activities only. In India, Srinivasan and Reddy (2009) reported 24–72 days per year of wage income loss due to various common sicknesses farmers reported. In both studies different sets of recall (reference) periods from one week to 12 months were applied[2].

In the Ethiopian study, the farmer estimated loss of income and treatment costs (Table 8.4) were probably creating distortion in the cost-benefit analysis. Treatment costs were for example estimated at 23.5 US$; although deworming costs less than US$ 1 per person and year (Hall and Horton 2009). Another example of the challenge of perception based costs assessments is presented in Box 8.2.

e. **Remaining risks.** It has to be flagged that the health risks described so far relate to pathogens. Even where wastewater is treated and the main pathogenic threats are under control, most treatment plants in low-income countries will not remove chemical contaminants from the water, which can have a potential long-term impact on soils, plants and humans (Hamilton et al. 2007). These risks vary with the wastewater source (share and type of industrial effluent), are still difficult to quantify and to cost in view of a potential health impact, and can only be controlled through more sophisticated treatment and/or a shift to low-risk reuse, like irrigated forest plantations.

Box 8.2 Assessing Farmer's Health Burden

Baig et al. (2011) compared in Faisalabad, Pakistan, wastewater and freshwater use for wheat, clover, sorghum and maize production. The results revealed that wastewater use has a higher benefit-cost ratio in the study area irrespective of its negative externalities like health risk. Net benefit from crop production per US$ invested for wastewater irrigation returned US$ 5.56 on an average as compared to US$ 2.20 for freshwater irrigation. Also, the average days of illness in the wastewater area, irrespective of reason, were 3.4 days per person per annum more than in the fresh water area. Very contrasting results were reported from the same peri-urban area of Faisalabad by Kouser et al. (2009), who focused on cauliflower production. While the financial analysis showed also in this study, a clear advantage of using wastewater compared to freshwater (US$ 13 per year and acre), internalizing the health externalities showed an economic loss of US$ −58 per acre largely based on 347.8 sick days, which farmers attributed to different types of possibly wastewater related illness they experience over the year. As farmers continue to use wastewater around Faisalabad without spiraling into poverty, the case might show the difficulty of assessing health risks externalities based on a long recall period, even within a sophisticated analytical approach.

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[2] A maximal one-week recall period for diarrheal related symptoms has been recommended (Arnold et al. 2013). As worm related infections can be without symptoms in otherwise healthy people, perception surveys are not recommended while a stool test (laboratory analysis) is the best option of verification.

8.4 Challenges of Health Risk Assessments at Scale

The primary concern related to the use of wastewater from the perspective of society is public health. Thus the primary objective of wastewater treatment or sanitation in general is prevention of human contact with the hazards of wastes. If treatment is combined with reuse, the added value of resource recovery has to be compared with potentially increased cost through the added reuse for environment and society. The quantification and valuation of actual or likely risks and benefits are important steps for informing public policy decision.

There can be substantial benefits from reuse for the environment or other stakeholders than farmers who might be direct or indirect wastewater 'users', benefiting, for example, from water swaps, i.e. fresh water savings the reuse enables (Condom et al. 2012; see also Chap. 11). Reuse can impact society at large especially where alternative freshwater sources for providing for example fresh fruits and vegetables are missing. Benefits can extend across the value chain and the food-energy nexus by reducing refrigerated transport or storage, packaging costs, food spoilage, etc. However, there might not be a large difference between beneficiaries and those at risk. In the case of Accra, Ghana, for example, every day, about 280,000 people from different parts of life consume fresh vegetables produced on urban farms, as part of popular street food or in canteens and restaurants (Amoah et al. 2007). As most of these farms use polluted water, the same 280,000 urban dwellers are also potentially at risk, not only of getting sick but also transmitting infections within their families and communities. An increasingly used option to assess the likely disease burden of a larger number of stakeholders is probabilistic exposure modeling via quantitative microbial risk assessment (Box 8.3).

Box 8.3 Risk Assessment at Scale

Quantitative microbial risk assessment (QMRA) can be applied at farmer or consumer level, and in situations of treated or untreated wastewater use, to assess for example the probability of residual health risks in formal reuse schemes (Mara et al. 2007). The results can be expressed as disability-adjusted life years (DALY) which is a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death. In other words, mortality and morbidity are combined into a single, common metric. This loss of healthy life years is in principle an economic indicator and can be valued within an economic assessment, although this is not without methodological as well as ethical questions (Anand and Hanson 1997; Winpenny et al. 2010).

A time-saving alternative or supplement to a comprehensive assessment of health risks and related health costs at larger scales, is to compare the costs of different options to reduce or eliminate identified risks. If for example worm infections within a larger community are difficult to quantify and cost, the cost of controlling the risk through protective gear and chemical deworming would be easy to estimate. Or in other words, instead of costing for example the possible health implications for children passing wastewater irrigated farms, the actual costs of fencing the area might be a more practical step for comparing costs and benefits. If the risk reduction potential of certain interventions has been quantified, it is also possible to compare their cost-effectiveness in terms of US$ per DALY averted (Drechsel and Seidu 2011).

However, based on the WHO (2006) promoted multi-barrier approach for health risk reduction, a realistic cost assessment in low-income countries should not rely on wastewater treatment only, but also consider for example investments in food hygiene and disinfection as powerful means for pathogen removal. Multiple barriers are important as in many low-income countries, centralized as well as decentralized wastewater treatment plants appear to follow after commissioning a run-to-failure trajectory (Murray and Drechsel 2011). The costs of risk prevention might be shared among different control points and actors depending on reuse purpose and water quality needs. These needs will also depend on local effluent standards of the receiving water body, as it is unlikely that a reuse scheme will absorb all wastewater (Morris et al. 2005).

8.5 Conclusions

The use of wastewater after appropriate treatment is an important component of sustainable water resources management, and cost benefit analysis a key instrument to inform decision makers about related benefits and costs for the different stakeholders involved, and to determine whether the water reuse activity is worthwhile also compared to other possible solutions.

In this chapter of the book we flagged selected methodological challenges as they are common in the assessment of the benefits and costs of productive wastewater use, with special emphasis on the common comparison of wastewater and freshwater systems and the challenges of assessing actual or possible health risks.

Many commonly cited studies indicate the advantage of wastewater irrigation in terms of crop yields based on the additional or more reliable access to wastewater or its nutrient content where the wastewater is not diluted in other water bodies. We are not questioning these findings, but see significant space for an improved analysis where fresh- and wastewater systems are compared which considers among others the common spatial difference between both systems in terms of soil fertility, and actually analyze the water to verify the assumed nutrient content compared to crop yields. The same applies to the assessment of health risks. In many cases, especially of ‘indirect’ wastewater use, where farmers irrigate along streams or rivers which are receiving wastewater, the difference between freshwater and diluted wastewater can be marginal compared to other socio-economic differences between the test and control groups. The same ambiguity in water quality can occur between ‘treated’ and 'untreated' wastewater given the challenges and low coverage many treatment plants in low-income countries have. Based on the experience, also with students, it is very important to have multi-disciplinary teams in place to build any economic appraisal on locally verified physical differences which are often most visible in the dry season. This applies even more to likely health risks and related perception studies which can turn out to be a Pandora's box for an economic assessment. Since the valuation method in particular for health related externalities is still not stable, and can result in different answers, also based on the applied methodology, specific sensitivity analyses will be important to show the impact of uncertainties on the presented valuation (Condom et al. 2012).

Take Home Messages

- The analysis of costs and benefits is an important instrument for assessing the value of reuse compared to alternative options, for reuse operators, the farmer as well as society.
- The type and scale of benefits and costs of water reuse are location-specific, such that generalizations or case comparisons are difficult and can be misleading unless the biophysical and socio-economic conditions have been verified.
- Risk management, in particular safeguarding public health, receives most policy attention and thus requires special care in any assessment. This includes appropriate recall periods if assessments are based on the experience of stakeholders.
- The analysis of the costs and cost-effectiveness of different risk mitigation options might facilitate the economic appraisal compared to a detailed costing of the risk.

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Chapter 9
Costs and Benefits of Using Wastewater for Aquifer Recharge

Manzoor Qadir, Eline Boelee, Priyanie Amerasinghe and George Danso

Abstract While direct use of wastewater in treated, partially treated, untreated, and diluted forms has been in practice in irrigation systems for a long time, planned use of wastewater for aquifer recharge has been practiced over the last few decades only. We address tradeoffs of using wastewater for aquifer recharge and present the case studies on (1) recharge of groundwater in the Mezquital Valley, Mexico to provide a source of water supply for irrigation and other uses; (2) recharge of depleting Ezousa and Akrotiri aquifers in Cyprus to support irrigation of a range of crops and landscape; (3) supply of wastewater to Amani Doddakere Lake close to Bangalore in India for groundwater recharge, later to be used in irrigation; (4) injection of wastewater into the Bolivar aquifer in Australia in winter for recovery in summer when peak horticultural demands exceed supply; and (5) revitalization of the over-exploited Mashhad Plain aquifer in Iran to reduce contamination and improve water quality for irrigation. While valuation of treated wastewater use for aquifer recharge reveals favorable environmental and economic benefits, public acceptance of indirect use is not yet universal. Moreover, related legal frameworks and supportive policies and institutions are lacking in many countries. These aspects need to be addressed to implement and promote planned use of wastewater for aquifer recharge for multiple benefits.

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9.1 Introduction

Aquifer recharge is the enhancement of natural groundwater supplies with the purpose of both augmenting groundwater resources during times when water is available, and recovering the water from the same aquifer in the future when it is needed for various uses (Dillon et al. 2006; Khan et al. 2008; Bahri 2009). This can be deliberately planned using for instance man-made conveyance systems such as infiltration basins having permeable media, or direct injection through wells. Other terms commonly used for planned aquifer recharge are artificial recharge and managed aquifer recharge. Aquifer recharge may also be unplanned, resulting from infiltration through unlined canals and water courses, excess irrigation, rainfall, and agricultural drainage systems.

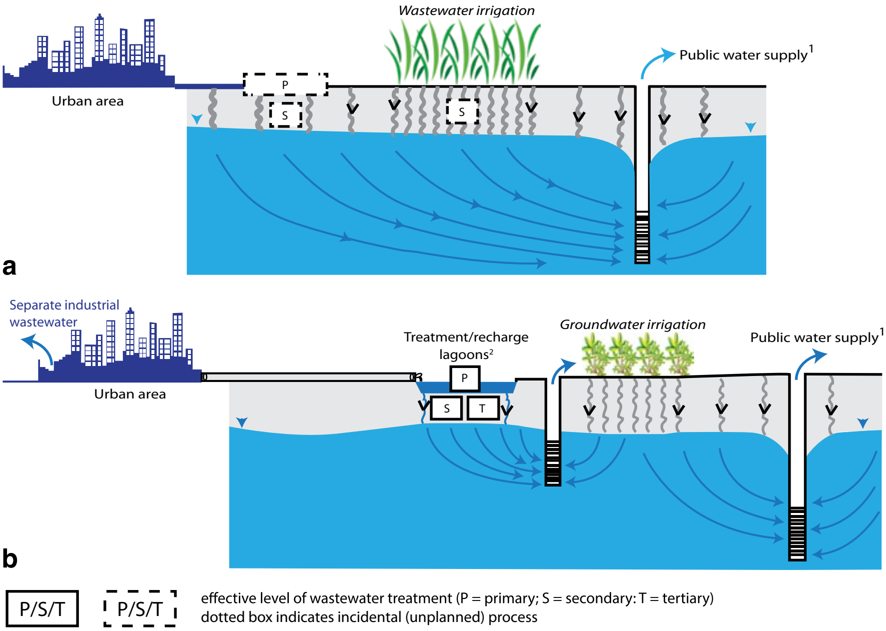
Similarly, aquifer recharge with wastewater can be planned or unplanned. Soil-aquifer treatment (SAT) is another form of recharge where soil and groundwater conditions are favorable and partially-treated sewage effluent, such as primary treated wastewater, is used to infiltrate into the soil and move down to the groundwater (Bouwer 1991; Pescod 1992). Research and practice on the use of wastewater for aquifer recharge have focused primarily on planned aquifer recharge in developed countries and on unplanned aquifer recharge in developing countries (Ying et al. 2003; Jiménez and Chávez 2004; Dillon et al. 2006).

While direct use of treated, untreated, and partially treated wastewater in irrigation systems has been in practice for a long time, planned use of treated wastewater for aquifer recharge has been practiced over the last few decades only. Aquifer recharge with partially treated wastewater or municipal water has been described under suitable soil and groundwater conditions (Bouwer 1991; Pescod 1992; Foster et al. 2005; Voudouris 2011). The principle behind the treatment is that most of the suspended solids, biodegradable materials, and an array of microorganisms, nitrogen, phosphorous, and metals and metalloids are minimized at the unsaturated or "vadose" zone, which acts as a natural filter. For example, certain metals and metalloids and some organic substances may be effectively removed from wastewater through the sorption process during aquifer recharge (Dillon et al. 2006). With increase in the recycling time, aquifer recharge also allows more time for biodegradation, which is particularly relevant for those contaminants that degrade slowly (Ying et al. 2003). However, in case of using highly polluted wastewater for recharging good-quality groundwater, there may be obvious implications for groundwater quality deterioration which have to be avoided.

This chapter addresses economics of planned and unplanned use of wastewater for aquifer recharge primarily in developing countries, while providing also some examples from developed countries. The focus is on the tradeoffs in the context of benefits such as contributions to water banking and ecosystem services as well as potential negative impacts like health risks and groundwater contamination. The chapter also touches upon the challenges with regard to public acceptance, legal frameworks, and policies for aquifer recharge with wastewater.

9.2 Mechanisms of Aquifer Recharge with Wastewater

Wastewater infiltration to groundwater occurs directly from effluent handling facilities and indirectly from unlined wastewater channels as well as through the application of agricultural irrigation in excess of crop water requirement; a common practice in wastewater-irrigated areas. Water stored through aquifer recharge by treated wastewater can provide a reliable supply of water during times of water shortages, reverse falling groundwater levels, reduce water losses associated with leakage and evaporation, and provide ecosystem and economic benefits. However, planned aquifer recharge is practiced in developed countries (Dillon et al. 2006; Khan et al. 2008; Birol et al. 2010) while mostly unplanned aquifer recharge in developing countries (Jiménez 2008; Alaei 2011; Fig. 9.1).



[1] Should have appropriate surveillance and treatment

[2] Treatment plant can substitute for lagoons (especially where land is at a premium) if higher capital and running costs are acceptable

Fig. 9.1 General mechanisms of wastewater generation, treatment, use and infiltration to aquifers with reference to **a** commonly-occurring unplanned and uncontrolled situation; and **b** economical interventions aimed at reducing groundwater source pollution risk. (Adapted from Foster et al. 2005)

While most wastewater generated in developing countries remains in untreated or partly treated forms, use of highly contaminated wastewater for aquifer recharge may pose health and environmental risks in the long run, particularly if the wastewater receiving groundwater is used for drinking. The potential pollutants in groundwater moved through wastewater infiltration may include pathogenic microorganisms, excess nutrients, and dissolved organic carbon; and where significant volume of industrial effluent is combined, toxic metals and organic compounds may also concentrate (Foster et al. 2005; Jiménez 2008; Heinz et al. 2011). However, the actual impact on groundwater quality varies widely with: (1) the pollution vulnerability of the aquifer; (2) the quality of natural groundwater and its potential use; (3) the origin of sewage effluent and likelihood of persistent contaminants; (4) the scale of wastewater infiltration; and (5) the quality of wastewater, and its level of treatment and dilution (Foster et al. 2005). In general, wastewater would have to be treated before recharge to the lowest level that would not affect overall groundwater quality. Periodic monitoring of groundwater quantity and quality would be needed to assess long-term effects.

9.3 Aquifer Recharge in Relation to Water Banking and Ecosystem Services

As one of the important strategies for water banking, water stored through aquifer recharge can provide a reliable supply of water during times of inter-seasonal and inter-year water shortages. It can reverse falling groundwater levels, and also reduce water losses associated with leakage and evaporation, as compared with surface water storage (McCartney and Smakhtin 2010; O'Donnell and Colby 2010; Box 9.1). Similarly, aquifer recharge through wastewater can provide ecosystem services through a range of mechanisms (MEA 2005; TEEB 2013; Box 9.2). Also by increasing access to water, aquifer recharge may contribute to achieving food security (Van Steenbergen et al. 2011).

Box 9.1: Aquifer Recharge and Water Banking

In many countries, water supply and availability remain highly variable across seasons and years and may become even more difficult to manage and predict with increased climate variability and change. Water banking is one of the strategies that may help in addressing variability in water supply and availability under specific situations (O'Donnell and Colby 2010). As a mechanism designed to facilitate transfers of water on a temporary, intermittent, or permanent basis through voluntary exchange, water banks are generally established to (1) create a more reliable water supply for use during dry seasons or years; (2) ensure a future water supply for various water needs;

(3) promote water conservation by encouraging water users to conserve and deposit conserved water into the bank; (4) facilitate and enhance water market activity; and (5) resolve issues between groundwater and surface water users (Clifford et al. 2004).

Where legal frameworks and institutions governing water rights and water use allow for water banking activities, water banks may result in great variety in their geographic coverage, objectives, services they provide, and legal authorizations under which they operate. Water banks range in geographic scale from involving local water users in a specific urban area or a county to offer services across broad regions, sometimes including several provinces or states.

Box 9.2: Aquifer Recharge and Ecosystem Services

Many ecosystem services relate to water, directly or indirectly (MEA 2005; TEEB 2013). These can be categorized as provisioning services such as water supply, production of food, fish, and timber; regulating services such as control of floods and disease; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on the earth in the long term (MEA 2005; TEEB 2013).

Wastewater collection, treatment, and use provide ecosystem services (GWI 2009). Aquifer recharge through wastewater also provides benefits to ecosystems by (1) providing a source of water and counterbalancing groundwater pumping through groundwater replenishment (Dillon et al. 2006; Birol et al. 2010); (2) recycling and reusing water and essential nutrients such as nitrogen and phosphorus for irrigation (Jiménez and Chávez 2004); (3) avoiding or minimizing pollution of surface water bodies and safeguarding environmental, human, and animal health (Papaiacovou and Papatheodoulou 2013); (4) reducing the costs of technologies to treat wastewater to a required standard where it can be considered (Nema et al. 2001); and (5) contributing to climate change adaption (Van Steenbergen et al. 2011).

9.4 Economics of Aquifer Recharge with Wastewater

Depending on the recharge method, estimated costs of artificial recharge with freshwater in Australia range from US\$ 0.05 m^{-3} (1000 US\$ = 1195 Aus\$ in 2008) to US\$ 0.15 m^{-3} (Khan et al. 2008). In the case of wastewater, the recharge cost depends on the level of wastewater treatment in addition to the recharge system. In developed countries where tertiary treatment of wastewater is practiced, the

Table 9.1 Cost analysis (US\$)[a] of soil-aquifer treatment (SAT system) compared with other conventional wastewater treatment systems based on 55,000 m^3 d^{-1} (55 MLD) system capacity (Modified from Nema et al. 2001)

Treatment system	Capital cost	Annual cost[b]	Treatment cost[c]
Conventional activated sludge process	3,073,988	1,047,276	0.052
Trickling filter	2,961,628	1,151,155	0.057
Anaerobic filter	2,755,989	909,476	0.045
Up-flow anaerobic sludge blanket	2,331,991	794,997	0.040
Soil-aquifer treatment(SAT)	1,907,992	674,157	0.034

[a] Capital, annual, and treatment costs converted from Indian Rupee (IRs) to US\$ (1 US\$ in 2001 = 47.17 IRs)

[b] Annual cost consists of all operational and maintenance costs

[c] Treatment cost per m^3 based on annual cost only without including capital cost of treatment systems

cost of recharge (including the cost of wastewater treatment and recharge system) may range from US\$ 0.45–1.20 m^{-3} (GWI2009). According to the Water Reuse Inventory of the Global Water Intelligence, artificial recharge projects using tertiary treated wastewater constitute 2.17 % of the total water reuse projects (GWI 2009).

In developing countries, few studies have been undertaken on the economics of aquifer recharge with wastewater (Nema et al. 2001; Papaiacovou and Papatheodoulou 2013; Zekri et al. 2014). Using a soil-aquifer treatment (SAT) system, Nema et al. (2001) carried out a pilot study in Sabarmati River bed at Ahmedabad, India. The infrastructure for the SAT system comprised of two wastewater primary settling basins, two infiltration basins, and two production wells located in the center of infiltration basins for pumping out recharged water. They compared SAT with other treatment systems such as conventional activated sludge process, trickling filter, anaerobic filter, and up-flow anaerobic sludge blanket (Table 9.1).

The performance data indicated that SAT had potential for removal of organic pollutants (90 %), nitrogen (50 %), phosphorus (90 %), and bacteria (4–5 order of magnitude). The cost of wastewater treatment by the treatment systems evaluated was lower than generally reported (Table 9.1), which was due to exclusion of the capital cost in economic analysis and consideration of primary treatment of wastewater. Based on the economic estimates undertaken more than a decade ago, Nema et al. (2001) found the SAT system to be more economical than the conventional wastewater treatment systems and recommended for adoption under Indian conditions. Similar conclusions were drawn also more recently from riverbank filtration trials in New Delhi (Sprenger et al. 2014).

9.4.1 Mezquital Valley Aquifer in Mexico

In the Mezquital Valley, north of Mexico City, about 75,000 farmers irrigate 90,000 ha with mostly untreated wastewater (Carlos Pailles, personal communication 2013). Wastewater irrigation allows agricultural development in the valley where annual average rainfall is 550 mm and soils are characterized by low organic matter content and low levels of nutrients essentially need for crop growth. On an annual per hectare average basis, the contribution of wastewater to the soils is 2400 kg organic matter, 195 kg nitrogen, and 81 kg phosphorus (Jiménez and Chávez 2004). Due to the anticipated benefits of irrigation, the annual rental value for land irrigated with wastewater is about US$ 1000 ha^{-1}. By comparison, the rental value for non-irrigated land in the valley is about US$ 400 ha^{-1} (Carlos Pailles, personal communication 2013).

With small land holdings (1.2 ha per farmer), the farmers try to maximize productivity of the land they cultivate with wastewater irrigation. In doing so, they tend to over-irrigate at the annual rate of 15,000–22,000 m^3 ha^{-1} with the goals of (1) avoiding any water deficit to crops; (2) providing adequate/excess nutrients from wastewater; and (3) leaching potential contaminants and salts from the root zone. The aquifer is being recharged due to infiltration from (1) high rate of irrigation; (2) unlined dams and water channels; (3) rainfall; and (4) drainage systems.

Based on the estimates of the British Geological Survey in the 1990s, the water infiltration rate in the wastewater irrigated area would be around 25 m^3 s^{-1}, i.e. 8760 m^3 ha^{-1} yr^{-1}, indicating that 40–58 % of the applied irrigation would pass through the soil profile and contribute to groundwater. This unplanned recharge, which has been in practice for several decades, has raised the water table in some places in the Mezquital Valley from 50 m deep to the surface. Springs have appeared and have become a source of water supply to the people living in the valley.

The infiltration of wastewater through the soil profile to groundwater has improved its quality in certain aspects. Organic matter is reduced by 95 %, heavy metals by 70–90 %, and levels of more than 130 organic compounds by about 99 % by the time water enters aquifer. Salt concentration, however, has increased over time (Jiménez and Chávez 2004). To bridge the gap between freshwater demand and supply in Mexico City, the government is planning to return 6–10 m^3 s^{-1} (0.19–0.32 billion m^3 yr^{-1}) of recharged water to the city. This option would be more cost-effective than transporting freshwater from areas that are more than 1000 m lower than Mexico City and 200 km away.

Amid several benefits, wastewater irrigation and aquifer recharge can generate negative impacts as revealed from the Mezquital Valley in some studies (Jiménez 2008; Heinz et al. 2011). For example, research on the health implications of wastewater in the valley indicated that children living in wastewater irrigated areas have higher rates of helminth infections than children not living in wastewater irrigated areas (Jiménez 2008; Heinz et al. 2011). The government has initiated many programs to educate the affected population on how to reduce risks associated with the use of wastewater. In addition, the government has moved forward with the construction of a large wastewater treatment plant in recent years to improve wastewater and groundwater quality and expected decrease in health risks.

Initiated in 2010 on the basis of Build-Operate-Transfer (BOT) contract, the wastewater treatment plant is expected to be completed in the final quarter of 2015. Once completed, the treatment plant will treat wastewater at 35 m^3 s^{-1}; i.e. about 1.1 billion m^3 yr^{-1}. The total expected cost on the completion of this plant will be Mexican Peso 10,022 million or US$ 763 million (1 US$ = 13.14 Mexican Peso). Of this cost, 49 % will be covered by the government, 31 % credit from the government, and 20 % by private partner. The plant will be run for 25 years by the private partner to recover their investment and then it will be handed over to the government. The annual operational cost of plant is estimated at Mexican Peso 1066 million (US$ 81 million). The cost of wastewater supply for irrigation will be Mexican Peso 1.05 m^{-3} (US$ 0.08 m^{-3}), which is expected to be affordable by the farmers. The sludge from the treatment process will be landfilled around the treatment plant on contours or used, based on its quality. In terms of energy requirement and supply, the plant will generate 70 % of its own energy requirement through biogas production and its utilization. There are also plans to build three relatively small treatment plants in other parts of Mezquital Valley.

With the perception that nutrients in wastewater would be removed during the treatment process, the wastewater irrigating farmers in Mezquital Valley have expressed displeasure with the program of wastewater treatment. To address farmers' concern, the treatment plant management plans to establish demonstration sites using treated wastewater and growing the same crops farmers grow, to demonstrate that the amount of nutrients left in the treated wastewater would be sufficient for crop growth without yield reduction.

9.4.2 *Ezousa and Akrotiri Aquifers in Cyprus*

All of the treated wastewater produced in the southwestern coastal city of Paphos in Cyprus is used for Ezousa aquifer recharge, which is subsequently pumped for irrigation through diversion in an irrigation channel. Irrigation with treated wastewater in the country is regulated by the Code of Good Agricultural Practice. The treated wastewater can be applied to all crops except leafy vegetables, bulbs, and corn eaten raw. The major crops irrigated with treated wastewater are citrus trees, olive trees, fodder crops, industrial crops, and cereals. In addition, it is used for landscape and football field irrigation (Papaiacovou and Papatheodoulou 2013).

Similar to Paphos, wastewater generated by the southern coastal city of Limassol in Cyprus is collected, treated, and used for many purposes. During winter when the demand for water in agriculture decreases, treated wastewater is pumped to an irrigation dam for storage or recharge of Akrotiri aquifer. In 2010, about 15 % of treated wastewater was used for the aquifer recharge. There are considerations to increase the volume of treated wastewater to replenish the Akrotiri aquifer.

Based on a comprehensive literature review, focus group discussions, and informal interviews with local experts, policy makers, farmers, and members of the general public, Birol et al. (2010) evaluated stakeholders' participation and economics of Akrotiri aquifer recharge by wastewater. They identified local farmers and the residents of Limassol city as the main stakeholders that would benefit from aquifer recharge. Farmers in and around the area depend on both direct use of treated wastewater and/or from the aquifer. Limassol residents, on the other hand, derive indirect use values through the consumption of locally produced vegetables, as well as non-use values from the ecological status of the local environment and the employment of local population in agriculture, both of which are supported by the aquifer.

Under the aquifer management plan, Birol et al. (2010) estimated the total annual value for the 6 million m^3 of treated wastewater to replenish the Akrotiri aquifer as US$ 1.182 million (1.000 US$ = 0.442 Cyprus Pound in 2010); i.e. US$ 0.20 m^{-3}. The economic evaluation revealed that the net benefit generated by the aquifer recharge is positive and the benefits extend well into the future. The continuation of Akrotiri aquifer recharge by wastewater would yield a welfare improvement that would increase the economic benefits to all the stakeholders in both the short-and long-term, and would help Cyprus in its efforts to meet the European Union's (EU) Water Framework Directive, WFD (2000/60/EC) requirements by 2015. In compliance with Article 9 of the WFD (2000/60/EC), Cyprus has launched a new water pricing policy to recover the cost of water services. To encourage the use of treated wastewater for agricultural irrigation, it is supplied to potential users without full cost recovery at a cost lower than freshwater (Table 9.2) while full cost recovery is expected to be implemented gradually.

9.4.3 Aquifer in Bangalore, India

In 2011, the Department of Minor Irrigation, Bangalore launched a long planned lift irrigation project to provide water from Yellemallappashetty Lake to Amani Doddakere Lake in the Hoskote area. Yellemallappashetty Lake receives mostly untreated wastewater from northeastern and eastern parts of Bangalore. The Amani Doddakere Lake was dry for more than 20 years, due to reduced rainfall in its catchment area. The project aimed at refilling Amani Doddakere Lake, which resulted in seep-

Table 9.2 Proposed charges (US$ m^{-3}) for the different uses of treated wastewater and unfiltered freshwater used for irrigation in Cyprus. (Adapted from MANRE 2010)

Potential use	Treated wastewater	Freshwater
Agricultural organizations for agricultural production	0.07	0.20
Individuals for agricultural production	0.09	0.23
Sports activities	0.20	0.45
Landscape and hotel gardens irrigation	0.20	0.45
Abstraction from aquifer recharged by wastewater	0.11	—

age of wastewater from the lake to groundwater and as a consequence an increase in the water level in the existing wells. Intense tube well drilling in the past had decreased the groundwater level, which led to dysfunction of many wells in the area.

The increase in the water level in the existing wells around Amani Doddakere Lake has provided the local farmers a cost-effective means of acquiring water for irrigation, which tends to reduce their farm production costs and increases crop yields. This strategy has also helped the farmers to remain in the local community and be productive by contributing to the agricultural economy of the city. There are indirect benefits associated with this project, as land with access to (waste) water would have more value than land without access to water/wastewater. In addition, there is another business opportunity as many truck operators in the Hoskote area are selling water from recharged wells to several small and medium businesses (Scharnowski 2013).

A recent study stemming from the farmers' perspectives on the project shows that farmers in Hoskote area who faced serious problems with the supply of irrigation water in the past due to the dysfunction of many wells are willing to pay US$ 30 ha^{-1} for each crop season for the recharged groundwater to be used for irrigation (Scharnowski 2013). Furthermore, the farmers are willing to contribute around 25 % of the operation and maintenance costs. The payment mechanisms by the farmers are expected to be finalized and operational soon.

Empirical analysis of the sustainability of the project (Scharnowski 2013) suggests that the planned use of wastewater in this scheme could serve as a viable option to reduce water scarcity challenges in similar peri-urban and rural areas in India. However, the research also suggests that variables such as education, household size, health perceptions, and quality of wastewater may affect farmers' willingness to pay for groundwater recharge.

9.4.4 Bolivar Aquifer in Australia

The first reclaimed water aquifer storage and recovery project in Australia was proposed in 1996 in Bolivar, which is 25 km north of Adelaide. The project aimed at testing the technical, economic and environmental viability of storing reclaimed water in an aquifer in winter, for recovery in summer, when peak horticultural demand may exceed the capacity of the water reclamation plant to supply water through its pipeline. Surface storage was prohibitively expensive and recharge by surface infiltration was not viable, due to thick surficial clay formation. Therefore, wastewater was injected for groundwater recharge.

A unique aspect of the project is that the injected water is treated only to a level suitable for unrestricted irrigation. Thus, the water retains substantial nutrient concentrations (Dillon et al. 2006). Given the proximity to farm drinking water supplies, it was vital that the drinking water supplies were protected. After initial drilling, suitability of the site for aquifer recharge and drinking water protection was confirmed and a monitoring program has been in place for water quality assessment.

The estimated cost of the recharge project, excluding water treatment and pipeline costs, is between Aus$ 0.06 and 0.14 m^{-3} (1.000 US$ = 1.328 Aus$) depending on the volume of water recovered per well, the depreciation rate, and the assumed working lives of wells and pumps. This overlaps the range of costs for groundwater extraction by individual irrigators for typical annual production volumes (US$ 0.09 to 0.26 m^{-3}), taking into account capital and operating costs and the expected lifetimes of wells and pumps. However, the initial sale price of reclaimed water, Aus$ 0.06–0.11 m^{-3} depending on season, was not sufficient to cover the cost of aquifer storage and recovery, leading to a gradual increase in pricing. In terms of technical and environmental assessment, when summer demand would exceed the pipeline's capacity, the option of aquifer storage and recovery would be technically and environmentally viable. Preliminary modelling suggests that the aquifer has adequate storage capacity for annual storage and recovery volumes in the range of 5–10 million m^3.

9.4.5 Mashhad Plain Aquifer in Iran

The metropolitan city of Mashhad is located in Mashhad Plain in the northeast of Iran. Mashhad is the second largest city of Iran. Water demands have increased with the city's expanding population and industrial growth. The annual volume of water withdrawn from the Mashhad Plain aquifer (1492 million m^3) exceeds annual recharge (1203 million m^3), which is contributed by surface water of the plain (252 million m^3) and water infiltration into aquifer (951 million m^3). As a result of overexploitation of groundwater through excessive pumping, groundwater balance in the area has been disturbed and its level is declining every year (Alaei 2011). At the same time, the volume of wastewater from domestic and industrial sectors is increasing.

Since 2005, much of the untreated wastewater from the city has been injected into the aquifer, through wells, while the remainder has been disposed into the Kashafrud River and its tributaries. This approach has resulted in: (1) the contamination of groundwater 'Ab-khan' of Mashhad with a range of pollutants; (2) excessive pumping from the eastern part of the aquifer, resulting in depletion of water at a fast rate and abandoning of drinking water wells east of Mashhad, thereby affecting the well-being of the city population; and (3) contamination of Kashafrud River and its tributaries, particularly with microbiological pollutants (Alaei 2011). With contamination of both surface water and groundwater, farmers in urban and peri-urban Mashhad irrigate several crops, including vegetables, with polluted water.

To minimize pollution of water resources and augment water supply of good quality, the government has constructed wastewater treatment plants to produce treated wastewater for groundwater recharge, disposal into the Kashafrud River, or direct use for irrigation. Two treatment plants have been completed and another is under construction. With the implementation of the water recycling plan of Mashhad, the following allocations have been made for annual volume of the 253 million m^3

wastewater (Alaei 2011): (1) 150 million m^3 per year to replace the use of existing and permitted use of groundwater; (2) 95 million m^3 per year to stabilize groundwater level and to prevent mixing of saline and good-quality groundwater; and (3) 8 million m^3 per year to supply water needed for industry and green spaces.

9.5 Public Acceptance, Legal Frameworks, and Policies for Aquifer Recharge

Several municipalities worldwide are augmenting their drinking water supplies with treated wastewater through aquifer recharge or reservoir enhancement. Yet public acceptance of indirect use is not universal (Asano and Cotruvo 2004; Nijhawan et al. 2013; Zekri et al. 2014; see also Chap. 5). While assessing the potential of treated wastewater for aquifer recharge as a favorable and appealing project in Oman, Zekri et al. (2014) suspect that the project may face rejection from domestic users, who may be unwilling to accept mixing treated wastewater with the current water supply due to perceived health risks.

In a recent online survey conducted in India, 64 % of 194 respondents favored using treated municipal wastewater for groundwater recharge, while 28 % opposed, and 8 % remained indifferent (Nijhawan et al. 2013). The primary concern among respondents was skepticism that wastewater might not be treated properly before being injected into the aquifer. If the survey is indicative of broader public perceptions, then efforts to ensure residents that only fully treated wastewater will be used in the recharge program would be helpful in securing public support. Providing additional information, e.g. details on wastewater treatment and quality of treated wastewater, would enable residents to better evaluate the pertinent risks and benefits.

In addition to public concerns for acceptance of aquifer recharge with wastewater and indirect use of recharged water, legal frameworks and supportive policies and institutions are lacking in many countries to implement and promote planned use of wastewater for aquifer recharge (Asano and Cotruvo 2004). Therefore, relevant legislation and pertinent policies and institutional settings are essentially required to accommodate and regulate the use of wastewater for recharge.

9.6 Conclusions

Water stored through aquifer recharge by treated wastewater can provide a reliable supply of water during times of inter-seasonal and inter-year water shortages, reverse falling groundwater levels, reduce water losses associated with leakage and evaporation, and provide ecosystem and economic benefits. However, there is clear distinction between developed and developing countries with regard to the quality of wastewater used for aquifer recharge. Research and practice on the use of wastewater for aquifer recharge have been mainly focused on planned aquifer recharge in developed countries and on unplanned aquifer recharge in developing countries.

While most wastewater generated in developing countries remains in untreated or partly treated forms, use of highly contaminated wastewater for aquifer recharge may pose health and environmental risks in the long run, particularly if the groundwater-receiving wastewater is used for drinking. In general, wastewater would have to be treated before recharge to the lowest level that would not affect overall groundwater quality. Periodic monitoring of groundwater quantity and quality would be needed to assess long-term effects.

Site-specific economic analysis has revealed that underground storage capacity can possibly be developed at less cost than surface storage facilities without evaporation losses. In addition, aquifer recharge through certain approaches such as the SAT system could be more economical than the conventional wastewater treatment systems. However, presence of permeable media in infiltration basins or injection wells is essential for effective recharge.

Take Home Messages

- Wastewater use for aquifer recharge can yield many benefits through increase in groundwater level for later reuse, decrease in environmental pollution by preventing indiscriminate discharge into surface water bodies, and decrease in evaporation losses.
- Wastewater needs treatment before recharge to the lowest level that would not affect overall groundwater quality negatively.
- In many countries, (new) legislation and institutional arrangements are required to accommodate and regulate the use of wastewater for aquifer recharge and related ecosystem services.
- Efforts are needed to address public concerns for acceptance of aquifer recharge with wastewater and indirect use of recharged water for different uses.

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Chapter 10
Economics of Water Reuse for Industrial, Environmental, Recreational and Potable Purposes

Miriam Otoo, Javier Mateo-Sagasta and Ganesha Madurangi

Abstract Water reuse offers considerable economic value through the provision of health and environmental benefits, water and energy cost-savings and opportunities for businesses. In addition, activities associated with water reuse can generate revenue through the sale of water, energy, carbon credits, and by-products. Data limitations restrict the degree to which we can conduct a fully informed economic analysis of all pertinent costs and benefits. Yet the available information suggests the net benefits of water reuse can be substantial. We examine selected empirical cases of water reuse, highlighting the costs and benefits, and also reflecting on the enabling environment, challenges and opportunities for selected reuse options. The country-level experiences we describe provide insight for countries whose water resources are stretched by increasing urbanization and a changing climate.

Keywords Wastewater economics · Data limitations · Landscaping · Water reuse · Value proposition

10.1 Introduction

Reuse of water for industrial, domestic and agricultural purposes has occurred throughout history. However, planned reuse only gained importance two or three decades ago with increasing demands for water due to technological advancement, population growth, and urbanization (AQUAREC 2006). In many emerging economies, such as India, Mexico and Thailand, rapidly growing industries such

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as textiles place new demands on limited groundwater, while also degrading water quality by discharging untreated effluent (Lazarova et al. 2013). The reuse of industrial wastewater for water-intensive processes such as washing, bleaching and dyeing reduces the industry's demand on water resources up to 75 % (WRG 2013). The reduction in urban water withdrawal can improve water availability for other users such as farmers operating near cities. In addition, the cessation of untreated effluent discharges improves the return flow to water bodies.

Water reuse for recreational, environmental and potable purposes is also increasingly relevant. There are cases in numerous countries where wastewater has been used to create artificial lakes or wetlands, restore natural wetlands, and irrigate golf courses, parks and gardens (Alfranca et al. 2011; Jimenez 2013; Muciñio 2001). In countries such as Kuwait, Morocco and Mexico, alternative water sources, such as brackish water, continue to be insufficient to meet the growing demands for water for landscaping, agriculture, and other non-potable uses. Reclaimed water is used in combination with brackish water and supplied for non-potable uses, such as irrigating landscapes along highways, roads and public gardens, and for agricultural lands and groundwater recharge. These practices have resulted in a reduction in freshwater withdrawal and increased urban supply.

Related benefits also extend to cases of wastewater use for potable purposes. Unplanned and indirect use of wastewater for potable purposes has always occurred, however planned and indirect potable reuse (PIPR) spans now for more than 60 years. This practice has been reported mainly, but not only, in industrialized countries (Royte 2008; Rodriguez et al. 2009; Quayle 2012). Several cases exist in Australia, England, Belgium and the United States (Meehan et al. 2013; Essex and Suffolk Water 2008) where recycled effluent contributes on average about 5–8 % of the water supply during dry periods. Direct "pipe to pipe" potable reuse is also possible, and occurs in practice, as the case in Windhoek, Namibia, demonstrates, although it is a unique case (Lahnsteiner et al. 2013b; WRG 2013).

The socio-economic and environmental benefits of wastewater use must be considered along with the direct or indirect costs. In the textile industry, for example, energy-intensive processes are required for effluent treatment. This has profitability and competitiveness implications for the businesses and represents an increased urban energy demand, in a context of energy scarcity and intersectoral competition. Landscaping competes with potable uses for wastewater in some cities (Jimenez 2013; Muciñio 2001). The use of inadequately treated wastewater for irrigation of parks and gardens carries the risk of groundwater contamination and potential health hazards. In addition, many urban households and industries are not yet ready to accept treated wastewater as potable, choosing instead to rely on alternative sources of water.

Advocating for water reuse for industrial, landscaping and potable uses requires that the reuse options demonstrate the principle of no appreciable harm. Thus, wastewater use must not impose a net economic loss, or increase environmental and human health risk. This means the reuse options must leave no one worse off while generating benefits for some (Chap. 7). Several studies have assessed the socio-economic benefits and costs of the multiple uses of wastewater (Lazarova et al. 2013; Weldesilassie et al. 2011). Cost assessments are often straightforward, while benefits are typically associated with monetary and non-monetary factors that are difficult to measure. Furthermore, although there are many valuation methods for estimating socio-economic benefits, none is universally accepted, such that the comparison of results is difficult. In addition, economic assessments are particularly scarce in developing countries.

Despite these complexities in the economic assessments of water reuse, there are examples where the introduction of water reuse has served the dual purpose of addressing water scarcity and waste management challenges. From that perspective, one would expect an extensive application of reclaimed water for industrial use, landscaping, and potable purposes. However, the potential for water reuse has not yet been fully exploited in many developing countries and emerging economies (Asano 2002). To the best of our knowledge, a comprehensive documentation of water reuse for industrial, potable and non-potable purposes is not available. Motivated in part by this lack of information, we assess the costs and benefits of water reuse for industrial, environmental, recreational, and potable uses in developing countries and emerging economies. In particular, we examine selected examples of wastewater use that might provide helpful insight for countries in which water resources are stretched by increasing urbanization and changing climatic conditions. We apply the conceptual framework outlined in the previous chap. 7.

10.2 Motivation and Trends in Using Wastewater for Industrial, Landscaping and Potable Purposes

Globally, about 80 % of the water produced by tertiary treatment in wastewater facilities is used for irrigation of crops or landscape, for industrial purposes, or for environmental enhancement (GWI 2010). While water scarcity is the primary motivation for reuse, each type of reuse contributes to a well-defined purpose and follows a notable pattern or trend. While chap. 8 in the volume looked at agricultural water and the challenge of assessing its costs and benefits from a larger economic perspective, in this chapter, we will examine the use of wastewater in non-agricultural settings.

Water Reuse for Industrial Purposes Increasing incentives for industrialization in many developing countries have resulted in increased groundwater abstraction and water quality degradation as a result of effluent discharges from industries. Many industries have the capacity to use recycled water in their operations (Asano 2002) as shown in Table 10.1. Many textile firms in India, Thailand and Vietnam, use wastewater for water intensive processes such as washing, bleaching and dyeing. Internal process water, with appropriate treatment, is also used for washing tanks, and in boilers and cooling towers in the food industry as seen in the examples of Nestlé and Unilever in South Africa (WRG 2013).

While these practices are implemented largely as part of a water use reduction strategy, particularly for industrial purposes, a key motivation is also to reduce water pollution. Increasing enforcement of legislative mandates related to environmental protection, such as zero industrial effluent discharge standards, is motivating

Table 10.1 Examples of water reuse projects for industrial, environmental/recreational and potable purposes. (Source: IWMI (based on secondary data sources))

Type of Reuse	Name of the reuse project	Country	Type of industry/use	Scale of production	Freshwater consumption without reclamation[a]	Driving factors of water reuse	Purpose of water reuse[a]	Technology for wastewater treatment	Source of data
Industrial purposes	Tiruppur textile sector	India	Textile	121,600 tons/year of textile	1,200,000 m^3/year	Zero liquid discharge legislative mandate Production risk reduction[b]	Washing, bleaching, dyeing, cooling towers	Reversed osmosis and thermal evaporation system	WRG (2013); Buvaneswari (2014)
	Essar Steel and Power	India	Steel industry	10,000,000 tons/year of steel	3,900,000 m^3/Year	Reduce freshwater consumption Water and energy cost-savings	Cooling towers, furnace cleaning, fire lighting systems	Pressure filtration	WRG 2013
	Panipat refinery	India	Petro-chemical industry	12,000,000 tons/year of oil	Data not available	Stringent regulation—zero liquid discharge Fluctuating raw water quality Diversify regional water supply portfolio	Boiler makeup water; process for production of purified terephtalic acid; cooling tower	Pressure sand filtration, ultra filtration and reverse osmosis	Lahnsteiner et al. (2013a)
	Unilever	South Africa	Food industry	65,000 tons/year of dry foods; 320 m^3/day of milk[c]	88,000m^3/year	Reduce demand for municipal water supply Reduce production risk	Fabrication, washing, dilution and cooling towers	Lagoon bioreactor, filtration and reverse osmosis technologies	WRG (2013)
	Middle East Paper Company	Saudi Arabia	Paper industry	400,000 tons/year of paper	8,000,000 m^3/year	Water cost-savings	All production processes	Aerobic and anaerobic treatment; reverse osmosis	Jung and Pauly (2011); WRG (2013)

Table 10.1 (continued)

Type of Reuse	Name of the reuse project	Country	Type of industry/use	Scale of production	Freshwater consumption without reclamation[a]	Driving factors of water reuse	Purpose of water reuse[a]	Technology for wastewater treatment	Source of data
	Rio Tinto Argyle Mine	Australia	Mining	Data not available	3,645,000 m^3/year	Reduce freshwater abstraction	All production processes	Retention pond	WRG (2013)
Environmental and Recreational purposes	Marrakech wastewater treatment plant	Morocco	Greening of landscapes	Not applicable	287,000–600,000 m^3/Day	Water cost-savings Insufficient alternative water resources	Landscape and agricultural land irrigation; groundwater recharge	Micro-filtration; reverse osmosis	Weblink[d]; Sun et al. (2013)
	Sulaibiya wastewater reclamation project	Kuwait							
	Quighe and BeiXiaoHe Water Reclamation Plant	China							
	Jonan Three River Project	Japan	Restoration of wetlands and reservoirs	Not applicable	43,200–380,000 m^3/day	Drying up of natural water resources—restoration of water channels, lakes and rivers	Water channels and river restoration	Activated sludge; sand filtration; advanced treatment with A_20 nutrient removal process	Jimenez (2013); Muciñio (2001)
	Texcoco Lake	Mexico							

Table 10.1 (continued)

Type of Reuse	Name of the reuse project	Country	Type of industry/use	Scale of production	Freshwater consumption without reclamation[a]	Driving factors of water reuse	Purpose of water reuse[a]	Technology for wastewater treatment	Source of data
Potable purposes[b]	Windhoek municipality	Namibia	Direct potable water	Not applicable	70,000 m^3/day	Shortage of drinking water due to severe & long droughts Alternative (economical) sources of potable water	Potable water use; non-potable use (landscape irrigation)	Micro-filtration;, reverse osmosis; UV/H_2O_2	Lahnsteiner et al. (2013b); WRG (2013)
	NEWater project	Singapore	Indirect potable water	Not applicable	20,000–350,000 m^3/day	Replenish groundwater levels and reservoirs to address limited natural water resources	Indirect potable water use via groundwater recharge & reservoir replenishment; artificial aquifer recharge; non-potable uses	Advanced dual-membrane (micro-filtration & reverse osmosis); activated sludge process; denitrification	Houtte et al. (2013); WRG (2013)
	Toreele project	Belgium							

[a] For potable purposes and environmental/recreational purposes, we define by the reclaimed water used

[b] As related to unreliable availability/supply of water

[c] Data applicable only to cases of Unilever and Nestlé, South Africa

[d] Source: http://www.xylemwatersolutions.com/scs/Middle-East/en-us/press/Case%20Studies/Documents/Biological%20treatment%20%20%E2%80%A2%20%20Water%20Reuse%20Sulaibiya,%20The%20World%E2%80%99s%20Largest%20Water%20Reuse%20Plant%20in%20Kuwait.pdf

industries to install infrastructure for wastewater treatment and to comply with effluent discharge standards both in developed and developing countries. Investments for wastewater treatment particularly in the paper industry, steel production, textile manufacturing and food industries are increasing, as non-compliance usually is more costly (Wang et al. 2008).

Additionally, particularly in the food sector, businesses face increasing *production risk* with growing variability in urban water supply (Asano 2002). To reduce the risk of any impact on the plant operation due to poor water availability, these businesses make use of alternate sources of water, such as rainwater harvesting and condensate recovery. These practices often come with high investment costs and some businesses choose to invest in additional revenue-generating or cost-saving activities such as energy recovery or the sale of by-products, noting the incremental benefits from wastewater treatment and use as related to new *revenue generation opportunities*. An example is the Indian textile industry in Tiruppur, which uses large amounts of salts in the dyeing process. The water reclamation process regenerates these salts as a byproduct, providing an additional revenue stream to the water reuse process and contributing to the business' sustainability strategy (Buvaneswari 2014).

Water Reuse for Landscaping Many cities and environmental agencies use wastewater to create artificial lakes or wetlands, restore natural wetlands or irrigate golf courses, parks and gardens. In water-stressed countries such as Peru, Kuwait and parts of South Africa, water reuse represents a sustainable water management strategy, especially given that the country's water resources, including brackish water, are insufficient to meet the increasing demands from landscaping, agriculture and other non-potable uses. Water scarcity and the increasing cost of importing water from afar motivate much of the water reuse to irrigate landscaping along highways, roads and public gardens. In addition to landscape irrigation, reclaimed water has been used to restore natural wetlands areas in Spain and Mexico (Jimenez 2013; Muciñio 2001).

Water Reuse for Potable Purposes Unplanned and indirect use of wastewater for potable purposes has always occurred. There is a long history of human settlements withdrawing water for drinking from rivers receiving wastewater from upstream communities. This happens in both developed and developing countries, although for the latter, wastewater is mostly discharged untreated, posing health risks for downstream communities. Planned and indirect potable reuse (PIPR) occurs when treated wastewater is deliberately blended with conventional drinking water supplies (i.e., a reservoir, river, or aquifer) and then re-treated to meet drinking water standards before delivery. This practice has been reported mainly, but not only, in industrialized countries. For example, Singapore (NEWater) mixes its potable supply with 2.5 % recycled effluent (Liam and Seah 2013). Drinking water in California's Orange County Water District contains 10 % recycled effluent (Rodriguez et al. 2009); and the drinking water supply of Atlantis, South Africa, consists of 25–40 % recycled effluent (Quayle 2012). During dry periods, the Langford Recycling Scheme in Essex, England, is capable of contributing 8 % recycled effluent to the overall water supply (Essex and Suffolk Water 2008). Other examples of indirect potable reuse are found in Australia and in Torreele in Belgium (Houtte et al. 2013; Troy et al. 2013; Meehan et al. 2013).

Historically, much of the use of wastewater for industrial, environmental, and potable purposes has been motivated by water scarcity or by a desire to reduce water pollution and protect the aquatic environment (Asano 2002). In recent years, technological innovations, such as ultrafiltration, reverse osmosis, and ultraviolet irradiation have generated perceptions of enhanced safety of blending reclaimed water in reservoirs or aquifers for potable purposes, such as those shown in Table 10.1. Adoption of technology-driven approaches that promote advanced reuse is increasing, as indicated by the example of NEWater project in Singapore. In this case, a Water Efficient Homes Programme was launched to alter behavior at the domestic level. Additional community engagement, educational programmes regarding wastewater treatment and development of programmes encouraging Singaporeans to take ownership of their surrounding water bodies engaged the public in understanding the value of water (WRG 2013). This strategy increased public acceptance of indirect potable water reuse.

10.3 Economics of Water Reuse for Industrial Purposes, Landscaping and Potable Purposes

10.3.1 Empirical Cases of Water Reuse for Industrial Purposes

Water reuse for industrial purposes is motivated largely by one or more of three considerations: (1) water scarcity; (2) business sustainability strategy and (3) compliance with legislative mandates. While many business sustainability strategies and related new investments are geared towards mitigating production risk (mostly due to poor water availability—in our case), compliance with legislative mandates is gaining importance in many investment decisions. In Tiruppur, India, a high court mandated zero liquid discharge for all textile businesses (WRG 2013). The sum of the investments required to achieve zero discharge by the nine effluent treatment plants in Tiruppur was $ 84 million[1], due largely to the scale of the businesses and the need for highly advanced technologies (combined reverse osmosis and thermal evaporation systems). The implicit cost of non-compliance was comparatively higher, as the industry generates more than $ 1 billion in annual exports.

The sale of captured dye salts provides an additional revenue stream to the water reclamation process. The industries reclaim 95 % of effluent discharge, which is resupplied as freshwater for process use, thus satisfying 75 % of the textile plant's water requirement. As a result, the demand on urban water supply reduced by 900,000 m^3 per year. With an estimated unit cost of water of $ 5.00 per m^3, the estimated cost savings generated from water is $ 4,500,000 per year (Table 10.2). The

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[1] All $ values refer to United States dollars.

Table 10.2 Economic assessment of water reuse for industrial, landscaping and potable purposes. (Source: IWMI (based on secondary data sources))

					Financial costs		Financial benefits		Economic benefits
Purpose of water reuse	Type of industry/ Specific reuse	Name of reuse projects	Type of water reuse	Volume of Treated Wastewater	O&M costs	Investment cost for treatment	Cost savings from water reuse	Revenue generation	A = Reduced fresh-water withdrawal B = Reduced groundwater contamination C = Reduction in effluent discharge
Industrial purposes	1.Textile	Tiruppur textile sector, India	Washing, bleaching and dyeing processes	922,000 m^3/year	$ 4.0/m^3	$ 84,000,000	$ 450,000/month	Sale of captured dye salts	A = 900,000 m^3 (−75 %) B = 691,500 m^3/year C = Zero discharge
	2. Steel	Essar Steel, India	Washing tanks and cooling towers, sludge for horticulture	NA[a]	$ 0.05/m^3 [b]	$ 380,000	$ 32,200/month[c]	NA	A = 644,000 m^3/month B = 86 % of generated wastewater
	3. Power	Essar Power, India	Cooling, Electricity	1,500,000 m^3/year	$ 0.05/m^3	$ 380,000	$ 381,000/year	NA	A = 835,000 m^3/year B = 718,000 m^3/year (86 % of generated wastewater)
		Matimba Power, South Africa	Cooling, Electricity	327,000,000 m^3/year	Not available	$ 3,600,000[d]	$ 3,125,000/year[e]		A = 62,500,000 m^3/year B = not provided

Table 10.2 (continued)

					Financial costs		Financial benefits		Economic benefits
	4. Petrochemical	Panipat refinery, India	Cooling towers	11,000,000 m^3/year	$ 0.46/m^3	NA	$ 66,000–165,000/month	NA	A = 2,400,000 m^3/year Increased industrial water supply security A = 6,000,000 m^3/year
		RARE Project, USA		4,280,000 m^3/year	NA	$ 55,000,000	$ 2,300,000/year		
	5. Food industry	Unilever, South Africa	Washing tanks and cooling towers; Energy generation	95 m^3/hour	$ 5.0 m^{3f}	$ 2,900,000	$ 720,000/year	Sale of electricity, carbon credits and H_20	A = 12,000m^3 B = 88,000m^3 (lower limit)
		Nestlé, South Africa		NA	$ 0.10/m^{3g}	$ 145,000			A = 120,000 m^3/year (50 % reduction)
	6. Paper industry	Middle East Paper Company, Saudi Arabia	Processing, washing, dilution, cooling	8.0 million m^3/year	$0.10/$m^{3h}$	$ 5.7 million [1.2 million—internal recycling unit; 4.5 million—effluent treatment unit]	$ 2.3 million/year	NA	A = 6,000,000 m^3
	7. Mining	Rio Tinto Argyle Mine, Australia	Processing, washing, dilution, cooling	3,600,000 m^3/year	$ 0.10/m^{3i}	$ 4,500,000	$ 392,000 [reduced costs of pumping water = $ 150,000/year)	NA	A = up to 95 % of original consumption

Table 10.2 (continued)

					Financial costs		Financial benefits		Economic benefits
Environmental & Recreational use purposes	1. Greening of public city areas	Quighe and BeiXiaoHe Water Reclamation Plant, China	Landscape irrigation; road washing; potable water	180,000 m^3/day	0.12 euros/m^3	NA	113,800 euros/year	NA	A = 1,800,000 m^3/year B = 360,000 m^3/day
		Sulaibiya wastewater reclamation project, Kuwait		600,000 m^3/day	$ 0.65/m^3		$ 11.0 billion over lifetime		
	2. Golf courses	Marrakech Wastewater Treatment Plant, Morocco	Landscape irrigation; energy generation; groundwater recharge	110,000 m^3/day	NA	110.0 million euros	$ 2,000,000; Supply of 30 % of WWTP electricity consumption; 624,880 CERs	NA	A = 19.0–20.0 million m^3 B = 110,000 m^3/day C = 30 % treated water discharged to river bed
	3. Reservoir restoration	Texcoco Lake Restoration, Mexico	Restoration of channels to supply drinking water and for irrigation purposes	37,300,000 m^3/year	$ 0.99/m^3	$ 3,000,000	$ 12,000,000/year	NA	Avoided costs of $ 1.3 million/year from protection of 11,000 ha of urban area, 20,000 ha of ag. land and 750 ha of the airport from floods.

Table 10.2 (continued)

					Financial costs		Financial benefits		Economic benefits
Potable purposes	1. Direct potable use	Windhoek Municipality, Namibia	Potable (drinking) water; Landscape irrigation	6,700,000 m^3/year	\$ 0.35/m^3	\$ 27,700,000	\$ 2,350,000/year	Potable water sale= \$ 0.33–0.98/m$^{3;}$ Non-potable water sale= \$ 0.25–0.98/m^3	Supply 15–30 % of potable water demand; increased water supply security resulting in industrial development
	2. Indirect potable use (and non-potable use)	NEWater project, Singapore	Aquifer/groundwater recharge; Water for industrial and commercial purposes	511,000,000 m^3/day	1.22 SDG (Singaporean dollar)/m^3	NA	NA	NA	Supplies currently 30 % of overall non-potable water demand; 2.5 % of potable demand; reduced future water supply risk
		Managed Aquifer Recharge of Torreele, Belgium		3,300,000 m^3/year	0.64 Euros/m^3	7,000,000 Euros	0.15–0.33 Euros/m^3 (0.27–0.6 million Euros/year)	NA	A = 1.8–2.17 million m^3/year

[a] NA means data is not available for the considered case

[b] Defined by the unit cost of water

[c] Assuming estimated unit cost of water is less than US\$ 0.05/m^3

[d] Based on the annualized capital cost of a 500 MW wet cooled system

[e] Based on the assumption that the estimated unit cost of waster is US\$ 0.05 and the water savings is 62.5 million m^3 /year

[f] As measured by the unit cost of water

[g] As measured by the unit cost of water

[h] As measured by the unit cost of water

[i] As measured by the unit cost of water

scale of reuse in the textile industry is large and increasing, resulting in improved water quality and significant reductions in freshwater withdrawals. This however comes at a high financial cost to businesses, which affects their profitability and competiveness. Additionally, the use of energy intensive processes necessary to meet zero effluent discharge implies that city authorities must now face the additional challenge of supplying energy to an increasing population in competition with these other sectors.

Similar cases can be found in other industries including petro-chemical businesses, power-generating entities and mining in India, South Africa, Australia, and the United States (Lahnsteiner et al. 2013a; Towey et al. 2013; WRG 2013). Good examples include the Panipat refinery project in Haryana, India and the RARE project in California (Lahnsteiner et al. 2013a). Wastewater treatment for the RARE project occurs on a large-scale basis and produces up to 4.3 million m^3 per year of treated wastewater, fulfilling their own water requirements for cooling towers and boiler makeup. The use of advanced treatment technologies results in high investment costs, up to $ 55 million. Innovative public-private partnerships creating a win-win for all parties can mitigate the challenge of sourcing capital investment. In this project, the East Bay Municipal Utility District (EBMUD)—publicly-owned water supplier utility to eastern San Francisco has established a unique collaboration with a Chevron crude oil refinery. EBMUD agreed to supply 3.5 million gallons per day of recycled water to Chevron. The direct economic benefit to EBMUD is the saving of an equivalent amount of potable water at virtually no cost to its taxpayers, while for Chevron (a 240,000 barrel per day crude oil processor); this represented a drought-resistant water supply for its boilers. EBMUD's commitment to sustainability and reliability motivated Chevron to bear all the capital and O&M costs for the project (EBMUD 2014). In some cases, such as the Panipat refinery in India, where all costs are self-absorbed by the refinery, there is no direct economic benefit to the business, as the cost of boiler make-up water production from the treated Yamuna Canal water is much lower than the cost of using treated wastewater ($ 0.46/m^3) (Lahnsteiner et al. 2013a).

Water-intensive industries such as pulp and paper producers and food industries reuse treated wastewater to mitigate production risk (Jung and Pauly 2011). Especially in high-water stress areas, imminent droughts and less sustainable water management approaches, for example desalination, are causing businesses such as Nestlé (Durban, South Africa), Unilever (Mossel Bay, South Africa) and Thai Biogas Energy Company-TBEC (Thailand) to rethink their business sustainability strategies. Wishing to reduce plant operation risk due to poor water availability, Nestlé self-financed the installation of a water treatment and capture plant at the cost of $ 145,000. Depending on the scale of the industry, the cost can vary significantly (Table 10.2). It is noted that although these plants can reduce their outside water requirements from 50 to 80 %, invariably contributing to increased water availability to other users, there are no significant financial gains to the businesses, as these water reuse measures come at a significant cost. This is comparable to Unilever, which invested $ 2.9 million to reduce its municipal water demand, as part of its sustainable policies on implementing alternative water efficiency measures.

This suggests that the value businesses place on reliability of water supply is greater than the cost of capital investments and operations. Many food industries are geared towards total water self-sufficiency under their water saving strategies. This however does not refute the opportunities for additional revenue generation that exist from treatment of industrial wastewater although limited to specific food/agro-processing industries such as palm oil, cassava and ethanol processing. An example is The Thai Biogas Energy Company (TBEC) which generates treated water and electricity for its industrial processes and earns direct financial benefits via the sale of excess water, energy and carbon credits to other agro-industries, the Electricity Authority and European market respectively (TBEC 2014).

While revenue-generation from industrial water reuse may be limited and sector-specific, cost-savings for water and energy, and industrial effluent disposal often involve many industrial sectors. Some sectors, such as pulp and paper industries, treat and use their own wastewater, thus reducing their municipal water demands and the cost of effluent disposal. The Middle East Paper Company (MEPCO) in Jeddah, Saudi Arabia, once purchased treated wastewater from the Khumarh wastewater treatment plant (WWTP) and paid for sending its process effluent back to the WWTP (Jung and Pauly 2011; WRG 2013). Expansion of the paper plant implied both increased cost of water supply and effluent treatment. As a cost-savings measure (to minimize business costs and water demand), MEPCO invested $ 5.7 million in an onsite water reclamation system ($ 1.2 million for internal recycling unit, with a 2-year payback period; $ 4.5 million for effluent treatment, with a 2-year payback period). MEPCO was able to reduce its annual urban water demand by 6.0 million m^3 and realized an annual cost-savings of $ 2.3 million. Using an innovative biological treatment unit to reduce organic loading in effluent, the business reduced its operating cost for effluent discharge. The primary societal economic benefit is the increased availability of water to meet competing demands.

Water reuse for industrial purposes extends across many sectors providing both monetary and non-monetary benefits such as (1) boosting industrial water supply security; (2) reducing freshwater withdrawal; (3) improving quality of surface water and groundwater. The empirical cases presented suggest that although opportunities for additional revenue generation for wastewater treatment may exist, water-intensive industries traditionally adopt water reuse measures at a significant cost with limited to no financial benefits, and mainly as part of their sustainability policy. High investment costs result from the use of advanced treatment technologies given the requirement of low to zero effluent discharge in some cases. Economic benefits include minimized environmental stress from averted discharge of untreated wastewater in water bodies and resulting averted health risks particularly for direct users of these water bodies. Decreased urban water demand implies increased water availability to other competing sectors, especially agriculture where the main actors are traditionally poor, smallholder farmers in developing countries.

Economic costs to society have been notably related to the challenge faced by municipalities in supplying energy to a growing population in competition with industrial businesses. In the case of energy-poor countries, increased energy demand for industrial wastewater treatment suggests the possibility of leaving certain sectors or communities worse off while generating benefits for some. This may result from increased energy prices to curtail demand or simply not supplying to some sectors. There is very limited data available on economic costs of water reuse for industrial purposes (Table 10.2), thus difficult to assess the related impacts. Based on the empirical cases presented here, it is fair to state that while businesses receive limited financial benefits from treatment and use of wastewater, the net economic benefits can be substantial.

10.3.2 Empirical Cases of Water Reuse for Environmental and Recreational Purposes

There are numerous cases of water reuse for the creation of artificial lakes and restoration of natural wetlands which have demonstrated significant environmental and recreational benefits (Wang et al. 2008; Wang et al. 2010). To conserve their limited water supply, governments in countries such as Kuwait, are investing in water reclamation system such as Sulaibya—the world's largest membrane-based water reclamation facility. The plant treats 600,000 m^3 (60 %) of domestic wastewater daily. The reclaimed water is mixed with brackish water and then supplied for non-potable uses, such as irrigation of landscapes along highways, public gardens in Kuwait city and agricultural lands and groundwater recharge. The plant also provides potable quality water at approximately \$ 0.65 per m^3 (\$ 0.40 per m^3 for conventional wastewater treatment and pipeline costs and \$ 0.38 per m^3 for tertiary treated wastewater). While no data are available on the possible sources of cost recovery for operational and maintenance costs, the plant is expected to generate about \$ 11.0 billion over its lifetime (Alfranca et al. 2011; Jimenez 2013).

With large landscapes serving as leisure areas for residents in Beijing and Xi'an, China, similar driving factors of urban expansion, decreased water availability and frequent droughts have increased reclaimed water use for irrigation, urban planning and river and lake restoration (Wang et al. 2008). In Beijing, two water recycling facilities (Qinghe and Bei Xiao He Water Reclamation plants) supply up to 180,000 m^3 per day of treated domestic wastewater for many purposes with 33 % for city landscaping, 28 % for urban agriculture irrigation and 11 % for non-potable purposes such as road washing and flushing toilets. With a capacity of reclaimed water usage of 1.8 million m^3 per year, the city of Beijing saves approximately \$ 160,000 annually, assuming the price of tap water is \$ 1.04 (Wang et al. 2010). With all costs borne by the city, operational cost-recovery strategies are imperative for sustainability. Although not stated, viable revenue stream options that can be considered include charging entrance fees to users of recreational parks.

Chen and Wang (2009) assess the cost-benefit evaluation of a decentralized grey water treatment and reuse system for landscaping and environmental purposes. The authors note that the city of Xi'an (China) increased its water tariff from \$ 0.16 per m^3

to \$ 0.48 per m^3 to generate revenue to cover related treatment costs[2]. The estimated annualized construction cost of the decentralized system was \$ 0.04 per m^3 under an assumption of 25 years lifetime for the treatment facilities. Direct operational and maintenance cost was \$ 0.22 per m^3, but at full operational design capacity (current operation is 50–60 %), the unit cost would be \$ 0.13 per m^3. The total cost, assuming operation at full capacity, would be \$ 0.17 per m^3. From a cost-effectiveness point of view, greywater reclamation and reuse at a cost of \$ 0.17 per m^3 remains a competitive alternative, when compared to using tap water at a cost of \$ 0.47 per m^3 (Wang et al 2008; Wang et al 2010).

City landscapes extend beyond parks to include recreational areas, such as golf courses which are rapidly increasing due to changing urban lifestyles. Even in water-stressed regions such as Marrakech, Morocco and Arizona, U.S, large amounts of water (19–27 million m^3 per year) are used to irrigate golf courses. With an increasing population and changes in household water use behavior, the city of Marrakech began collecting all its wastewater for treatment and use for irrigation of its groves and golf courses, while producing electricity for internal plant use. The plant treats 82 % of the 36 million m^3 of wastewater collected annually, generating electricity with a capacity of 30 MW (Table 10.2). Similar initiatives are traditionally publicly-funded. However, this Moroccan case was implemented via a public-private collaboration with investment contributions from the government, the Marrakech Electricity and Water Board, and private promoters including golf course organizations. While the operational and maintenance costs of the WWTP will be borne by the government, the viability of the project is reinforced by the generation of certified emission reductions (expected volume of 624,880 of CERs).

The economic benefits from irrigating parks, gardens, and golf courses with wastewater include: (a) Cost savings to the wastewater treatment plant (33 % of WWTP's electricity consumption from national grid replaced from plant generated electricity); (b) cost-savings of water equivalent to \$ 2.0 million/year[3]; (c) future earnings from touristic (golf) destinations; (d) averted health risks to users of recreational areas[4]; (e) increased water availability for other users and averted environmental degradation[5]. Although not all of these benefits were monetized in the presented cases, Chen and Wang (2009) estimate the benefits of reducing wastewater discharge at \$ 4089 per year and the local environment improvement at \$ 13,825 per year; approximately equivalent to the total annual costs of \$ 21,300 per year, assuming a plant capacity with wastewater flow rate of 100 m^3 per day.

The restoration of natural wetlands and reservoirs with reclaimed water is increasing in arid cities such as Mexico City and Catalonia, Spain with limited avail-

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[2] Exchange rate: 1 Chinese yuan = US\$ 0.16 (2014 data).

[3] Assuming an estimated unit cost of water = 10 cents/m3 and 70 % of all treated wastewater is used for recreational purposes (i.e. irrigation of golf courses, palm groves, etc.)

[4] Prior to the project, untreated wastewater from the Marrakesh-Tensift-El Haouz region was disposed directly into open fields, palm tree groves, rivers (e.g. Tensift Wadi) and finally to the sea, resulting in severe pollution of the phreatic water and Atlantic Ocean; and increasing exposure of the local population to the waterborne diseases.

[5] As related to unreliable availability/supply of water. Same as for footnote 2.

able water resources and overexploited local aquifers (Pearce and Crivelli 1994; Alfranca et al. 2011; Jimenez 2013; Muciñio 2001). Mexico City continues to promote water reuse as a response to water scarcity, as the alternative of importing water from distant sources (e.g. 130 km far away and 1100 m below the level of the city) is not a sustainable option. At present, a total volume of 248 million m^3 per year of wastewater is treated using public facilities and reused as follows: 54 % for agricultural irrigation, 31 % for industrial cooling, 11 % to restore lakes and 5 % for the urban solid wastes and car washing. In Mexico City, the discharge of untreated wastewater into the Texcoco Lake has had a negative impact on the water body as well as its surrounding ecosystem. The total disappearance of some flora and fauna species as well as increased vector borne diseases have been observed as a result of this practice. As a solution, one of the biggest water reuse projects in the city was implemented to restore the Texcoco Lake. Capital investments for the restoration of the lake remain relatively high, with construction of the facultative lagoons costing $ 7.2 million (2014 prices)[6] and operational costs estimated at $ 2.36 per m^3 (prices of 2014).

In Mexico City and surrounding areas there is a gap between the cost of water supply and amounts recovered from service users. The Texcoco area is no exception: the cost recovery of the lake restoration project via tariffs is very low[7] and the gap is effectively bridged though subsidies, which are justified given the wide range of environmental and recreational benefits created from the project (Jimenez 2013; Muciñio 2001). The economic benefits of restoring the Texcoco lake area and creation of different artificial ponds, lakes (Nabor Carrillo lake-1000 ha) and wetlands exceed the financial costs. The Narbor Carrillo Lake and its surrounding environment have played a major role in dust storm control, flood control, flora and fauna restoration, regulation of the local temperature and humidity, and reduced the burden of disease as compared when wastewater flowed untreated. The recreational value of the wetland was estimated to be $ 1.56 per m^3, calculated with the travel cost method[8]. The construction of lakes protected 3 million people and 550,000 households in Ciudad Netzahualcoyotl, Ecatepec, and the airport area from floods. Considering that only 20 % of the area is vulnerable to floods, 11,320 ha of urban area, 20,100 ha of agricultural land and 750 ha of the airport were protected. This represents avoided costs of 500 million pesos per year ($ 1.9 million per year—prices of 2014). The scenic beauty of the lake has attracted many individuals for recreation and bird watching. The lake has also had a positive impact on the local weather. In the Twentyth century, the temperature in Mexico City increased by 2.5°C due to drainage of water bodies in the Texcoco basin (Jazcilevich et al. 2000). Jazcilevich et al. (2002, 2003) assert that the restored lakes would increase superfi-

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[6] The sources were not clear on whether this cost includes the cost of the activated sludge treatment, or if the activated sludge treatment is connected to the lagoons. Cost of land was not included as it was considered as federal property and land purchase was not required.

[7] The average tariff across users in Mexico is US$ 0.32 m^3 which is just half of the Latin American and Caribbean average of US$ 0.65/m^3 (CONAGUA, 2014).

[8] The expenditures incurred by households or individuals in reaching these sites are considered to be lower-bound estimates of the willingness to pay for the recreational activity.

cial air flow as a result of the land-water breeze increasing ventilation and dispersion of pollutants and decreasing local air contamination. Environmental, social and health costs (negative externalities) were assumed to be negligible.

10.3.3 Empirical Cases of Water Reuse for Potable Purposes

The practice of planned and indirect potable reuse (PIPR) has been reported mainly, but not only, in industrialized countries (Essex and Suffolk Water 2008; Royte 2008; Rodriguez et al. 2009; Quayle 2012). Severe droughts and increasing population growth increased the search of alternative sources of potable water in Beaufort, South Africa and Texas, U.S.A.; and several options were implemented such as managing water losses, optimizing existing aquifers and exploring new groundwater sources (Table 10.3). Water reclamation was found to be more economical than transporting water from distant sources or seawater desalination (Ivarsson and Olander 2011; Meehan et al. 2013).

Direct "pipe to pipe" potable reuse is also possible and occurs in practice, as the Windhoek (Namibia) example demonstrates, although it is still a unique case worldwide. Windhoek's total water demands amount to 25 million m^3 per year which is partly covered by reclaimed water (28 %). Plant treatment capacity is around 21,000 m^3 per day and produces about 5.8 million m^3 of treated water annually. A multi-barrier approach is used for reclaimed domestic wastewater which is blended (maximum 35 %) with treated surface water (Goreangab dam water). Differences in the percentage of reclaimed water blended with freshwater are dependent on national guidelines, treatment, technologies, and public acceptance. The treatment technologies (i.e. level of sophistication) are traditionally correlated with investment costs. The cost of building the Windhoek reclamation plant was $ 17.3 million.

The total annualized costs amount to $ 1.04/m^3 (capital costs $ 0.28/m^3, operational costs $ 0.88/m^3), which was less expensive than importing water from alternative sources (e.g. transport from Okavango river would cost US$ 19.4/m^3 and from the Tsumeb Karst Aquifer, US$ 5.55/m^3). The estimated annual cost savings is between $ 9.0 and $ 36 million.

While the plants in Beaufort, South Africa and Texas, U.S.A. generate revenue via tariffs and grants to cover costs—achieving only partial cost-recovery, the plant in Windhoek fully recovers all costs using a differentiated pricing strategy. The plant earns revenue from potable water sales at the following prices: municipal consumers = $ 0.35/m^3, commercial consumers = $ 0.98/m^3 and non-potable water sale for landscape irrigation = $ 0.25–0.98/m^3 (depending on consumer type). The project has been sustained for many years, due to its progressive consumption-related pricing for potable water. These tariff rates allow for full cost-recovery of annualized costs of the reclamation plant. Although, relatively high for Windhoek urban dwellers, the public has accepted the project and has been willing to pay the tariff rates partly due to their awareness of acute water scarcity problem and under-

Table 10.3 Estimated costs and benefits of treating wastewater for direct potable purposes in three selected cases. (Source: IWMI (based on various secondary data sources))

	Economic factors	Countries		
		Windhoek, Namibia[a]	Beaufort, South Africa	Texas, U.S.A
1.	Driving factors for water reclamation	Severe droughts, water stress, population growth; non-economical alternative sourcing of water	Severe and lengthy drought, shortage of drinking water supply	Need for additional water sources, offset reductions in reservoir yield
2.	Percentage of treated wastewater blended with freshwater	35 %	20 %	15 %
3.	Scale treated wastewater	5.8 million m^3/year	0.75 million m^3/year	5.0 million m^3/year
4.	Alternative uses of treated wastewater	Recreational areas irrigation		Non-potable irrigation and industrial use
5.	Investment cost for treatment ($)	17.3 million	2.24 million[b]	–
6.	O&M costs ($/m$^{3)}$	0.88	0.16[c]	–
7.	Cost savings from water ($/m^3 or $/year)	$ 4.14–18.0/m^3	$ 0.12 million/year	–
8.	Revenue generated via tariffs/water Sale	Potable water sale = $0.33–0.98/m^3 Non-potable water sale = $0.25–0.98/m^3	$ 0.08/m^3[d]	Via tariffs
9.	O&M cost recovery status	Fully based on water tariffs	Government grants support (partial)	Unknown
10.	Reduced freshwater withdrawal	~2.0 million m^3/year	~1.0 million m^3/year	~2.5 million m^3/year

[a] 2011 data

[b] Estimation based on data for Namibia, assuming similarities in prices and cost of living standards

[c] Estimate based on assumption that the cost of treating wastewater with the reclamation system is approximately double that of purified drinking water using a conventional system

[d] Estimate based on cost of drinking water, purified with a conventional system

standing of limited affordable alternatives[9]. The main economic benefit of potable water supply security, guaranteed by reclamation, has benefited tourism, industrial and commercial development and urban dwellers well-being. Citizens now have secure access to clean water to fulfill their need for drinking, cleaning, cooking, and leisure. Without reclaimed water there would be an unfulfilled demand for water of almost 30 %, with deleterious effects on development in Windhoek.

Severe water shortages and growing interest in ecological systems has led many countries (South Africa, Singapore, and Belgium) to search for alternative sources to replenish decreasing groundwater levels and guarantee future water supply (Ivarsson and Olander 2011; Houtte et al. 2013). In Torreele (Belgium), artificial recharge of an unconfined dune aquifer with wastewater effluent from the Wulpen WWTP was implemented due to the unavailability of any alternative year-round water source in the area. The managed aquifer recharge scheme of Torreele/St-Andre operates through the multi-barrier principle, and consists of an activated sludge wastewater treatment plant and an advanced water reclamation plant in Wulpen. The capital investment of $ 9.7 million was borne by the Inter-municipal Water Company (IWVA) with a ten-year maintenance contract. The cost of recycled water is recovered as part of the overall cost of drinking water, even though the incremental increase in drinking water price was only $ 0.35/m^3 (increased from $ 1.62 to $ 1.97/m^3). Even with increasing production costs due to reductions in water production quantities[10] (from 2.17 million m^3 in 2005 to 1.8 million m^3 in 2011), the water reclamation process seems to be more economical, as the cost of importing water from neighboring areas ($ 1.1/m^3) is higher than the cost of the water reclamation process ($ 0.64/m^3 in 2005 and $ 0.89/m^3 in 2011). The project facilitates the sustainable management of groundwater with high ecological interest while reducing future water supply risk.

Driven by similar factors for reservoir replenishment, the NEWater reclamation project in Singapore reclaims water from sewerage network (used water from domestic and non-domestic sources) with stringent purification and treatment processes using advanced dual-membrane and ultraviolet disinfection. 'NEWater' is supplied and mostly used for non-potable industrial and commercial uses in wafer fabrication plants, electronics factories and power generation plants and supplements Singapore's potable water supply via indirect potable use (blending with reservoir water), which represented 1 % of the daily water consumed (13,500 m^3/day) in 2003 and about 2.5 % in 2011 (Lim and Seah 2013). As seen with water reclamation for direct potable use, operations of indirect potable use of treated wastewater via reservoir replenishment like the case of NEWater is funded by a public tariff (SGD 1.22/m^3); which is between the normal domestic water tariffs of SGD1.17 and 1.40/m^3 depending on consumption[11].

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[9] The cost of treating wastewater with the reclamation system is approximately double that of conventional treatment of freshwater, but still less costly than desalination of seawater, which costs about four times as much.

[10] This is noted to be attributable to decreasing demand and infiltration rates.

[11] http://www.pub.gov.sg/general/Pages/WaterTariff.aspx (accessed 23 June 2014).

These water reuse practices have facilitated the sustainable management of groundwater while reducing future water supply risk. In contrast to the case in Windhoek, Namibia, where society is hugely accepting of reclaimed water blended with freshwater; in Singapore with the NEWater project, the public remains diffident in accepting even the indirect use of reclaimed water for potable purposes. This is clearly indicated by the marginal percentage of 2.5 % of NEWater that was injected into Singapore's freshwater reservoirs in 2011 in comparison to that of 35 % in Namibia (see Chap. 5). The key driving forces for the experienced success with public acceptance in Namibia has been attributed to absolute water scarcity, no reported related health problems since its initiation and unaffordable water alternatives.

10.4 Conclusions

Despite the increasing number of cases of water reuse and recycling for industrial, environmental, recreational and potable purposes, the potential is yet to be fully exploited, particularly in many developing countries and emerging economies. Planned reuse and recycling is gaining importance in many industries, including steel production, mining industries, food processing industries and power plants, with the capacity and capability to use recycled water in their operations. The key (and non-mutually exclusive) factors driving water reuse and recycling for industrial purposes are: (1) water scarcity; (2) business sustainability and (3) compliance to legislative mandates. While water reuse and recycling practices are noted to be mainly implemented as a water use reduction strategy, compliance to environmental water quality standards is taking a forefront in the decision to invest in treating for recycling rather than treating for discharge. Water recycling for industrial purposes has both monetary and non-monetary benefits such as (1) boosting industrial water supply security; (2) reducing freshwater withdrawals with increased availability to other competing sectors, especially agriculture; (3) improving quality of water bodies from reduction of raw wastewater discharge, to name a few. This however comes at a very high financial cost to businesses from the use of advanced treatment technologies, with no direct financial benefits, thus affecting business profitability and competiveness. Nevertheless related total annualized costs are noted to be significantly cheaper than alternative approaches like importation of water from other and often distant sources and seawater desalination. Additionally, these practices are often adopted by many water-intensive businesses mainly as part of their sustainability policy, with image benefits. Although rarely documented or simply not considered, some economic costs to society exist from increased wastewater for industrial purposes. For example, in the case of energy-poor countries, increased energy demand for industrial wastewater treatment suggests a possible trade-off with supplying one sector over another, leaving one better than the other. While there is very limited to no data available on economic costs to society, there are many examples that suggest substantial net economic benefits from wastewater use for industrial purposes.

Water reuse for environmental and recreational purposes occurs in many countries where reclaimed water is used for irrigation of golf course, landscapes along highways, roads and public gardens or for wetland or forestry restoration. A key driving force for this practice remain related to looming water scarcity conditions and increasing costs of importing water from distant sources. Capital investments and operational costs remain relatively high for practices of water reuse of environmental and recreational use. With traditionally huge gaps between the cost of water supply and amounts recovered from service users via tariffs, cost recovery is effectively bridged though subsidies which are justified given the wide range of environmental and recreational benefits created from the projects. Related benefits of wastewater use extend beyond potable purposes. Confidence in technological innovations has risen to the point at which the public is beginning to have an absolute assurance of the safety of reclaimed water blended in reservoirs or aquifers for potable purposes as seen with the NEWater project in Singapore. Water reclamation was found to be more economical compared to transporting water from distant sources or seawater desalination. The main economic benefit is that potable water supply security is guaranteed by reclamation, benefiting tourism, industrial and commercial development and urban dwellers well-being. Without reclaimed water there would be an unfulfilled demand for water of almost 30 % with deleterious effects on development in the case of Windhoek, Namibia. Many of these initiatives are traditionally fully publicly-funded with limited to no operational cost recovery. However, exceptions exist as with the ‘pipe-to-pipe’ water reclamation plant case of Windhoek, Namibia, which fully recovers all costs using a differentiated pricing strategy. Although, relatively high for Windhoek urban dwellers, the public has been willing to pay the tariff rates partly due to their awareness of acute water scarcity problem and understanding of limited affordable alternatives. Gaining public support for potable reuse project like this will prove vital to the reuse industry in general.

Take Home Messages

- Wastewater use for industrial, environmental and recreational, and potable purposes is motivated by water scarcity, compliance with legislative mandates and business sustainability strategies.
- Many water-intensive industries initially adopt water reuse measures at a cost, with limited financial benefits. Yet the alternative costs of non-compliance with legislative mandates, importing water, or accepting business production risk are potentially higher.
- Successful collaborations between public and private entities can mitigate the challenge of sourcing capital investment, particularly for wastewater treatment for industrial purposes.
- Water reuse for wetland restoration and parks irrigation is frequently subsidized, due to the environmental benefits. Yet the increasing water reuse

for golf courses tends to achieve full financial cost recovery, as the beneficiaries are clearly identified and their capacity to pay is usually high.

- Although usually funded by public grants, there are options for full operational cost-recovery for potable water reclamation plants through innovative pricing strategies.

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Part IV
Thinking Business

Chapter 11
Business Models and Economic Approaches Supporting Water Reuse

Krishna Rao, Munir A. Hanjra, Pay Drechsel and George Danso

Abstract Water reuse has significant environmental benefits that include mitigating water scarcity, and offering opportunities for revenue generation, especially if more resources than water are recovered, or if treatment can deliver water of potable quality. Options for achieving cost recovery or cost savings range from the promotion of greywater use at household or community level, to inter- and intra-sectoral water swaps, the replenishment of natural resources, on-site value creation through treatment related aquaculture, and reclaimed water sales for different purposes. Value might also be derived from emerging models of water hedging for future reuse markets. A key element of the business model approach is the move toward operational cost-recovery *at minimum* and profit maximization *at best*. Although cost recovery is typically low in wastewater use projects and treatment is primarily a 'social business model,' several empirical examples highlight opportunities for enhancing the business character of wastewater use by pursuing different value propositions and innovative mechanisms to achieve overall system sustainability.

Keywords Cost recovery · Benefit sharing · Private sector · Institutions · Water swap · Value proposition · Potable water · Industrial reuse · Irrigation

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11.1 Introduction

Given the common situation of public financed wastewater collection and treatment, the term "business models" might appear to be an oxymoron, attention grabber, or over-ambitious wording. However, with increasing calls for cost recovery and private sector participation, the sector and the thinking are changing (Koné 2010). While wastewater treatment has been primarily a 'social business model' with a strong economic justification and returns on investments through safeguarding public health and the environment, cost recovery is a significant advantage from the financial perspective, not only for private sector engagement, but also within the public sector where in low income countries overdue and delayed payments for repairs and salaries accelerate the breakdown of treatment infrastructure. Also regular household billing to cover the costs of conveyance, treatment, and disposal of wastewater or fecal sludge, as known from developed countries to finance their treatment systems, might not reach far in low-income countries where fees are low, and enter the same municipal cashbox which has to support all bottlenecks the municipality at large is facing. Effective billing and dedicated accounting systems, as reported by Choukr-Allah et al. (2005), are seldom put into place. As a result, most facilities—especially high-end-facilities, appear to be on a run-to-failure trajectory from their inception (Nhapi and Gijzen 2004; Murray and Drechsel 2011; Libhaber and Orozco-Jaramillo 2013).

Shifting incentives for financing sanitation from "front-end users" to "back-end users" could build on demand for the products of sanitation (e.g., treated wastewater) to motivate a shared finance model and more robust operation and maintenance of complete sanitation systems (Murray and Ray 2010). This requires a reuse-oriented planning approach to sanitation, like the Design for Service paradigm shift promoted by Murray and Buckley (2010). In this approach, treatment is matching reuse needs (Box 11.1) and water reuse business models are seen as a component of the overall sanitation service chain which starts with the toilet and ideally feed parts of its reuse revenues back into the functioning of the overall chain.

Box 11.1 Reuse Oriented Planning

The state of North Carolina, USA, has long been a leader in implementing alternative wastewater treatment technologies to handle new growth and development. Quality standards for the treated water reflect the level of risk associated with particular use the reclaimed water is intended to meet. Thus, the intended use of the water is determined early in the design process through collaboration with stakeholders and end users. Once the intended use is known, risk associated with that end use can be determined–and from the risk; appropriate standards are set. When the proposed use of reclaimed water carries a high potential for human contact (for instance, treated domestic wastewater used for lawn irrigation), the highest standards for both water quality and treatment system redundancy/reliability are applied to protect the public against both bacteriological and chemical contaminants, but if the risk is lower, also lower standards are applied (CAWT 2009).

However, this is not as easy as said given the number of often independent operators along the chain; thus the first cost recovery target of the treatment operator will be to **regain the extra cost induced** by the resource recovery and reuse value proposition. In other words, if the reuse requires for example additional water treatment or water conveyance towards the beneficiary which are not straight away borne by the beneficiary, these costs should be recovered first. There can be large variations in this regard. Chenini et al. (2003) reported a cost recovery of 13 to 76 % of the operational expenses for the agricultural water supply component in water reuse schemes across Tunisia. Better is if any extra costs can be covered by the beneficiary. For industrial reuse, for example, the industry (and not the treatment provider) can undertake further quality refinement through own investments.

The second target is to recover as much as possible the **normal operational and maintenance cost** of the treatment process. This can be very ambitious, but is not impossible as we see in case of energy recovery or the reclamation of potable water. The third target, i.e. **to break even and to start making profit** to recover capital costs, is seldom but also possible for example where (i) treatment technology is low cost (like pond based systems), (ii) more than water is recovered allowing a more sophisticated value proposition (Fig. 11.1), and (iii) the corresponding market for the recovered resources or their products is sufficiently large.

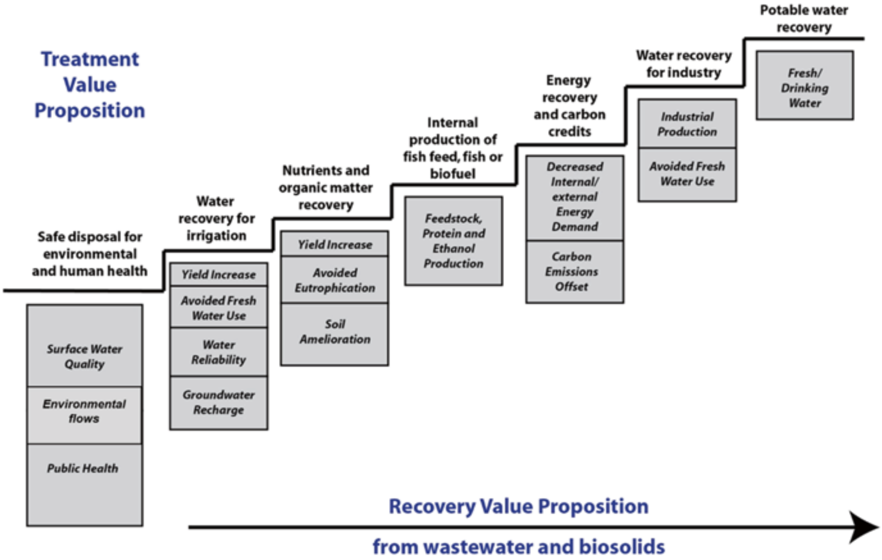


Fig. 11.1 Ladder of increasing value propositions related to wastewater treatment and water, nutrient and energy recovery. (Source: IWMI)

This chapter introduces water reuse examples that depict different value propositions and business models for social or financial benefit. Some of these examples were introduced in an earlier chapter drawing on Otoo and Drechsel (2015). As most of the examples are located in low-income countries, agricultural reuse is a common element.

It is difficult to capture in one grand business typology the various forms of reuse, even if limited to irrigation (direct and indirect reuse, formal and informal, treated and untreated, etc.) (Van der Hoek 2004; Evans et al. 2013). However, there are options cutting across different forms of reuse based on the actors involved, and the purpose or the value proposition. A possible typology could be based, for example, on the ownership of the "business" and the motivation of the owner(s) between welfare maximization, cost recovery, and profit maximization. As resource recovery and reuse usually cut across sectors, decisions might not only depend on the supply end but also be driven by demand where resources are increasingly scarce. This change in motives sets the scene for new opportunities and innovative solutions for the reuse businesses. In this chapter, the typology used to describe the business models for wastewater use is differentiating between opportunities related to advanced water treatment and low-cost water treatment and largely based on the value proposition the reuse solution offers. As illustrated in Chap. 1 (*this volume*) many governments and the private sector actors are beginning to realize the 'double value proposition' in water reuse: Without reuse, wastewater treatment has a significant economic value in terms of environmental safety and public health, but no financial value. Water, nutrient and energy reuse adds new value streams to the recovery value proposition (Fig. 11.1). The water recovery options shown in this figure could be expanded to the examples as shown in Fig. 11.2.

11.2 Advanced Treatment for Producing High Quality Water

The most common business model is aiming at cost recovery by treating wastewater to a standard acceptable by a user. Cost recovery from sale of treated wastewater for irrigation is however very limited although it is the largest reuse sector. Especially in developing countries farmers seldom pay for fresh- or groundwater (except for pumping) while treated and piped water is usually significantly subsidized. Therefore it is not feasible to price treated wastewater as required to achieve cost recovery of treatment plant operations. However in the case of industries, there is potential for pricing treated wastewater at a higher sale price and achieve greater cost recovery if not profit. According to GWI (2009) the market for high end water reuse on the verge of major expansion while migrating to higher value applications with the greatest market growth being expected is the highest grade of urban water reuse using the three step process of ultrafiltration (or microfiltration), reverse osmosis and UV irradiation (or similar advance disinfection technology). This will create water of and beyond that standard normally expected of tap water and can be sold to high value industrial or domestic customers, injected in aquifers or blended in reservoirs for indirect potable reuse.

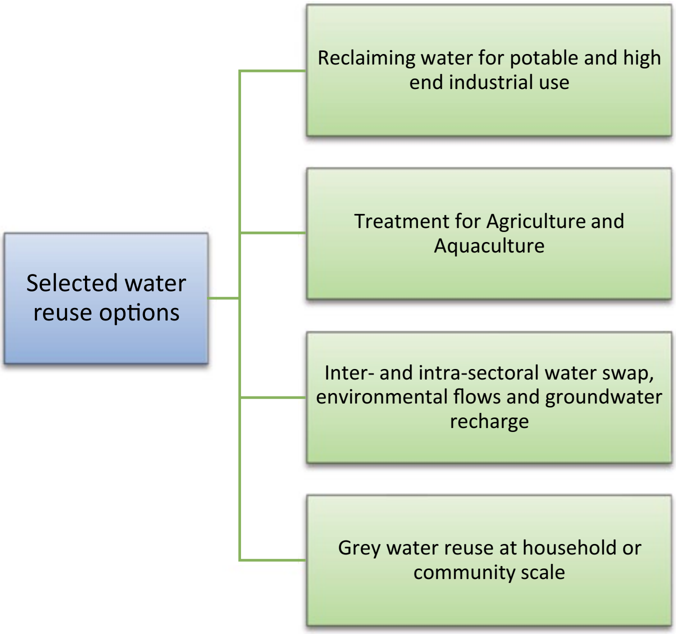


Fig. 11.2 Selected value propositions related to the use of wastewater. (Source: IWMI)

Recent major successes include Singapore's NEWater programme, the Orange County Water Reclamation Scheme in California, and the Western Corridor in South East Queensland in Australia, which have set the standard for a new approach to urban water reuse (GWI 2009).

High quality water output has its costs but can be a key driver in improving the cost recovery within the treatment sector. Singapore's NEWater factories supply reclaimed water directly to industries such as wafer fabrication, electronics, power generation, and commercial complexes for cooling purpose. The operational and maintenance costs of NEWater factories were about US\$ 0.26/m^3 in 2010 and the Singapore Public Utilities Board NEWater project charged industries and others since 2012 about US\$ 0.98/m^3 based on a full cost recovery approach which includes the capital cost, production cost, and transmission and distribution cost (NRC 2012; www.pub.gov.sg/general/Pages/WaterTariff.aspx). Other examples of water reuse and pricing are shown in Table 11.1.

In general, the potential for industrial water reuse for cooling, boiler feed, and process water differs from one industry to another. Tertiary treatment is not always needed, at least not originally. In Baotou City, Inner Mongolia, for example, the Baotou Donghua Power Plant is using reclaimed municipal secondary effluent as make-up water for its cooling water circuit after an additional nitrifying biological aerated filters (BAF) processing step performed by a private reclamation plant (Lahnsteiner et al. 2007).

Industries consuming a large volume of water obviously have greater potential for *internal* recycling, while others can absorb domestic wastewater treated by the

Table 11.1 Water reuse and pricing examples from around the globe. (Source: Based on Xu et al. 2001; ADB 2014; GWI 2009)

Setting	Reuse project	Capacity (m^3/day)	Price of reuse water (US\$/m^3)
Australia	Rese Hill, Sydney, recycled water scheme	13,000	\$ 1.28 (residential)
China	Shiweitou Sewage Treatment Plant, Xiamen, Fujian province, China	24,000	\$ 0.04 (greenbelts in the city)
French island of Noirmoutier (Atlantic coast)	La Salaisière secondary effluent	220,000	\$ 0.32–0.42 (irrigation)
Israel	Shafdan wastewater treatment facility	397,000	\$ 0.22
Kuwait	Sulaibyia water and wastewater reclamation plant	375,000	\$ 0.01(tertiary treatment) \$ 0.02 (reverse osmosis)
Mexico	Durango wastewater treatment plant	173,000	\$ 0.23 (irrigation and other reuse)
Morocco	Ben Slimane water reclamation system	6600	\$ 0.81 (landscape irrigation)
Spain	Valle de San Lorenzo WWTP	4000	\$ 0.22 (recharge, agricultural reuse)
Singapore	Sembcorp Changi NEWater Factory	227,000	\$ 0.98
USA	Tampa, Howard F Curren WWWP, Florida	365,000	\$ 1.60 (industrial)

public or private sector. The premier target is cost savings. Visvanathan and Asano (2002) reported a saving of A\$ 1 million per year by using 4000 m^3d^{-1} reclaimed water in the Earing power station near Newcastle, Australia. There was an additional cost savings by eliminating the need to pump wastewater 15 km from the treatment plant to the disposal site. Sappi Pulp and Paper Group's Enstra mill in South Africa is fulfilling 50 % of its water demand from a municipal wastewater treatment plant effluent thereby reducing the burden on fresh water resources. Reports on area-wide use of reclaimed water in Japan indicate the second highest volume is in the industrial sector with a utilization rate of reclaimed water of 15 million m^3 d^{-1} and a total reclamation of 85.5 million m^3 d^{-1} (Visvanathan and Asano 2002).

11.3 Treatment for Other Value Propositions

There are many options for turning used water into an asset. A cost reduction model based on reduced fresh and wastewater treatment volumes could start with the decentralized support for grey water reuse at household level before any conventional treatment. Grey water generated through bathing and in kitchens can be locally captured, treated and reused at household, garden and community level. This reuse can be encouraged through subsidies for the installation of on-site treatment and reuse equipment, or through reduced drainage/wastewater fees and green building environmental rating tools for buildings benchmark and new building zoning laws, where not every cubic meter of grey water is needed to flush the sewer. Studies in Jordan showed that grey water reuse can also be financially attractive for the household with cost-benefit ratios of about 1.80 (over 5 years) and 2.58–2.75 over a 10 year period (Bino et al. 2010).

Where greywater and blackwater (from toilets) are captured within the same sewer system feeding into a decentralized or centralized treatment plant, the treated water can be reclaimed and made available for agricultural irrigation, groundwater recharge, aquaculture, as well as inter- and intra-sectoral water swaps with freshwater users and newly emerging models such as water hedging in futures markets depending on demand and required treatment standards. (Table 11.2)

11.3.1 Inter- and Intra-Sectoral Water Swaps

Against the backdrop of worsening water scarcity situations in many parts of the world, policy makers are looking for sustainable solutions to ensure safe and adequate water supplies for society. As part of a broad strategy encompassing inter-sectoral water transfers, water swaps have been suggested which aim at the provision of treated water for example to farmers for irrigation, in exchange for freshwater for domestic and industrial purposes (Winpenny et al. 2010). The business model can equally be applied to water swaps with other water-intensive users such as golf courses.

Water swaps will not change total water availability in the river basin context but more freshwater might be allocated to higher valued uses. This system is possible where water allocations are controlled and changeable and farmers get an incentive to agree to the trade. The incentive could be financed from the gains of the urban center through higher revenues based on a larger freshwater supply and treatment cost savings. If the farmers are upstream of the city, there will be costs for pumping the wastewater back to the farm areas (Fig. 11.3). Distance will matter as distribution system costs can be the most significant component of costs for non-potable reuse systems, i.e. the cost of electricity to access and pump freshwater from long-distance sources and then to pump the waste out of the city (NRC 2012). If distances are short, water swaps could be a feasible mean of mitigating water scarcity problems with economic benefits both from the perspective of farmers and the society (Heinz et al. 2011).

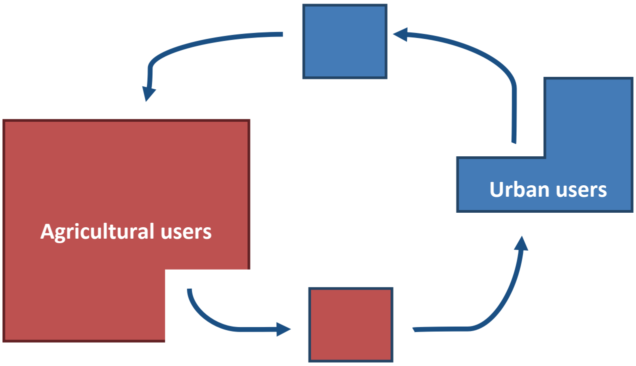
However, what looks in theory to be straight forward can be complicated in practice. This concerns the required institutional and incentive arrangements but also physical bottlenecks, like increased water salinity through (pond) treatment, making reclaimed water less suitable for farmers. Another challenge would be that in water scarce regions, where cities struggle to access water, also agricultural production is water limited. Providing farmers with an additional water source might result in expansion or intensification of irrigated farming, but not in a release of water.

Table 11.2 Examples of water reuse cases with business potential. (Source: Authors based on Otoo and Drechsel (2015))

Business model	Business case location	Business concept, products/services and beneficiary	Treatment type	Key figures	Drivers and opportunities
Water swap	Barcelona, Spain	Government initiated treated wastewater exchanged for freshwater used in agriculture. Treated wastewater used by farmers for cultivation	Secondary treatment + mixing with well water	19 million m^3/year of treated wastewater to irrigate 600 ha	Unavailability of fresh water during drought, increased pollution and salinity of river water and groundwater overexploitation
	Mashhad city, Iran	Agreement between regional water company and association of farmers for water exchange. Transfer of farmer's water rights from dams and groundwater in exchange for treated wastewater	Secondary treatment	About 185 million m^3/year of treated wastewater	Water scarce region; and need to reduce stress on freshwater
Replenishing natural capital (see Chap. 9)	Mezquital valley, Mexico	Wastewater disposed in Tula valley for large scale irrigation. Wastewater areas has higher prices for land; wastewater naturally recharges groundwater, potentially to be used for drinking water provision for Mexico city	No treatment	Around 60 m^3 per second of wastewater is produced by the city and farmers get 26 m^3 per second for irrigating 76,000 ha	Rising water security concerns and impact on ecosystem health
	Hoskote lake, Bangalore, India	Department of minor irrigation diverting untreated sewage from one part of the city to another. Recharging of dry lake and groundwater wells benefits small farmers and households around the region	No treatment except natural processes	Variable volume adequate to recharge the lake depending on drought conditions and groundwater levels	Need for lake restoration and replenishing depleting groundwater table and drying wells

Table 11.2 (continued)

Business model	Business case location	Business concept, products/services and beneficiary	Treatment type	Key figures	Drivers and opportunities
On-site valorization via aquaculture	Terraqua Barranca, Peru	Private Public Partnership(PPP) to treat city's wastewater to produce duckweed and fish and cultivate crops for supply to dairy processing company	Secondary treatment including nutrient removal through duckweed	Investment cost \$ 22.5 million; \$ 14.8 million revenue from sale of fish, payback period 2.8 years; treatment cost \$ 0.1 per m^3	Partnership with city authorities and support from Inter-American Development Bank to finance the investment
	Agriquatics, Bangladesh	Treatment of wastewater from hospital facility to produce fish feed (duckweed), raise fish, and water market crops as side products	Tertiary treatment using series of ponds	Full cost recovery through local sale of fish and crops, and net profits due to low cost treatment (ponds)	Partnership between hospital complex and the technology promoter and high demand for fish in the region
Marketing reclaimed water	Gaborone city, Botswana	Treatment of wastewater from Gaborone and reuse for irrigation of Glen valley farms and river flow augmentation	Secondary treated wastewater	About 50,000 m^3/day of wastewater treated and 0.03 % of this is used to irrigate 203 ha of crops at \$ 0.086 per m^3	Frequent droughts and water scarcity facing the city
	Drarga, Morocco	Treat wastewater from Drarga municipality. Treated wastewater is reused for irrigation, reed grass and compost from sludge are sold	Secondary treated wastewater	Pilot scale, water treated 1000 m^3/day	Need for treatment of waste water, reduce pollution and improve living environment, and water scarcity. Strategic partnership among several stakeholders
Hedging for future water markets	Prana sustainable water, Switzerland	Wastewater treatment pre-financed by future water sales via contractual agreements to secure water shares and finances	Tertiary or secondary treatment	Investment for hedging & matchmaking of about US\$ 0.5 million	Knowledge management on water markets, water trading and commodity pricing along with strong partnerships



1. Urban wastewater is reclaimed for agricultural production.
2. Farmers will release a freshwater share for urban or environmental needs.
3. The swap will not change total water availability in the river basin context but more freshwater could get reallocated to higher valued uses.

Fig. 11.3 Theoretic business model for an inter-sectoral water swap. (Redrawn from GWI 2009)

GWI (2009) is therefore suggesting an alternative model of water reuse where the urban water agency retains control of the reclaimed water for higher-value urban purposes. For example some water may be sold directly to industrial water users within the urban sector, and some may be blended in reservoirs or confined aquifers for indirect potable reuse. The related revenues per cubic meter would be higher than selling water to agricultural customers. Public agencies can also earmark some of the additional water supply for environmental amelioration, lowering urban water withdrawals from nature, while cross subsidizing this with revenues from higher value reclaimed water sales (Fig. 11.4).

In contrast to agricultural production which increases with increasing availability of water, GWI (2009) argues that in the urban context, there is no direct relationship between water availability and productivity in industry. And if meaningful tariffs are charged, there is no reason why domestic demand should increase with availability of additional water.

While GWI (2009) is thus pushing for high-end treatment for high-value use, and argues that farmers have no incentive to invest in water saving technologies if they receive free or very low-cost reclaimed water from cities. Huibers et al. (2010) argue for treatment levels matching reuse needs, especially from agriculture. Also Libhaber and Orozco-Jaramillo (2013) argue that especially in developing countries cutting-edge treatment pants are a risky investment for institutional capacity and financial reasons and appropriate technologies relying on simple processes with lower capital and operational costs will be much more sustainable, while offering various quality levels, also for agriculture.

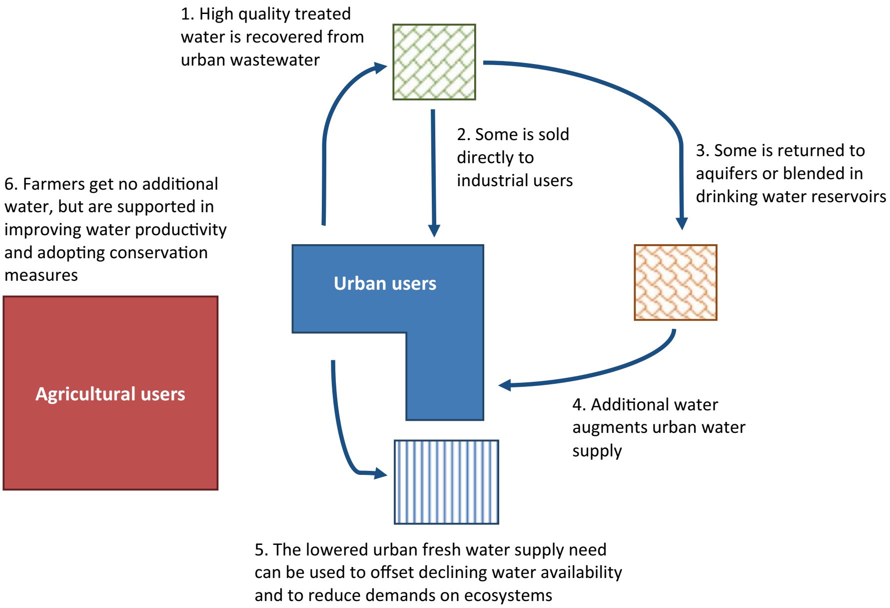


Fig. 11.4 Business case model for high value water swaps. (Redrawn from GWI 2009)

Examples of planned or existing water swaps are reported by Winpenny et al. (2010) and Otoo and Drechsel (2015): In Mexico and in Spain, the feasibility of water swaps has been evaluated and confirmed for different locations and wastewater treatment plants (Winpenny et al. 2010). In the case of the Spanish Sant Feliu de Llobregate wastewater treatment plant, for example, the treated effluent can replace freshwater from the main river which is used for irrigation. Currently, only a small proportion of the effluent is actually used by farmers (about 0.2 million m^3/year), who view it as a last resort to be used in drought periods when sufficient fresh water is not available. Further, the treated wastewater is used to recharge groundwater aquifer, which is used for irrigation. The economic net-benefit of water exchange between agriculture and municipality has been estimated at about € 7 million/year (Winpenny et al. 2010; Heinz et al. 2011).

The Mashhad Plain in Iran, is another example (see also Chap. 9) of a water swap where wastewater is collected, transferred and treated according to scientific standards and 15.6 million m^3 are exchanged against agricultural freshwater rights of farmers (Alaei 2011). This case had four sub-projects, involving diverse reuse options. The business model appears promising because of the diverse water swap strategies including: volumetrically more water for farmers, replacing freshwater rights of the farmers with wastewater instead of diversion of water from a dam; replacing the right of groundwater withdrawal with effluent reuse; storing part of the acquired water in groundwater aquifer to stabilize the water table; and supplying freshwater from the dam and aquifer to the city to help improve urban water supply, and achieve cost-savings and protect public health. Alongside, there were other instruments used to facilitate the water swap. For instance, before implementing the water swap, wastewater users association was formed and the contract was signed between the association and the regional water company. This participatory strategy enhances cooperation and limits any future potential conflicts associated with water allocation. Subsequently, the transfer of treated wastewater from the treatment plants to the fields of farmers in the downstream of dams was executed. However, a missing element in the business model is that low valued users such as agriculture get wastewater to reuse but farmers are not incentivized to undertake water conservation practices.

In summary, the above business cases demonstrate that water swaps business models are likely to be more successful in situations where local water security concerns are high and rising water demand motivates the utilities to find creative solutions and enter into cooperative bargaining agreements with farmers. Water scarcity is the main driver, while clearly defined water rights and incentives for farmers are the main anchors of a successful water swap. Diverse reuse strategies can offer more flexibility and value propositions as in the Mashhad water swap. Exchange of water to high value urban users such as households and industries, to recover costs and linking farmers to the high valued agricultural value chains is also an important incentive. Yet, using a business approach to facilitate water swaps across sectors faces some critical economic and policy challenges (**Box 11.2**) and can also fail due to safety concerns. In Cochabamba, Bolivia, for example, the release of treated wastewater to farmers was stopped to avoid potential problems due to the quality of the effluent (Zabalaga et al. 2007).

Box 11.2: Potential gains and conflicts in water swaps: Cities versus agriculture users

Water swap business models are not a panacea and not without their own problems, particularly where large inter-sectoral water transfers are involved. Moving water away from its main use in agriculture to higher economic value uses is one of the main measures widely seen as desirable, especially in view of inefficient water use in the agricultural sector. This apparent misallocation is often attributed to the failure of government to allocate water rationally. However, Molle and Berkoff (2006) argue that cities' growth is generally little constrained by the competition with agriculture. In general, rather than using a narrow financial criterion, cities select options that go along the "path of least resistance," whereby economic, social and political costs are considered in conjunction. The authors conclude that the frequent statement that reallocating a minor fraction of irrigation water to cities would suffice to cater to the needs of people with poor water supply conditions is deceptive: both the arithmetic and the causality are erroneous. Much of the water used by irrigation is diverted at times and places where there is no alternative use and a large part of return flows—in water short basins–is reused downstream. Thus the causal association between, on the one hand, the insufficient and precarious conditions of access to water in “thirsty cities,” highlighted in times of crises, and, on the other, water scarcity allegedly caused by a wasteful irrigation sector, is according to the authors largely misleading as the problem (in developing countries) lies more in the lack of capital, itself a notion relative to the local political economy and distribution of power in society (Molle and Berkoff 2006).

11.3.2 Replenishing Natural Capital

Secondary treated wastewater can be used to recharge groundwater, which can be a critical factor in water stressed regions. As the benefit is with the drinking water agency, a business model could be based on benefit sharing principles, where the drinking water agency or local government pays the treatment entity. In case they are the same entity or different ones, the drinking water entity would compare potential benefits with the costs for developing alternative freshwater supplies. Operational cost recovery will depend upon the prevalent price for fresh/potable water. The other primary beneficiaries from groundwater recharge are the private stakeholders neighboring the groundwater recharge zone who will gain from higher groundwater levels and can potentially sell the water through private tankers. Examples of intentional and unintentional aquifer recharge have been presented by Dillon and Jiménez (2008). An example of planned groundwater recharge has been presented in Chap. 9 for the city of Bangalore, India, where urban wastewater is been used to refill depleted irrigation tanks in the rural vicinity, which in turn helps to replenish the groundwater level and improves farmer access to irrigation water through tube wells. A typical case is the depleted Amanni Doddakere tank, situated in Hosakote in rural Bangalore which receives now excess water from Yele Mallappa Shetty Kere (YMSK) tank in urban Bangalore which serves as a stormwater and wastewater reservoir and is full year round. Farmers from Hosakote appealed successfully to the Department of Minor Irrigation to access the water of YMSK. It took more than a decade to complete the lift irrigation scheme. After some initial skepticism, farmers started to compete for the water, resulting in a number of illegal water diversions along the 20 km pathway with little water eventually arriving at its planned destination. Farmers who received water expressed their commitment to benefit sharing principles by stating an average willingness-to-pay of US$ 11.3 per acre, per season for the possibility to continue using their tube wells (Scharnowski et al. 2014). The results show that the farmers who could benefit in Hosakote are willing to contribute about 25 % towards the monthly operation and maintenance costs of the water lifting project. Extending the benefit sharing principle to those farmers currently excluded but illegally accessing the water along the canal probably finance even more. Other benefits that could enhance cost recovery and promote a move towards benefit sharing will be the transformation of the YMSK overflow from an environmental hazard into an economic asset, and the ability of the Irrigation authority in meeting its water supply obligations.

An important lesson was that engaging stakeholders in the process of formulation and the set-up of clear institutional arrangements could have avoided some of the observed challenges. This applies to various scales as the redistribution of the wastewater also resulted in additional water related tension between Karnataka and Tamil Nadu states of India.

A well-known case of unintentional recharge described in Chap. 9 of this volume is the "Mezquital Valley" in Mexico where wastewater of Mexico city is being discharged since 1789 into the Tula Valley[1] and is used to irrigate about 70–90,000 ha (Jiménez 2005, 2008). The irrigation activities, especially their low water use efficiency, are multiplying the benefit of natural aquifer recharge while the soil filters pollutants making the water with some additional treatment re-usable by Mexico City. Due to wastewater irrigation over 90 % of the aquifer in the valley is formed by urban wastewater; however, it was only in 1995 that the city realized due to observed changes in water salinity that its original groundwater had been replaced by infiltrated wastewater. Comprehensive water quality analysis found that the unintentional soil aquifer treatment worked better than the currently best wastewater treatment plant (Jiménez 2008).

Due to groundwater over-exploitation within Mexico City, additional water abstraction from soil is today prohibited and water rights markets support water reallocation from agriculture to urban use.

11.3.3 On-Site Value Creation

Business cases on wastewater based aquaculture can be found in Egypt, Morocco, Tunisia and Peru. Fish production can take place within or after the treatment process. Within the treatment process the reuse value proposition can be integrated by absorbing nutrients from the wastewater in biomass which can feed fish or other animals. Where such a low-cost treatment solution can be combined with high-revenue generation, businesses can move beyond cost recovery. An example is the pond-based treatment system supporting the production of duckweed as fish food, and/or fish itself. The operational cost recovery from this system is high and the low investment cost make the business model attractive for smaller treatment plants in towns and cities in developing countries. Agriquatics—Bangladesh, for instance, achieves 100 % cost recovery and makes net profits like its sister project Terraqua Barranca in Peru which is using comparable treatment technologies and achieves a payback period on capital costs of just 2.8 years. In the case of Peru, value propositions include well-treated wastewater at a nominal value of $ 0.1 per cubic meter which generates approximately $ 1 million in "new water value" to the community; and about 2500 tons of fish per year valued at $ 14.8 million in local revenues. In West

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[1] As one of the first irrigated areas within the Tula Valley is called El Mezquital, the whole reuse case is also often referred to as the Mezquital Valley.

Africa, fish are grown directly in the last pond of the treatment systems or in freshwater ponds which are fed with wastewater from livestock production. In Ghana, for example, Waste Enterprisers pioneered a model using existing wastewater treatment pond systems which limited their investment costs to the fish stock. Revenues from fish sales are shared with the municipal authorities to maintain the ponds, and to monitor fish quality and safety (Murray et al. 2011).

Given the favorable revenue situation, both duckweed cases do not rely on water fees or any subsidies. In Terraqua net profits are shared among the stakeholders including farmers, while there are no such arrangements in Agriquatics. Yet, the local community benefits from local sale of fish and crops, treated wastewater, and services made possible through the social enterprise model.

11.3.4 Marketing Reclaimed Water

As discussed in Chap. 1 and other chapters in this book, a cost recovery business model is usually constrained by low freshwater prices, making it difficult to charge appropriately for reclaimed water to achieve full cost recovery, unless high end treatment meets high end users (see 11.2). The values of using reclaimed water are multiple from freshwater savings to environmental benefits and cost recovery. Detailed business cases and examples can be found in Otoo and Drechsel (2015). Here we give a few examples only.

Lazarova et al. (2013) present a number of well-known and successful water reuse cases, some of which include agricultural reuse. In Milan, Italy, high quality filtered and disinfected wastewater is used for indirect use in agriculture, river restoration and environmental enhancement. In the case of one treatment plant, farmers pay a symbolic amount for a concession to use recycled water, while in the other case, a farmer association pays for water pumping. Charges are low to encourage farming in that area, but also based on historical reasons as formerly the mix of raw sewage and channel water was free. Based on impact assessments the environmental benefits of the reuse model are however significant.

In the case of the island of Noirmoutier, France, tertiary treated wastewater is sold at 40 % of the freshwater price to grow potatoes, allowing farmers to produce potatoes also in the dry summer period, while the authorities reduce their wastewater disposal costs, reduce environmental pollution and save on drinking water. In Australia, wastewater is used for various purposes depending on its treatment level. The largest (66 %) customer across the country is irrigation which allows farmers to deal with droughts and increasing water competition, which is strongly contributing to urban water supply security. Melbourne Water, for example, is a wholesale supplier of recycled water to the retail water companies, who then distribute it to customers. Recycled water prices include a variable component and are set so as to (i) consider the price of any substitutes and customers' willingness to pay; (ii) cover the full cost of providing the service with the exception of services related to specified obligations or maintaining balance of supply and demand (South East Water 2013).

In Botswana, the city of Gaborone is using a dual strategy for wastewater use—part for flow restoration in the tributary of the Limpopo river and drought mitigation, and part for irrigation for producing high value fresh vegetable for sale to the local super markets. Treated wastewater has been supplied by the Water Utilities Corporation of Ministry of Minerals, Energy and Water Resources since the scheme's inception in 2005. In principle, a tariff of US\$ 0.06/m^3 has been set by the Ministry of Agriculture for irrigation water. In practice, water fees are not collected at Glen Valley. Farmers have had to invest in the piping and control gear for drip-irrigation but not in pumps or water storage. When there are no major interruptions to water supply and farmers can use drip irrigation it is very profitable to grow tomatoes. The net return to tomato growing is around US\$ 17,800/ha. If the water tariff was raised to its full economic cost (of an estimated US\$ 0.36/m^3) the net return would fall by only 7 % as water supply costs make up a small proportion of the total production cost. Post-harvest losses can have a much bigger impact on the profitability of this enterprise (Yaron et al. 2012).

The sale of fresh vegetables at the farm gate to a buyer provides security in terms of market fluctuations and saves transportation cost, while making fresh vegetables available to the public. Yet, the water sale via the farmer association is only recovering a small fraction of the wastewater treatment costs. A higher level of cost recovery is achieved in the case of Mauritius, where the Irrigation Authority uses a more complex revenue strategy and tri-partite partnership for full cost recovery. This includes (a) generating income from the sale of treated water to the government from irrigated farming, (b) supply of treated wastewater to the farmers at a lower price than the price these farmers had otherwise to pay to the Irrigation Authority for irrigation water, (c) government subsidies to avoid financial shortfall for the Ministry of water and agriculture, and (d) energy production from sludge for on-site use thus saving electricity costs. The key stakeholders include Irrigation Authority, and Wastewater Management Authority, both represented by the Government; farmers with clear water rights; and international development partners including EU and Berlinwasser International providing finances and management services. Construction of the treatment plant, which has a capacity of 69,000 m^3 per day, was funded by the European Union in partnership with the Government of Mauritius. It was completed in 2005. Berlinwasser International has been responsible for the operation and maintenance of the treatment plant since 2008 and their contract will end in 2015.

Water reuse as a social business model saving freshwater with environmental benefits and a cost recovery component is common across the MENA region (Qadir et al. 2010). A particular case with multifold social objectives such as to reduce environmental pollution and promote better living, and a multi-resource recovery strategy for revenue generation is the Drarga plant near Agadir in Morocco. The Municipality collects sewage fees to recover its operation and maintenance costs and designed the plant to generate additional revenue from sale of (i) treated wastewater to crop farmers, (ii) reed grass from the constructed wetland, (iii) sludge compost, and (iv) methane gas from energy recovery. Although not all of these components have been implemented so far, a noteworthy innovation in this case is that all sales revenues and revenues from the water and sewage tariff and connection fee are deposited into a special account, independent of the main community account to serve solely the wastewater treatment plant. This special arrangement is a response to common bottlenecks in public financing of O&M costs like spare parts which contributed to the breakdown of about 70% of the wastewater treatment plants in the country (Choukr-Allah et al. 2005). The examples show the advantages of multiple value propositions and revenue streams. Chaps. 12 and 13 which focus on the recovery of nutrient and energy from wastewater will provide more examples.

11.3.5 Hedging Future Water Markets

This business model is based on the premise that the demand for reclaimed wastewater by industries and agriculture will increase in the future. The business concept is to hedge and match future suppliers of wastewater treatment and future buyers of treated wastewater through trading of water titles, and in this way securing parts of the investment capital beforehand for wastewater treatment projects. Supply side actors are municipalities, cities and/or entities producing wastewater. The demand side actors are organizations and companies wishing to offset their increasing water footprints via the purchase of water titles, or simply agro-industrial complexes in need of water. A private enterprise, like Prana Sustainable Water, based in Switzerland, would act as a broker, bringing together wastewater suppliers and wastewater buyers using a water title exchange platform. Similar platforms with a broader scope are provided for example by Mission Markets Earth (http://www.mmearth.com/; http://www.ecosystemmarketplace.com) which aims to be a one-stop shop that allows sellers to sell and buyers to buy credits from a variety of environmental markets including wetland banking, biodiversity offsets, water quality trading and voluntary carbon markets. By packaging environmental assets in a manner familiar to traditional investors, these platforms try to open untapped capital for environmental markets. An example for trading commoditized treated wastewater between water rich and water poor regions is provided here http://www.pranasustainablewater.ch/en/solution/trading.php.

11.4 Conclusions

The overarching priority of any wastewater treatment system is to safeguard public health, which requires that it remains continuously operational. This characteristic often is not achieved in many low-income countries where capital costs are covered by foreign aid and operations are the duty of national authorities with insufficient institutional, financial, or technical capacity (Murray and Drechsel 2011). Resource recovery and reuse offers opportunities for dedicated revenue streams to support sustainable operations.

Potential solutions vary with market opportunities, ranging from appropriate treatment for low-revenue but large volume agricultural reuse to high-end treatment for high value (potable) reuse. While GWI (2009) sees best opportunities for high-end treatment and high-value reuse, which might indeed be appropriate for many developed countries and emerging economies, others argue that especially in developing countries, cutting-edge treatment plants are risky investments and combinations of appropriate technologies with lower capital and operational costs will be a better fit, also in view of reuse (Huibers et al. 2010; Nhapi and Gijzen 2004; Libhaber and Orozco-Jaramillo 2013). Combining reuse with low-cost treatment increases the probability of full cost recovery as the ‘duckweed’ cases demonstrate, especially if there is a sufficiently large market for the value proposition that reuse offers.

On the other hand, choosing a level of treatment which treats water to a quality beyond that is required for its safe use will burden the service provider with higher capital and operational costs, with not enough revenue realization in the absence of demand for this high quality water.

Libhaber and Orozco-Jaramillo (2013) show that the investment costs in combinations of appropriate technology solutions are 20–50 % of the investments in e.g. activated sludge treatment, and in most cases only 20–25 % of the operation and maintenance cost, compared to activated sludge (Table 11.3). Such solutions will have a higher probability of sustainability within the revenue generation potential of towns and smaller urban communities and offer a range of non-potable water reuse opportunities.

One way to avert over-investments in treatment is that utilities treat water to the required regulatory standards and provide water to bulk industrial users first and the rest to the low valued agricultural market. Industrial users can further treat their water allocation through their own on-site advanced treatment facilities to match quality to their internal process needs. In settings where a reuse market for high quality water is well developed and higher grade treated water reuse is in demand, the utility can engage with users to co-fund the investments to provide advanced treatment and charge the additional cost thereof to the end users including third party customers.

Offering treated wastewater for agriculture only will struggle with low water prices. Charging farmers the full cost of water treatment would discourage them from converting to irrigation with wastewater and participating for example in water swap models, despite significant interest from urban users. In these cases, cost recovery has to be supported through the water bill; i.e., of wastewater producers following user/polluter pays principles, or subsidies justified by positive externalities for human and environmental health and savings on freshwater consumption. However, the degrees of freedom available when designing taxes and tariffs in low-income settings are limited, as tariffs must be pro-poor.

The water in wastewater is just one of the important economic assets in reuse solutions. Recovering several products from wastewater enables new opportunities, enhances revenue, and moves the business up on the economic value proposition ladder (Fig. 1.1). The As Samara wastewater treatment plant near Amman, Jordan and the Drarga plant in Morocco are examples of treatment plants designed to offer multiple revenue streams from resource recovery (water, organic fertilizer, carbon credits and especially energy).

Table 11.3 The capital (capex) and operational (opex) expenditures of some appropriate technology options for wastewater treatment solutions. (Libhaber and Orozco-Jaramillo 2013)

	CAPEX		OPEX	
	US$/capita	% of activated sludge costs	US$/year/capita	% of activated sludge costs
Rotating micro screens	3–10	4–10	0.1–0.15	1.9–2.5
UASB reactors	20–40	25–40	1.0–1.5	19–25
Chemically enhanced primary treatment (CEPT)	20–40	20–40	1.5–2.0	25–38
Mixer aided lagoon systems	20–40	25–40	0.2–0.4	5
Anaerobic filters	10–25	10–25	0.5–1.0	13–20
Conventional lagoon systems	20–40	25–40	0.2–0.4	5–8
Covered anaerobic lagoons and mixer aided facultative lagoons	20–50	25–50	0.2–0.4	5
Stabilization reservoir systems	30–50	30–50	0.2–0.4	5
Constructed wetlands	20–30	20–30	1.0–1.5	19–25
UASB-anaerobic filter combination	20–40	20–40	1–1.5	19–25
UASB-lagoon combination	30–50	30–50	1–1.5	19–25
CEPT-sand filtration combination	40–50	40–50	1.5–2	25–38
UASB-sand filtration combination	30–50	30–50	1–1.5	19–25
UASB-dissolved air flotation combination	30–40	30–40	1–1.5	19–25
Reference case—conventional activated sludge plant used for comparison with low cost technology				
Conventional activated sludge	100–150	100	4–8	100

Note: The investment cost of an activated sludge plant was set at US$ 100/capita. Compared to the conventional activated sludge (80–90 % removal of biological oxygen demand and total soluble solids) the treatment capacity of individual appropriate technologies can be lower and combinations are recommended which will still have the advantage of lower costs

However, recovering several resources can pose institutional challenges. For instance, should recovering these value streams involve a single business model and service provider or involve multiple private-public partnerships and models. If the target is that value created through reuse can help maintaining the sanitation service chain, it will require mutually negotiated and agreed on benefit sharing mechanism. Particular attention will be needed for the institutional and financial setup that revenues from reuse support overall sustainability of the system. The Moroccan example of an independent wastewater account to prevent the erosion of fees and revenues within common public budget gaps is a model to follow.

While the architecture of business approaches in facilitating local reuse solutions is dynamic, the salient factors that might shape the future of business models in promoting resource recovery solutions include appropriate technology, transition to multiple and higher value propositions, and well-designed institutional linkages. The interplay of these factors in delivering sustainable water and sanitation solutions to local communities through innovative business models, partnerships and strategic applications of science and technology requires further investigation. Existing and emerging challenges such as stricter regulations, changing risk awareness, new green market opportunities and adaptation to climate change will increasingly allow us to witness fresh ideas and new business approaches.

Take Home Messages

- Water scarcity will continue to drive the need for reuse solutions and shape the economic value of wastewater as an asset in an urbanizing world.
- Wastewater use business models offer several value propositions, which can extend the treatment benefits beyond the safety of human and environmental health and support industry, agriculture, domestic and institutional demands.
- Harnessing key resources in wastewater—water, nutrients, and energy, can extend the probability of recovering operational and maintenance costs, and even capital costs if these are low and the reuse market large.
- Distance, i.e. electricity costs for water transport via pumping are the key cost factor.
- Appropriate low cost technology holds the key to sustainability of treatment and reuse in developing countries, while high-end treatment for high value reclaimed water has a significant market potential in developed countries.
- Full cost recovery remains elusive in most (agriculture based) reuse cases, but not impossible especially if water quality allows also for industrial reuse. The inter-institutional arrangements for benefit sharing and dedicated accounting require particular attention to support overall system sustainability.

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Chapter 12
Business Models and Economic Approaches for Recovering Energy from Wastewater and Fecal Sludge

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Abstract Universal access to water, sanitation and energy services are key challenges in low income countries. The conventional model of providing water, sanitation and waste disposal as a social service is no longer viable because national authorities lack financial and human resources for operation and maintenance and for addressing the sanitation needs locally. Human excreta and wastewater represent resources that can be used to generate new income and support livelihoods through use as a source of energy. The reduction, removal and reuse of wastes must become financially feasible and economically profitable and yield high returns. This requires innovative and sustainable business models and financing instruments for their implementation. This chapter presents an overview of successful and emerging business cases for recovering energy and other useful products from wastewater and fecal sludge from low and middle income countries. The business cases are analysed for their business concepts and opportunities and challenges for scaling-up and scaling-out. Key policy implications and conclusions for supporting the business model approach in the developing world are discussed.

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12.1 Introduction

Rapid urbanization, increased economic growth coupled with increased consumption levels determine the amount of waste generated in a region or a country. With rapid urbanization in developing countries, greater volumes of wastewater are generated (Qadir et al. 2010). Most of the waste generated in developing countries ends up in open dumps and wetlands, contaminating surface and ground water and posing major health hazards. This poses substantial challenges for financing water, sanitation and waste management services (UNWATER 2013). The larger challenge might however be to maintain installed infrastructure operational as in many developing countries national authorities lack the required financial and human resources. Thus, cost recovery is high on the agenda and one way to address this is through waste reduction and recycling. In fact, there is an urgent need to go beyond business as usual and the linear ‘take, make, dispose’ pathway. Emerging recommendations propose a ‘circular economy’ (Ellen MacArthur Foundation 2012) which builds on resource recovery and reuse (RRR).

To achieve success, RRR must be technically feasible and profitable, be it with or without subsidies. It must yield high returns and the rewards must go beyond business certainty to health risk reduction. This requires innovative, inclusive and sustainable business models for RRR and financing instruments for their implementation to transform ‘pollution’ into assets that smart political leaders can accept voluntarily, from the bottom up, for benefit sharing across sectors and actors. However, scale matters. The RRR options must relate to local communities, economic circumstances, socio-cultural norms, safe use, public awareness and local capacity.

Energy security is a critical issue facing municipal authorities in the developing world. More than 2.8 billion persons are without access to electricity worldwide and most live in developing countries. This includes about 550 million in Africa and 400 million in India. Almost 2.8 billion use solid fuels such as wood, charcoal, coal and dung for cooking and heating. To achieve universal access by 2030, new capital investment of $ 35–40 billion per year is needed, in addition to the $ 450 billion needed just to sustain existing services (WEO 2011). Providing universal access to water, sanitation and energy services will remain a key challenge for many decades. The RRR approach offers affordable local solutions to water and energy security issues.

While the need to provide universal access to water, sanitation, and energy is well recognized, mechanisms to support implementation and enhance compliance are lacking. Human excreta and wastewater represent resources that can be used to generate new income, create livelihoods, and improve ecosystems. However, there are threats to human and environmental health, and negative social perceptions of nutrient recovery from wastewater, human excreta, and urine for use as fertilizer in agriculture (Jewitt 2011b). Examples of hurdles identified from the literature relate to poor understanding of the potential for urine reuse, social stigma to using dry sanitation and urine in agriculture, and poor operational knowledge of application practices (Roma et al. 2013). Taboos regarding human waste create barriers for the development of more appropriate excreta management systems, with consequences for human, economic and ecosystem health (Jewitt 2011a). However, there are some best practice case examples where the business approach has been used for energy recovery form wastewater and fecal sludge.

Against this backdrop, we examine the need for energy recovery from wastewater and fecal sludge (Sect. 12.2). We present several wastewater to energy business cases, and fecal sludge to energy business cases from developing countries (Sect. 12.3). We examine the economics of waste-to-energy business models, and we describe opportunities for scaling-up those models (Sect. 12.4). We also provide policy recommendations for supporting the business model approach in developing countries (Sect. 12.5).

12.2 The Need for Energy Recovery from Wastewater and Fecal Sludge

Water treatment, delivery, and wastewater recovery and treatment require substantial energy. Thus, water and wastewater management decisions are also energy management decisions. Wastewater can also be used to generate energy (GWRC 2010). There is a strong scientific consensus that the consequences of climate change will impact the water cycle, both directly and indirectly affecting all economic and social sectors, and the effects are likely to be much stronger in developing regions and for the poorer citizens (Kriegler et al. 2012; Oate et al. 2014; Qureshi et al. 2013). In particular, the water industry is one of the first to be significantly impacted by climate variability. Hence, issues associated with and links between climate, energy and water will become more critical in future. Reduced rainfall and declining inflows have placed pressure on traditional water supplies and forced reconsideration of current water use practices in many areas (Lempert and Groves 2010). Therefore, increased concern about climate change and the need for greenhouse gas (GHG) emission abatement options has focused attention on water-related energy use and GHG implications (CSIRO 2008).

In this context, water authorities are facing the challenge of implementing a wide range of integrated water management initiatives including water reuse, desalination, decentralised water supply options, etc. On the one hand, the non-conventional water sources are more energy-intensive than conventional sources (Medeazza and Moreau 2007). On the other hand, energy consumption for treating wastewater has grown considerably, both through increases in treated volume and the implementation of new technologies aimed at achieving higher protection of the environment (Hernández-Sancho et al. 2011). Hence, simultaneously addressing urban water cycle issues while reducing energy use and GHG emissions represents a challenge that will require fresh concepts coordinated across both the water and energy sectors.

Table 12.1 Average sewage energy consumption per cubic meter of wastewater treated by country. (Source: WERF 2010; GWRC 2010; IDAE 2010)

Country	Energy consumption per cubic meter of wastewater treated (kwh/m^3)
United States	0.45
Netherlands	0.36
Singapore	0.56
Switzerland	0.52
Germany	0.67
United Kingdom	0.64
Australia	0.39
Spain	0.53

Reducing carbon footprint of the wastewater treatment plants (WWTPs) is not just an environmental issue; there are also important economic implications. For instance, the trend of rising energy costs in recent years is likely to continue. Carbon credits and carbon trading programs also offer incentives for reducing the carbon footprint of WWTPs. Hence, water authorities and wastewater operators are motivated to reduce energy consumption, both from an economic and environmental point of view. Nonetheless, average energy consumption per cubic meter of wastewater treated does not differ much across developed countries, despite any technology differences (WERF 2010; Table 12.1).

Energy demand in wastewater treatment plants will grow over time due to a number of factors, such as population growth and the corresponding growth in the waste load to be treated, as well as increasing international calls for universal access to these services for all in the developing world and more stringent regulatory and environmental protection standards for effluent quality and water reuse in the developed world. These changes are expected to result in more energy intensive processes (Schosseler et al. 2007). Thus, optimization of energy consumption, energy efficiency in design, equipment and technology operations, energy recovery processes, and energy pricing are being increasingly considered in the field of wastewater treatment.

For the network-based wastewater treatment in urban areas, energy costs are 5–30 % of total operating costs among water and wastewater utilities. Energy costs are generally higher in developing countries and can be 40 % or more of the total (World Bank 2012). Such high energy costs contribute to high and unsustainable operating costs and directly affect the financial health of utilities. Improving energy efficiency is a core measure to cut operational costs and many energy efficiency measures have a payback period of less than 5 years (World Bank 2012). Investing in energy efficiency makes cheaper to operate the system, supports quicker and greater expansion of access to the poor, helps alleviate fiscal constraints, and lessens upward pressure on water and wastewater tariffs. At the national and global level, it reduces the need to add new power generation capacity and emissions of local and global pollutants (World Bank 2012). Alongside energy efficiency programs, onsite energy generation from wastewater and human waste can enhance the energy cost savings and reduce the pressure on the national electricity grid in the developing countries.

Energy generation along the wastewater value chain from household and industrial wastes offers greater opportunities for energy cost savings. Examples of energy recovery from wastewater in the existing literature include: electricity and natural gas generation from wastewater treatment plant sludge (Bidart et al. 2014); evaluation and control of WWTPs for reducing greenhouse gas emissions and economic costs (Flores-Alsina et al. 2008); energy savings through the utilization of municipal wastewater for cooling in power plants (Walker et al. 2013); and for biodiesel production (Phalakornkule et al. 2009).

12.3 Waste-to-Energy Business Cases in Developing Countries

12.3.1 Wastewater to Energy Business Cases

The energy content of wastewater is in the form of thermal, hydraulic and chemical energy. Thermal energy is the heat energy contained in the wastewater, which could be from users of hot water, flow by gravity or forced through sewer mains by pumps. This type of energy from wastewater is useful in places requiring large amounts of energy for heating water, as the heat can be used to preheat the water via heat exchangers or heat pumps. An example of such application is in Dalian, a modern city in southernmost part of the Liaodong peninsula in northeast China, where heat from sewage is reclaimed to meet part of the heating and cooling requirements of the Xinghai Bay business district, resulting in savings of more than 30 % energy compared to conventional solutions (Friotherm 2012). In most developing countries with warmer climates, there is a limited need for using thermal energy in wastewater for space heating. However, there is an opportunity to meet industrial cooling needs by using wastewater as a heat sink.

Hydraulic energy is of two types—potential energy from water elevation and kinetic energy from moving water due to gravity or from pump stations. Most treatment plants are located at lower elevation; however few have the opportunity to take advantage of significant difference in elevation that makes it technically viable to run a hydro turbine. At an elevation difference of 50 m, the potential energy content of wastewater is 6 kwh/capita/year (Meda et al. 2012). The As-Samra wastewater treatment plant serving Amman, Jordan is a well-known example that benefits from its favourable elevation. The difference in elevation from the city and the As-Samra treatment plant and between the treatment plant and the outlet enables the installation of upstream and downstream turbines, generating about 3 MW of electrical energy. The hydraulic energy content in wastewater is relatively small, however in the case of As-Samra, 30 % of the plant's energy needs are met by hydraulic turbines.

Chemical energy is from the organic content in the wastewater, and anaerobic treatment using bacteria converts the organic matter into biogas that comprises primarily methane and carbon dioxide. Biogas can be used as a fuel to either generate electricity or as heat energy. Based on the maximum chemical oxygen demand (COD) load per capita of 110–120 g/L, Meda et al. (2012) estimate the maximum theoretical chemical energy content of wastewater to be 146 kwh/capita/year.

Anaerobic digestion can provide several benefits in wastewater treatment plants, such as (a) ease of biogas generation from wastewater and sludge resulting in a renewable and green energy source, (b) reduction in sludge volumes and reduced disposal costs, and (c) significantly eliminating pathogens and potential use of dehydrated sludge as a fertilizer. Many treatment plants use anaerobic digestion (Table 12.2). The As-Samra plant, in addition to harnessing hydraulic energy upstream and downstream, captures and uses biogas for electricity generation. As-Samra has met 90 % of its electricity needs through this combination since its commissioning in 2008. Other examples include the St. Martin wastewater treatment plant in Mauritius and the Okhla sewerage treatment plant in New Delhi, which capture biogas and meet 25 and 60 % of their energy needs, respectively.

Anaerobic digestion technology is also used by agro-industrial units to treat the effluent discharged during production. Nyongara slaughter house in Nairobi, Kenya piloted a biogas plant to treat the effluent and waste generated when processing meat. Similarly, Thailand Biogas Energy Company (TBEC) uses a covered lagoon bio-reactor to treat the effluent from cassava palm oil and other starch processing agro-industrial units (Otoo and Drechsel 2015).

There are other technology options emerging to harness the energy in wastewater. For instance, Aqwise, a private Israeli company, specializes in developing customized wastewater treatment systems using patented Attached Growth Airlift Reactor (AGAR) technology. Aqwise implemented its patented system to treat raw sewage supply from the local sanitation facility and filter it for use in cooling a large Telmex data center in Queretaro State, Mexico. The wastewater-based cooling system provided an eco-friendly alternative to common data cooling systems such as air conditioning or potable water-based systems, thus reducing Telmex's electricity costs and consumption of potable water. The data center is located near a sewage drainage system whereby the company could buy raw sewage from the municipal government for a low price of 0.5 pesos/m^3 (1 US $ in 2012 = 13.147 Mexican pesos) of water. Telmex saves an estimated $ 2 million per year by using wastewater rather than electricity for the air cooling system. The municipality saves 200 m^3/day of potable water, which is a notable volume in this arid region of Mexico (Otoo and Drechsel 2015).

Coupling wastewater treatment with algal biofuel production has been evaluated in several studies (Lundquist et al. 2010; Clarens et al. 2010). Other emerging processes include the incineration of bio-solids in wastewater into heat energy (Stillwell et al. 2010), converting solids to synthetic gas or bio-fuels (Domingues et al. 2006, 2008), and using microbial fuel cells to generate electricity (Zhuwei et al. 2007) from organic matter.

Table 12.2 Energy recovery from wastewater business cases. (Source: Based on Otoo and Drechsel 2015)

Business case	Start-up year	Business concept	Products/ services and beneficiary	Organization type	Scale and key figures	Drivers and opportunities	Challenges	Key to success
Okhla Treatment Plant, New Delhi, India	Built 1937, expansion in 2011	Government funded social business model to treat wastewater from New Delhi	Biogas for on-site use; treated wastewater for irrigation; compost to farmers	Public	60 % of plant energy is met from biogas, 5400 m^3 of biogas, 600 kW of power generation, installed power generation capacity of 1.5 MW	Reduce pollution and increase food production	Threat that government funding might shift to other projects	Ideal setting for placing a number of WWTPs
As Samra Treatment Plant, Amman, Jordan	Built 1985, expansion in 2008	Treat wastewater from Amman city on a Build Own Transfer (BOT) model	Hydropower from influent and effluent and biogas for on-site energy use; treated wastewater for irrigation	Public private partnership	Biogas—two gas holders each of 5000 m^3, 3 MW of hydroelectricity, 90 % self-sufficient in energy	Water scarcity, demand for treated wastewater in agriculture, target to achieve energy self-sufficiency	High capital investment, operational and maintenance costs, large land requirement; technological barriers	Strong partnerships, institutional support, favorable elevation difference to generate hydropower
Thailand Biogas Energy Company	2003	Treat effluent generated from agro-industries on a BOOT model	Electricity generation from biogas to national grid	Private	Generates 1.4 MW from biogas	Environmental conservation	Getting license to sell power	Strong partnerships

Table 12.2 (continued)

Business case	Start-up year	Business concept	Products/ services and beneficiary	Organization type	Scale and key figures	Drivers and opportunities	Challenges	Key to success
St. Martin Treatment Plant, Mauritius	2005	Treat wastewater from Plaines Wilhems region	Biogas for on-site use; treated wastewater for sugar cane farming	Public Private Partnership	Generates 25 % of its electricity requirement from biogas	Scarce water for irrigation, reduction of pollution from sugar plantations entering coast	Water pollution issues	Clear water rights; scarcity of water for irrigation; Clean, green image for society and tourism
Nyongara Slaughter House, Nairobi, Kenya	2011	Process meat, treat effluent and waste generated during meat processing	Biogas for on-site use, households, other slaughter house units; compost	Private	25 m^3 biogas, 10 KVA electricity	Reduce pollution to meet local environmental norms	Cost of gas deliveries	Participation by other slaughter house units
Aqwise, Mexico	2012	Patented system to treat raw sewage supply and filter it for use in cooling a large Telmex data center	Cooling system (air conditioning units) for Telmex data center	Private	350 m^3/day of wastewater treated	High cost of common data cooling systems such as electricity or potable water based systems	Prices of raw sewage fluctuates by municipality	Proximity of data center to sewage drainage system; low price of raw sewage

12.3.2 Fecal Sludge to Energy Business Cases

Recently, a number of initiatives for energy recovery from fecal sludge have emerged in several sub-Saharan African cities, Southeast Asia, and Latin America. The objective of these initiatives is to improve sanitation and find a business-orientated solution to sanitation problems that create economic incentives for the public and private sector institutions to invest in sanitation and to generate income for private operators. Total Sanitation and Hygiene Access (TOSHA), a bio-centre managed by a community based organization (CBO) in Kenya is one such initiative (Table 12.3). The bio-centre project was initiated in 2004 and thus far there are 52 bio-centres in Nairobi informal settlements.

TOSHA 1 is one of the bio-centres within the informal settlements of Kibera. The bio-centre is a multi-purpose facility consisting of toilet facilities, a bio-digester, a rental space and a meeting hall. The facility is designed to improve access to sanitation services, while providing affordable and clean energy sources and other income generating opportunities for the urban poor. It is used by an average of 1000 people per day, making it one of Nairobi's busiest toilets (Otoo and Drechsel 2015). The biogas produced at TOSHA 1 is used either within the toilet complex and thus saves on operational costs or it is sold to community or other productive end uses. Using a pay-for-use revenue model, the bio-centre currently makes an average net income of about US $ 1100 per month (Otoo and Drechsel 2015). The Trust which initiated the bio-centres offers technical support and builds capacity of the members of TOSHA 1 to run the bio-centre successfully.

Another case example of a business-oriented solution to sanitation with energy recovery from fecal sludge is the Sulabh public toilet complex with biogas plant in India. Sulabh is a pioneering organization in biogas generation from public toilet complexes. Based on the "Sulabh Model" it has thus far installed 200 biogas plants with a digester capacity of 35–60 m^3 in different states of India. It implements a build operate and transfer (BOT) model for public toilets. For the construction of the public toilets, Sulabh is approached by the municipality or other local government agencies and private sponsors to build a public toilet in a specific location. The sponsoring agency is responsible for capital expenditures, while Sulabh takes care of the operational and maintenance expenditure. Sulabh charges a consultation fee of 20% of the project cost, which is the primary source of income that covers the overhead and administrative costs (Otoo and Drechsel 2015). Sulabh has thus far installed more than 1.2 million household toilets, over 7500 public pay-and-use toilet complexes, and 200 public toilets with biogas systems in several states of India.

Biogas production from human waste provides opportunities in the domestic, institutional, commercial and industrial sectors for cooking, power generation, and lighting. Energy recovery from fecal sludge through the installation of biogas systems has been a success in institutions such as schools, hospitals, and prisons. Good examples include the Rwanda, Nepal and Philippines prison biogas systems which aim at reducing prison costs, reducing wastewater pollution and improving prisoner's lives through the installation of biogas systems. These systems were installed

Table 12.3 Energy recovery from fecal sludge business cases. (Source: Based on Otoo and Drechsel (2015)

Business case	Start-up year	Business concept	Products/ services	Organization type	Scale and key figures	Drivers and opportunities	Beneficiary	Challenges	Key to success
Sulabh, India	1970	A pay-and-use public toilet with a biogas system; implements build operate and transfer (BOT) model	Biogas for heat, sanitation service, compost	NGO	Community. Constructed 200 public toilets with biogas systems; Capacity 35–60 m^3	Lack of access to affordable basic sanitation facilities	Access to affordable sanitation to communities		Low-cost technology; partnership with local governments, local authorities, international organizations and local communities
Rwanda prison biogas plants, Rwanda	2001	Cost recovery in institutions through installation of a large scale bio-digester	Biogas for cooking and nutrient	Public	Communities of prison (5000 inmates)	Health hazard for surrounding communities from sewage disposal from prisons, deforestation due to high demand for fuelwood for cooking	Reduction in prison costs, reduce use of fuelwood for cooking, better living conditions for detainees	Over dependent on one technology provider, absence of installation manuals	Partnership with local expertise, provision of technical and business training to local residents including prisoners
TOSHA 1, Kenya	2004	A bio-centre with a multiple-stream revenues from toilet facilities, a bio-digester, and rental space	Biogas for cooking, sanitation service, rental space, compost	Community based organization (CBO)	Community. 54 m^3 biogas, 1000 toilet users/day	Lack of access to affordable basic sanitation facilities in urban areas; high and rising cost of fuel	Livelihood and jobs to the members of the CBO, street food vendors, farmers, private businesses	No market for bioslurry	Community-lead strategy with support from other entities (NGO, national entities); proper construction of bio-digester

Table 12.3 (continued)

Business case	Start-up year	Business concept	Products/ services	Organization type	Scale and key figures	Drivers and opportunities	Beneficiary	Challenges	Key to success
Nepal district jail biogas plants, Nepal	2008	Cost recovery in institutions through installation of a bio-digester	Biogas for cooking and nutrient	Public	Communities of prison (100–270 inmates)	Poor sanitation conditions	Reduction in prison costs, reduce health risk of detainees, reduce wastewater pollution	Stigma against use of bio-slurry as a fertilizer	Partnership with local expertise and technical institutes
Philippines Prison biogas plants, Philippines	2009	Cost recovery in institutions through the installation of a bio-digester, and setting-up of a new inmate-run bakery fuelled in part by the biogas	Biogas for cooking and nutrient	Public	Communities of prison (1000 inmates)	Ban on the use of firewood for cooking in prisons; Poor sanitation, inappropriate treatment of waste, high cost of cooking fuel	Reduce prison costs, reduce wastewater pollution, improve prisoner's lives		Partnership with local expertise. Ban of the use of firewood for cooking in prisons by Bureau of Jail Management and Penology

through partnerships between different local and international institutions. Partners include Kigali Institute of Science and Technology (KIST) in Rwanda, Biogas Sector Partnership Nepal (BSP-N) in Nepal and Practical Action consulting in Philippines. In Rwanda, dissemination of large-scale biogas digesters to prisons to treat toilet wastes and generate biogas for cooking has registered significant success. The initiative by KIST won the Ashden Award for Sustainable Energy in 2005. The first prison biogas digester became operational in 2001 and currently KIST has installed biogas digesters in almost half of the 30 prisons in the country. The Ministry of Internal Security purchases the biogas plants for the prisons.

Biogas systems are installed in several prisons in the Philippines. In the jail within the City of Cagayan de Oro, in addition to reducing costs to the prison by reducing the need for the purchase of cooking fuel, the biogas systems empower the lives of the prisoners by engaging them in a new inmate-run bakery that is fuelled in part by the biogas (ICRC 2011). In Nepal, in collaboration with the local expert partner, Biogas Sector Partnership Nepal, five biogas systems were installed in three district jails. An important factor for the success of the initiative is that local residents, including prisoners, have received technical and business training.

12.3.3 Upgrading Biogas to Biomethane

In sections 12.3.1 and 12.3.2, in the cases described, biogas is a common factor for energy recovery and the cases highlight commercial production of biogas from sewage sludge and fecal sludge through the process of anaerobic digestion. In general, biogas can be classified into two types: (a) raw biogas which has often around 60% methane and 30% Carbon dioxide, with trace components of Hydrogen Sulfide and moisture, and (b) upgraded biogas which has more than 90% methane and comparable to natural gas. Upgrading biogas to biomethane involves the process of removal of Carbon dioxide, Hydrogen Sulfide and other possible pollutants from the biogas. Removal of Carbon dioxide increases methane concentration and therefore increase in the calorific value of upgraded biogas.

Most often biogas is combusted on-site either in a gas engine or as a fuel in a stove for cooking and boiler to generate heat and/or electricity. The upgraded biogas can be directly injected into a natural gas grid/pipeline and/or directly used as a vehicular fuel. Raw biogas due to its low percentage of methane content is not ideal for use as a vehicle fuel apart from local on-site use (e.g. farm tractors), and it is also not suitable for direct injection into natural gas pipeline. Hydrogen sulfide in biogas produce sulfuric acid which corrodes the inside of pipes, fittings etc. Upgrading biogas is increasingly gaining popularity on both economic and environmental grounds. In regions, where there are no existing natural gas pipelines, distribution of upgraded biogas through dedicated pipelines can be impractical. Upgraded biogas can be compressed and bottled so as to facilitate ease of storage and transportation (Krich et al. 2005).

Table 12.4 List of biogas upgrading plants at wastewater treatment. (Source: PURAC Puregas 2013; VALORGAS 2011)

City, Country	Technology	Plant capacity Nm^3/h of biogas input	Operating since	Utilization
Ulricehamn Sweden	PSA	20	2003	Vehicle fuel
Zalaegerszeg, Hungary	Water scrubber	50	2010	Natural gas grid, Vehicle fuel
Gothenburg, Sweden	Chemical Aasorption	1600	2006	Natural gas grid
Oslo, Norway	Chemical adsorption	750	2010	Vehicle fuel, local biomethane grid
Karlstad, Sweden	Chemical adsorption	200	2010	Vehicle fuel, local biomethane grid
Asten, Austria	Water scrubber	500[a]	2009	Gas grid

[a] Total annual production of raw gas is 4.4 million m^3

In Europe—Germany, Austria, Denmark, France, Sweden, Switzerland and the Netherlands are the leading countries that upgrade biogas for vehicle fuel or grid injection. Table 12.4 provides examples of the wastewater plants in Europe that are generating biogas from sewage sludge and are coupled with biogas upgrading plant. Several cities in Europe use biomethane as fuel for buses in the public transportation system. However in the developing countries, despite huge potential for biogas, upgrading and bottling of biogas are being carried out as research projects. The Ministry of New and Renewable Energy (MNRE) in India has sanctioned central financial assistance up to 50% of the cost (excluding land) for 14 bottling biogas for demonstration purpose. Some of these plants have been commissioned and are operating in an entrepreneurial mode (MNRE 2014). None of these demonstration or commercial plants are targeted for biogas generated from feedstock—sewage sludge and fecal sludge. Upgraded biogas for grid injection and vehicle use requires composition and quality similar to that of natural gas. There is no international standard on quality either for grid injection or vehicle use. Several European countries (Austria, Denmark, Germany, the Netherlands, Sweden and Switzerland) have defined national standards and have developed regulations on the use of biomethane for vehicle fuel or grid injection, however, these standards vary from country to country and also differ according to the end use (VALORGAS 2011).

In Europe, commercially there are five biogas upgrading technologies used—chemical absorption, pressure water scrubbing, pressure swing adsorption (PSA), cryogenic process and membrane separation (VALORGAS 2013). High pressure water scrubbing and pressure swing absorption are considered to be most appropriate at a small scale due to their low cost, easy maintenance, high purity and yield (Kapdi et al. 2005). Most upgrading plants in Europe are focused on large-scale biogas production sites, and are optimised for maximum methane and energy efficiency.

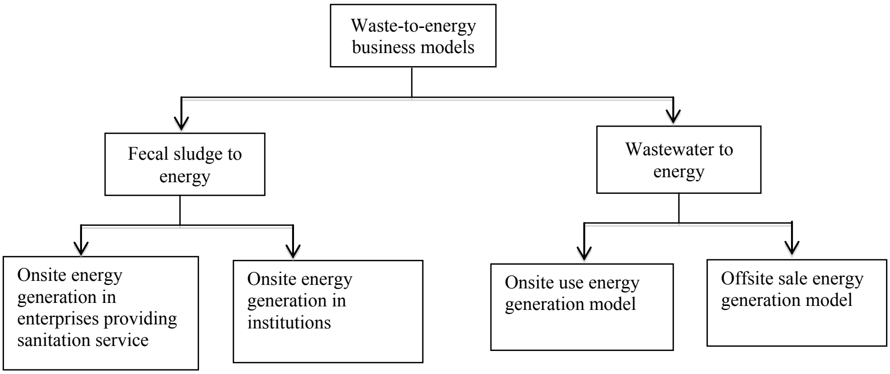

Fig. 12.1 Simplified typology for sewage and septage based business models for energy recovery (see Otoo and Drechsel, 2015); without consideration of fecal sludge based off-site dry fuel production

12.4 Typology of Business Models

The typical business concept employed in wastewater treatment in developing countries is that the utility treats sewerage generated from the city or effluent generated by agro-industrial units to produce value added products, high quality treated wastewater for use in agriculture, biogas production to generate electricity or heat and dried sludge as fertilizer. In the case of recovering energy from fecal sludge, the business concept is cost recovery through the installation of biogas systems, while simultaneously improving waste management and reducing environmental and health risks.

12.4.1 Wastewater to Energy Business Models

The energy component in the examples described above is from generation of biogas, which is used as fuel for electricity generation and for thermal energy; except in the case of the As-Samra wastewater treatment plant, which also harnesses hydraulic energy. The typology of business model (Fig. 12.1) is based on the value proposition along the waste value chain and the end use of the energy generated. The examples in Table 12.2 can be broadly classified into two key business models, (a) energy generation for on-site use and (b) energy generation for off-site sale.

Onsite use Energy Generation Business Model In the onsite use energy generation business model, the energy generating unit is set up by the utility primarily for its own internal needs. Most of the examples mentioned in Table 12.2 fit under this model—the As Samra treatment plant in Amman, Jordan, Okhla treatment plant in New Delhi, India, and St. Martin in Mauritius. In each of these cases, biogas is produced in anaerobic digesters during the process of sludge stabilization. Biogas is used to power gas engines, generating electricity that is mainly consumed onsite for the operation of aeration tanks (approximately 70 % of the total energy consumption). Moreover, the thermal energy from the biogas can be used for prior sludge heating and during anaerobic digestion. These utilities reduce their energy needs for operating the treatment plant and hence reduce their operation and maintenance costs, otherwise incurred due to the purchase of electricity from an external source.

Offsite Sale Energy Generation Business Model In the offsite sale energy generation business model, the energy generated during the treatment of wastewater is sold to the electricity grid or to the households in the neighboring areas. The business model employs either a Build-Own-Operate-Transfer (BOOT) structure or a service provision structure to deliver energy to its end consumers. In the BOOT structure, the waste generating entity or the utility partnering with a private entity is responsible for treating the effluent. The private entity invests in the capital infrastructure for treating the effluent and operates the facility for an agreed fixed number of years; the facility is transferred to the waste generating entity or the utility at the end of the term. For instance, Thailand Biogas Energy Company (TBEC) is a private entity and uses BOOT structure to partner with agro-industries processing palm oil and cassava. TBEC invests in the technology to treat the effluent and the electricity generated from biogas is sold to the national electricity grid. In the case of service provision, the energy is sold to either households or enterprises for their energy requirement. The proprietor of the Nyongara biogas plant plans to expand its operations to treat the waste generated from other slaughter house units and sell the energy to the units and to nearby households. Okhla treatment plant supplied the biogas to 4000 households near the plant. However, due to the deterioration of gas distribution infrastructure, the gas supply for domestic use was stopped in 2008–2009.

12.4.2 Fecal Sludge to Energy Business Models

Energy recovery from fecal sludge in developing countries is predominantly driven by the need to find a business-orientated solution to sanitation and waste disposal. There are essentially two business models: (a) onsite energy generation in enterprises providing sanitation service and (b) onsite energy generation in institutions.

Onsite Energy Generation in Enterprises Providing Sanitation Service The primary objective of the business is to improve access to sanitation services to low-income settlements, while providing affordable and clean energy sources. The business generates revenue mainly from the sanitation service fees by applying a pay-and-use model. The biogas generated can be used onsite for internal consumption, thus reducing operational costs, or the energy can be sold to other users as cooking fuel. TOSHA 1 and Sulabh fit in this business model. The slurry produced after digestion can be used directly as fertilizer, but low demand and social taboo is often a concern.

Onsite Energy Generation in Institutions This business model can be applied in schools, hospitals and other institutions with many residents. The objective is to improve sanitation in the respective institutions, reduce costs, and reduce wastewater pollution through the installation of biogas systems. The prison biogas systems (Table 12.3) are good examples of a model for government to achieve cost reductions.

12.5 Economics of Wastewater to Energy Business Models

The economics of water reuse for energy is directly linked to the energy consumption of WWTPs, as treatment is energy intensive and it varies with the type of treatment process applied. Collecting, treating, and disposing of wastewater to acceptable standards requires energy (Stillwell et al. 2010). However, wastewater can be used to generate energy, which results in energy cost savings.

12.5.1 Energy for Wastewater Treatment

There are typically three levels of treatment; primary, secondary and tertiary. Primary treatment consists of solids removal through sedimentation which is followed by secondary treatment to remove organic matter and remaining suspended solids through biological treatment. Activated sludge, which relies on aerobic microorganisms to digest and mineralize organic matter, is the most commonly used in WWTP (Stillwell et al. 2010). The energy required per volume of wastewater treated varies with the capacity of wastewater treatment plants (Table 12.5). Large treatment plants require half the electricity requirement of smaller facilities, per unit of water treated. The energy costs and associated diseconomies of scale pose challenges to providing low cost systems to suit the needs of smaller communities.

Table 12.5 Energy consumption for wastewater treatment by type of treatment and size of plant. (Source: EPRI 2002)

Wastewater treatment plant capacity (m^3/day)	Electricity consumption (kwh/m^3)			
	Trickling filter	Activated sludge	Advanced wastewater treatment	Advanced wastewater treatment with nitrification
3,785	0.479	0.591	0.686	0.789
18,925	0.258	0.362	0.416	0.509
37,850	0.225	0.318	0.372	0.473
75,700	0.198	0.294	0.344	0.443
189,250	0.182	0.278	0.321	0.423
378,500	0.177	0.272	0.314	0.412

Table 12.6 Theoretical energy potential of wastewater (assumptions: water consumption 122 liters/capita/day, flow rate 5 m/s, altitude 50 m, greywater 40 L/capita/day, and 115 g COD/capita/day). (Source: IWA 2012)

Type of energy	Energy content in kwh/capita/year
Potential energy	6
Kinetic energy	0.2
Thermal energy	509
Chemical bound energy	146

12.5.2 Energy Recovery Potential from Wastewater

The theoretical energy potential from wastewater is based on the assumptions that water consumption is 122 liters/capita/day, with a flow rate of 5 m/s, at an altitude of 50 m and 40 L/capita/day of greywater generation, with temperature difference of ~15 K and 115 g COD/capita/day. Based on these assumptions, the estimates of energy potential range from 0.2 kwh/capita/year of kinetic energy to 509 kwh/capita/year of thermal energy (Table 12.6). However, it is not practical to harness all the energy content in wastewater. The kinetic energy is too low to harness and the potential energy varies with geography (IWA 2012). In addition, for elevated settings, the energy required for pumping can offset considerably the net energy gained. For thermal energy, it can be harnessed through heat exchangers, however to achieve optimum recovery, the process has to take place as close to the origin of hot water. Otherwise within the sewer system, warm greywater is mixed with rain water, infiltration water and remaining wastewater, causing significantly lower temperature levels.

Among the four forms of energy in wastewater, chemical bound energy has the highest recovery potential and can be transported in the wastewater via the sewer system almost without losses (IWA 2012). The maximum theoretical chemical bound energy content is 146 kwh/capita/year and at the treatment plant, this chemical energy content present in the organic constituents are distributed throughout the process steps and are not completely available in the sewage sludge. At the treatment plant, about 55 % of the COD load is consumed by either respiration process or remains within the effluent. Taking only 55 % of the organic content in wastewater to degrade, from the 146 kwh/capita/year, about 68 kwh/capita/year is transferred to digestion unit (raw sludge). Of this, 38 kwh/capita/year results in methane generation which can be converted into electricity. Taking 32 % conversion efficiency rate, net electricity generation from the chemical bound energy in wastewater is 12 kwh/capita/year (IWA 2012).

12.5.3 Investment in Wastewater to Energy Processes

Wastewater treatment plants can significantly reduce their energy costs by harnessing the energy contained in wastewater i.e., energies from sewage flows (2–10 %), sludge (40–60 %), as well as improving energy efficiency of wastewater treatment (up to 20 % energy savings) and generating renewable energy onsite through wind and solar systems (5–10 %). These are major components of the *positive net energy-zones*, yet only some Swiss plants are net energy neutral, and two wastewater treatment plants in Austria are energy self-sufficient while still other projects are ongoing (Lazarova et al. 2013). In 2005, the 'Strass im Zillertal' Wastewater Treatment Plant near Innsbruck, Austria became the first wastewater treatment plant in the world to achieve electrical self-sufficiency and ultimately became a net energy producer. Since then many other wastewater treatment plants have become energy neutral and net energy producers as well.

The investment costs, operational and maintenance costs and the resulting energy savings achieved vary with the scale of operation (Table 12.7). The treatment capacity of the plants in Table 12.7 ranges from 4 m^3/day in the smallest case, Nyongara plant in Kenya, to large scale plants with a capacity of 530,000 m^3/day in the case of Okhla Plant in India. The energy savings in the WWTP ranges from 17 to 90 % of the energy needs of the WWTPs. For example, while Amberpet Plant achieved 17 %, St. Martin 25 % and Okhla plant 60 % energy self-sufficiency, through a combination of biogas and hydraulic energy, As-Samra is able to achieve 90 % energy self-sufficiency.

Energy generation in wastewater treatment plants offers greater opportunities for earning additional revenue from carbon credit trading as carbon credits are created by a project that reduces GHG emissions relative to a baseline scenario (Mitchell 2011). The revenue streams for As-Samra plant and Thailand Biogas Energy plant include, not only energy cost savings but also revenue from carbon credit sales (Table 12.7). The value of carbon credits depends on the amount of GHG emissions savings relative to a baseline scenario and the price of carbon credits. Since the beginning of carbon credit trading in 2005, the price of carbon credits, with each credit equal to 1 metric ton of CO_2 ranges from € 10–25 (US$ 13–33) per ton traded on the European Climate Exchange (Brohe et al. 2009).

12.6 Economics of Faecal Sludge to Energy Business: The Case of Institutional Biogas Systems

The economics of institutional biogas systems consists of investment costs, operation and maintenance costs with mostly free waste material input. Economic benefits include cost recovery from use of biogas as cooking fuel or electricity and heat for internal consumption as well as the savings on money previously spent for septic tank emptying (Amigun and von Blottnitz 2007). Other values such as the slurry produced after digestion, which can be directly used as fertilizer, can also be added. When evaluating the performance of institutional biogas systems, in addition to the technical and financial performance of the plant itself, one should take into account the cost of fuels and fertilizers under baseline scenario. Moreover, the performance of the system depends on the efficiencies with which the fuels are currently being used before the biogas system is installed (Amigun and von Blottnitz 2007).

Table 12.7 Capital investment, operation and maintenance (O & M) cost of wastewater-to-energy cases from developing countries. (Source: Based on Otoo and Drechsel 2015)

Business case name	Year	Technology	Capacity (m^3/day)	Total capital investment (million US$)	O & M cost	Energy generated or savings achieved	Revenue streams
Okhla Plant, India	2011	Activated sludge process	530,000	9.86	2 million US$/year	60 % energy self-sufficient; installed capacity of 1.5 MW	Energy cost savings; sales of treated wastewater for irrigation
As-Samra, Jordan	2008	Hydraulic and Anaerobic digestion	267,000	223.00	3.9 US$/$m^3$	90 % energy self-sufficient; Biogas, two gas holders of 5000 m^3; 3 MW of hydroelectricity	Energy cost savings; sales of treated wastewater for irrigation; revenue from certified carbon credits
Thailand Biogas Energy Company	2003	Covered Lagoon Bio-Reactor	150,000	3.10–3.70	–	Installed capacity of 1.4 MW	Sales of electricity; revenue from certified carbon credits
St. Martin, Plaines Wilhelms, Mauritius	2005	Activated sludge process	69,000	198.56	2 million US$/year	25 % energy self-sufficient	Energy cost savings; sale of treated wastewater for irrigation
Nyongara Biogas Plant, Kenya	2011	Anaerobic digestion	4	0.035–0.06	–	25 m^3 biogas; 10 KVA electricity	Energy cost savings; sale of energy service to households
Aqwise, Mexico	2012	Attached Growth Airlift Reactor	350.00	0.78	66,000 US$/year	–	Energy cost savings
Amberpet Plant, Hyderabad, Andhra Pradesh	2007	Up flow Anaerobic Sludge Blanket	339,000	10.1	3.51 million US$/year	17 % energy self-sufficient; 4.3 mega units generated annually	Energy cost savings

An assessment on the performance of institutional biogas plants in Rwanda by the KIST showed that the application of biogas at institutional level has resulted in significant reduction in cost of energy as biogas cook stoves at institutional level are running on gas generated from human waste. Savings in wood fuel energy realized from applying biogas technology have been on average 40 % (KIST 2006). Similarly the study on Nepal prison biogas systems by Lohri et al. (2010) reported that cost savings from replacing conventional cooking fuel ranged between 17 and 41 %.

Table 12.8 shows capacity of biogas plants, the investment cost and the resulting savings from cooking fuel and savings from septic tank emptying for institutional biogas plants in prisons of Rwanda, Philippines and Nepal. The data contained in Table 12.8 were compiled from various studies (Gauthier et al. 2011; ICRC 2011; Lohri et al. 2010; Munyehirwe and Kabanda 2008; KIST 2006; Butare and Kimaro 2002). Most of the digesters are of a fixed dome type with an estimated useful life of 20–30 years. The capacity of the digesters in the case of Rwanda prisons varied between 200 m^3 in the smallest installation, to more than 1000 m^3 in the largest plants, while the largest plants in Nepal have a capacity of 35 m^3 and in the Philippines, 25 m^3.

The investment costs depend on the size of the digester and include cost of raw materials needed for the construction of a biogas system such as the digester, stoves, pipes and other accessories. The original cost data were converted from local currency to US$ at the rate applicable in the year of construction which range from 2002 to 2008 in the case of Rwanda with the majority of the plants installed in 2005 and 2008. Majority of the plants in Nepal and Philippines were installed in 2008. As the costs reflect data from different years and locations, to account for inflation, costs for the Rwanda plants were adjusted to the same base year of 2008 using Consumer Price Index (CPI) published by the National Bank of Rwanda. Average investment cost per unit was US$ 285 in Rwanda, US$ 201 in Nepal and US$ 230 in Philippines. Annual operating and maintenance cost is assumed to be 2 % of total installation cost. The digesters are set up with the objective to treat toilet wastes at the prisons and, in the process, generate biogas for cooking, which reduces the need for cooking fuel and septic tank emptying. Annual savings from cooking fuel, per unit of capacity, is US$ 17 in Rwanda and US$ 29 in Nepal. The estimated savings from cooking fuel vary with the type of cooking stoves used, the type of cooking fuel previously used in the institution, and the efficiency with which the biogas is used.

Economies of Scale for Institutional Biogas Plants Studying the relation between capital costs and plant capacity of existing institutional biogas plants provides insights into whether increased opportunities for growth will allow cost reduction to be achieved (Wibowo and Wuryanti 2007). In theory, individual firms in any industry can achieve economies of scale which are associated with firm size. The variation of capital investment cost with plant capacity is used to assess whether capital cost increases more or less than proportionately with plant capacity. That is, firms realize economies of scale if technology allows capacity costs to increase less than proportionately with plant capacity. Conversely, if capacity cost increases more than proportionately with plant capacity, diseconomies of scale are present.

Table 12.8 Overview of institutional biogas plants in Rwanda, Nepal and Philippines. (Source: IWMI,, based on Gauthier et al. 2011; ICRC 2011; Lohri et al. 2010; Munyehirwe and Kabanda 2008; KIST 2006; Butare and Kimaro 2002)

Item	Rwanda ($n=12$)		Nepal ($n=5$)		Philippines ($n=5$)	
	Mean	SD	Mean	SD	Mean	SD
Size of digester (m^3)	654	350	17	11	16	8
Investment cost ($/$m^3$)[a]	365	178	201	29	230	0
O & M cost ($/year)	4309	2440	105	57	75	35
Savings from cooking fuel ($/$m^3$/year)	17	11	29	20	–	–
Savings from septic tank emptying ($/$m^3$/year)	–	–	9	9	–	–
Saving in fuel wood (ton/year)	29	28	8	3	14	5

[a] Costs adjusted to base year of 2008

Thus, understanding the relation between capital costs and plant capacity is important in determining the optimal plant capacity.

Taking the institutional biogas plants in prisons of Rwanda, the capacity cost factor method is used to assess the relation between capital costs and plant capacity. The empirical relationship between capital investment and plant capacity is given by (Amigun and von Blottnitz 2007, 2010):

$$\frac{C_1}{C_2} = \left(\frac{Q_1}{Q_2}\right)^n$$

Where C_1 is the investment cost at a capacity Q_1 and C_2 is the estimated investment cost of a new plant at a capacity Q_2, n is the cost capacity factor. This can also be written as $C=kQ^n$. The coefficient n depends on the type of industry. In petrochemical industries, for example, n is normally taken as 0.6 and hence it is called the six-tenth factor rule (Wibowo and Wuryanti 2007). Economies of scale exist where the capacity factor value is less one $(n<1)$, indicating that capital investment costs per unit of capacity decrease with an increase in plant capacity, while a value of $n>1$ depicts diseconomies of scale. A value of $n=1$, indicates a constant return to scale and capital costs increase proportionately with plant size. The objective in this exercise is to determine the coefficient n that holds for institutional biogas plants in Rwanda.

Table 12.9 shows the plant size, the year of construction and the cost data for biogas plants in prisons of Rwanda. The data were compiled from various studies (Gauthier et al. 2011; Munyehirwe and Kabanda 2008; KIST 2006; Butare and Kimaro 2002). The original data were converted from local currency to US$ at the rate applicable in the year of construction and also adjusted to base year of 2008 to account for inflation using Consumer Price Index (CPI) published by the National Bank of Rwanda. In order to improve the relationship between the investment cost and the plant size, their values are transformed by taking the natural logarithm of their values.

Table 12.9 Total investment cost and capacity of biogas plants in prisons of Rwanda. (Source: Gauthier et al. 2011; Munyehirwe and Kabanda 2008; KIST 2006; Butare and Kimaro 2002)

Name of prison	Year built	Size of digester (m^3)	Original Investment cost (US$)	Normalized cost to base year 2008 (US$)
Cyangugu	2002	600	261,565	489,568
Nyagatare	2004	200	74,432	111,224
Gitarama	2005	1250	210,653	288,510
Rilima	2005	800	180,010	246,541
Kabutare I	2005	600	145,122	198,758
Kabutare II	2008	300	89,552	89,552
Mpanga	2006	1000	292,788	368,593
Remera	2006	700	77,292	97,303
Gikongoro	2007	300	112,994	130,455
Muhanga	2008	500	150,000	150,000
Nsinda	2008	1200	263,246	263,246
Miyove	2008	400	151,640	151,640

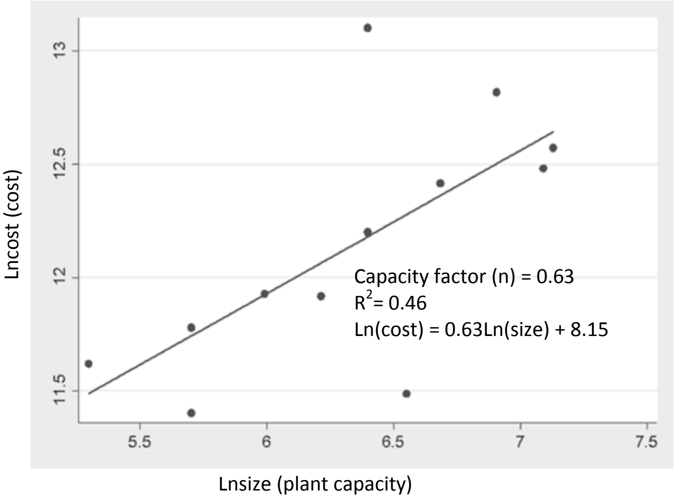

Fig. 12.2 Investment cost and capacity factor for institutional biogas plants in Rwanda. (Source: IWMI, based on Gauthier et al. 2011; Munyehirwe and Kabanda 2008; KIST 2006; Butare and Kimaro 2002)

Figure 12.2 shows the investment cost versus plant capacity on a log-log scale using least square method. The cost capacity factor, *n* for the institutional biogas installations in Fig. 12.2 is 0.63 indicating that a 1 % increase in plant size increases capital cost by 0.63 %. This means capital cost increase less than proportionately with plant capacity and thus economies of scale exist in these plants. This is contrary to studies by Amigun and von Blottnitz (2007, 2010) in which a cost capacity factor of 1.20 for small and institutional scale biogas industry in Africa has been obtained on the basis of an analysis of 21 projects across eight countries. The strength of the relationship between the capital cost and plant capacity can be assessed by looking at the value of the coefficient of determination (R^2). The value of the coefficient is 0.46, which is rather low indicating that 46 % of the variation in the capital investment cost is explained by the variation in plant capacity.

Understanding the relation between cost and capacity of existing institutional biogas systems provides useful insights into the particular characteristics of the biogas systems and provides simple equations for preliminary cost estimations needed in investment decision making.

12.7 Economics of Upgrading Biogas to Biomethane

The cost of upgrading biogas to biomethane is a critical factor in commercialization of the technology as the price of biomethane has to be competitive with competing fuels. The production costs depend not only on the technology cost but also on cost of transport of feedstock to generate raw biogas and the cost of delivery of gas to its end use application. In addition to these, local conditions vary, and it can be a significant factor for the production cost. For different feedstock used for production of biogas, sewage sludge has the lowest production cost as it usually takes place at an existing wastewater treatment plant, where digesters already exist (VALORGAS 2011). The primary cost is towards the investment for upgrading biogas to biomethane plant.

The upgrading cost depends on the plant size with small-scale units having lower cost than larger. However, for small scale plants (< 100 Nm^3/h of raw biogas), it is not feasible to upgrade raw biogas to a quality to either inject it directly into natural gas grid or as commercial fuel at a gas station. At current pricing of competing fuels with biomethane, small scale plants do not have the economies of scale to produce biomethane at competitive price point and simultaneously control for quality and cost incurred in gas transportation to nearest end use commercial application. There is scope for viability from local application within small community or farms. Small-scale biogas upgrading can be made economically viable by reducing the main costs of upgrading (electricity and water costs), upgrading at low temperature (15–20 °C), use of low cost high pressure storage containers, and compressing to high pressures (250–270 bars) so as to reduce the electricity costs at filling station (VALORGAS 2011).

According to Linné and Jönsson (2004), in Stockholm, the cost for production of biogas from sewage sludge for vehicle use (upgraded and pressurized), excluding value added tax (VAT) comes to about 0.22–0.48 € Nm^{-3}. In a report by Swedish Gas Centre in 2003, economic and technical performance of 11 of the Swedish upgrading plants with longest operation experience concluded that for small-scale units (< 100 Nm^3/h of raw biogas), upgrading costs are between 0.03–0.04 € kWh^{-1} upgraded gas (NSCA 2006). A study done by SevernWye Energy Agency under the Bio-methane Regions project (2012), assessed upgrading of biogas plant at wastewater treatment facility in Zalaegerszeg, Hungary. According to this study the total capital of the upgrading facility was estimated at 600,000–700,000 € with annual operation cost at 25,000 €. The Swedish Gas Centres report also concluded that upgrading plants in the range of 200–300 Nm^3 h^{-1} of raw biogas have costs of 0.01–0.016 € kWh^{-1} of upgraded gas (NSCA 2006). In addition, the electricity demand for upgrading corresponds to 3–6 % of the energy content in the upgraded biogas (NSCA 2006).

An example of the upgrading experience in North America in wastewater treatment plant in the case of Greenlane Biogas, a subsidiary of the Flotech Group of companies. Greenlane biogas uses water scrubbing process for the Woodward wastewater treatment plant, located in Hamilton, Ontario, Canada to purify raw biogas and inject it into the gas grid. The plant installed capacity is 10,000 Nm^3/day of raw biogas to biomethane. Greelane Biogas has installations in wastewater treatment plants in France, Japan and Sweden. The facility in Ontario has total investment cost of about USD 4 million which includes equipment, engineering, site preparation, installation and transfer station of biomethane to the Union gas grid. Annual operation and maintenance cost is just under US$ 150,000. The Ontario wastewater treatment plant also continues to generate power and recover heat from its CHP facility where its annual operation and maintenance cost is about US$ 337,000 (Gorrie 2012).

Experience in Asia on upgrading is limited with most cases are either demonstration or research oriented. A significant research has been carried out on the application of upgraded biogas as vehicle fuel. For example: in Thailand, a study conducted on the use of bottled biogas in a Liquefied Petroleum Gas (LPG) cylinder to run a motorcycle found that using upgraded biogas can save energy cost € 0.08/km more than that of gasoline. According to this study a motorcycle modified with biogas engine kit costs about € 540 and if used for about 50 km/day, it has a payback period of 2.5 years (VALORGAS 2012). Another research conducted in Korea on the feasibility of using upgraded biogas as a vehicle fuel produced from food waste water revealed that the price of the upgraded biogas can be 60–80 % more profitable than electricity generation with the current feed-in-tariff system (VALORGAS 2012).

Upgrading biogas to biomethane offers new business models in addition to the business models described under 12.4.1 and 12.4.2. These wastewater and fecal sludge based business models are already generating biogas and they can make additional investment for upgrading plants to purify raw biogas. The purified biogas can be directly injected into natural gas grid, sold to gas stations or it can be bottled and sold to households as fuel for cooking and to energy intensive businesses.

12.8 Conclusion and Discussion

Recovering energy from wastewater and fecal sludge requires consideration of a number of technical and non-technical aspects including policy and institutional environment, social and economic aspects, private service providers, value chain and market development, capacity building and pro-RRR regulatory framework to support public-private investments. For instance, since recovering energy from wastewater and fecal sludge involves several institutions and stakeholders, key national ministries that must be involved include ministry of water, sanitation, health, agriculture, environment, finance, economic planning, hydropower and energy, roads etc.

Most wastewater treatment plants in developing countries are operated by public sector utilities and rely on financial support from government and external donors. The wastewater treatment plant cases discussed in this chapter are primarily driven by the need for treatment to protect human and environmental health by avoiding pollution of ground and surface waters and the environment at large, whereas in the water scarce regions, the treated wastewater has high demand for irrigation in agriculture production. Energy is a critical requirement for the running of the treatment plants and it is the largest controllable cost in the operations and maintenance cost of a wastewater treatment plant. The ability to control the energy cost and achieve savings is a key motivation for the wastewater treatment cases to make the necessary capital investment to capture the biogas and generate energy. Moreover, biogas is a green energy source and it can potentially reduce greenhouse gas emissions and other air pollutants especially if it replaces fossil fuels. This nonetheless requires enabling conditions and pro-RRR policy framework. The case example is As-Samra where aside from favourable elevation difference which was an important reason for implementing an additional technology option for hydropower generation from influent and affluent flows, the government support and donor funding catalysed that investment to promote best practice. In the cases where the energy generated during the treatment of effluent is sold to external consumers, the key driving factor for success is the revenue from sale of energy to consumer and public service driven motive of the public enterprise.

There is also a need to involve private sector investors, financiers, civil society organizations and international development partners. Stakeholder engagement is the key to innovation and success. For instance, our case examples show that where partnerships are stronger, finances are guaranteed, regulations are pro-RRR, and value addition opportunities are greater, the business model works well and vice versa. Examples include:

- As-Samra and Okhala case examples of energy generation from wastewater where the overall framework is supportive and stakeholder engagement is stronger and international partners are involved.
- TOSHA, Sulbah and Prison case examples of energy from human waste where government ban on the use of firewood and regulations were a catalyst to innovation. While partnership with local expertise, capacity building, provision of technical and business training to local communities constitute important prerequisites for successful implementation of the business model and for ensuring sustainability of the business.
- Nyongara slaughter house case in Nairobi, where meat demand and using waste for other slaughter house pose challenges.

There are a number of challenges encountered by waste to energy business models for scaling up and scaling out. Recovering energy from wastewater and fecal sludge requires high investment costs and high maintenance and operation costs. Project developers and financial institutions face challenges in financing of waste to energy projects. This problem becomes more complicated in the case of waste-to-energy projects which are funded fully or partially by the government as competition among projects for limited funds could threaten their sustainability. Moreover, wastewater to energy projects require large land areas, which poses constraints, especially in heavily populated cities and with rapid urbanization. Some other challenges are:

- Wastewater treatment plants are dependent upon government or external funding to manage their capital and operational costs and any cuts in funding allocations can significantly impact their performance as in the case of Okhla plant in New Delhi. However this risk can be mitigated if treated wastewater and recovered energy have market value, enabling the entity to self-finance its operations.
- Fecal sludge based business models such as the Sulabh example and the prison biogas in Nepal experience can face social stigma against using energy from human waste used for cooking purpose.
- Social stigma are also associated with bio-slurry as fertilizer in TOSHA, Kenya, making it potentially difficult to market the product.
- Upgrading raw biogas to biomethane offers increased revenue opportunities with European case examples providing significant insight on the minimum economies of scale required to be feasible. However the challenge of regional pricing of fuels that compete with biomethane is a critical measure that dictate viability of upgrading in a specific regions and countries.

In order to scale up/out, the business models should be further supported by cutting edge research on outstanding supply-side issues, such as energy efficiency improvement programs, incentives to reduce the carbon footprint through water-energy efficiency improvements, and public-private financing models to support upscaling and uptake across communities and at a wider scale. These programs must also consider demand side measures such as community education to address social attitudes and taboos, and promote water conservation and water-use efficiency that are key strategies to generate significant mitigation benefits by reducing the energy demand of wastewater and human waste.

Take Home Messages

- Onsite energy generation from wastewater and human waste has a high potential to contribute to energy cost savings.
- The ability to control energy cost and achieve savings is a key reason for wastewater treatment plants to make the necessary capital investment for energy producing units.
- The economics of water reuse for energy vary with the energy consumption of WWTPs, design features, and end markets for energy and wastewater products.
- Managing urban water supply and demand, while reducing energy use and GHG emissions, in an urbanizing world will require fresh concepts involving both the water and energy sectors.

- Upgrading biogas to biomethane can have high applicability to developing economies under increasing fossil fuel prices if incentives are provided to help leapfrog this technology from demonstration to commercial stage.

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Chapter 13
Business Models and Economic Approaches for Nutrient Recovery from Wastewater and Fecal Sludge

Miriam Otoo, Pay Drechsel and Munir A. Hanjra

Abstract Plant nutrient recovery from wastewater and fecal sludge is high on the development agenda, driven by the need to feed the global population, the discussion around peak phosphorous, increasing fertilizer prices and stricter regulations for safeguarding the environment from pollution. With a shift in thinking from nutrient removal to nutrient recovery, new public-private partnerships are developing to capture nutrients from the waste streams for reuse in agriculture. The prospects for cost recovery from capturing phosphorous are significant, if savings in wastewater treatment and sludge disposal costs are considered, as so far the phosphate recovery costs still result in prices higher than those of phosphate rock, unless niche markets are targeted. The chapter differentiates between nutrient recovery options commonly seen in sewered and non-sewered (on-site) sanitation systems, looking at wastewater, fecal sludge, biosolids and urine. To date, nutrient recovery from wastewater is driven more by the treatment sector and its challenges or by changing regulations, rather than by market demand for alternative fertilizers.

Keywords Nutrient recovery · Fecal sludge · Phosphorus · Nitrogen · Struvite · Composting · Value proposition · Private sector · Cost recovery

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13.1 Introduction

Wastewater offers beyond water also nutrients and organic matter with a high application potential in farming and landscaping. This reuse opportunity is especially important where soils are poor and the availability of alternative inputs is constrained. There is great potential to close the nutrient loop, support a 'circular economy' and cost recovery within the wastewater sector or even to create viable businesses. Where wastewater is captured in sewer systems, extra steps are required to separate the organic fraction and/or recover particular nutrients. Where wastewater is source-separated at the point of generation, such as in urine-diverting toilets, or excreta are collected in septic tanks and not mixed with other urban wastewater, resource recovery processes can be even simpler.

Resource recovery and reuse (RRR) struggles with many technical, regulatory, perception and economic challenges, and the scale of planned resource recovery from wastewater and fecal sludge is far below its potential (Shu et al. 2006; Monteith et al. 2008; Mihelcic et al. 2011), even though the value of these resources is well recognized by their users. Many waste managers view waste as a problem, rather than a resource, and sanitation more as a public service than a business. In theory, RRR seems to be a win-win situation for waste managers and farmers, yet success stories in low- and middle-income countries often are small scale and seldom viable without significant subsidies. The sanitation-related public sector and the fertilizer oriented private sector, could play important roles in resource recovery. However, many RRR examples are driven by the private treatment sector with bias to technical solutions and with limited attention to the reuse market and its segments, to base any business plan on more than savings and a potential demand for a theoretical nutrient value. However, there are also successful examples of private and public entities engaged in nutrient recovery at different scales (Otoo et al. 2012; Otoo and Drechsel 2015). This chapter will synthesize, and document information that showcases emerging and successful RRR business options and models for cost-recovery or profit.

13.2 Driving Factors for Nutrient Recovery

Recovering water and nutrients from otherwise wasted resources is nothing new and has been practiced for generations in many countries (Smit and Nasr 1992). It is expected that RRR will gain momentum where resources for agricultural production are increasingly limited under progressing climate change, competition for clean water, diminishing global nutrient reserves and increasing fertilizer prices. These challenges are particularly evident in developing countries with lower purchasing power of individual households.

At the global level, the following three topics steer the discussion for increasing nutrient recovery from wastewater and other forms of human waste:

- **Food security**. Increasing amounts of plant nutrients will be needed to feed the expanding global population. While a century ago, food waste was locally recycled, urbanization has polarized food flows, creating centers of consumption and waste generation. Nutrient recycling is needed to prevent cities from becoming vast nutrient sinks (Otoo et al. 2012). At present, the primary goals of urban waste management include waste collection and safe disposal. Nutrient recovery and recycling often appear only as future targets. This situation must change, given that agricultural nutrient depletion is advancing with every crop harvested. In Sub-Saharan Africa, nutrient depletion accounts for more than 7 % of agricultural GDP, with continuously decreasing nutrient stocks (Drechsel et al 2004).
- **Circular economy**. In a 'circular economy' which aims at closed loops of materials and resources, wastewater treatment plants could be seen as hot spots for resource recovery (Ellen MacArthur Foundation 2012; Wallis-Lage 2013). This is of particular importance in view of non-renewable resources, like phosphorus. As large portions of our phosphate rock deposits cannot be mined efficiently at competitive costs, the discussion on when the world will reach a situation of 'peak phosphorous' and how far market prices will regulate the phosphorus supply is lively (Edixhoven et al. 2013). Agreement exists that the recovery of phosphorus is an increasingly important task, especially as in many tropical countries soils are of very low fertility and fertilizers already now too expensive.
- **Environmental regulations**. With increasing population growth, nutrients accumulate in consumption centers and contribute to pollution, wherever the coverage of waste collection and treatment is insufficient. With increasing environmental awareness and regulatory efforts 'traditional' options for wastewater and sludge treatment and disposal are transitioning toward zero-waste options that protect the resource base and support water and nutrient recovery.

13.3 Business Approaches and Economics of Nutrient Recovery

Irrigated agriculture is the largest water user, and most wastewater use occurs in farming. This includes the planned or formal use of advanced treated wastewater (GWI 2009) and the unplanned or informal use of non- or only partially treated wastewater including septage (Scott et al. 2010; Kvarnström et al. 2012). However, based on the driving factors discussed, the situation is changing. The pace is quicker in developed countries, yet we see also in low- and middle-income countries an emerging set of entrepreneurs recognizing the opportunities that RRR offers. By leveraging private capital, entrepreneurs help realize the commercial value of waste, shifting the focus from treatment for waste disposal to treatment of waste as a resource (Murray and Buckley 2010; Murray et al. 2011, EAI 2011).

13.3.1 Typology for Nutrient Recovery Business Models

As described in the previous chapters, there are many options for classifying business models, in the emerging RRR business domain (Evans et al. 2013). Isolating nutrient recovery from the basic function of wastewater treatment for safeguarding public health and the environment, and from the value proposition of reclaiming water or energy, appears artificial. However, depending on the local context, the market demands for water, fertilizer, and energy can be very different, and treatment operators might choose to pursue only markets with the highest probability of generating positive net returns or social benefits.

Business cases or models for nutrient recovery can be clustered according to their degree of (in)formality, or basic objective of operations, such as sustainable service delivery (cost recovery), profit maximization, or social responsibility. Models could also differentiate between the purposes of nutrient recovery, such as agricultural or industrial reuse, or crop or livestock farming. Other clustering options include the treatment technology and mode of financing/procurement (Box 13.1).

Box 13.1. Water Reuse Finance

The globally most popular means of procuring a wastewater treatment and reuse project is the design-build (DB) model, with 38 % of future plants where the approach has been disclosed being procured on this model (a DB project is owned and operated by the municipality). Private finance models, including build-own-operate-transfer (BOOT) and build-own-operate (BOO) represent around 33 % of future projects where the procurement method is known. Design-build-operate (DBO—where the municipality owns but does not operate the facility) represents 17 % of plants and design-bid-build (DBB), the standard model for public procurement, ownership and operation in the US, represents 13 % (GWI 2009).

To address nutrient recovery and reuse options in high- and low-income countries, including the informal sector, we distinguish between the two main waste streams; i.e., sewered and non-sewered (on-site) sanitation systems. Examples include nutrient recovery from wastewater/biosolids, septage and urine, with agriculture as the predominant end use.

Following these waste streams, the RRR value propositions beyond the fundamental one of any treatment; i.e.; safeguarding public health and the environment, are shown in the following figures. Figure 13.1 shows the principle options for nutrient recovery for sewage based systems, while Fig. 13.2 shows similar options for septage collected from on-site sanitation facilities. A third variation (Fig. 13.3) shows the case of ‘ecosan’ toilets, which separate fecal matter and urine at the point of waste generation, allowing the nutrients in urine to be reused as liquid or after dewatering as solid fertilizer crystals in the form of struvite (magnesium ammonium phosphate or MAP).

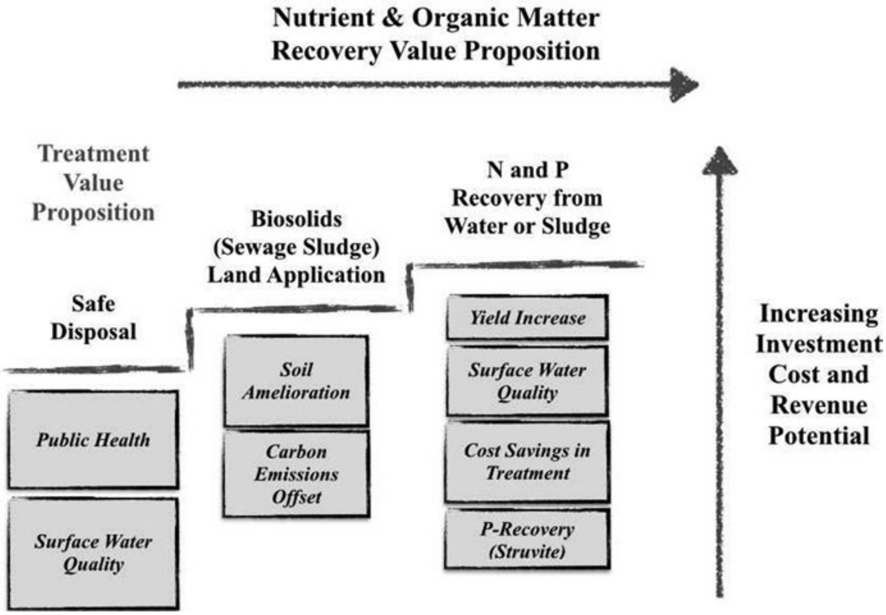

Fig. 13.1 Value propositions for nutrient and organic matter recovery and reuse from sewage

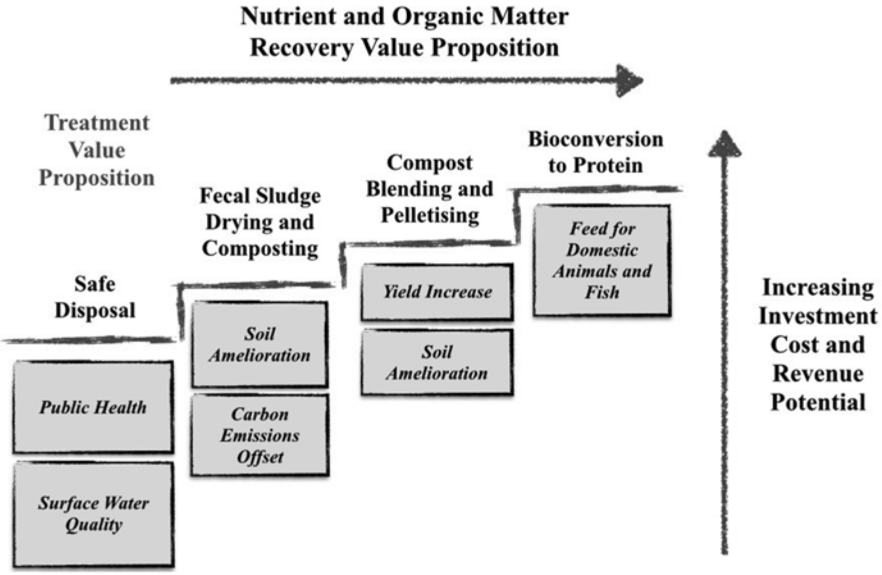

Fig. 13.2 Value propositions for nutrient and organic matter recovery and reuse from septage

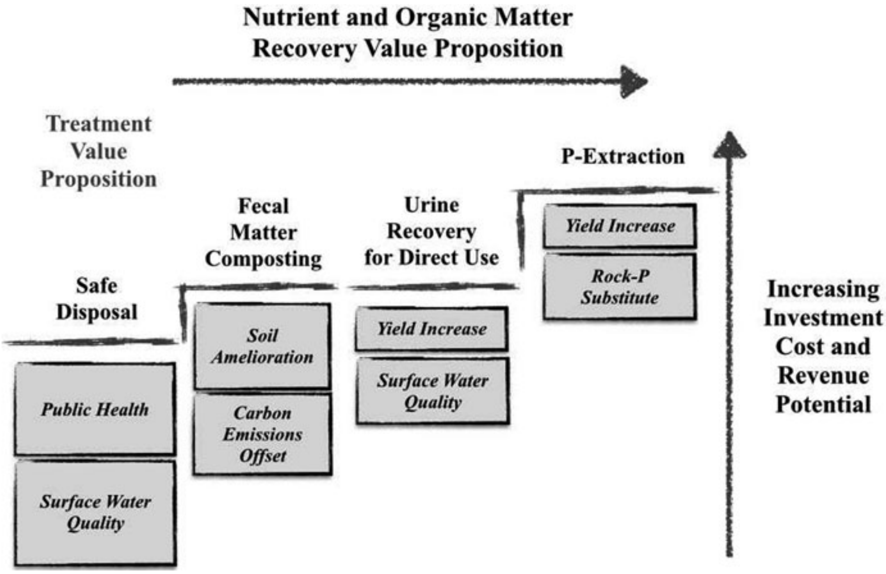

Fig. 13.3 Value propositions for nutrient and organic matter recovery and reuse from Urine Diverting Dry Toilets (UDDT)

13.3.2 Wastewater from Sewered Systems as a Nutrient Source

The conventional view of wastewater as a public and environmental health concern results in the linear model where large amounts of energy and chemicals are utilized to ensure that wastewater is effectively treated and/or transformed into products which meet stringent human health and environmental standards before they are released back to the environment (WERF 2010).

Where such treatment is in place, and contaminants are controlled, the beneficial uses of wastewater and sludge (biosolids) produced during the treatment process are well documented. There are various technology options for achieving Class A or Class B biosolids standards for reuse (USEPA 2012). However, technical possibilities do not imply a business opportunity. There are constraints but also opportunities. A common restraint to entering the sludge market is lack of regulatory and financial support. However, in a context where landfills are filling and sludge is being produced in ever greater quantities, growth in sustainable solutions for sludge treatment are on the horizon. With increasing competition for valuable landfill space and new government guidelines and compulsory policies emerging, many countries such as the UK, USA, Australia, South Africa, India, and Japan are phasing out landfilling of sludge, in favour of sludge dewatering and utilization (Box 13.2). Land application, soil amelioration, energy and heat recovery, and the production of bricks and cement blocks are among the value propositions being considered (Harper 2013; WERF 2010).

Box 13.2: Sludge Management in China

In China, 80 % of the produced sludge is transferred to landfills, with good reason, as industrial contamination makes the sludge unsuitable for most reuse options. However, with government policies setting national goals of treating 70 % of the sludge in large cities and 50 % in small cities, significant investments have been made in sewage sludge treatment. The Ministry of Environmental Protection, together with the Ministry of Housing and Urban-Rural Development and the Ministry of Science and Technology published the "Policy on Sludge Treatment and Pollution Prevention Technology in Urban Wastewater Treatment Plants," which aims to regulate and promote beneficial sludge utilization practices, which can be exploited as a Clean Development Mechanism (CDM) project. These plans demonstrate government recognition that shifting from disposal to utilization is compatible with the idea of a 'circular economy'. They also provide a clear signal that sludge treatment and utilization can have a future in the environmental protection industry (Harper 2013; GTZ 2009).

One common problem with biosolids-as-fertilizers in developed countries is that the amount of nutrients, in particular nitrogen, is too low to support a market price that enables an independent company to be profitable. Only 5–15 % of the available nitrogen in the wastewater can be recovered through phosphate based precipitates. It is more likely that phosphorus recovery will drive the process which can capture between 45 and 90 % of the P in wastewater. However, making a high value biosolids-fertilizer mix could also become a viable option, due to increasing tipping fees by municipally operated wastewater treatment plants to dispose of their biosolids, especially in medium to large municipalities (Burnham 2008).

The currently dominant process to recover phosphorus with market value from wastewater treatment streams is based on crystallization and precipitation of struvite (magnesium ammonium phosphate) (Rahman et al. 2014; WERF 2010).

While unplanned struvite precipitation within a treatment plant is a common problem as it blocks pipes and its regular removal can be a severe cost factor, a steered struvite precipitation offers opportunities for phosphorous recovery, be it as slow release fertilizer or raw material for the fertilizer industry (Gaterell et al. 2000). Given that the world's affordable reserves of phosphorous are declining and the price of high-quality rock phosphate will increase over time, alternative high-quality phosphorus sources, such as struvite, will become more competitive (Rahman et al. 2014). Regulatory limits restricting effluent discharge will support the development of resource recovery. The number of treatment plants recovering phosphorus is increasing, as is the number of technologies offered for phosphorus recovery, particularly in the Netherlands, Germany, Austria, Canada, and Japan.

Technology plays a significant role in phosphorus recovery business models, as there are many options with very different costs and efficiencies. While the conditions for the precipitation of struvite can be generated at different entry points in the treatment process, the greater difficulty is ensuring that the struvite formation occurs in a location where it can be recovered economically. These location or streams are, among others: the settled wastewater, the sludge liquid and the sludge itself, and the incinerated sludge ash, each with a different phosphorus concentration and recovery potential. The ideal location for the recovery of struvite requires that the flow should have a high concentration of soluble phosphorus and ammonium nitrogen, a low concentration of suspended solids and a relatively high phosphorus load. This is not easy to find. At present, crystallization processes based on the liquid phase from sludge dewatering are considered most effective from cost and energy perspectives. Processes building on phosphorus recovery from sludge ash are more expensive, but have a more favourable phosphorus recovery capability. Options for recovering phosphorus from sludge can extract similar amounts of phosphorus than those following incineration, but the additional energy demand and costs makes them less attractive (Morf and Koch 2009).

Two examples of struvite recovery from digested sludge dewatering, and sewage sludge ash are described in Box 13.3.

Box 13.3: Phosphorus Recovery Gaining Momentum

The company Ostara in Canada, which is specialized in private-public partnerships with wastewater treatment plants, transforms the problem of clogging pipes through unwanted struvite formation into an opportunity. The applied technology recovers from sludge dewatering liquid 75–90 % of phosphorus and 10–40 % of the ammonia load in the liquid as crystalline struvite pellets. Since 2005, Ostara has installed the phosphorus recovery technology in sewage works in Canada, USA and UK and purchases the struvite at a guaranteed price from the treatment plant operator/city for marketing as a commercial fertilizer (or fertilizer input) under the brand of Crystal Green® (NPK: 5-28-10 + 10 % Mg). Examples of Ostara supported treatment plants are in Suffolk, Virginia with a capacity to produce one million pounds of Crystal Green fertilizer annually, while saving US$ 450,000 by reducing chemical use to remove unwanted struvite and reduced sludge disposal. Revenue from the sale of fertilizer is shared with the city to offset the costs of the facility, as reported also for treatment plants in Saskatoon, Saskatchewan (Canada) and Gwinnett County, Georgia, USA, and the new Thames Water Sewage Works at the town of Slough, east of London, UK. In the project Ostara was designing, building and financing the nutrient recovery facility, while Thames Water has agreed to pay a monthly fee (over 20 years) for the treatment capacity provided by Ostara, which is less than what is currently required for costly maintenance resulting from the damaging build-up of struvite in pipes and valves (www.ostara.com). Ostara's turn-key solution for treatment plants costs between € 2–4 million, with an advertised pay-back time of 3–5 years (Nieminen 2010).

In Austria, the ASH DEC technology has been successfully tested for incinerating sewage sludge to completely destruct pathogens and organic pollutant, followed by a chemical and thermal treatment to produce an ash-based multi-nutrient fertilizer, sold under the PhosKraft® brand, with significantly lower levels of heavy metals than in other products including conventional mineral fertilizers. The process can treat ashes with phosphorus concentrations ranging from 5 to 30 %. The feasibility of the recycling technology was based on large-scale application of 30,000–50,000 t of ash per year and has been marketed since 2011 (www.outotec.com/en/Products–services/Energy/Phosphorus-recovery).

It is interesting to note the difference between the amounts of information on the scale of struvite production compared to the lack of numbers on its use in agriculture. Limited information is available on how far the fertilizer sector is accepting the product, and if this is at the scale of its production, or only for niche markets. To date, the market value of the struvite is not a motivation for phosphorus recovery and recycling (P-REX 2013). The chemical reagents necessary for struvite production (in particular magnesium chloride) cost in many regions more than the market value of the produced phosphate fertilizer. However, savings in removing unwanted struvite and avoiding blocked pipes, reducing sewage sludge production and disposal, and sustainable development objectives make the innovation an appreciated and viable value proposition, with payback periods of 3–7 years (Shu et al. 2006).

In those, often low-income countries, where industrial recovery options are not available, energy supply is a challenge, and treatment plants are based on low-cost systems, biological processes can be used for recovering nitrogen and phosphorus from wastewater. Such approaches include using aquatic plants growing in treatment ponds, aquaculture, and wastewater irrigation. Aquatic plants, such as algae and duckweed that grow naturally as a part of pond and lagoon treatment systems, can accumulate large amounts of nutrients and be harvested for many purposes, including biofuels, or a source of protein for animal and fish feeds. Ozengin and Elmaci (2007) reported 83–87 % total nitrogen removal and 70–85 % total phosphorus removal for duckweed fed with municipal and industrial wastewater. In the U.S., most wastewater treatment ponds and lagoons are functionally high rate algae producers, and in recent years the systems have been designed to grow specific types of algae which produce oil to be converted to biodiesel fuel (WERF 2010). Biological nutrient recovery via the production of fish food (duckweed) and/or fish has been tested successfully in environments from Bangladesh to Peru with full recovery of the additional costs and all operational costs of the pond based treatment system (http://www.agriquatics.com/Case_Studies.html; Otoo and Drechsel 2015).

Table 13.1 provides an overview of selected nutrient recovery options from sewered systems with and without wastewater treatment.

Table 13.1 Trajectory of selected nutrient recovery options from wastewater and biosolids

Level of economic value[a]	Level of formality[b]	Waste stream	Value proposition /output	Trends/Current practices for reuse	Case Examples
Low economic value ↓ High economic value)	Highly informal reuse ↓ High formality of reuse	Waste-water	Indirect use of untreated wastewater[c]	Due to dilution of the wastewater in other water bodies the nutrient recovery benefits for farmers can be low. If combined with on-farm risk reduction, the system provides business opportunities for farmers especially where freshwater access is limited.	Common in 3 of 4 low-income countries
			Direct use of untreated wastewater	Raw wastewater is rich in nutrients but also potentially harmful substances for crops, soils and farmers. Nutrient capture from raw wastewater streams can give farmers a significant business advantage (see chapter 8).	Mexico, Pakistan
			Direct use of treated wastewater	Depending on treatment level, nutrients might be removed. Treatment should thus be designed for reuse while taking care of environment risks from unused effluent.	MENA, India
			Use of treated bio-solids	Land reclamation/restoration and landscaping, selected agricultural or silvicultural use (e.g. fodder production, forestry) using nitrogen and phosphorus rich treated sludge as a fertilizer and organic soil conditioner.	USA, Uganda, UK, Australia, South Africa, China
			Biological nutrient recovery	Common in pond-based systems where nutrients are extracted for biomass (fodder) production which is used for value creation, like fish food. High cost-recovery/profit potential if overall system is low-cost.	Peru, USA, Bangladesh, Australia
			Chemical/thermal nutrient recovery	Most common process is phosphorus and nitrogen recovery via struvite. Technology intensity and cost-benefit ratios can vary across scales.	USA, Canada, Europe
			Blending and/or pelletizing treated biosolids or extracted struvite	Used on parkland, farmland, lawns, golf courses etc. Fortifying the organic product with fertilizer or creating an organically-enhanced inorganic fertilizercan create a product which is competitive to industrial fertilizer.	USA

[a] The level of economic value of the recovered nutrients to the users

[b] Defined as activities governed by regulations and policies

[c] Wastewater is defined as domestic, industrial/commercial and storm wastewater

However, even where wastewater is collected by a piped sewer system, treatment might be rudimentary or missing, resulting in widespread pollution of urban and peri-urban water bodies. Millions of peri-urban farmers depend on these water sources, often due to lack of alternatives. As described in Chaps. 8 and 11, many farmers seek untreated and nutrient rich wastewater, as they are aware of its agronomic benefits. The global area under informal wastewater irrigation with untreated, raw or diluted wastewater has been estimated as about 10 times the area under formal irrigation with treated wastewater (Scott et al. 2010). Although this informal reuse constitutes a viable business sector in many low-income countries (Raschid-Sally and Jayakody 2008; Kvarnström et al. 2012), the common lack of conventional treatment requires alternative options for risk reduction (e.g. Amoah et al. 2011; Keraita et al. 2014) to promote the related business models in the context of this chapter. Adding safety measures to informal reuse businesses could be seen as a priority 'value proposition', and will require incentives for farmers to change behavior especially where regulations are hard to enforce (Drechsel and Karg 2013).

13.3.3 Fecal Sludge from On-Site Sanitation as a Nutrient Recovery Stream

While developed countries with extensive sewer systems require advanced technology to separate nutrients from the waste stream, the low chemical and metal[1] contamination in household based on-site treatment facilities, such as septic tanks and latrines, makes the resulting fecal sludge (septage) a valuable soil ameliorant. The dried and composted material can be pelletized or blended with particular nutrients to meet farmers' needs, as shown in South Africa and Ghana (Harrison and Wilson 2012; Nikiema et al. 2012).

Fecal sludge is an abundant and valuable resource, similar to other organic manure, such as farmyard manure, which is used as a source of fuel and fertilizer. However, with diarrhea among the primary contributors to the global disease burden and 88 % of cases of diarrhea attributed to fecal matter contamination, the management and possible reuse of human waste containing fecal matter receives priority attention across the water supply, sanitation, food and health sectors (WHO 2010).

A controlled resource recovery approach can reduce the negative impact of fecal matter on the environment and have a positive public health impact, by turning a potential threat into an asset for food production. Several nutrient recovery options are available for use with on-site sanitation systems (Fig. 13.4) as described e.g. by Tilley et al. (2008) and Koné et al (2010).

One of the possible trajectories for increasing the value proposition for agricultural reuse builds on the use of raw sludge as shown in Fig. 13.5:

1. The simplest option of nutrient recovery is the direct land application of raw fecal sludge for agriculture or forestry. The value addition occurs in the form of sludge collection and transportation to the farm or plantation, usually followed by natural solar-treatment (sun drying) or incorporation in the soil as an alternative treatment and risk reducing option (Keraita et al 2014).
2. To limit the risks for farmers, the fecal sludge can also be dumped on designated unplanted drying beds followed by composting (or co-composting with other organic waste to improve the carbon—nitrogen ratio) before sale. The value addition lies in removing pathogens, reducing the volume, and concentrating the nutrients. Moreover, co-composting is an approved Clean Development Mechanism (CDM) activity.
3. Pelletization and blending of fecal sludge-based compost with rock-phosphate, urea/struvite or NPK could be the third value proposition, allowing the product to have nutrient levels specific for target crops and soils, and a product structure improvement (pellets) to improve its competitive advantage, marketability and field use.

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[1] Although heavy metal contamination of sludge from on-site systems is generally low, it can happen if households throw for example used batteries in the toilet.

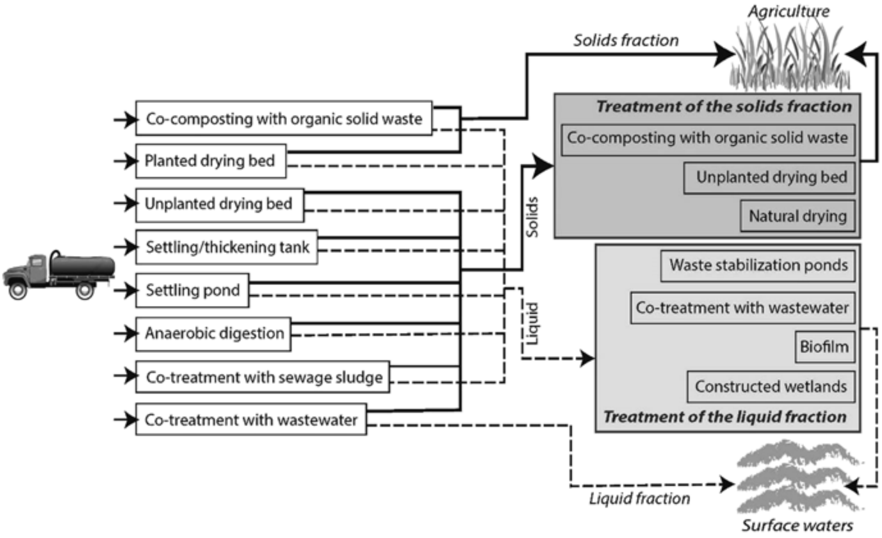

Fig. 13.4 Appropriate fecal sludge treatment options in developing countries with options for nutrient and water recovery. (Source: Strauss 2006, modified)

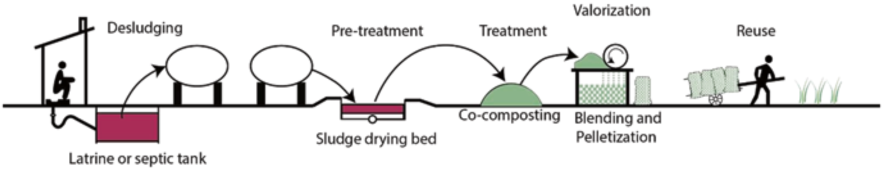

Fig.13.5 Example of reuse-oriented septage management as implemented in Ghana. (Keraita et al. 2014)

These steps and trajectories of increasing value proposition have been realized in different regions and are illustrated in the following.

13.3.3.1 Direct Land Application of Fecal Sludge

With a limited number of septage treatment systems in many parts of the developing world, entities that empty latrines or cesspits often discharge the waste onto open lands or into watercourses, instead of driving to remote official dumping sites. In areas where affordable fertilizer production is limited, smallholder farmers might use the fecal sludge for fodder, tree (crop) plantation or cereal production. Farmers in West Africa and South India re-direct cesspit truck operators to their fields to obtain the nutrient rich manure. The observed reuse business model is reversing the cash flow, as farmers pay the drivers for farm-gate delivery, while otherwise the transporter must pay a tipping fee for desludging into a treatment pond. In an optimized business model the revenue would support the transportation costs of the cesspit operation, supplementing the fecal sludge collection fees.

An economic drawback in West Africa is the seasonality in demand for fecal sludge. The sludge is applied only at the start of the dry season, allowing it sufficient time to dry over several months before it is incorporated into the soil, and cereals are planted. The marketability is different in India with plantation crops. Health concerns by authorities concerning the use of raw fecal matter in food production limit the extent of this activity, although with sufficient solar drying as observed in Ghana, and crop restrictions, the risks can be minimized (Seidu 2010; Keraita et al. 2014), even where no other regulations govern the process.

Where cesspit emptiers dump the septage in planned drying beds, and not on-farms, plant operators can sell the dried sludge to farmers with transport facilities or farms near the treatment site. Although the direct revenues from sludge sale might be low, as seen in Dakar, Senegal, the cost of sludge removal, transport and final disposal are reduced. Farmer feedback indicates a higher willingness to pay for a dry and pulverized product (Diener et al. 2014).

13.3.3.2 Fecal Sludge Composting

To explore business opportunities in agriculture, horticulture, landscaping and gardening, both public and private sector entities across Africa and Asia have adopted commercial strategies to add value to fecal sludge. The main approach is to dry the septage followed by aerobic composting of the dewatered sludge, which sanitizes and reduces its volume. Although fecal sludge can be processed alone, co-composting with another organic waste, such as organic municipal waste is more common, as it improves the composting properties, in particular the carbon—nitrogen ratio and moisture content (Cofie et al 2009). For dewatered sludges, a ratio of 1:2–1:3 of dewatered sludge to solid waste can be used, while liquid sludges can be used at a ratio of 1:5–1:10 of liquid sludge to solid waste (Tilley et al. 2008).

However, composting also adds additional capital and operation and maintenance costs. Many governmental, community and non-governmental organizations in Asia and Africa, have introduced composting with varying degrees of success, cost recovery and sustainability. Key reasons for failure have included: missing market research, poor institutional linkages and lack of business plans (Evans and Drechsel 2010). Where farmers use low cost animal manure or already receive raw sludge for free or at a low fee, field demonstrations will be needed to encourage their appreciation of a new form of sludge with a likely higher price tag.

13.3.3.3 Pelletization and Enrichment

Value-added waste products such as composted fecal sludge represent alternative nutrient sources for cash-constrained farmers cultivating on poor lands. Yet the nutrient levels of composted fecal sludge can be lower than those of alternative products, such as poultry manure and chemical fertilizer. This nutrient gap represents additional costs to farmers, as they often must invest in supplementary inputs. Additionally, the bulky nature of composted fecal sludge acts as a barrier to the transportation of the product to markets, increasing the distribution costs, which are borne by the end-users.

Opportunities to increase the accessibility and usability of value-added fecal sludge products in agriculture are emerging, often driven by research, with cases identified in Nigeria, Ghana, Sri Lanka and South Africa. A common value-addition is fortification or enrichment of fecal sludge with nutrients to boost its fertilizer value, similar to the blending of biosolids as described above. The nutrient source can be 'natural,' such as rock-phosphate, struvite/urine, or industrial fertilizer. Another option is pelletizing composted fecal sludge, resulting in an easy to handle, safe, high-value product (Fig. 13.5). These commodity-value based approaches represent opportunities for both public and private entities to increase their income-generating options by gaining access to the mainstream fertilizer market.

Most resource recovery programs are driven by the sanitation sector and its challenges, with an assumed market for the recovered nutrients. This applies to large scale struvite recovery from sewage, and to nutrient recovery from septage. An example is the transformation of fecal matter into fertilizer pellets as pioneered in South Africa by eThekwini Water and Sanitation. The project was motivated by waste management, rather than agriculture. About 2 million ventilated improved pit latrines (VIPs) have been installed since the 1990s in the municipality of eThekwini and incentives were needed to encourage companies to engage in pit emptying. The LaDePa (latrine dehydration and pasteurization) process converts sludge into a usable pasteurized dry product. Even though the sale of the resulting fertilizer does not cover the process costs, the municipality gains through annual disposal cost savings, which can be used to attract and support private-public partnerships (Harrison and Wilson 2012).

A particular option for composting is the use of the Black Soldier fly larvae (*Hermetia illucens*) which feeds on organic matter, such as fecal sludge and organic wastes, and leapfrogs the nutrient extraction via crops by generating directly high value protein and fat which can be marketed for poultry, duck, pig and fish feed (Diener et al. 2009). The high crude fat content of black soldier flies can also be converted to biodiesel. There are larger companies building on this technology for example in USA and South Africa. Current mass production systems are still expensive, and investments are needed for the development of automation processes to make plants economically competitive with the production of meat (or meat-substitutes like soy) from traditional livestock or farming sources (van Huis et al. 2013). Preliminary market surveys in Uganda, Ghana and Senegal show a market potential also in low-income countries (Diener et al. 2014). Given the increase in global price for fish meal and the on-going increase of aquaculture, the revenue potential from alternative protein sources especially as fish feed appears attractive (Naylor et al. 2009).

Table 13.2 provides an overview about selected nutrient recovery options from fecal matter/sludge (septage).

Table 13.2 Trajectory of selected nutrient recovery options from fecal sludge

Level of economic value	Level of formality	Waste stream	Value proposition/ output	Trends/Current practices for reuse	Case Examples
Low economic value	Highly informal reuse	Fecal sludge	Use of raw fecal sludge from septic tanks delivered to the farm	Win-win for septic truck operators and farmer with the latter receiving a low-cost or free fertilizer but should observe on-farm safety measures.	*Ghana, India, USA*[a]*, Burkina Faso*
			Use of treated fecal sludge from septage treatment plants	Win-win for treatment operators (less need for disposal) and farmers who can access a high value and relatively safe soil ameliorant or fertilizer, although bulky/sticky in transport and use.	*Senegal, Indonesia*
			Use of co-composted fecal sludge	Opportunity for business. Safe product, reduced organic waste volume and disposal costs for waste managers, still bulky for farmers	Bangladesh
			Use of pelletized and blended co-compost	Blending allows creation of a competitive organic-mineral fertilizer with nutrient content tailored to customer (crop) needs. Pelletizing increases production costs but reduces bulkiness while simplifying crop application.	South Africa, Ghana, Nigeria
High social value	High formality of reuse		Bioconversion (nutrient extraction for protein building) via fly larvae	Protein source for e.g. pig, poultry and fish feed; side products have value as soil fertilizer	USA, France, South Africa

[a] See e.g. Michigan Septage Program (www.michigan.gov/deq/0,1607,7–135-3313_3682_3717---,00.html)

13.3.4 Urine from Urine Diverting Toilet Systems

Fecal sludge comprises both fecal matter and urine. While feces are high in organic matter content and pathogens, urine is rich in nutrients, especially nitrogen and phosphorus. In fact, due to the ban on phosphates in laundry detergents in many developed countries, human urine can contribute 60–75 % of the total phosphate load in municipal wastewater and also up to 80 % of the total nitrogen load (Wilsenach and Van Loosdrecht 2006; NESC 2013). To recover these nutrients and prevent eutrophication, the idea of capturing urine before it enters the wastewater stream and gets diluted appears most logical. Collecting urine in urine diverting toilets, and dewatering and transforming it into struvite is being explored at different scales in developed and developing countries (Pronk and Koné 2010). Although the yields are relatively low with about 1 kg struvite from 500 l urine, small-scale and large-scale struvite precipitation from source-separated urine has been piloted in many countries, such as South Africa, Sweden, the Netherlands and Nepal. In Nepal, Etter et al. (2011) concluded from their financial analysis that it is difficult to make struvite production self-sustaining given the current fertilizer prices. While the costs for building the reactor were kept low, the magnesium source remained expensive. The cheapest source in their case was a local mine, about 80 km from Kathmandu.

At larger scale, the Dutch GMB company is operating a urine treatment plant in Zutphen city, the Netherlands (Box 13.4). The plant has been running successfully since 2010, sourcing urine from music festivals, and is currently treating about 1300 m^3 of urine per year. The operational costs for the treatment of urine and recovering nitrogen and phosphorus are comparable with the costs of removing both elements in conventional wastewater treatment plants (www.gmb-international.eu).

Box 13.4: Nutrient Recovery from Source-Separated Urine at Scale

In the SaNiPhos® technology, the ammonium and phosphate are recovered in a struvite reactor followed by an acid gas scrubber for the additional recovery of ammonium. Struvite precipitation is provoked in a reactor compartment by elevating the pH through addition of NaOH and magnesium for crystal formation. The process consumes magnesium (MgO 0.6 kg/m^3), sulfuric acid (H_2SO_4 40 kg/m^3), caustic soda (NaOH 17 kg/m^3) and electricity (25 kWh/m^3). The struvite reactor achieves phosphorus -removal of 90 ± 5 % and recovery of 85 ± 10 %, attaining a production of up to 5 t of struvite per annum according to company information. The remaining ammonia rich aqueous solution is recovered in an acid gas scrubber that is capable of producing 65 m^3 of 40 % ammonium sulfate per year (Winkler et al 2013).

13.4 Cost Advantages and Disadvantages

There are no fertilizer market incentive for implementing phosphorus recovery technologies in the wastewater sector since it is still cheaper for the fertilizer industry to continue using rock phosphate as feedstock than struvite. However, based on an economic feasibility analysis taking into account cost savings and the environmental benefits, phosphorus recovery appears viable not only from sustainable development but also from an economic point of view (Molinos-Senante et al. 2011). There are also cheaper recovery options emerging which are trying to bypass the costs of magnesium oxide (and NaOH for pH adjustment) for struvite crystallization which are significant challenges[2] for keeping production costs sufficiently low. This challenge applies even more to struvite precipitation from urine diverting toilets, which cannot base its revenue model on unwanted struvite elimination and savings for the treatment operator.

The sector should also aim at a better balance between its technology drive and actual demand and ability to pay for recovered resources, because methods and processes are highly engineered, technology- and knowledge-intensive and therefore only with caution applicable in settings with limited capacity. However, there are also low-cost alternatives. Instead of extracting phosphorus from the waste stream chemically, biological means, like duckweed or flies, can be used to extract nutri-

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[2] The costs of the magnesium can be up to 75 % of the struvite production costs. Low-cost magnesium can be found in coastal areas where salt is produced, and magnesium remains after NaCl extraction (Dockhorn 2009).

ents directly from the water or sludge while turning them straight into protein as a potential feed source for domestic animals and fish. These biological means have a very high transformation rate and leap over the value chain from the raw waste straight to a high-value product, which could also be biofuel.

From the public sector perspective, sludge treatment and composting are measures in support of cost saving given the significant volume reduction; i.e., reduced transport and disposal costs. In Ghana, waste managers suggested to simply burn the compost instead of struggling with its marketing (Drechsel et al 2010). Similar responses come from water companies which do not wish to be involved in "marketing" of recovered phosphates. They are happy with the lower sludge volume and to treat the recovered nutrients as a publicity friendly by-product as long as it is reliably sold/removed at a relatively low price, as it is the case in the Ostara business model. It is then the task of Ostara to seek a market for the fertilizer.

To optimize the marketability of recovered nutrients, especially for premium or niche markets, full compliance with quality standards and branding are important, as all struvite based examples demonstrate. The new products, be it Ostara's Crystal Green® or Outotec's PhosKraft® might need to address mixed perceptions in a cost competitive landscape (Box 13.5). Strong partners who understand agricultural markets and can bridge between the sanitation and agricultural sectors are needed.

13.5 Conclusions

While the discussion of potable and non-potable water reuse is gaining significant momentum in particular in water scarce regions, nutrient recovery from wastewater is still one step behind and is determined more by regulatory pressure and technical opportunities for cost savings, than by actual market demand for recovering nutrients, food insecurity or responses to "peak phosphorous".

Environmental regulations can provide an incentive or a disincentive in this context. Following, for example, the passage of the Ocean Dumping Ban Act, New York had to find other ways to manage its sewage sludge. One option was to produce biosolids that are used as soil conditioners for parkland, farms and golf courses. Similar outcomes resulted from the increasing regulatory control and competition for valuable landfill space as mentioned above. However, in many developed countries the regulations for biosolid reuse became over time so strict that incineration became the first choice. In other countries more stringent quality thresholds are applied to recycled phosphate fertilizers than for natural rock phosphate, which undermines efforts to produce a competitive product (P-REX 2013).

To date, the recovery of nitrogen and phosphorus from waste streams is expensive, but new technologies that involve substitutes for costly inputs are emerging. From the business perspective, this could offer a financial breakthrough, even if the phosphorus price increases slowly over time. Winkler et al. (2013) report that struvite use in agriculture has not been well accepted in Europe, despite full compliance with required standards. A higher economic value on the market is needed to stimulate phosphorus recovery. While current phosphorus market forecasts see moderate demand growth but also new rock-phosphate supply, leading to a gradual increase of potential phosphorus surplus in the near term (Heffer and Prud'homme 2014), there is great uncertainty when the phosphorus price will eventually increase. Until then, the currently produced (surplus of) struvite might have to be kept in stores.

Box 13.5: Examples of Marketing Strategies for Recovered Phosphorous

In 2011, Outotec acquired the Austrian based ASH DEC Umwelt AG (see Box 13.1). The ASH DEC phosphorous product, marketed as PhosKraft®, has been fully licensed for fertilizer use in Austria and Germany. PhosKraft® is marketed as a high quality PK 12-20 fertilizer with calcium, and NPK 20-8-8 fertilizer. Considering reduced disposal costs, the production price is comparable to commercial fertilizers (Morf and Koch 2009). Investment in a full-scale plant was estimated as € 15–18 million in 2008 with a payback time of 3– 4 years. The price varies according to whether the plans are to build a plant producing ready-made fertilizer or a plant purifying the raw material ashes. To produce fertilizers that meet a wider spectrum of requirements of crops, soils and markets, the product may be enriched with additional primary, secondary and trace nutrients and compacted to fertilizer granules. As the production costs result in prices still significantly higher than those of phosphate rock, the ASH DEC process derives its viability from savings compared to business as usual (Nieminen 2010).

The Berliner Wasserbetriebe developed the AirPrex procedure to precipitate struvite in response to unwanted struvite coatings. The process is comparatively low in costs but also the phosphorus recovery potential is modest. Struvite production is 2.5 t/d and the quality meets the standards of the German fertilizer regulations. The nutrient composition is 12 % MgO, 5 % N and 23 % P_2O_5. The product is sold directly by the Berliner Wasserbetriebe under the brand name "Berliner Pflanze" in 1 and 2 kg bags to households for flowers, ornamentals and lawns, but is also available as raw material in fertilizer production. According to Nieminen (2010), the ideal cost-recovery price of the struvite is € 50/t. Converted to €/t phosphorus, the value is € 400/t which is a competitive price with commercial fertilizers (Nieminen 2010).

Ostara's Crystal Green® struvite product has received fertilizer certification from the Oregon State Department of Agriculture and does no longer fall under regulations concerning biosolids which will enhance its public acceptance. Ostara has established strong relationships with leading blenders and distributors across North America and in parts of Europe and target niche markets where a premium price can be obtained because of the product's specific qualities (slow-release, purity, closely defined and consistent mechanical and granulometry properties of the prills) but also high production price. Crystal Green is used in blends by the agriculture, turf and horticulture sectors in

Canada and the United States (www.crystalgreen.com/applications/retail). Ostara emphasizes that it is the recovery of struvite in a size-controlled, slow release format that allows the company to realise a financial driver with significant investments in market exploration. Although the magnesium in struvite is a valuable nutrient for plants, this is not a monetarised value (P-REX 2013).

Unitika Ltd., Japan, stated that struvite produced through the PHOSNIX process from returned water of sludge treatment in Japan, which was sold to fertiliser companies for € 245/t (2001 price) with transport costs from the sewage works covered by the purchaser. The recovered struvite was then sold as a premium value fertiliser for rice and vegetable cultivation. The product is marketed by two fertiliser companies, but *not* as a 'green' recycled product. The fertiliser, after mixing with other products to provide potassium, is then sold to the public for € 100–200 per 20 kg bag (Ueno and Fujii 2001).

The fertilizer industry appears to be open to new nutrient sources to help offset potential supply shortages and in view of environmental conscience, although the percentage of potential phosphorus recovery from treated wastewater is quite small compared to the global phosphate rock needs (Shu et al. 2006). There are however regional opportunities to expand market segments to customers interested in bulk purchase of soil ameliorants, such as sludge compost for landscaping, and organo-mineral products, such as fortified co-compost. From the wastewater treatment point of view, a partnership approach would be an advantage, given the marketing network of the fertilizer sector.

In view of water, nutrient and energy recovery, it could be concluded that wastewater use can generate revenue streams when the water quality matches industrial or potable needs, or when wastewater can be transformed into energy. The recovery of nutrients such as phosphorus is viable for a treatment plant operator based on savings for removing unwanted phosphorus and due to reducing or avoiding sludge disposal costs. To transform recovered nutrients into a profitable revenue stream it might be useful to bypass any uncertainties around nutrient prices and aim at higher value products such as biofuel or protein.

Take Home Messages

- Nutrient recovery can be accomplished in large scale treatment plants, pond based systems and on-site sanitation, for the benefit of agriculture and aquaculture.
- The prospects for costs savings in treatment and disposal through the recovery of phosphorous are significant, and subsidize the production of a high quality slow-release fertilizer.
- The market perspectives for recovered phosphorus are large, but currently limited by strong price competition from rock phosphate and commercial fertilizers.

- Technological advances will continue to support nutrient recovery processes that will improve the competitive potential of waste derived fertilizers and soil ameliorants.
- Nitrogen recovery could leap over the value chain through the direct generation of marketable protein via plant or insect based waste transformation.

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Part V
Outlook

Chapter 14
Transforming Urban Wastewater into an Economic Asset: Opportunities and Challenges

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Abstract We conclude the book with a reflection on the potential of urbanization to catalyze the recovery and use of water, nutrients and energy from wastewater, with a particular emphasis on low-income countries. We recall the charge set forth in the introduction and we reflect on the 'take home messages' in each of the chapters. Our goal is to summarize the challenges, requirements and research gaps we must address to make wastewater an asset and to continue promoting innovative business thinking in the water and sanitation sector.

Keywords Economics · Water reuse · Markets · Urbanization · Wastewater business

14.1 Urbanization and Resource Recovery

The resources embedded in the municipal wastewater generated annually across the globe could theoretically irrigate and fertilize millions of hectares of crop land and produce energy for millions of households. However, only a small portion of these waters is currently treated, and the portion which is safely reused is very small

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compared to the scale of the water scarcity discussion. This apparent disconnect is due largely to social, institutional and economic issues, including regional gaps in wastewater collection and treatment capacities, social resistance against reuse, and poor business planning, leading to limited expectations of cost recovery.

However, global change, and in particular those developments which are changing resource flows and allocations, such as urbanization, are generating significant demand for food, water and energy, often more than what is easily available, thus providing new opportunities for transforming the resources embedded in wastewater into valuable assets. Planning for resource recovery and reuse is gaining momentum in water policy and urban development circles, as reuse oriented investment strategies offer notable potential for supporting to different degrees various development goals, including poverty reduction, food security, achieving sustainable agriculture, improving potable water supplies, resource conservation, sustainable energy, and climate change adaptation. Resource recovery and reuse can thus fit well within a Green Economy or any climate change adaptation strategies.

Water scarcity and water competition will be strong factors in this context, but growing cities often face also practical challenges in developing water resources to meet their citizens' needs. For example, there may be insufficient space for reservoirs, or challenges involved in laying pipelines to transport water to new suburbs. In these circumstances, additional supply from indirect potable reuse may be necessary, even if scarcity is not strictly an issue (GWI 2009).

Increasing urbanization and wastewater generation also brings new responsibilities, given the high risk of pollution and the imperative to safeguard public health and ecosystems. Thus, safety is a primary requirement of any resource recovery program, especially in the challenged peri-urban interface, which still receives in many countries large amounts of untreated urban return flows. Well managed urbanization can lead reuse-oriented water systems, yet care is needed to safeguard public health and sustain ecosystem services at the rural-urban frontier.

Opportunities for investing in reuse are particularly notable where urban and peri-urban agriculture creates demand for nutrients and water derived from solid and liquid waste. In many low-income countries, the informal sector is responsive to these opportunities, and while significant in size, the sector is weak in compliance with safety requirements where most of the recovered resources derive from untreated wastewater. The challenge is thus twofold: (1) to introduce safety into existing (informal) reuse activities, and (2) to move beyond the technical possibilities of the informal sector to enhance the value proposition, by involving more customer segments and revenue streams, following the successful examples of water, nutrient and energy recovery from wastewater as reported in Chaps. 11, 12 and 13, and in USEPA (2012) and Lazarova et al. (2013).

Resource recovery and reuse are increasingly attractive alternatives for enhancing urban water supply, given the high costs of alternatives, such as inter-basin transfers and new water storage projects. In addition, environmental concerns related to marine outfalls and landfills for sludge disposal, and increasing interest in sustaining ecosystem services, such as water purification and nutrient cycling (Reid et al. 2005), also motivate investments in resource recovery and reuse.

Governments and the private sector are beginning to realize the advantages of the "double value proposition", by which wastewater treatment generates both environmental and financial values (GWI 2009). Significant cost savings and potential revenue streams can be generated by reclaiming water for potable or industrial purposes. There are increasing opportunities also for large scale phosphorous and nitrogen recovery, and opportunities for in-house generation of the energy the wastewater treatment process needs. These and other examples, such as transforming wastewater or sludge into biomass, feed or high value protein, offer new business opportunities, which in turn can create new incentives for sanitation service delivery.

To go to scale and explore larger markets, reuse investors must look beyond traditional urban boundaries and support linkages between the sanitation, water supply, energy, landscaping and agricultural sectors. Much of the phosphorus used in agriculture today is discharged to rivers or aquifers, and eventually reaches the ocean floor. Incentives are needed to support phosphorous recovery from wastewater before a global shortage of phosphorus leads to much higher prices of fertilizer, with negative consequences for food production and livelihoods in poor countries. Waiting for phosphorus recovery technologies to become price competitive will be counter-productive from political, social, and market perspectives.

Building on the double value proposition requires innovative financing solutions and partnerships based on sound planning and business models for opening new markets, and promoting investments in services and technologies. To this end, wastewater use can be one important component of a larger resource recovery and reuse strategy which considers beyond financial aspects all economic and social benefits of treatment and reuse, and the business and market opportunities that reuse solutions offer. Opening the waste and sanitation sector to opportunities beyond safeguarding public health could facilitate a paradigm shift towards other business models in this sector than ‘the municipality pays’.

14.2 Opportunities and Challenges to Reuse Solutions

Resource recovery and reuse solutions offer diverse economic opportunities, ranging from informal agricultural production to formal reuse of treated wastewater. Successful programs can support livelihoods and generate considerable value to regional economies. In many cases, cost savings is the primary goal of resource recovery, catalyzing for example on-site energy recovery for wastewater treatment, or phosphorous recovery before it precipitates where it is not accessible or wanted. In other cases, cost recovery motivates reuse, extending the reuse proposition to larger markets to break-even on operational and maintenance costs, or even to pay back the capital investment. However, there are also several challenges that resource recovery and reuse programs must address.

Challenge 1: Safety The primary challenge in promoting reuse is the imperative of ensuring safety—safeguarding human health and protecting the environment. Wastewater use in agriculture and other economic activities offers notable economic and social benefits, but also poses health and environmental risks, particularly where operational capacities and treatment levels are inappropriate and safety guidelines are ignored.

Safeguarding public health Advanced treatment technologies, such as membrane filtration, are increasingly popular and effective in removing pathogens and other pollutants to allow a large variety of reuse options. However, these technologies must match their environment, and must fit within the institutional capacity to maintain treatment standards. Often many treatment plants in developing countries have little effective impact, given the small percentage of collected wastewater. Many plants are poorly maintained and hardly performing as planned. Thus, the high investment, operation and maintenance costs of these technologies can limit their use in many low income settings. In these situations the use of low-cost technologies and alternative safety measures can be cost-effective and competitive in terms of safeguarding public health with about US$ 5 returns per dollar invested (see Chap. 3), although the range of reuse options will be limited. Where set standards are too stringent and enforcement capacities weak, there is a high risk that the informal reuse sector will continue business as usual.

Protecting the environment Environmental (and health) risks resulting from the disposal of treatment by-products, or the use of inadequately treated wastewater vary with the origin and type of the wastewater, the receiving water body and aridity. Thus treatment options to protect the environment against any combination of risk factors should be case specific. Depending on the location the risks can derive from toxic metals and metalloids above maximum allowable concentrations; excess nutrients causing nitrate pollution and water quality deterioration; salts or micropollutants such as residues from pharmaceuticals and personal care products, which can affect aquatic life. Only for some of these hazards, low-cost options based on biological processes are available, but additional data and further studies are needed to determine their long-term impact under increasing wastewater flows.

Challenge 2: Socio-economic Dimensions The second challenge pertains to social and cultural acceptability of wastewater and fecal sludge use. Stakeholder participation and trust building at the earliest stages of a reuse project are crucial. Public acceptance of water reuse is more likely in locations facing water scarcity, when wastewater is sufficiently treated, and positively branded. However, these criteria are not always sufficient reasons for the acceptance of reuse, especially when there are alternatives. Social, institutional and economic factors also play important roles in moving from informal to formal reuse, in understanding financial and social marketing options, and supporting the development of culturally acceptable and locally feasible guidelines and regulations. In many instances, gender dimensions of reuse also must be accounted for. These can include exposure and health risks as well as income opportunities, especially in peri-urban areas characterized by male out-migration.

Challenge 3: Appropriate Policies and Supportive Institutions for Motivating Reuse The third challenge is designing supportive public policy and building institutional capacities for the uptake of reuse solutions across scales. With increasing awareness for resource recovery, policy issues appear fairly straight forward in developed countries where public agencies determine water quality criteria and implement treatment protocols. However, the regulating and facilitating dimensions of reuse protocols differ. In many cases regulations do not match the available reuse options (Huibers et al. 2010) and can be stricter than necessary, even from a public health perspective (Mara et al. 2010). This increases treatment costs, while reducing the cost-competitiveness of resource recovery. An example is the application of stricter rules regarding the purity of recovered struvite than for mined rock-phosphate (Chap. 13).

Policy issues are generally more challenging in developing countries where waste collection, treatment, and disposal often are overwhelming tasks that absorb all available capacity, making resource recovery and reuse a secondary or future target. However, it is in this situation where regulatory capacities are often weak, and informal use of usually untreated wastewater is common. To minimize possible health risks, policies must support pathways and incentive mechanisms for interventions that should build on the long term strategy of achieving comprehensive wastewater collection and treatment, and also target risk awareness, safer irrigation practices by farmers, and increased food hygiene by consumers and communities.

Effective institutions and financial instruments also are needed to encourage safe reuse. These include guidelines for resource recovery, covering technical options and possible business models, operational manuals on health risk reduction, such as the WHO supported Sanitation Safety Planning Manual, social, financial and economic incentives for increasing reuse, and also compliance with safety measures, technical assistance, certification programs for reuse businesses, insurance packages covering personal and business risks, and public awareness regarding social benefits of reuse solutions across activities and scales. Most existing regulations and institutional frameworks cover only parts of this spectrum, and are often more restricting than facilitating or miss whole waste streams, like septage. A confounding institutional challenge relates to water governance with responsibilities for water supply, wastewater treatment and reuse spread over different entities. In Ghana, for example, even wastewater treatment is regulated by different ministries depending on the ownership of the facility serving e.g. a hospital, university or military camp (Murray and Drechsel 2011).

Challenge 4: Financing Reuse Solutions Most reuse solutions have public good dimensions and generate both private and (long-term) public benefits. The investment cost is substantial and must be financed by the enterprise promoting safe reuse. The financial costs are usually higher than financial benefits. Thus the economic benefits for environment and society must be assessed and budgeted. This is particularly important where wastewater must be priced attractively to encourage reuse and uptake. Such reuse models will struggle to achieve financial sustainability given the common low fresh water prices.

Economic analysis is helpful in understanding the wider benefits of reuse, which include the cost savings obtained, in comparison with alternative options for reducing water stress. Opportunities for generating revenue include the sale of nutrients and energy recovered from wastewater. The rising price of energy, and the increasing demand for plant nutrients in agriculture, over time, will enhance the profitability of businesses engaging in recovery and reuse. In the near term, public support for new firms will be needed to encourage new entrants to enter the wastewater recovery and reuse sector. Such support might be offered as low-interest loans for the initial investment costs, incentives that promote technology transfer, carbon credits, or cost-sharing arrangements in the context of public-private partnerships.

Challenge 5: Innovations and Future Markets Most water reuse projects can build on well-known wastewater treatment technologies. The situation is more dynamic in the domain of nutrient and energy recovery, where several innovations have appeared in recent years. New methods are available for recovering phosphorus from wastewater and for transforming dried and co-composted septage into pelletized fertilizer at low cost. Some of these technologies are not yet cost-competitive across scales. The same challenge applies to the upgrading of biogas to bio-methane, or the mechanized bioconversion of sludge to protein (e.g., for animal feed). Innovations will play a significant role in advancing resource recovery and reuse, especially in emerging markets.

The capital and operational costs of many appropriate technologies will be affordable in future, particularly as adoption becomes widespread. One example is the technology for treating water for use in irrigation. Agriculture might not generate the highest returns per m^3 but the sector can absorb significant amounts of water, generating additional benefits through such mechanisms as water trading. Other low-cost innovations, such as pond-based treatment systems, combined with the production of fish feed from duckweed, are sufficiently profitable to recover their capital investment. Where higher quality standards are required, water users (and not treatment providers) can undertake further treatment through their own investments on-site by using more advanced or more reuse-targeted technologies. Perhaps business thinking in itself is the most promising innovation in the sanitation sector, where enterprises can leap over potential challenges through innovative private-public partnerships for reaching larger markets and obtaining affordable finance. For instance, biogas upgrade projects are economically viable and enjoy substantial market demand, yet bottling remains at the experimental stage. Greater uptake by industry is needed to achieve economies of scale.

A particular example is phosphorous, recovered as struvite. A viable market for struvite use in agriculture might develop in future when the price of rock-phosphate rises substantially, due to increasing scarcity, making struvite production cost-competitive. Yet it might be wise for developing countries to begin investing in struvite production and marketing in the near term, rather than waiting for rock-phosphate prices to rise. If the price rise is abrupt, developing countries might be caught in a costly transition period in which the price of phosphorus becomes unaffordably high, while the national struvite production capacity is not yet sufficient to sustain successful agriculture and prevent a food crisis. Given the inherent uncertainty regarding precisely when the global supply of rock-phosphate will become limiting, it is not likely that many developing countries will invest on their own in struvite production and marketing. Yet support for such a program from international donors or corporate sponsors, to create for example national phosphorous depots from recovered struvite, might be very welcome and well timed.

Challenge 6: Methodological Issues Recovery and reuse solutions involve cross-cutting issues that transcend administrative, and disciplinary boundaries. Many reuse projects involve issues pertaining to economics, finance, sociology, health, the environment, engineering, water, energy, food, and plant nutrition. Developing a methodological framework reflecting these perspectives in a matrix of indicators that could serve policy makers is challenging. In addition to the financial costs and benefits, the social and environmental externalities of reuse projects have seldom been quantified, although an increasing number of tool kits and resources are available (see Chap. 7).

Despite significant advances in the development and application of environmental valuation techniques, some costs and benefits remain difficult to estimate empirically. Yet, in many cases, it is helpful to acknowledge the importance of indirect costs, externalities, and the public good aspects of recovery and reuse programs, with the goal of achieving a socially optimal level of investment. Some portion of that investment will continue to come from public sources in the near term, but we envision greater participation by private firms in future, as further research identifies a larger set of potentially viable business models.

14.3 Outlook

Our excitement in presenting this book builds largely from the opportunity to support business thinking in a sector that traditionally has relied on public funding, and to encourage the development of effective business models addressing resource recovery and reuse. We believe the private sector, supported by continued applied research and supportive policies and institutions, can spur the achievement of national and international sanitation and reuse targets within a reasonable time horizon, to the benefit of millions of households.

Finance will be the key to the reuse sector which has too long been driven by regulations rather than economic opportunities. The potential to reclaim wastewater for high value applications can create new revenue streams. GWI (2009, 2014) predicted that the municipal reuse market is on the verge of major expansion, especially towards higher value applications with a 2011–2030 growth rate of +271 %. The increasing pressure on natural freshwater resources will however be strongest from the agricultural sector, which can only be met through greater water usage. Over-exploitation of surface and groundwater resources is likely to be affecting millions of people by 2030 (GWI 2014), especially in peri-urban areas where 'treatment for reuse' as well as water swaps could become popular mitigation options for balancing urban and rural water stress.

Verifiable targets are needed to encourage reuse at scale also in view of the Sustainable Development Goals (OWG 2014). There is need for better data collection programs to support the assessment of resource recovery and to develop information for designing culturally acceptable reuse options. More research is needed also, regarding the impacts and cost-effectiveness of risk mitigation options and methods for promoting their adoption under different environmental, social, and economic conditions, particularly in peri-urban areas of low-income countries. Investments in resource recovery and reuse programs generally will enhance efforts to achieve food and nutritional security, alleviate water scarcity, and improve the reliability of energy supply, while helping to reduce urban-rural tension. The market for water and energy recovery from wastewater should become quite lively within the not-too-distant future.

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