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SANITATION, WASTEWATER MANAGEMENT AND SUSTAINABILITY

FROM WASTE DISPOSAL TO RESOURCE RECOVERY

GPA Global Programme of Action for the Protection of the Marine Environment from Land-based Activities

SEI STOCKHOLM ENVIRONMENT INSTITUTE

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Kim Andersson, Arno Rosemarin, Birguy Lamizana, Elisabeth Kvarnström, Jennifer McConville, Razak Seidu, Sarah Dickin and Caspar Trimmer

UN Environment Programme Global Programme of Action for the Protection of the Marine Environment from Land Based Activities and Stockholm Environment Institute

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CONTENTS

1. INTRODUCTION

1.1 Sanitation, wastewater and sustainability

Few areas of investment today have as much to offer the global shift towards sustainable development as sanitation and wastewater management.[1] Gaps in access to decent, functioning sanitation are clear markers of inequality and disadvantage. Unsafe management of excreta and wastewater expose populations to disease, and degrade ecosystems and the services they provide.

At the same time, there is growing recognition that societies can no longer afford to squander the water, nutrients, organic matter and energy contained in sanitation and other wastewater and organic waste streams. These resources can, and should, be safely recovered and productively reused. In fact, the vision of resource-efficient, circular economies is unachievable without radical change in how we manage wastewater, excreta and other biomass waste.

This book discusses how this radical change might take shape. It distils some of the latest thinking and experiences on how to make sanitation and wastewater management more sustainable; and on how they can contribute to broader societal sustainability. In particular, it focuses on the idea of sanitation and wastewater management as resource management functions: as ways of keeping valuable resources available for productive uses that support human well-being and broader sustainability.

To put the scale of the opportunity into perspective, globally we produce an estimated 9.5 million m^3 of human excreta[2] and 900 million m^3 of municipal wastewater every day (Mateo-Sagasta et al. 2015). This waste contains enough nutrients to replace 25 per cent of the nitrogen currently used to fertilize agricultural land in the form of synthetic fertilizers, and 15 per cent of the phosphorus, along with enough water to irrigate 15 per cent of all the currently irrigated farmland in the world (some 40 million hectares; Mateo-Sagasta et al. 2015). At the city scale, the wastewater (including excreta) from a city of 10 million people contains enough recoverable plant nutrients to fertilize about 500,000 hectares of farmland – which in turn could produce about 1.5 million tons of crops.[3]

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[1] Although sanitation waste is often considered part of wastewater, this report refers to it separately to reflect the fact that many sanitation systems are "dry" – i.e. they do not involve flushing with water, and keep faeces and urine separate from other wastewater streams. Such source separation of excreta, as discussed in Chapter 4, is often a desired function within sustainable sanitation systems.

[2] Based on 1.3 litres of excreta per person and a world population of 7.3 billion people.

[3] Based on one person producing roughly 5 kg of nutrient equivalents per year, at a fertilization rate of 100 kg/hectare of farmland producing 3 tonnes of grain per ha.

The opportunities become even more apparent when we consider where the biggest gaps in provision are found. As the maps in Figure 1.1 show, these gaps are largely found in sub-Saharan Africa and South Asia. These regions are badly affected by some of the key development challenges that could be alleviated through sustainable sanitation and wastewater management: food insecurity and associated under-nutrition, water scarcity and soil degradation (see Box 1.1). They are also expected to

FIGURE 1.1 **Sanitation the solution? Mapping some key global challenges sustainable sanitation could help to address**

FIGURE 1.1A **Sanitation gaps: Percentage of population with access to improved sanitation, 2015**

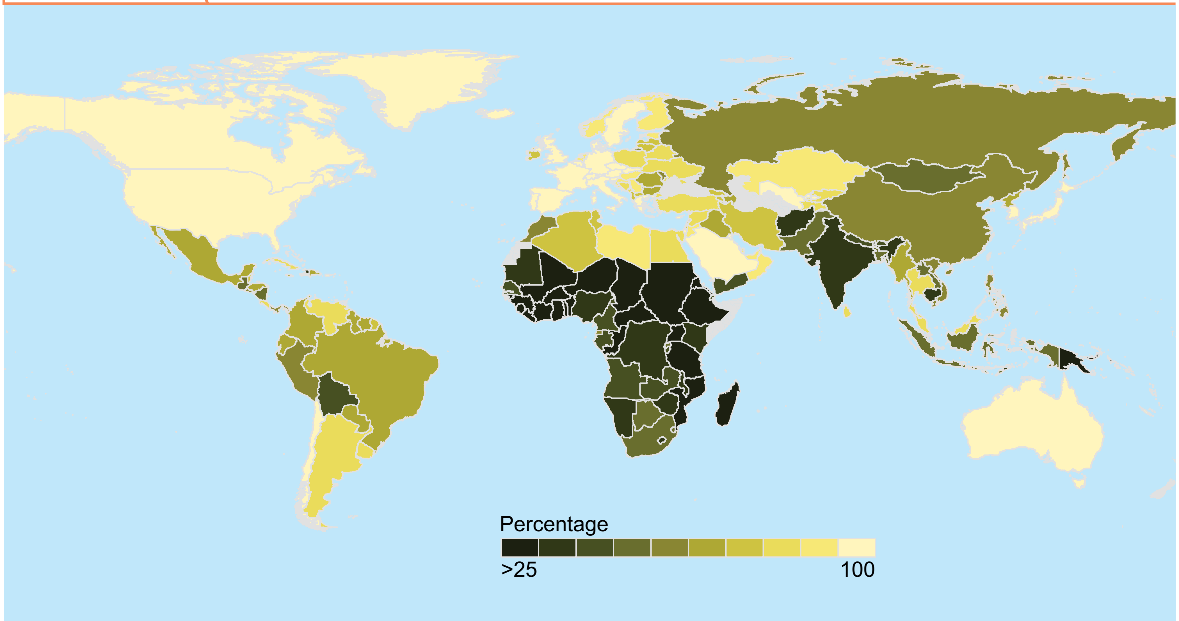


Figure: Based on Joint Monitoring Programme for Water Supply and Sanitation data (www.wssinfo.org/data-estimates/maps)

FIGURE 1.1B **Disease: Percentage of total deaths that are from communicable diseases or maternal, prenatal or nutrition conditions, 2014**

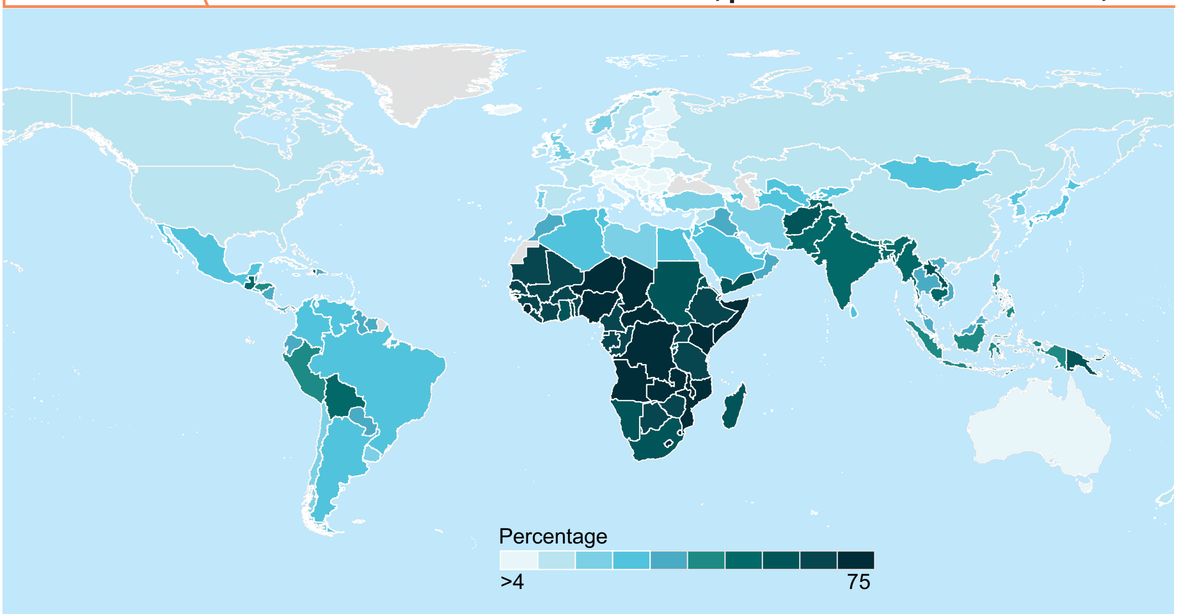


Figure: Based on World Bank data (http://data.worldbank.org/indicator/SH.DTH.COMM.ZS).

experience the greatest population growth by 2030, according to current projections (2030 Water Resources Group 2009). A large proportion of this future population is likely to live in fast-growing cities, where risks from inadequate sanitation and wastewater management, as well as opportunities to mitigate these risks are concentrated.

To realize these opportunities, massive investment in sanitation and wastewater management systems will be needed; to address existing gaps in provision and make the transition to more sustainable systems. What form those investments and systems take has major implications for global sustainable development.

FIGURE 1.1C **Water scarcity: Areas of physical and economic water scarcity, 2007**

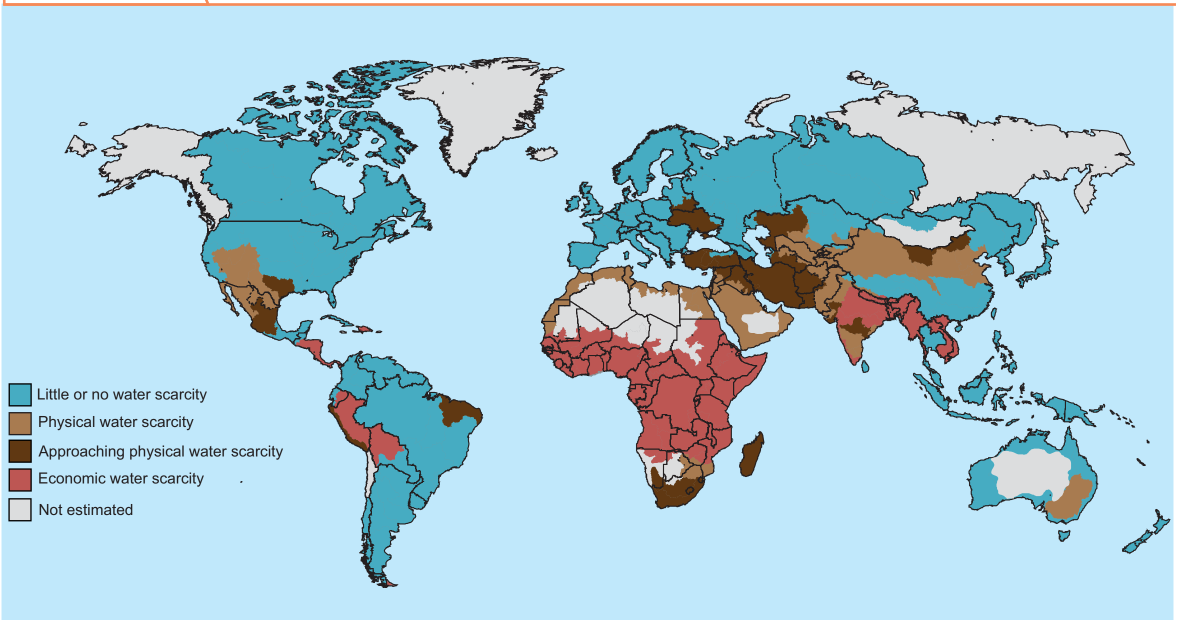


Figure: Based on International Assessment of Agricultural Science and Technology for Development data (www.grida.no/graphicslib/detail/areas-of-physical-and-economic-water-scarcity_1570).

FIGURE 1.1D **Malnutrition: Percentage of children under 5 with stunting, 2015**

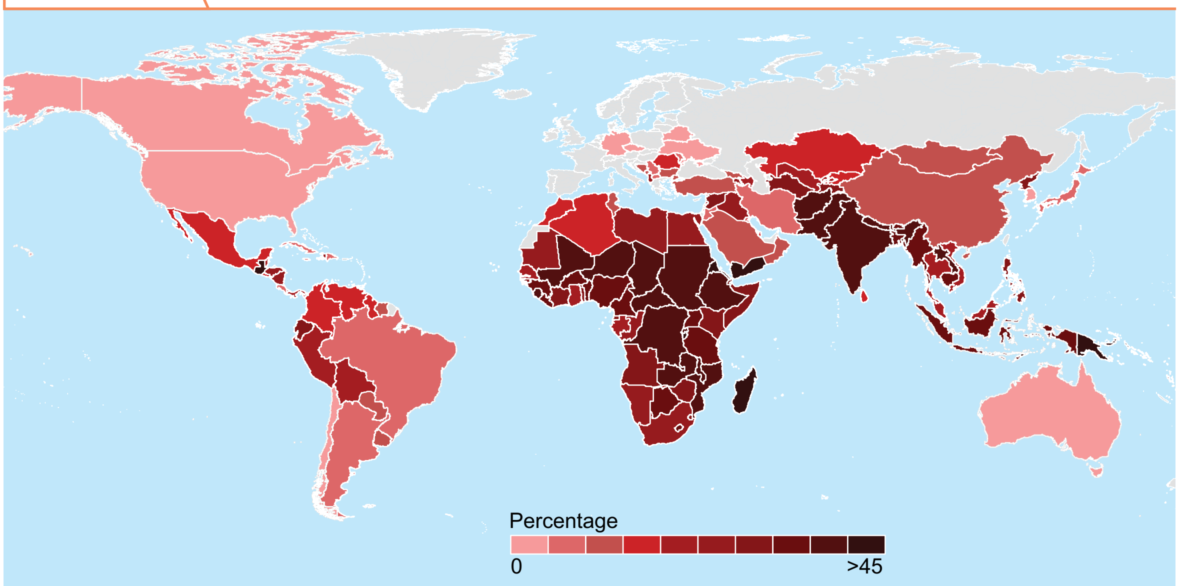


Figure: Based on UNICEF data (http://data.unicef.org/nutrition/malnutrition.html)

BOX 1.1

Poor sanitation access, wastewater contamination, undernutrition, low soil fertility and water scarcity: linked problems with common solutions

Current trends, including predicted population growth and ever more intensive consumption of natural resources, will only increase the need for improved excreta and wastewater management. In sub-Saharan Africa, water demand is projected to increase by 283 per cent between 2005 and 2030 (2030 Water Resources Group 2009). Even today, more than 300 of the 800 million people in this region live in a water-scarce environment (NEPAD 2006).

While malnutrition prevalence has declined, the absolute number of undernourished people in sub-Saharan Africa continues to rise. Demand for food is expected to rise with larger populations and economic development. In addition, agricultural productivity and soil quality are falling in some areas due to depletion of soil nutrients, mainly caused by inadequate nutrient management coupled with the extraction of biomass for household cooking and food production (Faurès and Santini 2008).

Untreated wastewater and farmland run-off often contain large amounts of plant nutrients. When they reach rivers, lakes and coastal waters in high concentrations they can radically alter how ecosystems function, boosting the growth of aquatic plants, changing the composition of the flora and fauna, and starving organisms in the water below – including fish – of oxygen. It can also lead to blooms of toxic algae that can make shellfish and freshwater dangerous to humans (see Chapter 6 for more on eutrophication and other environmental risks linked to wastewater and sanitation waste).

An algal bloom due to eutrophication in Dianchi Lake, Yunnan, China. Photo: Greenpeace China

1.2 The situation today

The status of sanitation and wastewater management today differs widely around the world (see Figure 1.2), as do the challenges of making them more sustainable. Waterborne excreta management (with flush toilets and sewer networks connected to a centralized wastewater treatment plant) is the standard in many places, especially in urban areas and richer countries. However, large segments of the population in some regions lack a sewer network connection. For example, only around 10 per cent of the populations of some sub-Saharan African countries (including Côte d'Ivoire, Kenya, Lesotho, Madagascar, Malawi and Uganda) are connected to a sewer system (Banerjee and Morella 2011). Worldwide, about 2.7 billion people are thought to use some kind of on-site sanitation system (e.g. pit latrine, septic tank) requiring faecal sludge management (see Chapter 4). Users of on-site sanitation are expected to almost double by 2030 (Strande et al. 2014).

Furthermore, in many countries untreated wastewater and excreta pollute streets, agricultural land and freshwater bodies. However, when making any generalizations about the global situation, it is important to acknowledge that there is limited information available concerning wastewater management worldwide. According to a global assessment, only 55 countries have collected complete data on their wastewater management, including information on production, treatment and reuse, while 57 other countries have collected no data at all. Based on the available data it has been estimated that on average 30 per cent of wastewater is released untreated in high-income countries, rising to 62 and 72 per cent, respectively, in upper-middle and lower-middle income countries, and 92 per cent in low-income countries (Sato et al. 2013). According to another analysis, globally perhaps 90 per cent of wastewater that is released into the environment is untreated (Corcoran et al. 2010).

The development of sanitation and wastewater management is also following very different paths in different parts of the world. Figure 1.3 illustrates this, comparing trends in urban populations and sanitation systems for sub-Saharan Africa and Latin America.

Many drivers shape sanitation development, not least patterns of urbanization, existing infrastructure and preconceptions about what constitutes "modern" sanitation. In many cases, current trends seem incompatible with

FIGURE 1.2

Share of population served by different sanitation technologies, by region

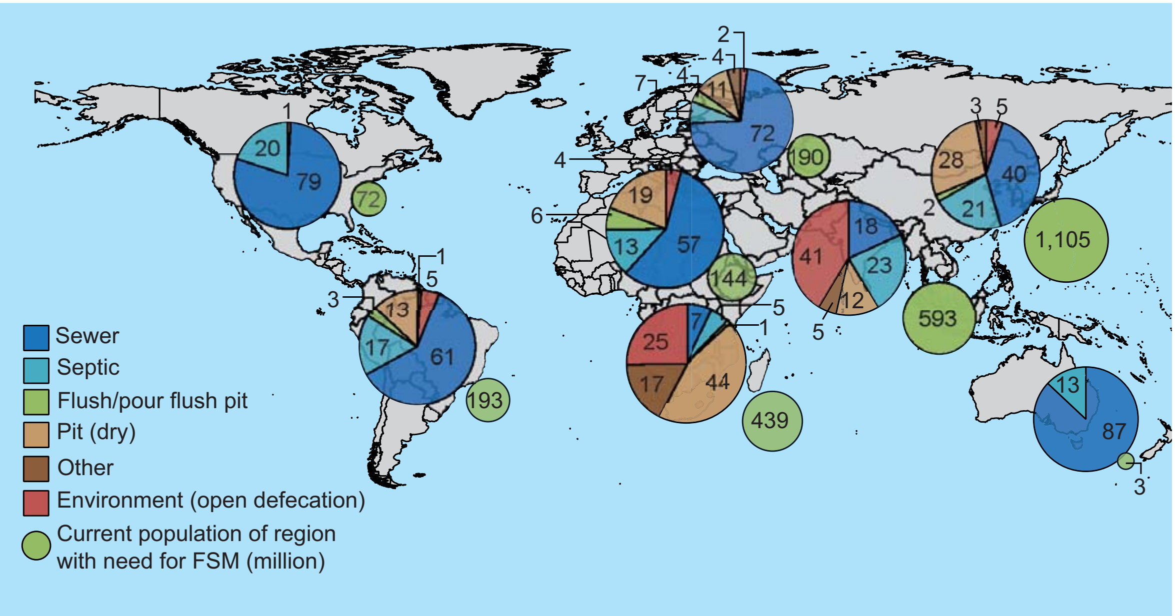


Figure: Based on Boston Consulting Group analysis of UN Joint Monitoring Programme data, from Strande et al. 2014 sustainable development. For example, while centralized waterborne systems are widely associated with modernity and advancement, they are being built in areas facing growing competition for limited water resources. And taking Africa as a whole, only 15 per cent of the population have private connections to piped water networks (Banerjee and Morella 2011), making waterborne excreta management far more difficult. As this book seeks to show, low-water and non-waterborne systems are being recognized as often the most appropriate, sustainable solution, even in high-income countries.

The sanitation and wastewater management sector has suffered from lack of political prioritization, further complicating already complex challenges. For instance, poor governance (e.g. weak regulation and enforcement, limited capacities of public authorities and service providers) and inadequate attention to operation and maintenance (O&M) have led to systems malfunctioning and falling out of use, particularly shared or public facilities. In addition, sanitation programmes have often failed to overcome cultural barriers to sustained behaviour change (e.g. ending open defecation).

The difficulty of overcoming these challenges can be seen in the low coverage achieved and high failure rates for sanitation and wastewater management projects reported in many countries around the world. In Cambodia, for example, following a sanitation promotion campaign only 15 per cent of households with a latrine used it regularly (WSP 2012). Similarly, an overview of school sanitation facilities in South Asia showed 30–60 per cent were not functioning properly (UNICEF 2012b). For more on these challenges, see for example WWAP (2015), Galli et al. (2014), Schweitzer et al. (2015), and Corcoran et al. (2010).

In addition, despite significant efforts many people still have no access to a safe, functioning toilet. It has been estimated that in 2015, 2.4 billion people did not use an improved sanitation facility, including almost 1 billion people who still resorted to open defecation (JMP 2015). The majority of these people lived in middle-income countries (UN 2014). However, this figure does not take into account dysfunctional piped sanitation and wastewater management systems that risk releasing untreated wastewater into the human and natural environment. If those are added, then perhaps as many as 4.1 billion

FIGURE 1.3 **Urban population and sanitation system trends, selected regions**

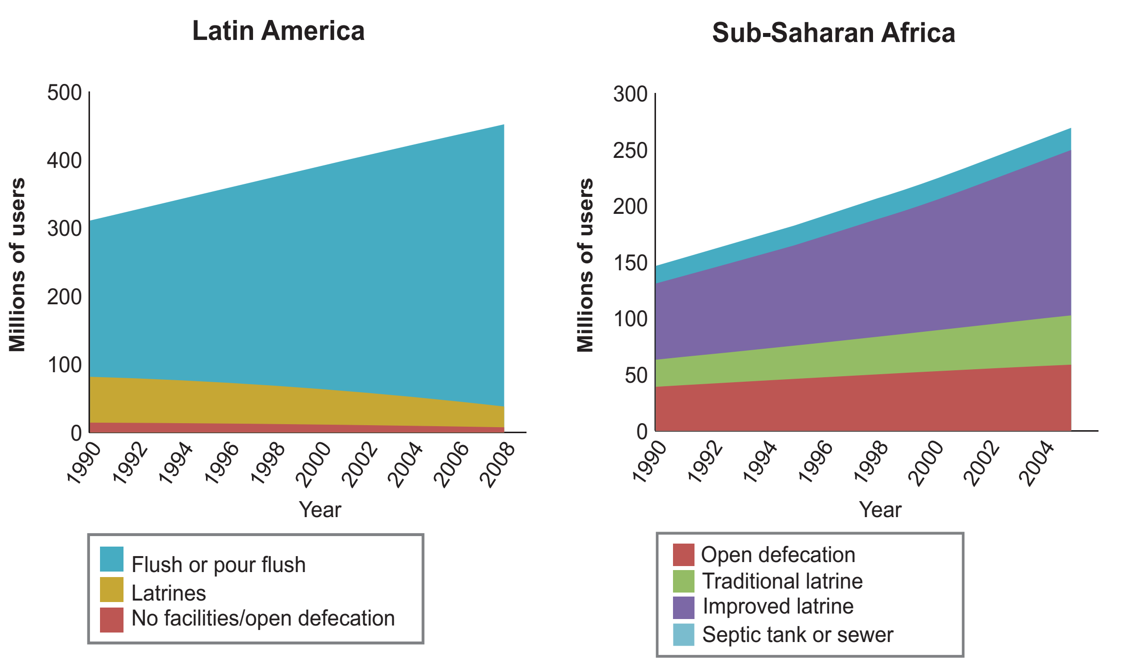


Figure: Adapted from Kjellén et al. 2012 people – 60 per cent of humanity – could be said to be without improved sanitation (Baum et al. 2013). Thus, much greater effort and investment will need to be dedicated to sanitation in the coming years.

The case for investing in sustainable sanitation is growing stronger. It is already well established that appropriate sanitation and wastewater management can pay for itself many times over due to to reduced health care costs and associated increases in productivity (WHO 2012a). The new global sustainable development framework adopted in 2015 – the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs) – can provide further impetus and arguments for transformative change.

1.3 Sanitation, wastewater management and the 2030 Agenda

While many of the Millennium Development Goal (MDG) targets for 2015 have been met or even passed, the MDG target of halving the share of the population without access to basic sanitation was missed by 9 percentage points.[4] While major resources have been allocated to health care, education and other development priorities since 2000, the sanitation gap has not been prioritized. UN Deputy Secretary-General Jan Eliasson has described sanitation as "the most lagging" of all the MDG targets (Eliasson 2014).

Furthermore, with their focus on sanitation *access* and their failure to address wider issues of wastewater and excreta management, the MDGs offered little incentive for investment in more sustainable systems. Thus, much of the sanitation and wastewater management development that has already taken place will require additional investment to make it both more effective and more sustainable.

The universal applicability and emphasis on integrated solutions in the SDGs and the broader 2030 Agenda provide strong arguments for investing in sustainable sanitation and wastewater management. The SDGs dedicate an entire goal to water and sanitation: "to ensure availability and sustainable management of water and sanitation for all," bringing greater awareness to sanitation challenges. Under Goal 6 are two targets directly linked to sanitation and wastewater management:

Target 6.2: *. . . achieve access to adequate and equitable sanitation and hygiene for all, and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.*

Target 6.3: *. . . improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse globally.*

In calling for universal access to meet the needs of all people, SDG Target 6.2 is much more ambitious than the previous MDG target, while also highlighting the need to improve hygiene and end open defecation.

The proposed indicator for measuring global progress on Target 6.2 is the: "percentage of population using safely managed sanitation services, including a hand-washing facility with soap and water". "Population using safely managed sanitation services" refers to those "using a basic sanitation facility at the household level . . . which is not shared with other households, and where excreta is safely disposed in situ or treated off-site" (UN Water 2015). This is promising not only in that it directly refers to treatment, but also in that it emphasizes the level of use rather than simply the level of availability of a technology, and thus brings in elements of accessibility, acceptability, and safety.

SDG Target 6.3 calls directly for improved wastewater management and, crucially, includes recycling and reuse. This wording

[4] It is estimated that in 1990 around half of the global population of 5.3 billion had no access to improved sanitation, while in 2015 the share was around 32 per cent, or 2.4 billion people (JMP 2015).

places wastewater management firmly in the context of resource efficiency and a circular economy.

Sustainable sanitation can also make cost-effective contributions to achieving a wide variety of SDG goals and targets, across development sectors. Figure 1.4. shows how improvements in sanitation and wastewater management could help countries to achieve up to 32 SDG targets. Also important is that the number of targets addressed increases with the level of ambition in sustainable sanitation and wastewater management investments. As examples, at the most basic levels of ambition (ending open defecation and preventing human exposure to pathogens and toxic substances in excreta and wastewater), improving sanitation and wastewater management could relieve a large burden of infectious disease (Goal 3), particularly child mortality. Lower incidence of disease means fewer days of education (Goal 4) and of productive work lost.

If systems also aim to prevent the release of untreated wastewater in natural ecosystems, and reduce the run-off of nutrients from agricultural soil by reusing organic matter, they could improve the status of freshwater and coastal ecosystems and the services they provide (Goal 14). Recovering and reusing the valuable resources present in excreta and wastewater also contributes to resource efficiency (Goal 12) and can help improve food security (Goal 2). Sustainable sanitation and wastewater management value chains provide new livelihood opportunities (Goals 1 and 8).

Making tomorrow's cities livable (Goal 11) is unthinkable without adequate sanitation and wastewater management. Furthermore, "equitable access" to adequate sanitation can also help to achieve non-discrimination targets under Goal 5 by increasing participation in school, the workforce, institutions and public life. A lack of suitable facilities effectively excludes women, girls and people with disabilities, especially during menstruation, and increases the risk of gender-based violence.

Sanitation has played a key role in enabling and catalyzing development throughout history, allowing cities to keep expanding and helping to keep increasingly urban populations healthy. Sustainable sanitation and wastewater management will be central, even fundamental, to fulfilling the 2030 Agenda.

1.4 What is "sustainable sanitation and wastewater management"?

This report builds its concept of sustainable sanitation on that of the Sustainable Sanitation Alliance (SuSanA):

Sustainable sanitation and wastewater management systems are those that minimize depletion of the resource base, protect and promote human health, minimize environmental degradation, are technically and institutionally appropriate, socially acceptable and economically viable in the long term. They should both be sustained – used by target population while functioning properly over the long term, as well as resilient to disasters – and contribute to broader socio-economic and environmental sustainability.

Based on SuSanA 2008

As this description makes clear, sustainability in sanitation and wastewater management has several dimensions. These dimensions are mutually supporting and mutually dependent: no system can be sustainable in one dimension if it is not sustainable in the others. In addition, the system's relationship with contextual factors such as physical geography, demographics, culture and institutions must be considered. No technology is inherently more sustainable than another, and systems that work well in one context might create serious sustainability problems in another.

If the dimensions of sustainability are mutually dependent, what is the central purpose of sustainable sanitation and wastewater management? This is a crucial question when it comes to planning investments. In the development context,

FIGURE 1.4

Beyond Goal 6: The many ways that sustainable sanitation and wastewater management can help in meeting the Sustainable Development Goals

Investments in sustainable sanitation and wastewater management can help countries to meet many of the other targets under the Sustainable Development Goals. In this figure, the coloured blocks indicate which targets can be promoted by providing sustainable systems with increasingly advanced and ambitious functions. Half-shaded boxes indicate a smaller (but still positive) potential contribution to achieving the target than fully shaded boxes.

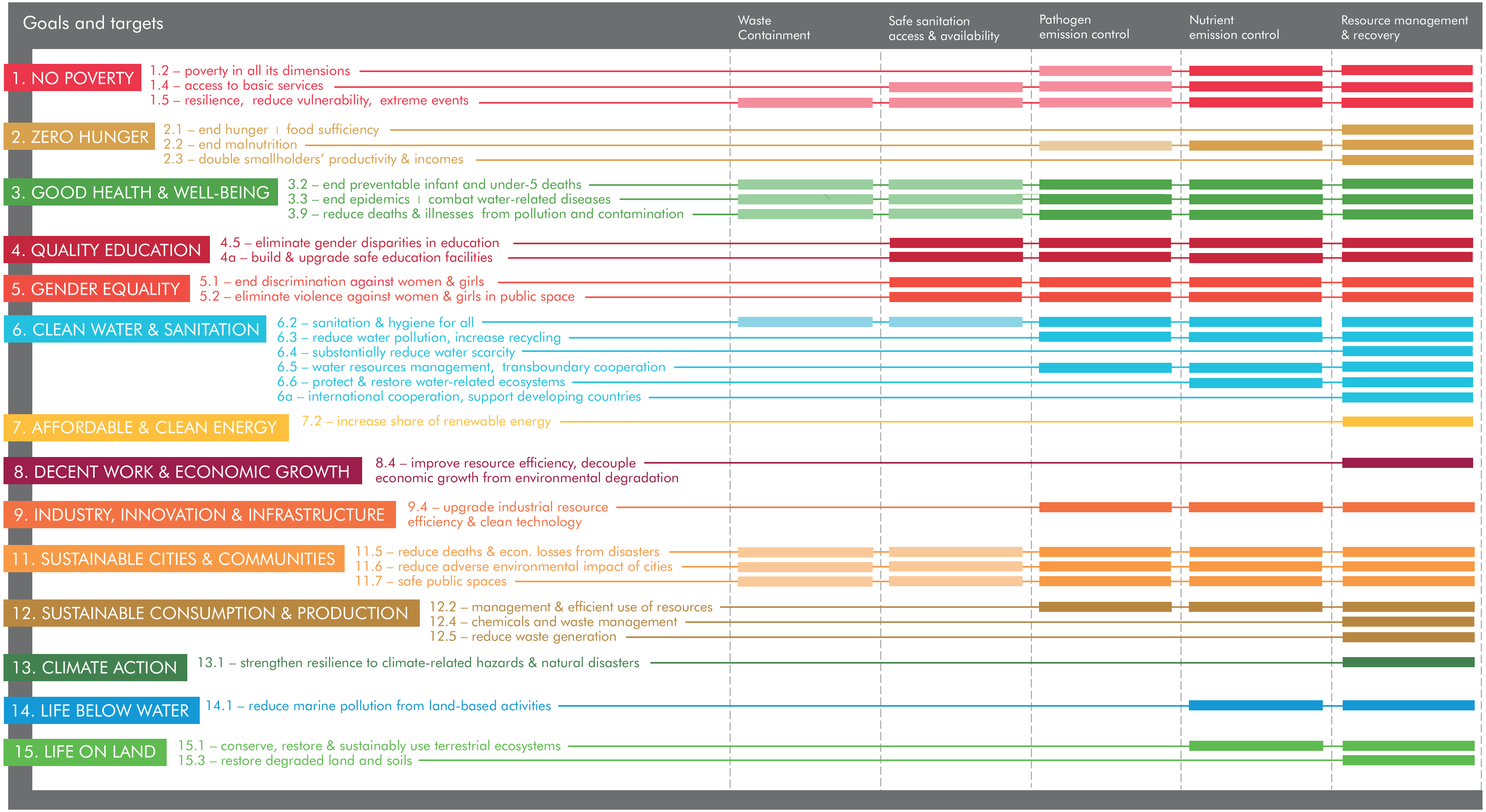


Figure: Stockholm Environment Institute

sanitation and wastewater management are currently thought of as public health and, more recently, as environmental protection interventions. Little attention is paid to how fulfilling these functions might affect the resource base.

Instead, this book proposes that resource management should be at the heart of sustainable sanitation and wastewater management systems (see Figure 1.5). Following this logic, a central consideration in system planning and design should be minimizing the resource inputs and recovering the resources contained in wastewater and other sanitation streams in a way that allows them to be safely reused. This recovery must be done in a way that protects human health and ecosystems, promotes social equity and well-being, is financially sustainable and is supported by strong, appropriate institutions.

1.5 Aims of this book

How do we bring about the transformational shift to sustainable sanitation and wastewater management? What does it look like in practice? We do not yet have all the answers, but we know a lot more today than we did even a decade ago. Technologies are developing fast. We have a much better understanding of the social and institutional factors that influence success. Small-scale and pilot approaches, particularly in resource recovery, have stood the test of time and are being successfully scaled up. Major donors are funding cutting-edge work. And importantly, there is a growing willingness to talk about sanitation and its role – among politicians, development practitioners and in public discourse.

This book brings together the latest thinking and practice in sustainable sanitation and wastewater management. Giving real-world examples and illustrations, it aims to make the key issues in system design,

FIGURE 1.5 **Key sustainability dimensions in sanitation and wastewater management**

Figure: Stockholm Environment Institute

implementation and operation accessible to policy audiences and development practitioners, while still providing a useful overview for technical and academic readers more directly involved in sanitation and wastewater management.

The book takes current thinking on sustainable development as an analytical framework. The main focus is on sanitation systems – which account for the vast majority of wastewater – and on recovery of the resources found in wastewater, excreta and other organic waste flows for productive reuse in agriculture, energy production and a range of other applications.

Chapter 2 discusses in broad terms some of the ways the resources in wastewater, excreta and other organic waste can be recovered, as well as the potential for sustainable sanitation and wastewater management with resource recovery, along with some of the major challenges that need to be overcome to realize it.

Chapter 3 delves deeper into the concept of a resource management approach to sanitation and wastewater management, and gives some guidance on how to estimate the potential for resource recovery and reuse in a given system. Chapter 4 looks at the technical dimension of sustainability, and particularly how to combine technologies into a system that best meets the needs and constraints of the specific context.

Chapters 5 and 6 look at two more dimensions of system sustainability: protecting public and environmental health, respectively. Chapter 7 discusses the role of the government and local authorities in creating an enabling environment for sustainable sanitation and wastewater management. It also explores sustainability issues in the social sphere, particularly how to win social support for sanitation and resource reuse, and how to maximize social benefits such as safe and equitable access.

Chapter 8 discusses issues of financial and economic sustainability, including how to calculate the costs and benefits of a shift to sustainable management, and how to finance it.

Chapter 9 presents some specific examples of technological solutions for resource recovery and reuse. The variety of case studies presented reflects the fact that while the benefits of sustainable sanitation and wastewater management are available in both developed and developing countries, urban and rural settings, established cities and new settlements, the means to exploit them remain highly context-specific. It also demonstrates the importance of a whole system perspective for sustainability in sanitation and wastewater management – mirroring the integrated approach of the 2030 Agenda.

Overall the book aims to demonstrate that sustainable sanitation and wastewater systems are not only smart, cost-effective investments for sustainability, but also practical, affordable – and already here.

KEY MESSAGES

- Unsafe management of excreta and wastewater is widespread and creates significant health and environmental risks.
- Sustainable sanitation and wastewater management systems are those that minimize depletion of the resource base, protect and promote human health, minimize environmental degradation, are technically and institutionally appropriate, socially acceptable and economically viable in the long term.
- A vision of resource-efficient, circular economies is unachievable without radical change in how we manage wastewater, excreta and other biomass waste.
- Sustainable sanitation and wastewater management will be central, even fundamental, to fulfilling the 2030 Agenda.

Rethinking wastewater

Bold, innovative solutions to the challenges of sustainable development will require new ways of thinking about wastewater and other sanitation waste.

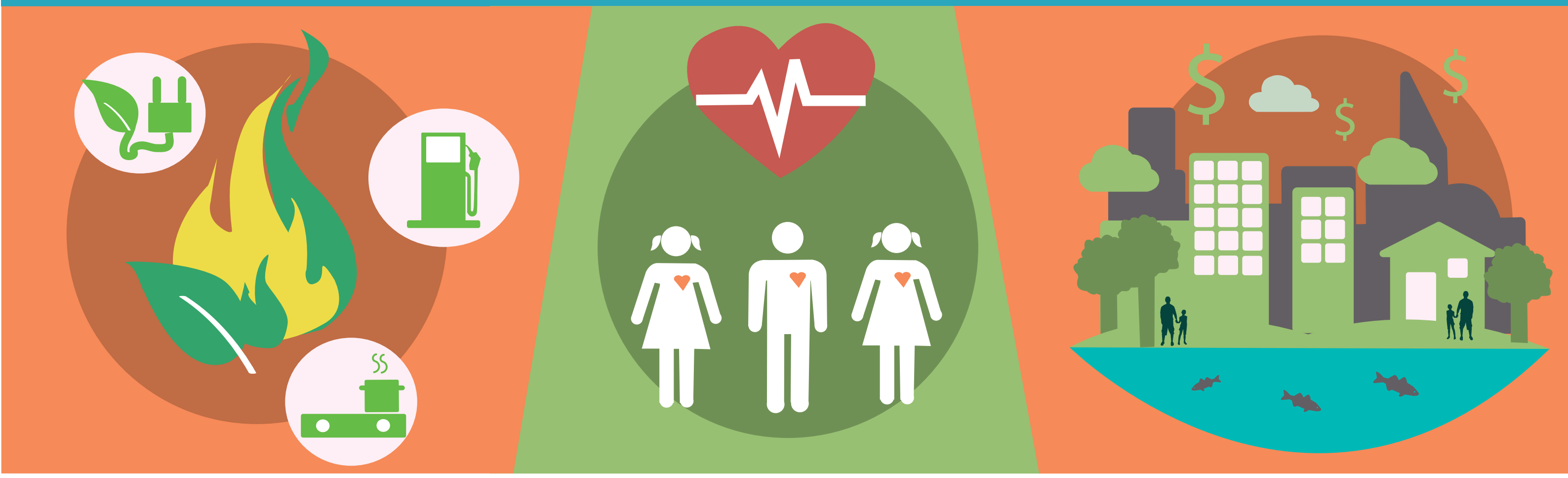
In rethinking wastewater, we can look to another major waste stream: solid waste. Until as recently as 20 or 30 years ago, even in the most advanced economies, standard practice was to mix various types of solid waste and dispose of it in landfills or incinerate it. More recently, however, recycling has become increasingly widespread, with different types of waste being separated at source and put to productive uses. We are seeing a similar change starting to take place in wastewater management – as evidenced by many of the experiences described in this book – but it is at a much earlier stage.

One reason for the slower progress in resource recovery from wastewater and sanitation waste streams may be a high degree of lock-in the shape of urban sewerage networks designed to mix and transport liquid waste flows, including waterborne excreta. These are expensive and difficult to upgrade or replace. As these systems age, however, the need for repair and replacement increases and it is here that innovations can be introduced. New urban and peri-urban developments have the chance to leapfrog over conventional sewerage and build source-separating systems optimized for cost-effective resource recovery from the beginning.

It is also important to realize that wastewater need not be seen as a fixed, unchangeable substance. Its nature and composition can be changed by restricting what is allowed to enter the wastewater stream, or by separating different streams at their source. Wastewater can be reduced in volume, and even be turned into a solid. It can be treated to remove the pathogens and pollutants that make it hazardous.

Additionally, more and more it can become a source of energy, of plant nutrients and other agricultural inputs, of water and many other valuable resources, bringing sizeable economic, social and environmental benefits, which are explored in the next chapter.

2. THE ADDED VALUE OF SUSTAINABLE SANITATION AND WASTEWATER MANAGEMENT



More sustainable sanitation and wastewater management could yield vast economic (as well as social and environmental) benefits for societies (Hernandez-Sancho et al. 2015). Many of these benefits come in the form of savings of costs linked to inadequate sanitation and wastewater management – most notably in health care, but also in terms of lost economic productivity, reduced ecosystem services and others. In India, for example, the estimated economic savings available through providing adequate sanitation to all (i.e. without taking into account benefits from wastewater/excreta management or resource recovery) have been estimated at US$54 billion annually (WSP 2011).

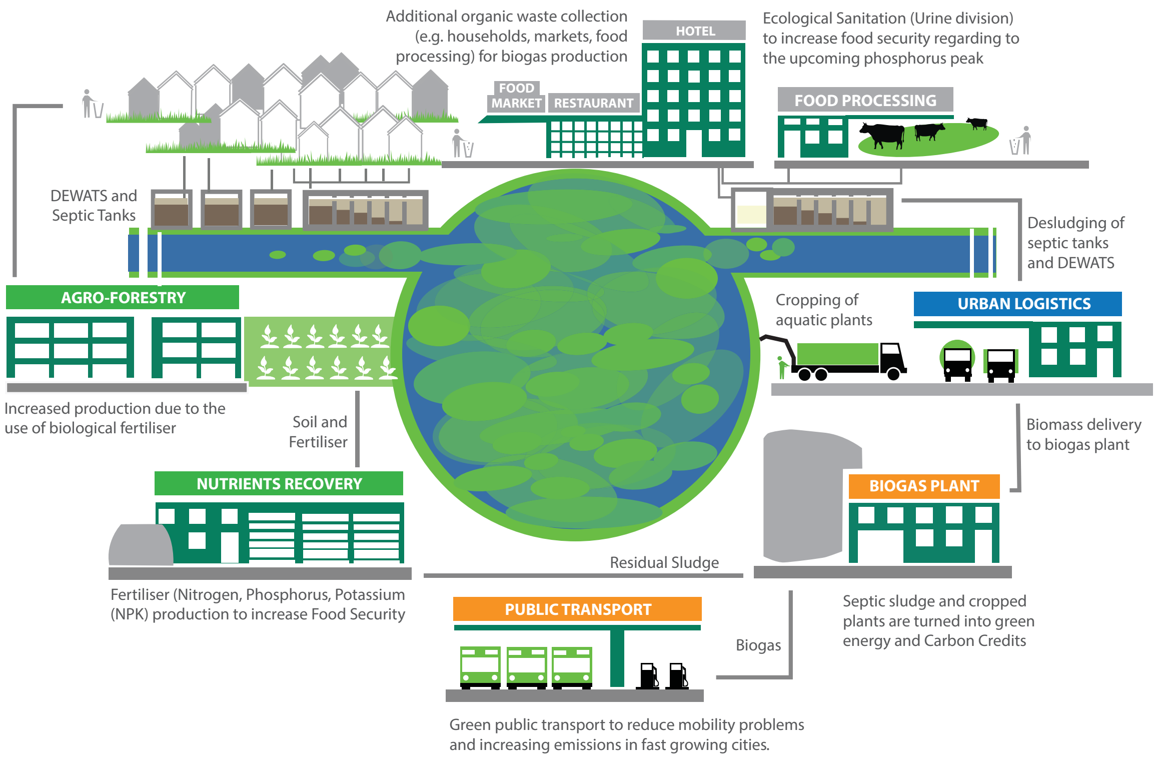
Such economic benefits should be explored and factored into the financial planning of any programme to build or upgrade sanitation and wastewater management systems. Figure 2.1 shows some estimates of the economic benefits that could become available from resource recovery, generated in an exercise in the Lao capital, Vientiane, as part of the CityBlues++ project (www.cityblues.la). As the figure shows, improved management and recovery of waste resources could produce additional benefits in areas as diverse as natural water management, food security, renewable energy production and climate change mitigation.

2.1 Health and social benefits

Poor sanitation and hygiene is the leading cause of diarrhoea, the second largest cause of death in children under age 5 in developing countries (UNICEF 2012a). In addition, many of the negative outcomes that follow from unsustainable sanitation and wastewater management overwhelmingly impact the poor, marginalized and vulnerable, and undermine efforts to reduce poverty and discrimination. Improved sanitation and wastewater management systems that prevent exposure of human populations to pathogens and toxic substances can make vast improvements in public health. Figure 2.2 shows estimated annual costs to the Indian economy stemming directly from inadequate sanitation. Most of the avoided costs are linked to direct and indirect health impacts (including lost work days).

It is important to note that these savings would not result simply from the installation of improved toilets; they would require systems that prevent human exposure to pathogens and other hazardous elements in wastewater and excreta all the way from the toilet until they had been treated and safely disposed of or reused. As will be emphasized in later chapters, sustainable sanitation and

FIGURE 2.1 **Potential added value of resource recovery in the city of Vientiane**



City population: c.760,000

- Water saving potential with low-flush/waterless urinals: 13,700 m^3 per day
- Agricultural potential using biogas digestate and urine as fertilizers is 40,000 ha. of rice cultivation
- Reduced CO_2 emissions due to substitution of mineral fertilizer and diesel: 44,000 tons CO_2/year
- Energy potential for transport sector in the organic waste is 10,000 km of bus travel per day (adjusted for energy consumption due to increased transport in waste collection)

Figure: Stockholm Environment Institute, based on image from Cityblues++

wastewater management is only possible with fully functioning and well-integrated systems.

Figure 2.2 also includes the opportunity costs of additional access time,[5] poor water quality and negative impacts on tourism. To these we could add a range of other sustainable development and human rights issues that can be addressed through sustainable sanitation and wastewater management:

- Disaster resilience: sustainable sanitation systems can contribute to keeping wastewater safely contained during floods and other disasters, reducing health risks, especially among the most vulnerable.
- Educational opportunities: diarrhoea and other sickness spread by untreated wastewater can result in missed school, and reduce the cognitive ability of children due to under-nutrition. Lockable sanitation facilities, especially with provision for menstrual health management, at schools can remove important obstacles to education for adolescent girls.
- Personal safety: people, especially girls and women, risk violence and other types of harm when they have to walk a long way for open defecation or to access a sanitation facility. Thus having close access to a facility can improve personal safety.

[5] Access time has been referred to as: "cost of additional time needed for accessing shared toilets and open-defecation sites compared to using a private toilet within the household, and cost of school absence time due to inadequate toilets for girls and work-absence time due to inadequate toilets for working women" (WSP 2011)

FIGURE 2.2 **Economic impacts of inadequate sanitation in India, by categories, 2006**

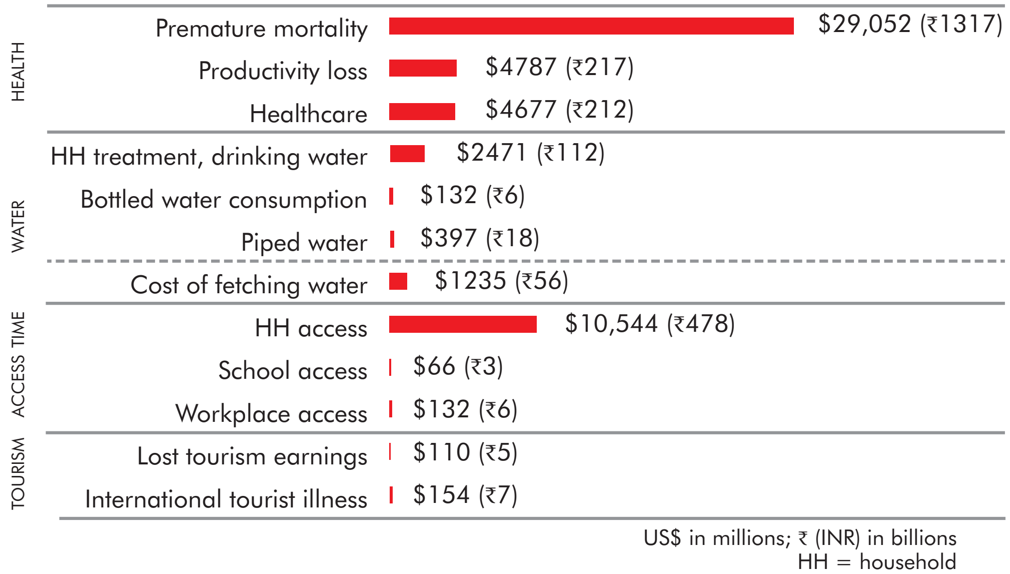


Figure: Based on WSP 2011

In addition to the reductions in disease incidence offered by improved sanitation, resource recovery and safe agricultural reuse can contribute a range of other health benefits, particularly in relation to nutrition (by safely boosting agricultural productivity). Especially in the case of smallholders, the livelihood improvements that agricultural reuse can bring to farmers can mean they can spend more on accessing health care or improving their quality of life in other ways.

2.2 Agricultural productivity and soil quality

Residential and agricultural wastewater and sanitation waste contains large amounts of the three most important and economically valuable inputs for agriculture: nutrients, organic matter and water. With appropriate treatment of wastewater or excreta, these can all be recovered and safely reused by farmers.

Nutrients

The most important source for nutrients in sanitation waste streams is human and animal excreta, which contains significant amounts of the three main components of agricultural fertilizer: nitrogen (N), potassium (K) and phosphorus (P; in the form of phosphates). If other organic waste is processed along with wastewater and other sanitation waste, even more N, K and P can be recovered. Excreta also contain micronutrients such as iron, chlorine, boron, copper and zinc, which are vital for plant and human or animal nutrition but are generally not found in synthetic fertilizers. The benefits of recovering, treating and safely reusing the nutrients for agriculture vary widely in different contexts. They include:

- low-cost replacement or supplementation of commercial fertilizers;
- reduced reliance on bought/imported commercial fertilizers;
- direct improvements in agricultural productivity at minimal cost for smallholders who use no fertilizers and have on-site sanitation systems;
- reduced health risks for farmers in communities practising open defecation in the fields or applying excreta and other wastewater directly to crops; and
- new business opportunities in the production and sale of fertilizers from recovered resources.

Depending on the quality of treatment and the practices followed, wastewater and agricultural inputs derived from it can be safely used in the cultivation of any kind of crop, including food crops for human consumption.

The quantities of nutrients that can be recovered from wastewater and excreta are significant. It has been estimated that in countries that are dominated by smallholder farming, including many countries in sub-Saharan Africa (IFAD 2011), *all current fertilizer use could theoretically be replaced with nutrients recovered from human excreta* (Rosemarin et al. 2008). Regions with high livestock production and major agricultural exports, such as South America, would require more nutrients (see Figure 2.3), but these could also be at least partially recovered from other organic waste streams such as animal manure, organic waste from the kitchen and waste from food industries.

At another scale, the urine and faeces excreted annually by one person contain nutrients equivalent to about 10 kg of synthetic fertilizer, with a value of approximately US$10 (Dagerskog et al. 2014). Its application would increase agricultural yield by a value of around US$50, which can make a significant different to the livelihoods of poor smallholder farmers, especially if they lack access to chemical fertilizers.

Looking at centralized waterborne urban systems, the annual monetary value of the recoverable resources nutrients and water discharged from Indian coastal cities and towns in wastewater has been estimated at 1.09 billion rupees (US$16 million at 2015 exchange rates). Of this, 93 per cent of the value comes from nutrients, the rest from water (CPCB 2009).

Some systems can even generate economic benefits by recovering nutrients *during* wastewater treatment. For example, spirulina and duckweed can be grown in effluent of a certain quality (usually after some pre-treatment) while it is stored in stabilization ponds.[6] These nutritious plants can then be used as feed in aquaculture and animal husbandry. In Niger, duckweed has been used to clean water in stabilization ponds, providing high-quality effluent that is then used for irrigating additional economically valuable crops (Quayle 2012).

FIGURE 2.3 **Nutrients consumed in chemical fertilizers vs nutrients available in human excreta in two continents, 2012**

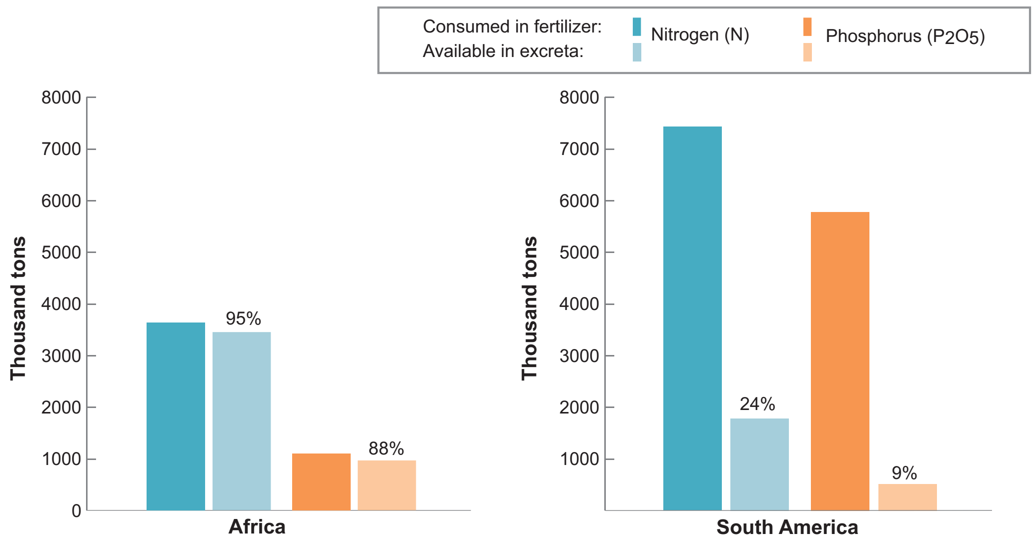


Figure: Based on data from faostat.fao.org.

[6] Stabilization ponds are large man-made basins, sometimes called lagoons that are often used in tropical and subtropical countries to treat wastewater. They may be a single pond or a series of ponds with different characteristics through which the wastewater flows.

Treated urine is a cheap, safe and effective fertilizer. Photo: Linus Dagerskog

Organic matter

The organic matter in wastewater and excreta mainly consists of proteins, carbohydrates and fats. If it is captured and processed (e.g. through composting or fermentation), this organic matter can be used as a potent soil conditioner as well as being a source of energy, as described below, especially if supplemented with food waste and agricultural residues (Lal 2008).

Increasing soil organic matter (SOM) supports soil functions such as retaining nitrogen and other nutrients, retaining water, protecting roots from diseases and parasites, and making retained nutrients available to the plant (Bot and Benites 2005). The organic matter itself also contains nutrients that will be released gradually as it is broken down by natural processes. It has been estimated that 1 per cent of additional SOM is worth about US$39 per hectare per year, due to the nutrients that are made available to plants (Land Stewardship Project 2013). Additionally, by improving retention of water and nutrients, SOM reduces run-off and eutrophication problems.

Declining SOM content is a widespread problem that directly impacts agricultural productivity and puts food security at risk. Annual soil organic carbon loss of 2–5 per cent has been reported for Africa (Bationo et al. 2007). In sub-Saharan Africa, 85 per cent of farmland has net nutrient losses that exceed 30 kg of nutrients/ha./year (Henau and Baanante 2006). Capturing organic matter from waste streams and applying it to agricultural land is a key strategy for improving soil fertility and productivity, alongside measures such as preventing overgrazing and the burning of natural vegetation, animal manure and soil residues.

2.3 Water security

Water consumption by human activities has grown twice as fast as the global population since 1900, from around 600 billion m^3 to 4,500 billion m^3 in 2010, and is expected to grow by more than 50 per cent again by 2050 (McGlade et al. 2012; WWAP 2015).

Sustainable development requires access to safe drinking water and hygiene facilities as well as protection of aquatic and terrestrial ecosystems. Water security is a growing problem for many arid and semi-arid areas, and those where demand from industry, energy generation, agriculture, freshwater supply and ecosystem replenishment outstrips availability. Sustainable sanitation and wastewater management systems can relieve these pressures in two ways: first, by reducing the input of freshwater into the system, particularly by using low-flush or dry toilets, and second by making the water fraction of wastewater available for safe reuse or environmental release.

In agriculture, water reuse can reduce the risk of drought to crops and facilitate irrigation, boosting productivity and even allowing an extra growing season. Farmers have identified year-round availability of wastewater as another important argument for its reuse (Drechsel et al. 2010). The 330 km³ of municipal wastewater produced globally every year could in theory irrigate more than 40 million ha. – equivalent to about 15 per cent of all currently irrigated cropland (Mateo-Sagasta et al. 2015).

Going down to national level, Figure 2.4 compares water withdrawals with the generation of urban wastewater in four countries. Clearly, current irrigation needs far outstrip urban wastewater production in some countries – although its contribution would still be significant (e.g. Brazil 22 per cent, Egypt 12 per cent, and Thailand 10 per cent). In an industrialized country like the Netherlands, the urban wastewater volumes produced are equivalent to almost a quarter of the water abstracted for industrial use.

Improved water use efficiency and reduction of water consumption can add up to significant water savings. This in turn reduces the energy and infrastructure requirements of the water and wastewater system, since it reduces the volume of wastewater that needs treatment and thus allows more efficient and specific treatment of different excreta and wastewater fractions. Water savings using dry or low-waste systems can vary between 6 m³/person and 25 m³/person annually, depending on waste separating techniques (Otterpohl 2009).

2.4 Clean energy

Organic waste produces methane when it decomposes. Methane is a greenhouse gas (GHG) more than 25 times as potent as carbon dioxide. Capturing the energy content of wastewater and excreta can be not only an efficient way to produce renewable energy, but also an effective climate mitigation measure.

The most efficient way to capture the energy content of these waste streams – and the one most compatible with resource recovery – is generating biogas. There has been a growing

FIGURE 2.4 **Water withdrawals vs wastewater production, selected countries**

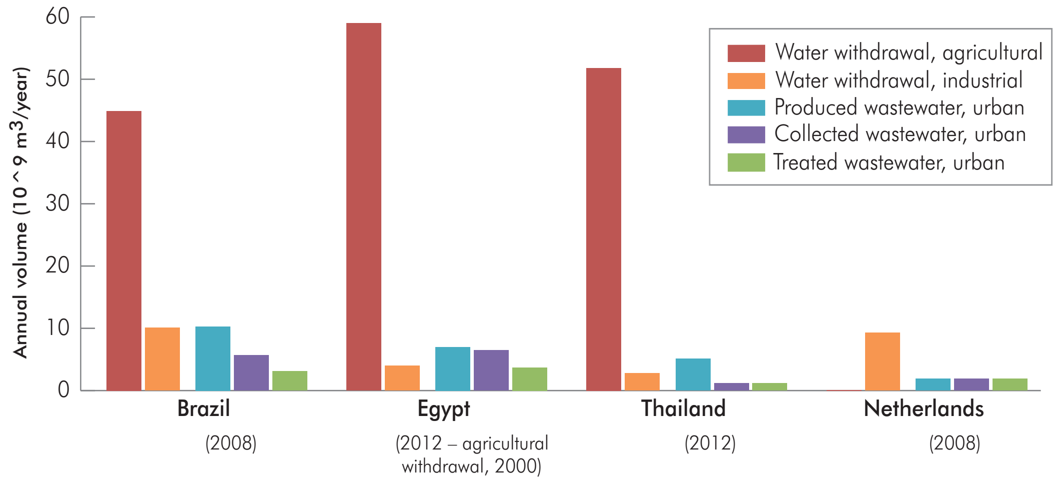


Figure: Stockholm Environment Institute, data from fao.org/nr/water/aquastat/main.

The Bio-Bus, running on biogas produced at a centralized sewage treatment plant, UK. Photo: Wessex Water

interest in using biogas as an alternative vehicle fuel, cooking gas or energy source for electricity production. Biogas can be used in large-scale applications to generate electrical or mechanical power, including as a vehicle fuel (Weiland 2010). It can also be a low-cost domestic cooking and heating fuel, a cleaner and healthier alternative to wood and other biomass fuels typically used by poor households. Thus, biogas generation from wastewater, excreta and other organic waste can help to expand access to modern energy.

According to one estimate, co-fermentation of wastewater in a decentralized treatment plant with food wastes and detergent could allow the generation of 0.9 kWh electricity per person per day, leaving the nutrients and parts of the organic matter intact for agricultural reuse. This corresponds to a monetary value of US$170 per year (Mang 2009; Mang and Li 2010). Based on an average annual electricity consumption of 3,500 kWh/household, the estimated global wastewater production of 330 km^3 could thus theoretically provide electricity for about 130 million households (Mateo-Sagasta et al. 2015).

Another way of recovering the energy from waste streams is incineration or controlled combustion. This has become widespread in many countries, including Denmark and Sweden, and China is currently investing heavily in incineration of solid waste (Li et al. 2015). There is some debate, however, over whether solid waste incineration discourages waste minimization or recycling, since it creates a demand for waste (Seltenrich 2013). If plastics are burnt, moreover, waste incineration cannot be counted fully as renewable energy production.

2.5 Climate mitigation

Closely linked to the question of energy recovery are reductions in GHG emissions. Improved sanitation and wastewater management can make an important contribution to climate mitigation, reducing emissions of several key GHGs, primarily CO_2, methane, and nitrous oxide. Methane emissions from wastewater contributed to approximately 7 per cent of total global methane emissions in 2010 (US EPA 2012b), and they are expected to grow by approximately 19 per cent between 2010 and 2030, with Africa, the Middle East, Asia, and Central and South America projected to have the greatest increases. Overall, the waste sector contributes <5 per cent of global GHG emissions (Bogner et al. 2007). Landfills are the largest contributor to GHG emissions

TABLE 2.1 Comparison of CO_2 emissions from consumption of different fuels

Fuel	kg CO_2 (excluding production of fuel)	kg CO_2 (including production of fuel)
Gasoline	2.36	2.65
Diesel	2.72	2.98
Biogas*	0.12	0.39

** Biogas is measured in m^3. One m^3 of biogas is equivalent to about 1.1 l of gasoline*

Source: Örebro Municipality 2010

in the waste sector, and organic solid waste in landfills can keep emitting methane for decades.

There are four basic ways in which reduced emissions can be achieved in the wastewater and organic waste cycle:

- avoiding uncontrolled methane emissions from waste,
- substituting fossil fuel with renewable energy recovered from waste streams,
- substituting chemical fertilizers that are produced with high inputs of energy, and
- carbon sequestration through the return of organic matter to soils.

The potential mitigation of GHG emissions is dependent on the system set-up. For example, in the case of more conventional wastewater management, modifying the treatment configuration can reduce CO_2 emissions by 35 per cent (Khiewwijit et al. 2015). Similarly, digestion of wastewater sludge and excreta (especially with other organic waste) can reduce unwanted methane emissions in post-processing of wastewater sludge by approximately 70 per cent (Rogstrand et al. 2012). For every kg of digested food residue, about 0.3 kg of CO_2 emissions can be avoided, if the biogas is collected and substitutes fossil fuel.
Table 2.1. shows CO_2 emissions from biogas compared to gasoline and diesel.

One study using lifecycle assessment methodology found that the use of source-separated urine as a fertilizer for wheat production in Sweden reduced CO_2 emissions by 33 kg CO_2/person/year compared to chemical fertilizer use and conventional wastewater treatment (Tidåker et al. 2007). GHG emissions from the production of chemical fertilizers are currently around 1.2 per cent of total global GHG emissions. While most of these emissions derive from the production of nitrogen fertilizer, emissions from the transport of the 30 million tons of phosphate rock traded globally each year are far from negligible (Cordell 2013).

Returning organic matter to soil is a recognized carbon sequestration approach. Recent research suggests that the carbon sequestration is most effective if different types of organic matter are treated differently. For example dry carbon-rich material is best converted into biochar (a soil enhancer) by pyrolysis, while wet nutrient-rich material is better processed by anaerobic digestion in order to maximize the fertilization value, thus helping to produce more organic matter (Smith et al. 2014).

If the estimated 46,200 million m^3 of methane that could be produced annually from the world's wastewater (Mateo-Sagasta et al. 2015) substituted diesel, it could lead to a potential GHG reduction of about 70 million tons of CO_2 equivalent.

2.6 Environmental protection and healthier ecosystem services

Preventing environmental damage has become an increasingly recognized and valued function of wastewater treatment, and a component in the sustainable development agenda (see Chapter 6). Systems that ensure wastewater is treated before any release into natural receiving waters reduce threats to ecosystems and the services they provide, including by improving the quality and safety (and thus usability) of freshwater, and reducing pollution and eutrophication in ecosystems that provide food (Corcoran et al. 2010).

Constructed wetlands[7] are a commonly used and effective link in the treatment chain for many types of wastewater – exploiting the physical, biological and chemical processes that occur in natural wetlands to purify and treat the water. (Constructing wetlands for wastewater treatment is considered an "environmentally sound technology" under Agenda 21.[8]) They are themselves valuable ecosystems, supporting biodiversity and providing many of the same important services for human society as natural wetlands.

Constructed wetlands can also attract many visitors. An example is the Park Huascar, in Lima, Peru, where treated wastewater is used to maintain a multi-purpose facility with a large lake, offering educational trails, a small zoo, a tree nursery, demonstration farms, playgrounds, and picnic areas under shady trees (di Mario and Drechsel 2013). The park provides important benefits for ecosystems (e.g. erosion prevention, soil fertility, and local climate regulation) in addition to the services it provides to residents and visitors.

At the same time, if wastewater is recycled and water-saving techniques are used, less freshwater needs to be abstracted from natural systems to meet human demand, leaving more of it available for other uses, including preserving ecosystem services and ensuring environmental flows. In cities with combined wastewater and stormwater sewage systems, moreover, there are various options available for keeping stormwater out of the system; for example, making surfaces in the built environment more permeable by leaving green spaces and ditches or using permeable paving (Charlesworth 2003). This can contribute to treatment of stormwater and replenishment of the water table. Alternatively, stormwater run-off can be used for irrigation, though it may require some treatment and may not be suitable for food crops.

2.7 Green business and employment opportunities

There are economic beneficiaries and employment opportunities along almost any wastewater management and sanitation value chain: from construction to operation and maintenance, transport, treatment and financing. Recovery and reuse add many more potential direct and indirect beneficiaries: farmers, transporters, vendors, processors, inputs suppliers and consumers. According to one estimate, increased investment in sanitation in India could create new business markets for the country up to an annual value of US$152 billion (WSP 2011).

In urban areas, resource recovery and reuse can improve the feasibility and profitability of urban agriculture by using wastewater as a source of water and nutrients: shortening the route to market, and allowing aquaculture and the production of high value crops such as flowers. An example is the harvesting of biomass grown within wastewater treatment systems – in particular, if this is used as feed for on-site aquaculture or animal husbandry it can provide an additional income stream, adding to the financial stability and sustainability of the systems.

Faecal sludge management – emptying pits and septic tanks, transporting the sludge

[7] A constructed wetland is an artificial wetland used to treat wastewater. Flora and fauna growing in the wetland can help to remove sediment, and micropollutants and to deactivate pathogens.

[8] Environmentally sound technologies are defined in Chapter 34 of Agenda 21 as technologies that: a) protect the environment; b) are less polluting; c) use all resources in a more sustainable manner; d) Recycle more of their wastes and products; and e) handle residual wastes in a more acceptable manner than the technologies for which they are substitutes.

New business: urine collection service for reuse, Burkina Faso. Photo: Linus Dagerskog

and treating it – is an area of growing business interest. It has proved to have strong market potential in many African and Asian cities, where it is common to rely on pit latrines and other on-site systems (Chowdhry and Koné 2012).

Apart from these businesses, there are also economic opportunities in recovering energy from the faecal sludge and processing this nutrient-rich organic waste into commercially attractive products.

KEY MESSAGES

- Sustainable sanitation and wastewater management could yield vast economic (as well as social and environmental) benefits for societies.
- Reuse of water, nutrients and organic matter in excreta can contribute to improving agricultural productivity and soil quality.
- Improved sanitation and wastewater management can generate energy resources and mitigate GHG emissions.
- Recycling water resources results in less freshwater that must be abstracted from natural systems to meet human demand, contributing to environmental sustainability.
- There are economic beneficiaries and employment opportunities along almost any wastewater management and sanitation value chain.

3. RESOURCE MANAGEMENT AND RECOVERY

3.1 Current status

Quantifying the current status of resource recovery is difficult. Considering the general lack of wastewater data, it is not surprising that the data on reuse is even scarcer, and only very rough estimates are available. However, we know that sanitation and wastewater management today are almost exclusively focused on disposal rather than resource recovery and reuse. Wastewater treatment, where it exists, generally only reduces pathogen content and less often chemical pollutants and excessive nutrients before release into the environment.

While resource recovery can add challenges to sanitation and wastewater management (see Table 3.1), it can also alleviate growing pressures facing these systems, such as reducing the need for advanced treatment when nutrients and organic matter can be reused in agriculture.

There are numerous systems for recovering and reusing resources from wastewater and excreta in operation today. The establishment of some of them was motivated by business opportunities, some by regulatory frameworks aimed at ensuring environmental protection, and some by tangible resource scarcity.

A healthy harvest from a urine-fertilized banana tree, Mali Photo: Linus Dagerskog

TABLE 3.1 Overview of challenges reported from resource recovery initiatives

Health/ environment	• There are potential problems related to the presence of both toxic chemicals (e.g. from industrial sources of effluent) and pathogenic micro-organisms when resources are reused. Even irrigation with treated wastewater can lead to excess nutrients, pathogens, heavy metals and salts building up in irrigated soils (UN Water 2015). • The degree and risks related to faecal cross-contamination are sometimes overlooked; it is essential to understand pathways of human exposure. Often there is too much focus on the risk related to end-products, while those present along the entire sanitation or wastewater value chain are not assessed and mitigated (Stenström 2013).
Social	• There is a lack of public environmental awareness generating acceptance of alternative solutions and also a lack of rigorous user training to ensure adequate usage, operation and maintenance (Rosemarin et al. 2012). • Non-waterborne or source-separating sanitation technologies may challenge users' perceptions because they break with the "flush-and-gone" paradigm of centralized wastewater management (Lienert 2013). Some people may be repulsed by the idea of handling human excreta in systems where they are stored or treated for reuse on-site (Andersson 2014a). • However, culturally rooted unease about reusing human waste has been found far less often than anticipated. Much larger challenges concern the ability of individuals and farm communities to adopt and sustain post-treatment risk-mitigation options, since many farmers and consumers are unaware of the potential negative health impacts of excreta and wastewater reuse (WWAP 2015).
Institutional	• Resource recovery will require much stronger governance and an active public sector working across sectors (Corcoran et al. 2010) • Time and resources for ensuring the adequate testing, trials and follow-up are required when implementing innovative solutions. There is a need to develop adequate institutional instruments to promote change (Rosemarin et al. 2012). • Many national behaviour-change programmes are not sufficiently informed by research into users' attitudes (WHO 2012b).
Technical	• For an end-product to be interesting to customers (reusers) it is important that quality, e.g. nutrient level, is constant over time. This may place requirements on the composition of incoming material. Consistency in produced volumes is also of importance to maintaining a designated level of supply (7th World Water Forum 2015). • Technical innovations may require a high level of craftsmanship among builders. • Going from pilots to full scale may result in challenges to the feasibility of technologies and logistics. • Retrofitting or replacing existing systems may be costly (Larsen and Gujer 2013).
Financial	• Cost-benefit analyses may be crucial to providing support for the higher initial investments that may be required for improved resource management and recovery (WHO 2012a) • One of the biggest challenges when considering other value-added components is the overall economics of market in focus. For example, metal recovery involves high start-up and operating costs (7th World Water Forum 2015).

3.2 From linear to cyclical resource use

Ecosystems are highly efficient at recycling resources. Organisms interact with each other and with the environment, allowing nutrients, water and other resources to move through the system, with the "waste" products from one process becoming valuable inputs to the next process. Very little is lost except energy, which is replenished by sunlight. However, human interventions such as agriculture have resulted in large-scale extraction of resources from certain ecosystems and the release of various wastes and by-products into other systems (DeFries et al. 2004).

With industrialization, growing use of non-renewable resources, and transformation of the landscape through urbanization and agricultural expansion, volumes of waste are growing and the capacity of natural systems to absorb them – and to produce new resources – is shrinking. In the long term, sustainable development requires keeping resources in circulation, making productive use of them at every stage.

One of the three essential plant nutrients, phosphorus, illustrates the highly inefficient ways in which we currently manage vital resources found in wastewater. Only 20 per cent of phosphorus mined for food production systems ends up in food consumed (Schröder et al. 2010). Much of the remainder is lost to rivers and coastal waters, where it can cause eutrophication. The system requires constant new inputs. It is also worth noting the large (usually fossil) energy inputs the system requires, including for fertilizer production. (For more on synthetic fertilizers and their production see Box 3.1.)

There is an urgent need for societies to manage their resources more efficiently in order to meet current and future needs. A large part of sustainable development concerns "closing the loop": turning linear resource management schemes into cyclical ones, within so-called circular economies.

In the case of sanitation and wastewater management, there are many "loops" to consider. Two of the most important of these link sanitation with food production: those for nutrients and organic matter. The loop for (waste) water takes in not only agriculture but also ecosystem flows and a variety of other human uses, including industrial. While wastewater often eventually returns to water bodies (ideally after treatment), it is not always possible to reuse it directly, for example because it is too polluted, or

A phosphate mine in Tunisia. Phosphorus is a serious issue for food security; mineral phosphate prices rose around 800% in 2008, and 75% of the limited commercial reserves are in Morocco/Western Sahara. Photo: Reuters / Zoubeir /Souissi

BOX 3.1

Chemical fertilizers: agricultural productivity, but at what cost?

Modern chemical fertilizers originated only in the early 20th century. Comprising mainly nitrogen, potassium and phosphates, they have led to massive increases in crop yields. Yet our increasing reliance on them comes with many costs.

First, anthropogenic nitrogen production is energy-intensive. The main method used, the Haber-Bosch process, involves combining nitrogen from the air with hydrogen, usually produced from natural gas, under high pressure and heat. As well as the energy, it consumes large volumes of natural gas.

When nitrogen fertilizer is applied to farmland it releases large amounts of nitrous oxide (NO_2), a greenhouse gas that has 300 times the atmospheric warming effect of the equivalent weight of CO_2. In areas where a lot of synthetic fertilizers are used, this can account for the bulk of anthropogenic NO_2 emissions – as much as 74 per cent in the USA (US EPA 2010). Other impacts are diminished stratospheric ozone, contribution to acid rain, changes in the global nitrogen cycle, and nitrate pollution of groundwater (Roy et al. 2002).

Similarly, anthropogenic phosphorus production depends on mining of phosphatic rock. The main remaining deposits are concentrated in a handful of countries, with the largest reserves in Morocco, Western Sahara and China. It is estimated that half of the phosphorus mined every year finds its way into watercourses and oceans (Rockström et al. 2009), where – along with nitrogen – it contributes to eutrophication and oxygen depletion. On a global scale, the phosphorus available from human excreta, if collected, could equal 22 per cent of total global phosphorus demand (Mihelcic et al. 2011). This is a significant share, but it is also an indicator of how much of the nutrients applied during farming are lost before entering the human food chain.

The worldwide use of synthetically produced fertilizers is estimated at 170 million tons every year (FAO 2011), though it is very unevenly distributed. At the same time, conventional sanitation and wastewater management systems annually dump nutrients the equivalent of around 50 million tons of fertilizer, with a global market value of around US$15 billion (Werner 2004), into pits and the natural environment.

released downstream of where freshwater is abstracted. However, there are many ways of closing the loop in terms of freshwater and wastewater, such as recovering water from urban sewage and returning it to potable use (after thorough treatment) as is being done in Windhoek in Namibia (see the case study in Section 9.1), or reusing wastewater in agriculture or forestry, or filtering it through constructed wetlands.

Closing these loops requires fundamentally new approaches to sanitation and wastewater management, which need to be reflected not only in technological systems but also in social, environmental, institutional and financial arrangements. When resource management becomes the central function of sanitation and wastewater management, this suggests a new order of logic for planning and designing a sanitation and wastewater

FIGURE 3.1

Framing sustainable sanitation and wastewater management from a resource management perspective

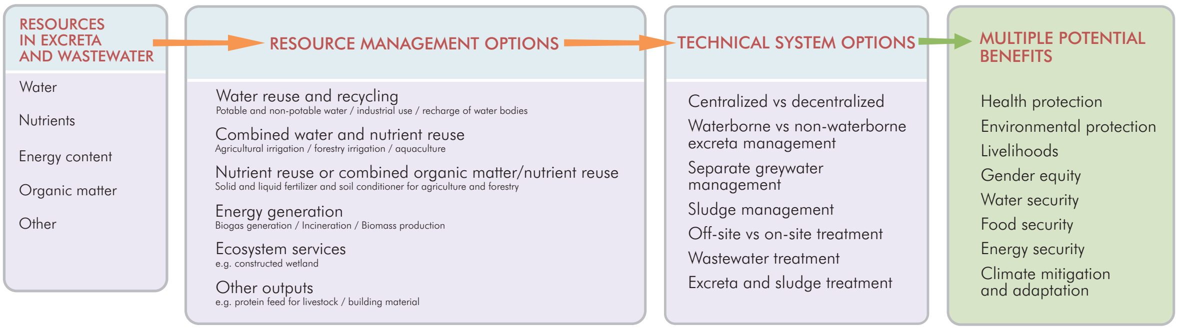


Figure: Stockholm Environment Institute

management system (see Figure 3.1). The first question to ask is what resources are available in the waste streams, what demand there might be for them, and how they could be economically recovered. Box 3.2 presents an exercise in mapping available resources and their potential value for an urban centre.

3.3 Identifyting resource demand and availability

For resource recovery to be viable, there must be the prospect of future demand or products derived from the resources, as well as the possibility of bringing them to centres of demand without prohibitive economic, environmental or social costs.

Calculating demand is not just a matter of identifying shortfalls in a particular resource. Demand depends on the "utility" of a product to the consumers; this is, how much they are willing to pay for it, which can be affected by myriad factors linked to their attitudes and expectations. For example, there is often resistance to the idea of excreta-based fertilizers, from users, neighbours and potential consumers of the crops grown with them. However, experience suggests

Faeces composting by a local enterprise, El Alto, Bolivia. Photo: Flickr / SuSanA Secretariat

BOX 3.2

Estimating the potential value of waste resources

Step 1: Mapping waste streams

The first step in estimating potential supply is to map existing and potential future sanitation and wastewater streams. This should be relatively simple in cities with large centralized sewer networks; however, as the first figure below shows for Dakar, there can be a wide variety of streams in low- and middle-income cities and peri-urban areas. This figure was created using an approach for sanitation waste inventories, "faecal waste flows", developed by the World Bank Water and Sanitation Programme.

Step 2: Estimating resource content

The next step is to estimate what resources may be available in the different streams. The second figure shows how the potential added values for Dakar if the faecal waste flows from on-site systems (along with a share of urine) were efficiently managed for resource recovery. In this initial exploratory exercise the focus has been limited to recovering sanitation waste from on-site systems, which in the case of Dakar could cover 76 per cent of all existing sanitation installations.

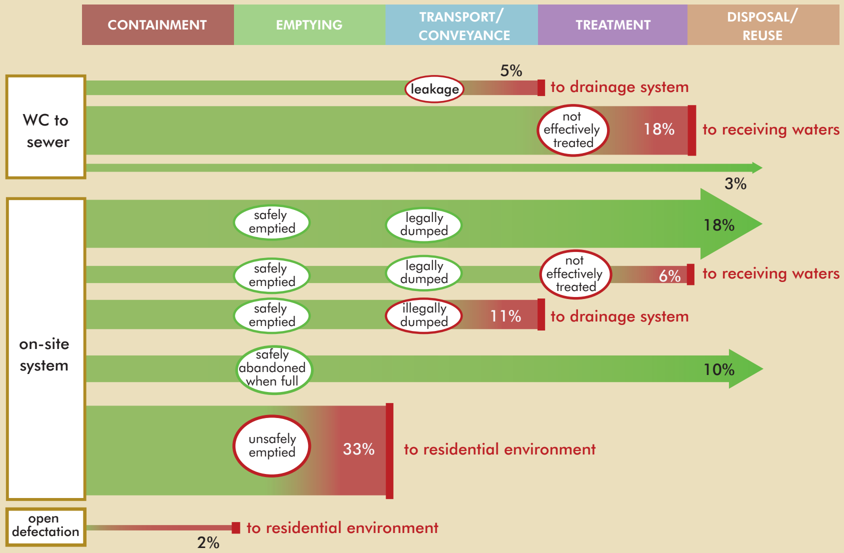
If the faecal sludge were co-digested with organic municipal waste and co-digested to produce biogas, an energy surplus equivalent to about 3,000 m^3 of diesel fuel could be achieved (which excludes the extra energy required to collect the faecal sludge, organic waste and urine, estimated at about 3,300m^3 of diesel). In addition to this renewable energy production, the appropriate treatment and reuse of nutrients contained in urine, faecal sludge and organic waste would suffice to fertilize over 50,000 ha. of rice cultivation rice (yielding around 200,000 tons of rice per year), which for Senegal corresponds to a quarter of annual imports, and could therefore notably contribute to both food "sovereignty" and food security. Apart from offering the prospect of recovery of valuable resources, taking a reuse approach will make a significant contribution to controlling mismanagement and dumping in residential environments and receiving waters. From a climate change perspective, substituting diesel and chemical fertilizers could potentially reduce yearly carbon emissions by almost 70,000 tons per year.

that such resistance can be overcome with awareness campaigns and demonstrations. Recovery schemes also require public- and private-sector investment – and can create potentially lucrative business opportunities. Institutions, including legal and policy frameworks are needed to provide the critical support.

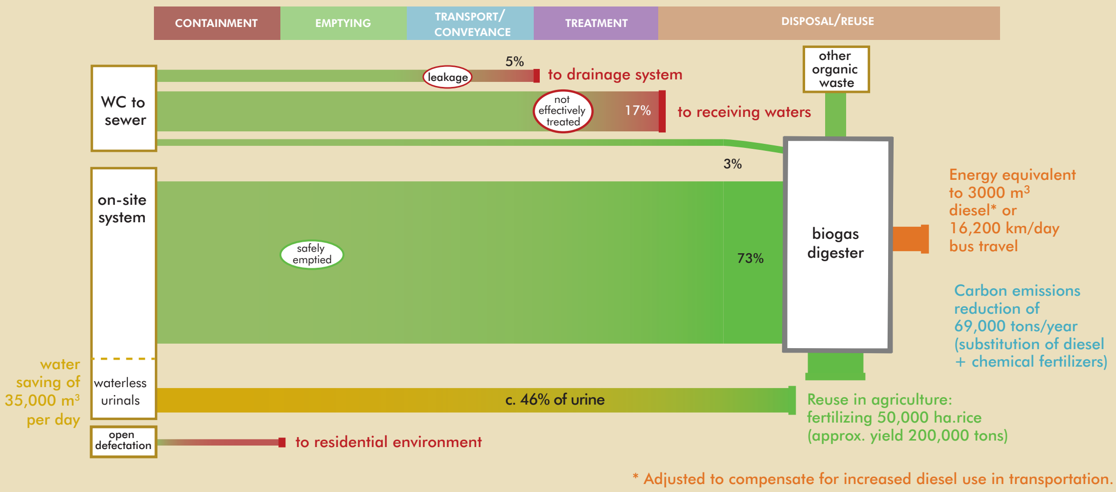
Once resource availability and potential demand have been established, it is necessary to look at the recovery options that provide the best fit in context. There are also questions of technical feasibility, and the possible need for new infrastructure or other arrangements.

The distance between where the waste is generated or processed and the locations where it can be reused is another crucial consideration. In the case of agricultural reuse, for example, this distance is likely to be negligible in smallholder farming communities, but can become more of an issue in urban and peri-urban settings far from farmland where the products could be applied.

Faecal waste flows in Dakar, Senegal – present status



Potential for resource recovery in waste flows, Dakar



The red arrows indicate unsafe waste management and the green arrows safe management, at least from a human health point of view.

Figure: Stockholm Environment Institute, based on WSP 2014, with additional calculations by SEI.

Other potential costs include treatment systems, providing regular quality testing, equipment and awareness-raising campaigns.

Figure 3.2. shows the main resources that might be recoverable from different waste streams, depending on the context. The sizes of the waste streams, and the quantities and concentrations of the resources, as well as the potential reuses, would require detailed, context-specific analysis. They would also depend on factors such as industrial activities, existing technologies and wastewater connections, diets, solid waste management practices, climate and geology (for more information on material flow analyses see e.g. Montangero 2006; Meinzinger 2009).

Nutrients and organic matter

Reuse of nutrients and organic matter from sanitation and wastewater streams has received more attention in recent years, but has in fact been practised since ancient times as a way of providing local fertilizers. Despite the many options, this type of reuse from sanitation and wastewater systems still occurs on only a relatively limited scale around the world. There are many possible reasons for this, including widespread social resistance to the reuse of human waste, the potential risks of exposure to micro-pollutants (which have increased with the combination of domestic and industrial residues and a generally high societal use of chemicals), and the risks from pathogens. At the same time, chemical fertilizers are now widely accessible (and even subsidized by some national governments).

In agriculture and forestry, recovered resources in the form of nutrients and organic matter could complement or supplement current use of synthetic fertilizers and soil conditioners; hence an inventory of productive land use where there is (or is likely to be) an identifiable need for new inputs is a useful starting point. The inventory could include agricultural land with low fertility or dependence on uncertain or unaffordable supplies of synthetic fertilizers, and reforestation projects. However, there may also be demand for wastewater- and excreta-derived fertilizers and soil conditioners, on economic, social or ethical grounds, even when synthetic alternatives are readily available.

Many innovative measures have been tried around the world to make excreta-based fertilizer products attractive to the market. One is to market them with names, packaging etc. that underline their transformation from excreta to a new, safe product. For example, this helped a peri-urban initiative in Ouagadougou, Burkina Faso, to build a market for source-separated, treated urine as a fertilizer (see Dagerskog et al. 2014). In El Alto, Bolivia, herbs are added to treated urine to change the colour and odour. Products derived from sewage sludge and faecal sludge from on-site sanitation can be processed by, for example, making them into dry pellets, which are also more convenient to apply to cropland.

A human being excretes roughly the same amount of nutrients they consume. Thus it is possible to estimate how much of each nutrient should be available in a sanitation waste stream based on the food consumed by the relevant population (assuming that most of the population's excreta end up in the waste stream). Table 3.2 shows estimated average per capita nutrient content in human excreta in selected countries, as calculated by Jönsson et al. (2004) using data on national average food consumption from the UN Food and Agriculture Organization (FAO).

The concentration of nutrients in the waste stream depends on what other waste enters the stream alongside human excreta. In systems that keep excreta separate from other wastewater (for example, many rural on-site systems), the quantity of nutrients per unit of weight or volume of waste

FIGURE 3.2 **Overview of waste resources and potentials for improved management and recovery**

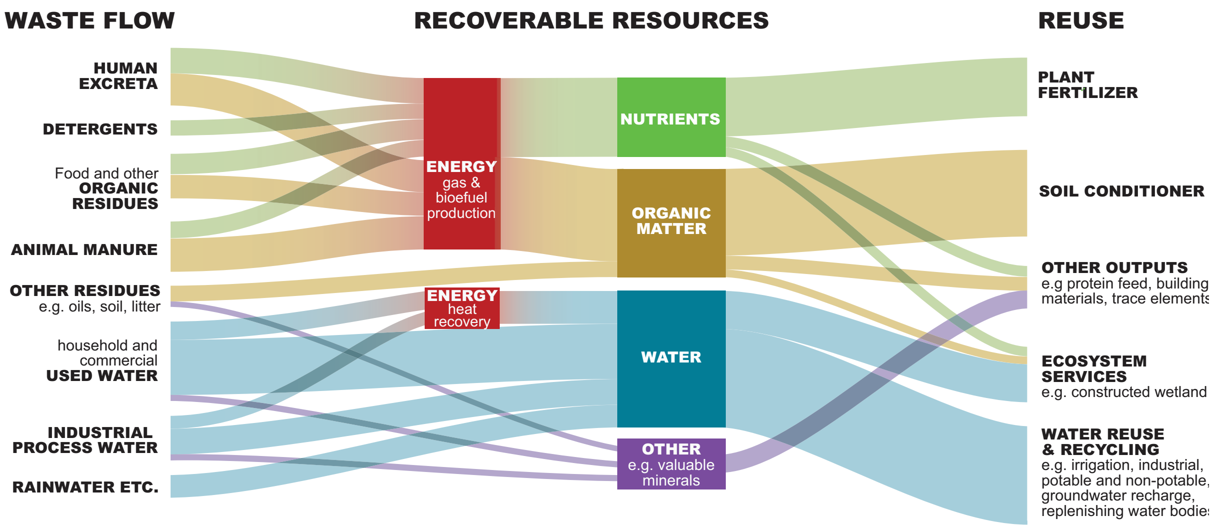


Figure: Stockholm Environment Institute

TABLE 3.2 **Estimated excretion of nutrients per capita in different countries**

Country	Nitrogen (kg/capita/yr)			Phosphorus (kg/capita/yr)			Potassium (kg/capita/yr)		
	Urine	*Faeces*	Excreta	*Urine*	*Faeces*	Excreta	*Urine*	*Faeces*	Excreta
China	3.5	0.5	**4.0**	0.4	0.2	**0.6**	1.3	0.5	**1.8**
Haiti	1.9	0.3	**2.1**	0.2	0.1	**0.3**	0.9	0.3	**1.2**
India	2.3	0.3	**2.7**	0.3	0.1	**0.4**	1.1	0.4	**1.5**
South Africa	3.0	0.4	**3.4**	0.3	0.2	**0.5**	1.2	0.4	**1.6**
Uganda	2.2	0.3	**2.5**	0.3	0.1	**0.4**	1.0	0.4	**1.4**

Adapted from Jönsson et al. 2004

will be much higher than in waterborne systems, especially when they mix household and other waste flows. Wastewater is often classified according to strength (i.e. concentration of non-water components), and these classifications can be combined with food consumption data to estimate approximate levels of nutrients. Table 3.3 provides estimated nutrient levels in domestic and municipal wastewater. (The difference between these two streams is depicted in Figure 3.6.)

It is also worth noting that the vast majority of nutrients in excreta are found in urine. Urine is particularly rich in nitrogen. It also contains P and K, but the ratios of N to these other nutrients are higher than in most commercial fertilizers. Urine also has far lower pathogen content than faeces. This is one of the main arguments in favour of source separation of urine (see Section 4.4). As a rule of thumb, one person's annual urine excretion is enough to meet the nitrogen fertilization needs of 300–400 m² of crops, and the phosphorus fertilization needs of 600 m² of crops for one growing season (Jönsson et al. 2004).

Faeces also contains nutrients, though here P is the most important. The faeces excreted by an average person contains enough P to fertilize 20–40 m² of wheat grown on low P soil; in soils with normal P content, one person's faeces can fertilize 200–300 m² of wheat production (EcoSanRes 2008). For further discussion of the agricultural value and reuse of excreta see Jönsson et al. (2004).

The content of organic matter in domestic sanitation waste streams depends largely on habits linked to diet and food preparation. Unlike nutrients, the organic matter content of sanitation waste is found almost entirely in faeces. This organic matter has two main reuse values, which are not mutually exclusive: as a soil conditioner and as a source of energy. The average person produces around 50 litres of faeces each year (EcoSanRes 2008). Where it is used, toilet paper is another significant source of organic matter in sanitation waste.

How much of the organic content in the sanitation waste stream can be recovered, and in what form, depends on treatment techniques. As faeces may contain a high pathogen load, treatment and safe handling are particularly important. In waterborne systems a large part of the organic content can be captured in the sludge that is produced during wastewater treatment. Depending on the efficiency of the system, about 20–30 kg/person/year of dry organic matter can be recovered in this way (Roy et al. 2011). Faeces may also be treated through composting or desiccation.

One important factor to note is that for soil conditioning, much heavier application of faeces is needed than if it is being used purely as a phosphorus fertilizer. The faeces

TABLE 3.3 **Typical nutrient concentrations in untreated domestic and municipal wastewater**

	Wastewater concentration	Nitrogen (mg/l)	Phosphorus (mg/l)	Total Organic Carbon (mg/l)
Domestic wastewater	*Low*	**20**	**4**	**80**
	Medium	**40**	**7**	**140**
	High	**70**	**12**	**260**
Municipal wastewater	*Low*	**20**	**4**	**80**
	Medium	**40**	**8**	**160**
	High	**85**	**15**	**290**

Adapted from Tchobanoglous et al. 2003

excreted by one person in a year contain enough organic matter to condition 1.5–3 m² of agricultural soil (Jönsson et al. 2004).

Other organic waste from households and industries also needs to be considered as a potential source of organic matter. According to data from Vögeli et al. (2014) the yearly generation of organic residues in 23 cities around the world ranges from 45 to 320 kg per person (see Figure 3.3).

Recycled water

In many places reuse of water resources is an important strategy for managing water scarcity, especially when there are competing demands for limited water from human settlements or industrial activities. Many small-scale farmers in urban and peri-urban areas in water-scarce countries already depend heavily on wastewater to irrigate crops – often as it is the only reliable source of irrigation water

FIGURE 3.3 **Composition of municipal solid waste in 23 cities**

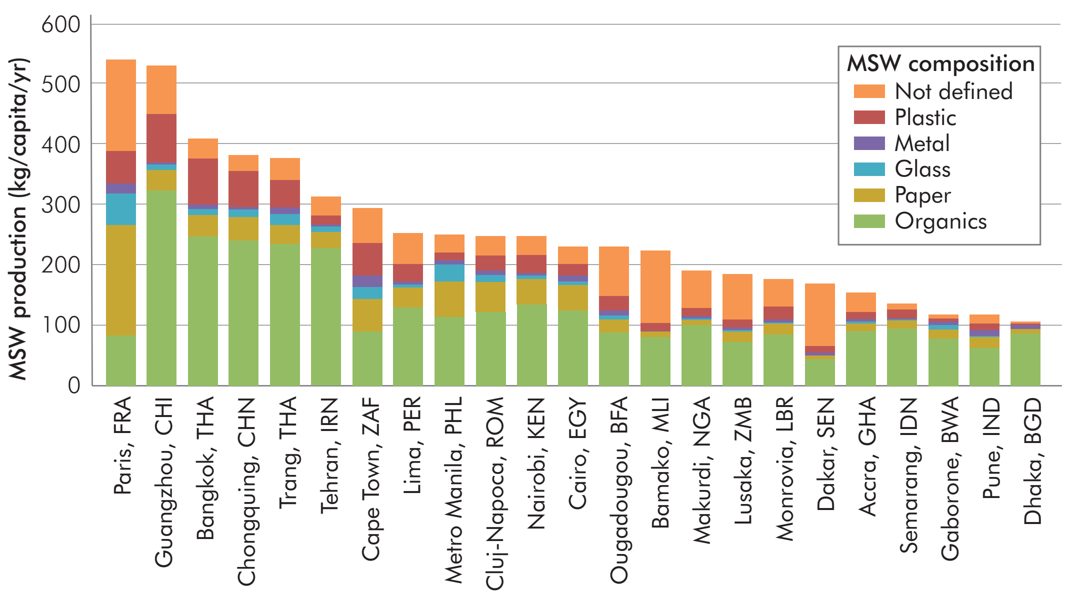


Figure: Based on Vögeli et al. 2014

available (Sato et al. 2013). The World Health Organization (WHO) has estimated that 20 million hectares of arable land worldwide (approximately 7 per cent of total arable land) is irrigated using wastewater (WHO 2006). In 2006 there were over 3,300 water reclamation facilities worldwide, with varying degrees of treatment and for various applications (Salgot and Huertas 2006). Most of these were in Japan (over 1,800) and the USA (over 800), but Australia and the EU had 450 and 230 projects, respectively. The Mediterranean and Middle East had around 100 sites, Latin America 50 and sub-Saharan Africa 20.

In addition, the reuse of greywater (water from washing, showering etc.) is gaining increasing interest at household and community levels (see a case study in Section 9.2). Greywater makes up most of a typical domestic wastewater flow and can be safely used for toilet flushing, landscape irrigation and similar uses if it is kept separate from excreta and free of toxic substances. For more on greywater recovery schemes see Section 4.4.

There are numerous examples of ways to reuse or recycle wastewater (see Figure 3.4). Some common ways include:

- agricultural and landscape irrigation,
- industrial uses (e.g. recycled process water, cooling),
- potable uses (e.g. mixing in municipal water supply),
- non-potable uses (e.g. toilet flushing, dust control, car washing),
- recharge of natural water bodies (e.g. groundwater),
- replenishing artificial lakes and wetlands.

For the management of water demand and potential scarcities it may be strategic to make an inventory of the main water supply flows, and then compare them with wastewater flows to see how the wastewater flows could be matched to demand – similar to the faecal waste flow diagram in Box 3.2. Here it makes sense to try to find wastewater streams and recovery options that best match the water quality requirements of each segment of demand, to avoid investment in unnecessary treatment. How to deliver separate streams of treated wastewater to

FIGURE 3.4 **Wastewater reuse, as part of natural water cycles**

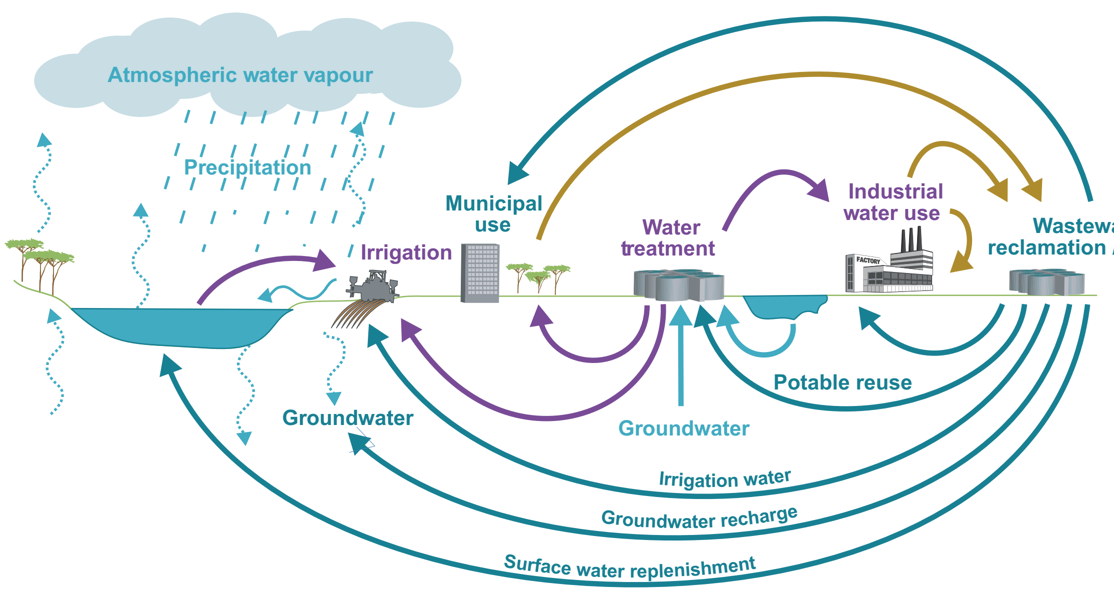


Figure: Based on Asano 2002

Cropland irrigated with recycled wastewater in drought-striken Watsonville, California. Photo: Flickr / USDA

the end-user is another relevant question – for example, to avoid the inefficient but widespread practice of using drinking water for irrigation.

By volume, water is the main component of any wastewater stream. A locality may produce a wide variety of wastewater types, depending on industrial and commercial activities, land use types, human settlements and urban structures. The volumes and content of the different streams can also vary widely. Figure 3.5 provides an overview of typical wastewater flows from different sources in an urban area.

The overall amount of wastewater generated within a locality can be very roughly estimated based on water supply data, which is usually readily available. Adjustments must be made for water that does not end up in wastewater, such as water used for irrigation; water incorporated into industrial products; or the portion of water drunk by people that does not end up in wastewater. Furthermore, if sewer networks are poorly maintained and leak, they can reduce the amount available for reuse, as well as contaminating groundwater and surface water with pathogens and pollutants.

FIGURE 3.5 **Origin and flows of wastewater in an urban environment**

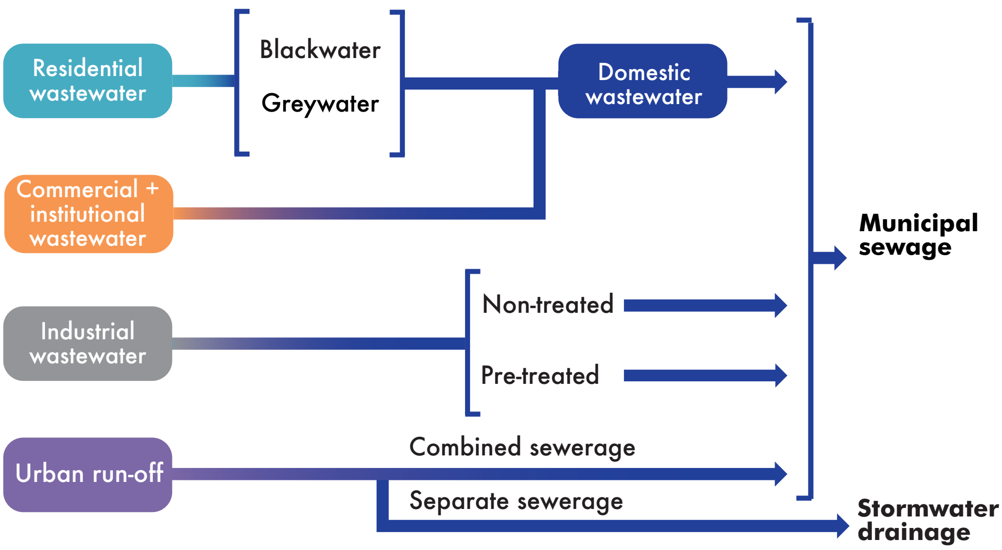


Figure: Based on Helmer and Hespanhol 1997

However, not all water in wastewater streams can be considered equal for the perspective of recovery and reuse. At one end of the scale, some types of wastewater can be safely reused for domestic cleaning, irrigation and even drinking after minimal treatment. At the other, some wastewater streams may be so contaminated that treating them for many types of safe reuse may be prohibitively expensive.

Because of this, it is worthwhile considering different wastewater streams separately. This allows more precise calculations of how much wastewater is available that could be suitable for particular types of reuse. There may also be opportunities for greater control and separation of wastewater at the source, to prevent relatively clean wastewater streams being contaminated and allow more targeted and (cost-)efficient treatment. For example, an industrial wastewater stream might consistently contain certain micro-pollutants but be otherwise relatively pure. This stream can then be given specific treatment to remove those micro-pollutants near the source, while it would be too expensive to treat all the wastewater generated in the locality in the same way. Chapter 4 discusses further the potentials of source separation of waste streams.

When making an economic calculation of the costs and benefits of wastewater recovery and reuse, it is important to exclude the cost of treating wastewater to effluent standards (i.e. standards allowed for release to the environment), which are the minimum standards for all wastewater treatment. This is relevant, for example, when comparing with the costs of an alternative drinking water production method, such as desalination.

At the household level, the generation of domestic wastewater varies greatly between locations, populations and even individual households. It depends not only on the availability of water but also, among other factors, on whether household members work outside the household, types of household installation (e.g. washing machines or water-saving equipment), and lifestyles. Another way to reduce treatment needs and conserve natural water sources is, of course, to reduce the amount of water input into the system. For example, a flush toilet's water consumption alone can consume around 6,000 to 15,000 litres per user annually (Larsen et al. 2013).

Combined water and nutrient reuse

For most types of reuse and disposal, it is necessary to separate nutrients and organic matter out from wastewater streams that include diluted excreta. However, in some circumstances it is viable to reuse this wastewater without doing so, particularly to fertilize and irrigate simultaneously in agriculture, forestry or similar activities. In urban areas, particularly in dry and water-

Treated sewage sludge being applied to cropland in Germany. Photo: Flickr / SuSanA Secretariat scarce regions, the wastewater can be applied to green spaces. In several Asian countries (among them China, India, Indonesia and Vietnam) it is already common practice to reuse water and nutrients together in aquaculture.

As well as promoting plant growth, this kind of combined reuse cuts out treatment stages (reducing investment and energy use), as there is no need to separate nutrients and organic matter from the water content. Often, water stabilization ponds and other low-cost wastewater treatments may be sufficient to bring pathogen and pollutant loads within acceptable limits (Alderson 2015).

Both conventional municipal wastewater and source-separated blackwater (flushing water and excreta) can be sources for combined water and nutrient reuse (see the case studies in Chapter 9).

Demand for and availability of energy

Biogas production using anaerobic digestion (or fermentation) of organic matter from wastewater treatment plants was first used in the early 1900s. Its application has diversified over the years in regard to the types of waste streams and scales of operation involved.

Biogas production can be done at the level of individual households or industries, of communities or districts, or centrally. It is often most efficient to add food and other organic waste to the wastewater or excreta, as both contain significant organic matter. Organic waste deriving from different industrial activities should also be considered as a potentially important energy recovery input. Many rural households in China have their own biogas digesters, which in most cases combine human excreta with animal manure and organic waste.

The energy potential of waste streams varies widely, depending on the concentration of organic matter– and in particular the excreta content. Faecal waste derived from higher-protein diets (typical of wealthier consumers) generates more biogas. Table 3.4 gives an overview of biogas production potential from some typical sanitation waste streams. In addition to these figures, roughly 10 kg (wet weight) of non-sanitation biowaste (e.g. kitchen and market waste) can produce 1 m³ of biogas (Vögeli et al. 2014).

In terms of how much energy can be produced in this way, 1 m³ of biogas yields approximately 6 kWh of energy, equal to

Part of the combined heat and power bioenergy plant at the Blue Plains Advanced Wastewater Treatment Plant, District of Columbia, USA. Photo: DC Water

TABLE 3.4 **Biogas production potential from excreta and sludge**

	Public and private pit latrine sludge	Septic tank septage	Normal domestic wastewater
Characteristics	High concentration, low stabilization	Low concentration, good stabilization	-
Biogas (m^3/kg total solids)	0.35–0.5	0.1–0.2	-
Biogas (m^3/m^3)	8.0–10.0	0.5–2.0	0.1–0.3

Source: Schmidt 2005

approximately 0.6 litres of diesel fuel (Vögeli et al. 2014). A very approximate rule of thumb is that human excreta from 10–15 people can provide enough biogas to cook three average meals a day for one person (Balasubramaniyam et al. 2008). Thus, energy recovery from wastewater can only be a contribution to energy security and move towards renewable energy, not as a whole solution. Furthermore, large-scale schemes are more likely to be economically feasible than smaller-scale schemes.

However, anaerobic digestion also serves as a form of wastewater treatment (e.g. removing pathogens), so a biogas digester serves both functions. Nutrients and organic matter can be recovered from the waste after digestion. Digestion can also reduce the high energy demand and greenhouse gas emissions typically associated with wastewater treatment by replacing energy-intensive conventional technologies, and reducing methane emissions.

In some jurisdictions, including the European Union, food waste and animal by-products are required to undergo "hygienization" to remove pathogens before being used for biogas production. The most common method is pasteurization (heating to a high temperature for a period of time). Pasteurizing wastewater sludge with such organic wastes increases the energy input significantly, but it has been shown that the process can still generate a positive net energy output (Rogstrand et al. 2012).

Incineration is also commonly used for energy recovery from sewage sludge and municipal organic solid waste. When incinerated, the calorific value of dry sewage sludge (12–20 MJ/kg) is close to that of coal (Samolada and Zabaniotou 2014). Incineration also greatly reduces the volume of waste. However, it also destroys most organic matter and nutrients (e.g. nitrogen, sulphur and plant-available phosphorus) that could otherwise be recovered (Niwagaba 2009). Thus incineration should only be considered as part of a sustainable system when nutrient reuse is not feasible.

Other energy recovery methods for sludge that have yet to move beyond small-scale implementation are pyrolysis and gasification. Thermal gasification of various biomass residues is a promising technology for combining bioenergy production with soil fertility management through the application

Pellets of cellulose fibre recovered from sewage. These pellets, marketed under the name Recyllose, can be used as fuel or in producing paper, insulation, construction materials and bioplastics. Photo: Reuters / Baz Ratner

of the resulting biochar for soil amendment (Hansena et al. 2015).

Recovery of heat from wastewater has attracted interest, especially in countries with housing heating demands. Building-level systems are being marketed that can recover heat from drain water to preheat hot water, while larger-scale systems can recover heat from municipal sewers. Heat can also be recovered from some industrial wastewater streams.

Combining biomass production and wastewater treatment is an integrated land-use-system approach that can yield many benefits. Biomass grown in wastewater during treatment can be used as input for energy recovery. An emerging approach is microalgae wastewater treatment (Sriram and Seenivasan 2012). This needs further development to become a competitive source for energy (Trivedi et al. 2015).

Other resource utilization

Besides these more common approaches to recovering resources from wastewater and sanitation waste, a number of others are available. For example, treated sludge and sludge ash can be used to manufacture bricks or other building materials if there is no market for other types of reuse (see Slim and Wakefield 1990). Another increasingly attractive approach is breeding insect larvae on organic waste, including sludge or faeces, to produce protein feed for livestock, while reducing waste volumes and preventing pathogen transmission. Section 9.8 presents a project using black soldier fly larvae in this way.

KEY MESSAGES

- There is an urgent need for societies to manage their resources more efficiently in order to meet current and future needs.
- While resource recovery can add challenges, it can also alleviate growing pressures facing sanitation and wastewater systems.
- “Closing the loop” requires examining what resources are available in the waste streams, what demand there might be for them, and how they could be economically recovered.
- One of the most important potential loops links sanitation to food production, which involves recovering nutrients and organic matter sanitation waste and putting them back into agricultural use.

4. TECHNICAL FUNCTIONALITY

4.1 Designing a system

A common mistake in many attempts to improve sanitation and wastewater management is to start with a preferred technology that has "worked", even as part of a sustainable system, elsewhere. This approach has left many cities and communities with less-than-optimal systems that, for example, cannot be easily adapted to changes in population density; put heavy demands on scarce water resources; break down or malfunction frequently, especially during flooding and heavy rains; and in some cases are not even used (Wong and Brown, 2009). Furthermore, models for financing and service delivery, and institutional arrangements that work in one city may not necessarily work in another.

No sanitation user interface (see below) or treatment technology is sustainable in itself – there are only technologies that serve specific functions within a more or less sustainable system. This system must be planned, designed and operated to suit the specific conditions in which it will operate. For example, on-site dry composting toilets, "arboloos"[9] and/or using minimally treated greywater to cultivate crops may be the most sustainable options for a rural smallholder; while waterborne systems with sewer networks leading to a centralized treatment plant that recovers and distributes resources in bulk may be more appropriate in large urban centres.

In between these two extremes are a range of possibilities with different functions taking place on-site, in decentralized or centralized facilities, depending on population densities, geophysical conditions and other factors. Fortunately, a wide range of technologies are now available from which to choose. This chapter gives a broad overview of the different functions of technology in a sanitation and wastewater system, and looks at how to identify and set up technologies to fulfil those functions within a locally appropriate, sustainable system. In doing so it introduces some of the most common and most interesting technologies.[10]

Technical elements of a system

A sustainable sanitation or wastewater management system needs to include

[9] Moveable latrines placed over a small pit; a tree is planted in the pit once it is full, and the superstructure moved over a new pit (Mara 2012).
[10] For a good overview of available technologies, see the Compendium of Sanitation Systems and Technologies (Tilley et al. 2014). A large collection of Wastewater Technology factsheets from the US EPA can be accessed at http://water.epa.gov/scitech/wastetech/mtbfact.cfm.

infrastructure or services to fulfil the following functions in a safe, efficient and appropriate manner:

User interface: This is the point at which the waste stream (excreta, wastewater, and potentially other organic waste) is first taken out of the user's immediate environment; for example a toilet or floor drain.

Collection and storage: The collection and storage of waste streams can take place on-site or at a more central point; for example in jerry cans for urine, and holding or septic tanks for wastewater.

Conveyance and transport: Depending on system configuration the waste stream may need to be conveyed between locations and technological functions, for example from the user interface to the collection point(s); from a collection point to treatment; and from treatment to reuse. Parts of the waste stream may be released into the environment after treatment or deposited in long-term storage (e.g. in the case of toxic content that needs to be isolated). The means of conveyance and transport can range from plastic containers to fixed pipe networks to trucks.

Treatment: This is a set of processes designed to eliminate or remove unwanted or harmful components and render other components safe and practical for reuse (or release into the environment). Treatment can be passive (storage) or active, using mechanical, biological or chemical processes.

Resource recovery and reuse: There are various methods for recovery and reuse or recycling the resources in waste streams, depending on demand and local conditions. Several may overlap with treatment (e.g. composting, digestion for biogas production).

Factors in system design

A range of factors should influence the choice and combination of technologies in a sanitation or wastewater system. Some of these are purely technical while others relate to broader aspects of system sustainability. They include:

- identified demand for recoverable resources (e.g. agricultural needs; see Chapter 4);
- geographical and geophysical factors (e.g. water availability, quality and sensitivity of receiving water, topography and sub-surface geology, urbanization structure and population density, existing infrastructure, and natural hazards);
- user needs, expectations and capacity. These include issues such as preferences for anal rinsing or wiping, need for menstruation hygiene management;
- protection of human health and environment (see Chapters 5 and 6);
- institutional capacity and access to local technical support (see Chapter 8);
- availability of materials for construction, operation and maintenance;
- projected developments (e.g. urbanization, population density, industrial expansion);

FIGURE 4.1 **Technical functions in a sustainable sanitation and wastewater value chain**

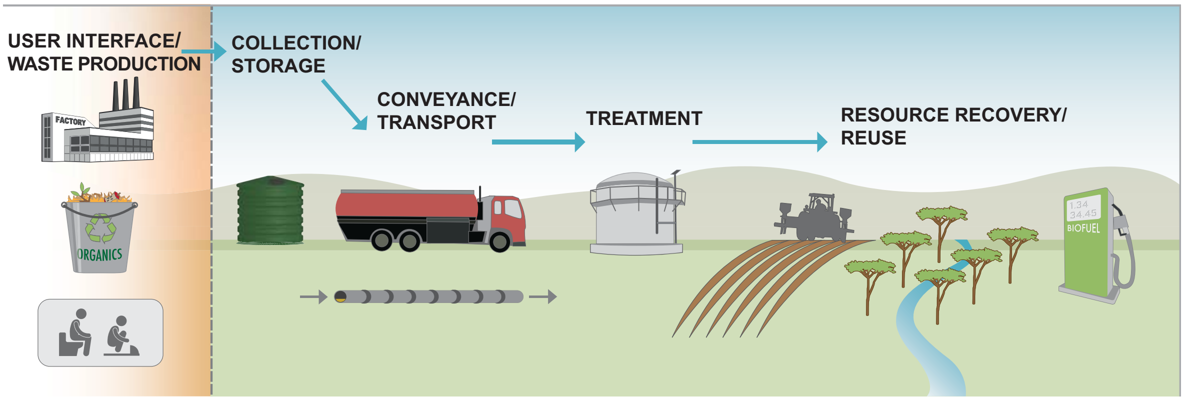


Figure: Stockholm Environment Institute

- availability of financial resources for construction and long-term operation.

Many of these are discussed in more detail in other chapters, as indicated in the list above, while this chapter focuses particularly on the geographical and geophysical factors and at technological configurations from a sustainable resource management perspective. Comprehensive guidance on how to plan and design sanitation and wastewater systems can be found in Tilley et al. (2014) and Parkinson et al. (2014).

4.2 Geographical and geophysical factors

The geographical and geophysical factors that determine what is and is not feasible when planning new or upgraded sanitation and wastewater management systems are often site-specific. This section discusses several of the most important. (For more in-depth discussion, see also Cruz et al. 2005.)

Water availability

An analysis of water availability needs to be carried out, covering access to water on the site, availability of energy for water pumping and anticipating seasonal or even daily variability of water access. This is especially important in the design of household sanitation systems, since flush toilets have become popular within development programmes – mainly because they are considered more convenient for users.

It is also important to look ahead. For example, population growth, industrial or agricultural development and climate change may all have major impacts on the future availability of water resources in some locations. An example is the metropolitan area of La Paz in Bolivia, where glaciers, which provide an estimated 30 per cent of freshwater, are retreating fast due to rising temperatures (Buxton et al. 2013). Other areas, for example in sub-Saharan Africa, have "economic" water scarcity (see Box 1.1) – that is, water scarcity caused by lack of economic growth and investment in water infrastructure. An increase in water availability may lead people to change sanitation technologies in their homes, which may in turn alter the compatibility of the user interface with the downstream parts of the system.

Topography, surface geology and sensitivity of receiving waters

Hilly topography can make centralized waterborne systems much less feasible, since wastewater needs to be pumped from one sub-catchment area to another. Similarly, rock formations close to the

Urine-diverting composting toilet in Niger (left) and a demonstration urine-diverting toilet at the Tarumitra Bio-reserve and Ecology Centre, Bihar, India (right), with rope to facilitate use. Photos: Linus Dagerskog, Kim Andersson.

surface can make it difficult and costly to lay sewerage pipes. For systems that are dependent on infiltration, such as pit latrines or leach pits/fields, the soil type and the level of the local groundwater table are both important.

In addition, biophysical factors such as the current quality and ecological sensitivity of receiving waters (groundwater or surface water) may restrict the technological options. They should also be taken into account in determining the minimum level of treatment needed before waste is released to the environment or in locating suitable points to discharge wastewater (especially if people abstract their drinking water or bathe nearby).

As an example, the technological options open to the city of Kochi in India are limited by flat terrain and high groundwater conditions, which are not favourable for a conventional underground drainage system. Septic tanks and pit latrines do not function properly, resulting in pollution of water and subsoil. The suggested solution in this case included sealing of on-site systems and black water collection through small-bore sewers (or simplified sewers) with decentralized treatment facilities (Municipal Corporation of Cochin 2011).

Natural hazards

Climate-related and other natural hazards, such as floods, heavy rains, droughts and water shortages, can affect the functioning of different components of the system, even adding major health risks from pathogen and pollutant exposure during disasters. Systems therefore need to be designed to be robust or resilient in the face of natural hazards to which the local area is vulnerable, especially to frequently recurring events such as seasonal flooding.

Climate may also have an impact on treatment processes, and seasonal requirements for nutrients and water need to be addressed in the design process. For example, a user interface or other system component that does not rely on water to carry human excreta (e.g. a dry toilet) may be less vulnerable during droughts (Andersson 2014a).

Urbanization and population density

Rural, peri-urban and urban (with increasing population and development density) conditions can strongly affect system design. A high concentration of population and residential units, especially with high-rise buildings and limited public space, tends to favour underground sewerage and centralized treatment services, whereas decentralized and on-site systems are more practical and economically feasible at lower densities.

Urbanization and population density also affect the opportunities and challenges for resource recovery. For example, in a rural context plant nutrients, soil conditioner and irrigation water are generally needed close to where sanitation (and other organic) waste is generated. This is generally not the case in urban areas, where logistics can be a major issue. At the same time, higher population densities make centralized collection services more appropriate, which may be more attractive from users' perspectives.

Existing infrastructure and services

The existing sanitation and wastewater management infrastructure can be a major determinant of what innovations are feasible. Existing systems may provide a good basis for improved management and recycling of some resources; but in other cases the costs and practicalities of replacing and retrofitting existing systems may limit resource management and recovery options. These limitations mostly apply to centralized waterborne, sewer-connected systems. For example, combined systems (mixing household wastewater and stormwater) may receive large quantities of stormwater during rainy seasons, diluting sludge and rendering it much less efficient to digest for biogas. Similarly, combined systems may receive complex industrial wastewater containing substances that make certain types of reuse unsafe, even after treatment.

However, there are many ways to at least improve the situation without costly infrastructural work; for example, awareness-raising campaigns with various user groups (household, commercial, industrial, institutional), possibly backed up with regulations, can greatly reduce hazardous substances entering the wastewater stream. Building ditches and local retention basins and installing permeable surfaces in public spaces are examples of ways to reduce the stormwater entering combined systems, also creating possibilities for treatment (see e.g. Charlesworth et al. 2003; Poleto and Tassi 2012). Hence, when planning for improved sanitation development it is important to make a detailed analysis of existing sanitation and wastewater systems.

4.3 Operational factors

Among the most important choices to make in designing a sanitation or wastewater management system are where collection, storage and treatment will take place, and with what degree of centralization; whether the system will be waterborne, low-water or dry; and what kinds of treatment and resource utilization to aim for.

Collection and treatment services can be organized as centralized or decentralized (see Figure 4.2), but also on-site or off-site or a combination of these. From a resource recovery perspective, there are both advantages and disadvantages to these different management schemes.

Centralized wastewater management is a common approach in large parts of the world. The often cited advantage of centralized management is economy of scale: the per capita investment and operational costs of a single large treatment plant are much lower than those for several small-scale plants, while the control of quality standards and plant operation procedures could also be more effective (Wendland and Albold 2010). Centralized systems can, however, be challenging from a resource management perspective due to the higher level of dilution and complexity of wastewater composition; source control of contaminants is more difficult in a larger system.

At the same time, centralized systems require large upfront investment in order to function, while more decentralized systems can often be developed in phases and still function. If reuse opportunities exist locally, the neighbourhood or locality may be the most relevant boundary for the system, for example to avoid costly logistics and to reduce the risk of dilution and pollution of waste resources (see Chapter 7 for more on system boundaries). Another fairly common

FIGURE 4.2 **Levels of centralization of collection services**

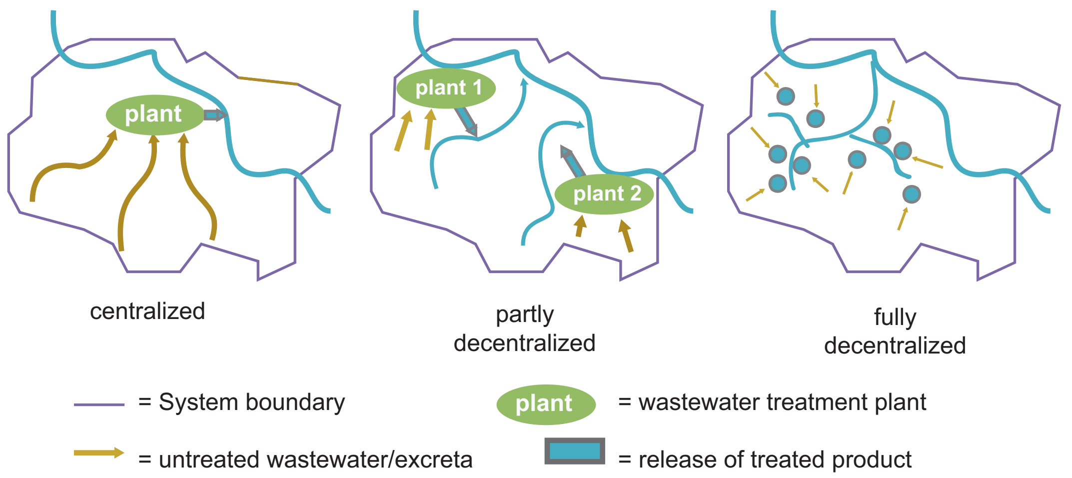


Figure: Stockholm Environment Institute, based on Parkinson et al. 2014 practice is to manage different wastewater fractions at different levels. For example, the liquid fractions can be collected centrally using a piped system, while solid waste fractions (e.g. sludge) can be collected on-site.

Table 4.1 provides an overview of possible centralized/decentralized and off-site/on-site configurations, including their main characteristics and implications. For example, an on-site wastewater scheme including septic tanks, may have a centralized service for sludge management. Here the reduction of volume at the source is often crucial to facilitate logistics.

4.4 Source separation

Keeping different wastewater streams separate, from the user interface through to treatment, is often a cost-efficient way of facilitating resource recovery. It allows more specific (and simpler) treatment of lower volumes of the different fractions, and ensures more consistent content, than is the case with blended wastes. This is particularly important in decentralized systems, as advanced treatment technologies can rarely be implemented and operated economically on a small scale, and suitable technical capacity may not be available locally. However, source separation generally depends on appropriate user behaviour – ensuring wastes

Faeces composting for agricultural reuse in a project in El Alto, Bolivia. Urine and faeces are collected separately using urine-diverting dry toilets. Greywater is applied to household constructed wetlands.   Photo: Kim Andersson

TABLE 4.1 **Type of wastewater collection systems and their characteristics**

Type of collection system	Characteristics
Centralized system, either combined sewerage (inc. rainwater) or separate sewerage (separate wastewater and rainwater sewers) Treatment options: Intensive wastewater system (e.g. activated sludge), extensive wastewater treatment (e.g. pond)	• Different types of sewerage system possible: high-tech like pressurized and vacuum sewerage or low-tech like free water-level gravity sewers • Sewerage system requires maintenance • A number of pumping stations may be required • Important global development how to design local and sustainable stormwater solutions (possible and necessary for all systems)
Combined on-site and centralized system Collection and pre-treatment of wastewater on-site in septic tanks combined with settled or simplified sewerage and intensive or extensive secondary treatment	• Sewerage (settled sewerage) less costly and less complex than conventional sewerage • Advantageous if septic tanks have already been installed
Semi-centralized system Number of smaller, semi-centralized treatment plants serve one agglomeration	• Advantageous if the agglomerations is clustered in several settlements • Flexible, can be built modular • Sewerage network is shorter
Decentralized on-site system (no sewerage) household based Treatment options: Intensive, extensive and innovative wastewater system possible	• Advantageous in sparsely populated areas and/or difficult site conditions for sewerage • No centralized sewerage required • Operation and maintenance to be done on-site by either owners or private/public managed services • Requires public and private rights and obligations properly identified • Potential to close the local water cycle (on-site water and nutrient reuse)

Source: Adapted from Wendland and Albold 2010 are kept separate and not contaminated by, for example, putting toxic products into separated greywater that might be reused or released to sensitive receiving waters with minimal treatment.

Although the tendency in sanitation development to date has been to combine wastewater streams and manage them centrally, source separation has emerged spontaneously as a response to water, fertilizer or energy scarcity (Lienert 2013). Over the last 20 years large efforts have been invested in research and development on source separation, including both low- and high-tech solutions in rural and urban contexts and on different scales. Comprehensive overviews of source-separating and decentralized systems can be found in, for example, Larsen et al. (2013) and Tilley et al. (2014). This section looks at some of the options for source separation of domestic wastewater and excreta streams. Some challenges associated with each are presented in Table 4.2.

One of the most important variables in source separation is whether the sanitation systems concerned are waterborne or dry. While local conditions (especially water availability and population density) necessarily play a major role in determining

TABLE 4.2 **Opportunities and challenges associated with source-separated domestic wastewater**

Waste stream	Opportunities	Challenges
Urine	Nutrient (N, P, K) recovery	Heavy to transport mechanically; risk for precipitation and clogging when transported in pipes; ammonia evaporation and odour
Faecal matter	Energy (biogas) production, soil amendment	Small volumes produced per person; transport and logistics may be difficult; high pathogen levels; odour
Blackwater (flush water, urine and faeces) or brownwater (flush water and faeces, with no urine)	Energy (biogas) production, nutrient recovery, soil amendment, will flow under gravity	Amount of water affects transport (clogging) and energy production value; pathogens; odour
Greywater (water used in shower, bath, hand washing, dish washing, and laundry)	Heat recovery, water recovery	Treatment required to prevent regrowth of bacteria; generation of parallel products (sludge and foam); impact of salinity and chemicals on soils; source separation; pathogens; odour
Faecal sludge (sludge collected in on-site systems, containing excreta and possibly other waste)	Soil amendment, fuel source	Collection and transport; identifying institutions responsible for management; pathogens; odour

Source: Adapted from Tilley 2013

whether waterborne or dry systems are more appropriate, the type of resource recovery aimed at should also play a role. For example, dilution of excreta makes recovery of concentrated nutrients less efficient; however, treated blackwater (see Table 4.2) can be used to irrigate and fertilize farmland simultaneously, if this is needed. Dilution also affects how easy it is to produce biogas for energy. Some dry toilet technologies separate urine and faeces, which can greatly increase the efficiency of nutrient recovery and pathogen reduction. The different conveyance options – from sewerage to pit latrine emptying services, to on-site composting and reuse – should also be taken into account.

The major challenge of resource recovery from more conventional, especially municipal, combined waterborne systems is the level of contamination. Sewerage systems commonly receive a mixture of wastewater from, for example, residential areas, hospitals, industries and stormwater, with potential loads of heavy metals and other toxic substances. Hence, control the quality (and composition) of these streams as close to source as possible is important to facilitate treatment and enable safe resource recovery.

If waterborne piped systems are found to be the most feasible but there is no direct demand for irrigation water, it may make more sense to concentrate the nutrients in sludge, making it easier to transport longer distances. This can be done during treatment. However, low-flushing or vacuum toilets can also help to reduce the water content at source.

One challenge with introducing source-separating or low-water user interfaces in piped systems is that the piped system may rely on a certain volume of liquid flow to function properly. Reduced flows can increase sedimentation and cause blockages and odour (Larsen and Gujer 2013). In this respect, decentralized systems offer more flexibility and opportunities to adapt to changing conditions (for example, urbanization) than do large centralized systems.

Separating waste streams

Source separation is in fact a traditional way of handling human excreta by keeping it separated from other waste streams. The systems involved can be either waterborne or dry/non-waterborne. Waterborne systems are generally divided into blackwater systems (which combine faeces, excreta and urine) and brownwater systems (combining water and faeces only). Conventional non-waterborne excreta-separating systems involve different types of latrine.

Neither type of system has traditionally been constructed for reuse. Instead they deposit or infiltrate the excreta underground, which is a significant source of contamination for groundwater, with negative health impacts for the population. However, both waterborne and non-waterborne source separation techniques for human excreta have good potential for resource recovery, especially if they are designed for that purpose from the outset.

Blackwater and brownwater systems
Source separation of blackwater is a conventional approach for wastewater management, for example with a flush toilet (often pour-flush) connected to a leach pit.[11] Such a system keeps pathogen-loaded excreta separate from the immediate domestic environment (although it can contaminate groundwater), but is not useful for resource recovery. However, various new types of blackwater and brownwater management system more appropriate for resource recovery are being implemented across northern Europe (see the case study in Section 9.4 for an example from Sweden; and Thibodeau et al. 2014). Leading reasons for the increased interest include the fact that it can be transported in piped systems, and the high availability of nutrients and organic material in blackwater (less so in brownwater, as nutrients are found mostly in urine). Such systems can be equipped with low- or vacuum flushing toilets, reducing the dilution of excreta. An indirect benefit is the fact that greywater will be managed separately, which can facilitate safe water reuse – see below.

[11] Leach pits are similar to pit latrine pits, but are designed so that water will percolate into the surrounding soil, rather than being retained in the faecal sludge.

Dry systems for combined excreta handling
Some systems mix urine and faeces but without using water for flushing, such as the commonly used pit latrines. These are built primarily to contain the excreta, but often allow for a certain level of resource recovery. Conventional pit latrines comprise a deep pit, where there is a risk of excess liquid being infiltrated into the soil and contaminating groundwater. Alternatives to facilitate resource recovery include shallow pits, a composting chamber, or a chamber for anaerobic digestion, depending on the context. The user interface may be a raised pedestal or a squatting pan, with one opening receiving urine and faeces and possible additives.

Source separation of urine
Urine makes up less than 1 per cent of total domestic wastewater volume, but contains most of the nutrients – about 80 per cent of the nitrogen and half of the phosphorous (Friedler et al. 2013). This means that for nutrient recovery in most cases it is more efficient to manage urine separately than to manage diluted wastewater. Facilitating safe reuse is another benefit of separate urine management, since the pathogens are found overwhelmingly in faeces, not urine. Source separation of urine also reduces the risk of eutrophication if wastewater is to be released to receiving waters (Tervahauta et al. 2013).

The most common user interface for source separation of urine is the urine-diverting dry toilet (UDDT). UDDTs are used across the world in low-, middle- and high-income settings. UDDTs are single interfaces that collect urine and faeces separately. Both raised pedestal and squatting models exist.

Urinals are ideal for source separation of urine, even though they are rarely installed for this purpose. Waterborne urinals for male users are the most common, especially in public facilities. But there are dry alternatives available that avoid dilution of urine and also save water. Women's urinals have also been implemented; however, these offer few advantages over urine-diverting toilets.

Separated urine can be channelled directly to cultivated land, combined with greywater (e.g. for irrigation of orchards where the fruit and workers will not be directly exposed to it), or collected in anything from small portable containers (e.g. jerry cans) to large tanks for storage – usually the only treatment needed to render it safe.

A waterborne technology for urine separation, the urine-diverting flush toilet

FIGURE 4.3 **Different types of urine-diverting toilet**

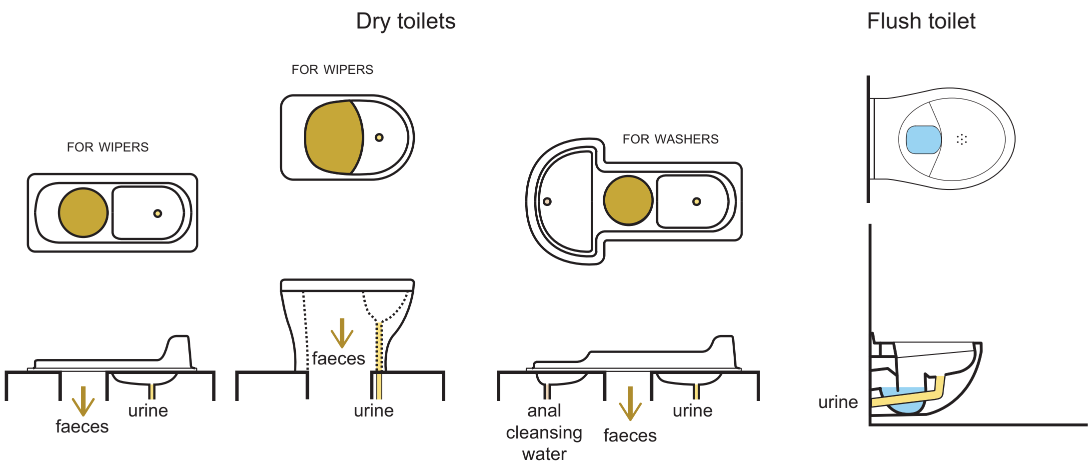


Figure: Based on Tilley et al. 2014

(UDFT), attracted some interest in Sweden during the 1990s, but demand has since been low. However, UDFTs have potential for source separation in waterborne systems, as they collect urine and faeces separately, only using water to flush away the faeces. Figure 4.3. shows the main basic designs of user interfaces for urine diversion.

Source separation of faeces
The quantity of faeces excreted daily by one person is small compared to other domestic sanitation waste streams (100–350 g/person). Since faeces contain high pathogen levels, keeping them separate can facilitate efficient treatment. In many cases source separation of faeces is a direct result of deliberate urine separation; the user interface will thus be the same as for urine separation.

Brownwater can be treated similarly to blackwater – for example anaerobic digestion to produce biogas and reduce pathogen load. Separated faeces from waterless systems can be managed with dehydration or composting. The nutrient content in these products will not be as high without the urine, but the additional organic matter is useful for soil conditioning.

Toilet paper and other solid waste
Many systems may not be able to cope with toilet paper or, especially, paper towels. These may be collected separately and managed with other solid waste or added separately to sludge for biogas digestion or composting. Also important, for both technical and social sustainability, as well as promoting gender equality, is to provide a safe space for menstrual hygiene management (MHM). However, the common practice of disposing of MHM products (such as tampons and sanitary towels) in toilets is generally problematic, raising the likelihood of blockages and other problems, along with possible chemical contamination of reuse products. In most cases it is preferable to manage menstrual waste through the solid waste management system (Kjellén et al. 2012).

Separation of greywater
Greywater is domestic wastewater that does not contain significant amounts of excreta: that produced from baths, showers and hand basins, as well as from laundry and dishwashing, whether manual or by machine (Morel and Diener 2006). The composition of greywater varies greatly depending on the sources from which it is generated. For example, greywater from kitchen sinks normally has a high content of oil and food particles, while greywater from bathrooms has shampoo, soaps, toothpaste, and if derived from shower or baths it may also have traces of human excreta. Greywater has a far lower content of solids and nutrients in comparison to urine, blackwater and brownwater.

Volume-wise, greywater generation may vary greatly, from 20 to more than 200 litres per person per day, and may make up anywhere between 65 and (in the case of houses with waterless excreta management), 100 per cent of the total domestic wastewater stream (Morel and Diener 2006).

To date, resource recovery from greywater has mainly been carried out through direct reuse, especially for garden or agricultural irrigation in areas with water scarcity. Greywater is also sometimes reused within the household instead of new potable water for flushing toilets and other non-potable uses (see the case study in Section 9.2). Another option being implemented in some places is recovering the heat in greywater to contribute to domestic heating.

4.5 Treatment

A treatment system for wastewater or excreta and other organic waste should be designed according to the reuse (or disposal) options chosen. This relates not only to the physical form of the finished product (including its volume, water content etc.) but also the level of pathogen reduction and nutrient removal. For example, if wastewater is to be reused in landscape irrigation it will generally require less treatment than if it is to be used for crop irrigation (especially if the produce is to be consumed raw and without peeling) or for recycling into potable water.

Wastewater

For water recovery from wastewater, there are four main functions that might need to be carried out:

- reduction or deactivation of pathogens,
- removal of organic material,
- removal of nutrients,
- removal of micro-pollutants.

A selection of the different techniques available is described below. More comprehensive reading on treatment technologies can be found in Tilley et al. 2014, at the Sustainable Sanitation and Water Management toolbox website (www.sswm.info) and in factsheets published by the US Environmental Protection Agency (available from water.epa.gov/scitech/wastetech/mtbfact.cfm).

Reduction or deactivation of pathogens
Most types of wastewater reuse require reduction of the live pathogen content to avoid exposing humans and fauna to disease risk. Different types of reuse, however, require degrees of live pathogen reduction; for example, direct production of potable water (see the case study in Section 9.1) requires much higher standards than mechanical application to non-food crops in areas of low population density.

Pathogen treatments are often designed in several stages, with biological stages (ponds, activated sludge, trickling filters) followed by filtration (e.g. in biological or in sand filters) and treatment with chemicals (e.g. chlorine or ozone) or ultraviolet light (UV germicidal irradiation). All of these methods require some pre-treatment to remove organic matter.

Removal of organic matter
If the chosen type of water reuse requires high standards in respond to, for example, particle content, treatment will need to remove organic matter and other solids from the wastewater stream. Removal of organic matter has been the major treatment priority in conventional systems where wastewater is discharged to water bodies; consequently, there is a wide range of technologies available. Examples of available treatment systems are anaerobic ponds, activated sludge, anaerobic digesters, and trickling filters. Some systems (for wastewater with high-BOD[12] content) can also favourably combine both organic matter reduction and biogas generation, such as the upflow anaerobic sludge blanket reactor.

Removal of nutrients
While wastewater reuse in agriculture clearly benefits from a high nutrient content, this is not the case for other types of reuse – such as groundwater recharge, toilet flushing, and potable water – and for release to receiving waters, where there is a risk of eutrophication. Both biological and chemical treatment methods are available for nutrient removal. The main biological treatment process for removing nitrogen is nitrification followed by denitrification.[13] Examples of nitrogen removal technologies are activated sludge systems, biofilm systems, sequencing batch reactors, rotating biological contactors and oxidation ditches.

Efficient removal of phosphorus requires removing both particle-bound and soluble phosphorus. A common process is enhanced biological phosphorus removal. The primary approach for chemical phosphorus removal is through precipitation, achieved by adding additives such as aluminium or ferric sulphates. Precipitation of nutrients has also gained interest as a resource recovery strategy to capture nutrients from the waste stream (e.g. for struvite precipitation[14]).

Removal of micro-pollutants
The risks associated with the content of micro-pollutants in wastewater are receiving greater attention. Depending on the sources of wastewater, the types and levels of micro-pollutants may vary greatly.

[12] Organic matter in wastewater is often quantified in terms of biological oxygen demand (BOD), which is the amount of dissolved oxygen needed for organisms in the water to break it down.
[13] In nitrification, bacteria convert ammonia (NH3) or ammonium (NH4+) into nitrite and then nitrate, under aerobic conditions. In denitrification, different bacteria convert nitrate into nitrogen gas.
[14] Struvite is a phosphate mineral that can form naturally or be induced by chemical precipitation.

Substances such as hydrocarbons, heavy metals, organochlorides and pharmaceuticals may be present in waste streams. The biological and chemical processes in more conventional treatment plants may partially remove micro-pollutants, but to enhance removal technologies such as ozonation, reversed osmosis and activated carbon are commonly applied.

Treatment of sewage sludge
A by-product of domestic or industrial wastewater treatment is semi-solid sewage sludge. The management, and especially the reuse, of sewage sludge from wastewater treatment is often complex, since there may be an accumulation of micro-pollutants. One solution that has proved efficient to address this problem is upstream pollution control, which reduces the micro-pollutant content in the original waste stream (see Chapter 6).

Anaerobic digestion is a widely used approach for treating sludge, converting most of the easily degradable part of the organic matter in the sludge into methane (which can be captured as biogas), and at the same time generating a residue with higher quality (reducing the odour and the live pathogen content). It is common to reduce the volume of sludge through dewatering,[15] making it easier to manage. The simplest approach for sludge treatment is drying beds, which can be either planted or unplanted (Strande et al. 2014).

Source-separated waste

Greywater treatment
The type of resource recovery aimed for will guide the appropriate greywater treatment approach. A wide range of options are available, from the advanced (e.g. systems that recycle greywater for toilet flushing within the same building) to low-tech natural treatment systems, such as constructed wetlands. Different types of constructed wetlands have become common for greywater treatment in decentralized systems, often in a context where the treated greywater is destined for irrigation of green areas or kitchen gardens. To avoid disturbance in the treatment processes or creating health issues in reuse, it is important to reduce the usage of chemicals (e.g. non-degradable, phosphorus-

Decentralized wastewater treatment plant with constructed wetland, Cochabamba, Bolivia. Photo: Kim Andersson

[15] Dewatering is reduction of the water content of sludge, for example using a centrifuge, a filter bed (or mechanical filtration system) or evaporation.

rich detergents), and where possible use biodegradable cleaning and hygiene products. Hence, technical measures need to be complemented by awareness raising among users.

Blackwater and brownwater treatment
If reuse is the main reason for separately managing blackwater or brownwater, pathogen reduction is generally the priority for treatment. An anaerobic treatment process may be appropriate but there are also more recently developed technologies such as wet-composting and urea treatment available (see the case study in Section 9.4).

Faecal sludge treatment
Faecal sludge may be raw or partially digested, depending on the collection and storage system.[16] It contains faeces and urine, and may also contain toilet paper, anal rinsing water, and even greywater or flushing water (Strande et al. 2014). The quality and quantity of faecal sludge depends on the design of the system, what processes were involved, and user behaviours.

Faecal sludge management often involves periodically emptying the collection vessel. It is unfortunately common for faecal sludge to be mismanaged (e.g. dumped untreated into receiving waters) or not managed at all, resulting in dysfunctional sanitation systems. Treating the sludge and resource recovery are far preferable. The treatment options are similar to those for sewage sludge generated from wastewater treatment.

Faeces treatment
Source-separated faeces from dry toilets is commonly treated through dehydration or some sort of composting, reducing pathogens and making it more suitable for reuse. The composting process can be enhanced by ensuring a high temperature through the addition of organic residues or by adding worms, larvae or microorganisms. Other means to reduce pathogens are chemical treatment with alkaline material such as ash, lime or ammonia, and thermal treatment or incineration.

Urine
The main treatment method for urine is storage in sealed containers. Chemical processes occur in the urine during storage that raise its pH and deactivate pathogens. It is important that the urine is as undiluted as possible for this treatment to work optimally.

Recommended storage times vary depending on system set-up and ambient temperature (higher temperatures mean pathogens die off faster), but they normally range between one and six months (Richert et al. 2010). Due to its volume, urine creates logistical challenges for centralized management. Methods to reduce urine volumes are therefore being explored, including combined nitrification and distillation, chemical struvite precipitation and dehydration (Larsen et al. 2013; Senecal et al. 2015).

Natural treatment systems
While many different technologies and processes exist to carry out these functions, it is important to stress the potential of natural treatment systems, for example constructed wetlands, which can be highly efficient and have low set-up costs and low operation and management requirements (Adrados et al. 2014). Natural treatment systems can be the main treatment stage or a late "polishing" stage, further enhancing the quality of one or several of the specific treatment priorities described above. A potential added benefit of these systems is the fact that besides treatment, they can provide opportunities for human recreation and wildlife habitat.

4.6 Planning and designing for the long term

A third key consideration in planning and designing sanitation and wastewater management systems, besides the local context and the resource management needs, is long-term use. This means taking into account the requirements and interests of the intended users, and their capacity to facilitate (and pay for) long-term operation and maintenance.

16 Faecal sludge is the slurry or semi-solids generated in different types of on-site sanitation system, and collected in a latrine pit, cesspool, septic tank or similar.

FIGURE 4.4 **A decision-making process with stakeholder participation**

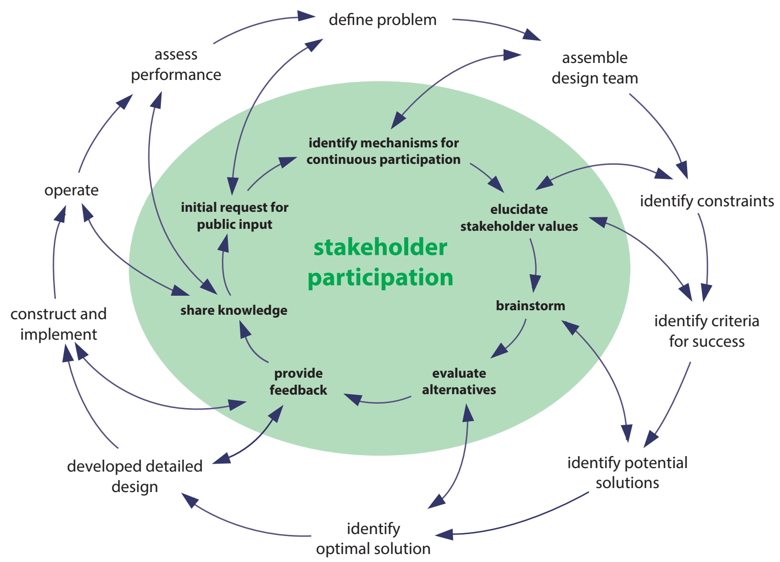


Figure: Guest et al. 2009

User and other stakeholder involvement

Many sanitation and wastewater management master plans focus on infrastructure, and pay little attention to the users and other system management stakeholders (Parkinson et al. 2014).

However, it is a mistake to ignore the human dimension of the system; in particular, the user interface and any other requirement for user involvement – for example handling composted faeces – should address the specific needs and expectations of the user group. If not, there is a high risk that the system will not be used, or will be used incorrectly, causing it to malfunction. This is especially important in low-income context where users may have little previous experience of sanitation facilities and hygienic sanitation habits.

Participatory planning and the involvement of users and other stakeholders in system management (such as those who will be responsible for O&M) are crucial if their needs and expectations are to be reflected in system design (see Figure 4.4. for illustration of how stakeholders can be involved in decision-making processes around a sanitation system).

Improved resource management, including resource recovery, makes participation throughout the entire planning and implementation cycle even more important, since new technological and logistical set-ups may be required. These may also put new demands on users and O&M personnel; for example, in keeping waste streams separate. Even greater attention is needed in order to achieve improved user-friendliness and facilitate correct use of the system.

Specific user training, as well as clear (visual) instructions on how to use the system, may also be required.

A broad range of stakeholders need to be involved in developing strategies for waste handling, treatment and reuse. Participatory processes and training also help to build awareness and ownership of sanitation and wastewater management systems.

Besides the more technical functions – from cleaning and emptying latrine pits and septic tanks to fixing broken toilets or leaking sewerage pipes – O&M also includes the administrative and institutional components required to achieve sustained functioning of the different components along the entire system (Bräustetter 2007). The technological complexity of the system and its components will determine the level of training required for the various O&M functions. Key factors to achieving sustained performance include: integrating O&M considerations into the design process; ensuring human and financial resources are constantly available; and establishing monitoring plans, for example on safety, health and environmental protection (Strande et al. 2014).

Technical robustness

Technical robustness is also an important parameter determining long-term functionality. The system needs to be able to keep functioning with variations in load, which may be significant, especially in small-scale decentralized systems (Larsen and Gujer 2013). Furthermore, the system should be designed to keep functioning during and after events such as power cuts, water shortages and floods. For example, flood-proofed, raised toilets can avoid sludge overflowing during floods (see Andersson 2014a). Given the uncertainties of climate change, it is advisable to develop sanitation and wastewater systems so that they are functional in a range of posssible climate scenarios.

Furthermore, it is important to consider the flexibility of the system, to adapt to changing resource demands over time. For example, it is relatively easy and cheap to build in the hardware for source separation when installing a new system, even if this capability is not immediately used, compared to retrofitting the hardware later.

4.7 Decision-support tools

As this chapter shows, many factors need to be taken into consideration when developing sanitation and wastewater management systems, especially those for resource recovery. Fortunately, there are some decision-support systems and tools available to assist in the selection and combination of the technologies (e.g. Chamberlain et al. 2014). These can complement to (but cannot replace) detailed technical feasibility studies and participatory processes.

One promising tool currently under development is the Wastewater Technology Matrix www.iwa-network.org/project/decision-support-matrix-for-wastewater-treatment-technologies). The matrix is aimed at decision makers and donors in low- and middle-income countries developing urban wastewater systems. It covers environmental aspects, social aspects, economic aspects, and local context. Resource recovery is considered in the tool, where desirable outputs of the system can be defined at an early stage, since it takes the entire sanitation chain into account. The tool is based on the Compendium of Sanitation Systems and Technologies (Tilley et al. 2014), which provides a good overview of relevant sanitation technologies and systems.

KEY MESSAGES

- Achieving technical functionality of the sanitation and wastewater management requires planning and designing along the entire sanitation chain (user interface, containment and storage, transport, treatment, disposal or reuse), and addressing all context-specific determinants (e.g. geographical and socio-cultural), both current and projected.
- A wide range of technical options are available that can be used and adapted to the context to make a sanitation and wastewater systems more sustainable. Key variables include operational levels (centralized, decentralized, off-site, on-site), waterborne or non-waterborne systems, source-separating approaches, and treatment technologies (depending on resource recovery and associated treatment priorities).
- System design should address the diverse needs of the different user groups, including being appropriate from a cultural and behavioural perspective. In addition, achieving improved resource management and recovery within this system and beyond requires an analysis of local resource demand and available waste volumes.

5. PROTECTING AND PROMOTING HUMAN HEALTH

A fundamental function of all sanitation and wastewater management systems is to prevent human contact with hazardous pathogens and chemicals, even when the main aim is resource recovery. Well-designed resource recovery systems not only protect health but also promote it by contributing to food and water security.

Open defecation and poor sanitation and wastewater management facilitate the spread of diseases caused by pathogenic bacteria, viruses, protozoa and parasites. They do this by exposing people to pathogens in untreated or inadequately treated excreta, either through direct contact or ingestion, or indirectly through contaminated water, food or soil. The negative outcomes can be multiplied during natural disasters such as floods and storms, which are expected to become more frequent and extreme in some regions, due to climate change. Thus sanitation, combined with good hygiene practices, is fundamental to breaking the cycle of waterborne disease.

According to a recent estimate 842,000 people – the vast majority young children – die every year due to water-related diarrhoeal diseases, and a large share of these deaths can be directly attributed to inadequate sanitation (Prüss-Ustün et al. 2014). Faecal contamination has been implicated in major disease outbreaks such as cholera, typhoid and *E. coli* O157:H7, in both developed and developing countries, with dire social and economic costs.

In some communities that practise open defecation or with poor access to properly functioning sanitation, hygiene and wastewater management systems there is a range of constant health threats, including diarrhoeal disease and helminth infections. These infectious diseases are associated with chronic malnutrition, child mortality, and lost work and school days. In addition, persistent exposure can lead to undernutrition and cognitive impairment. It has been estimated that improved sanitation – with its focus on protecting the user household – can reduce rates of diarrhoeal disease by an estimated 35 per cent (Fewtrell et al. 2005; Waddington et al. 2009).

Most of the different types of waste that enter wastewater streams may contain pathogens along with chemicals hazardous to public health (see Table 5.1). Exposure to contaminants can occur at multiple points in sanitation and wastewater systems – not only at the user interface (e.g. the household environment) but also during transport, storage, treatment and resource reuse (if the resources have not been rendered safe through treatment). Health protection in sustainable sanitation and wastewater management thus needs to encompass the entire system.

5.1 Hazards in waste streams

Pathogens

The load of pathogens in different waste streams depends on the level of infection in the source population. Faeces, which contain the vast majority of the pathogens found in human excreta, may contain particularly high levels of the common pathogen *Ascaris* and the parasitic protozoa *Cryptosporidium* and *Giardia*, particularly in rural areas. The relative importance of these biological hazards in causing illness also depends on factors such as their persistence in the environment, minimum infective dose, ability to induce human immunity, and latency periods (Shuval et al. 1989). For instance, helminths are of major concern in sanitation systems because their eggs are very persistent in the environment.

While fresh urine is generally sterile it may contain some pathogens, either excreted directly in the urine itself or through contact with faeces. Generally speaking these only pose a threat when infection rates are high – such in as the case of *Salmonella typhi*, which causes typhoid.

Reviews of microbial pathogens in greywater show that dishwater is often the most contaminated of household greywater streams, due to the presence of food particles (Eriksson et al. 2002; Lazarova et al. 2003). Other sources, such as showers, hand basins and washing machines are the principal contributors of organisms of faecal origin, attributable to the washing of soiled clothing or diapers, hand washing after toilet use, and showering.

Worryingly, there is evidence that greater proportions of multiple antibiotic-resistant coliform bacteria exist in treated than in raw sewage (Silva et al. 2006). Thus, wastewater treatment plants are important reservoirs of enteric bacteria carrying potentially transferable resistance genes. In this regard, wastewater from hospitals is of particular concern.

TABLE 5.1 **Pathogens and chemical hazards in wastewater and their potential health impacts**

Hazard	Examples of possible health impacts
Pathogens	
• Viruses, e.g. hepatitis A, rotavirus, enteroviruses	• Infectious hepatitis, diarrhoea, vomiting, paralysis, meningitis, fever
• Bacteria, e.g. Salmonella, Shigella, Campylobacter, Vibrio cholera	• Diarrhoea, bacillary dysentery, cholera
• Protozoa, e.g. Entamoeba histolytica, Giardia lamblia Cryptosporidium parvum	• Amoebic dysentery, diarrhoea, malabsorption
• Parasites, e.g. ascaris (roundworm), ancylostoma (hookworm), trichuris (whipworm)	• Ascariasis, anaemia, diarrhoea, abdominal pain
Chemicals	
• Heavy metals, e.g. arsenic, cadmium, lead, mercury, nickel	• Acute or chronic toxicity (e.g. neurological and kidney damage)
• Organic and emerging chemical contaminants, e.g. polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), DDT and metabolites, benzene, oral contraceptives	• Acute or chronic toxicity (e.g. carcinogenic, impacts on reproduction)

Chemical hazards

Chemicals such as heavy metals, pharmaceutical residues or their metabolic by-products, endocrine disruptors, and personal care products may also be present in different wastewater streams. High levels of pharmaceutical residues have been found in the influent and effluent of several wastewater treatment plants in the United Kingdom (Zhou et al. 2009).

Depending on household water use, greywater may contain as many as 900 different organic chemical compounds (Eriksson et al. 2002). For example, Palmqvist and Hanæus (2005) found polycyclic aromatic hydrocarbons (PAHs; by-products of incomplete combustion, many toxic), phthalates (plastic additives that are suspected to have a variety of negative health effects), and triclosan (an anti-bacterial and anti-fungal agent) among others in greywater from a Swedish source-separated sanitation system. Their study also found the same compounds in blackwater (flushing water mixed with urine and faeces).

The health risks associated with chemical contaminants from sanitation systems are insignificant, however, compared with those associated with pathogens (WHO 2006). Accordingly, this chapter focuses on microbial hazards. Environmental hazards from chemical pollution are discussed in Chapter 6.

5.2 Exposure pathways and health risks

Exposure to microbial hazards can happen at different points in a wastewater or sanitation system. They may occur during normal operation (e.g. due to improper use and operation, lack of maintenance); during partial or full system failure (e.g. power failure, equipment breakdown, faulty infrastructure, system overloading); or seasonally or due to climatic factors (e.g. flooding).

Depending on the type of system and the nature of the exposure event, different groups of people may be at risk, usually through direct or indirect contact with the system and waste streams. They include users, workers responsible for operation and maintenance of the system, populations living nearby, farmers using recovered resources (e.g. sludge and water), and people consuming agricultural products grown with recovered resources. For more on health risk assessments associated with components of sanitation and wastewater systems see Stenström et al. (2011).

On-site sanitation and wastewater systems

On-site sanitation systems can include both waterless and flush toilets, and may be combined with greywater-separating systems. Risks of exposure to pathogens in waterborne on-site sanitation systems are not significantly different from those in dry systems. Critical points of pathogen exposure risk are:

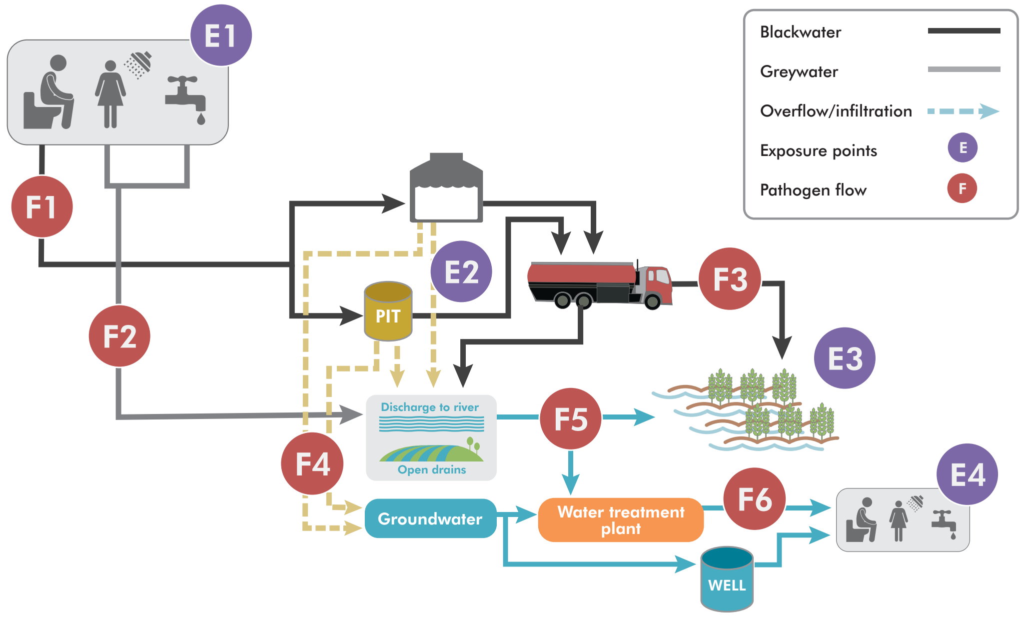
- user interface, such as a toilet;
- storage and on-site treatment technologies, such as simple pits, ventilated pits, or septic tanks;
- technologies to collect and convey sludge off site;
- technologies for sludge treatment;
- reuse/disposal.

The pathogen flow and main points of microbial pathogen exposure risk in a waterborne on-site sanitation system are shown in Figure 5.1. Infection risks may vary significantly at the different points. For instance, in the case of urine-diverting toilets, appropriate cleaning and management regimes are needed to reduce risk of disease transmission, such as from faeces that remain on the sides of the bowl. In addition, exposure to pathogens can occur during the emptying of septic tanks or pits, especially where done manually without any protective clothing. Rulin (1997) showed that workers emptying pit latrines were twice as likely to be infected with Hepatitis A virus as workers engaged in non-excreta-related activities.

The use of leach pits for storage, particularly in combination with pour-flush toilets, can result in the contamination of the community’s groundwater (Molin et al. 2010). Flush toilets connected to septic

FIGURE 5.1

Typical pathogen flows and exposure points: waterborne on-site sanitation and greywater chain



E1: Users and cleaners of toilet; **E2:** Ingestion of wastewater (workers); **E3:** Ingestion of sludge and consumption of crops (workers and consumers); **E4:** Consumption of contaminated surface and groundwater

Figure: Razak Seidu

tanks that are not properly sealed may also result in groundwater contamination. In addition, simple pits have been implicated in groundwater contamination that has resulted in disease outbreaks with enteric microorganisms (Fong et al. 2007; Falkland and Custodio 1991). The contamination risk is higher during heavy rainfall: for example, Fong et al. found an association between septic tank leakage and groundwater contamination in South Bass Island, Ohio during heavy rains. Discharges from septic tanks or pits into open drains and water bodies can also lead to disease transmission.

The typical pathogen flow and exposure points in an on-site system with greywater recycling are shown in Figure 5.2. (See the case study on building-level greywater recycling in Brazil in Section 9.2.)

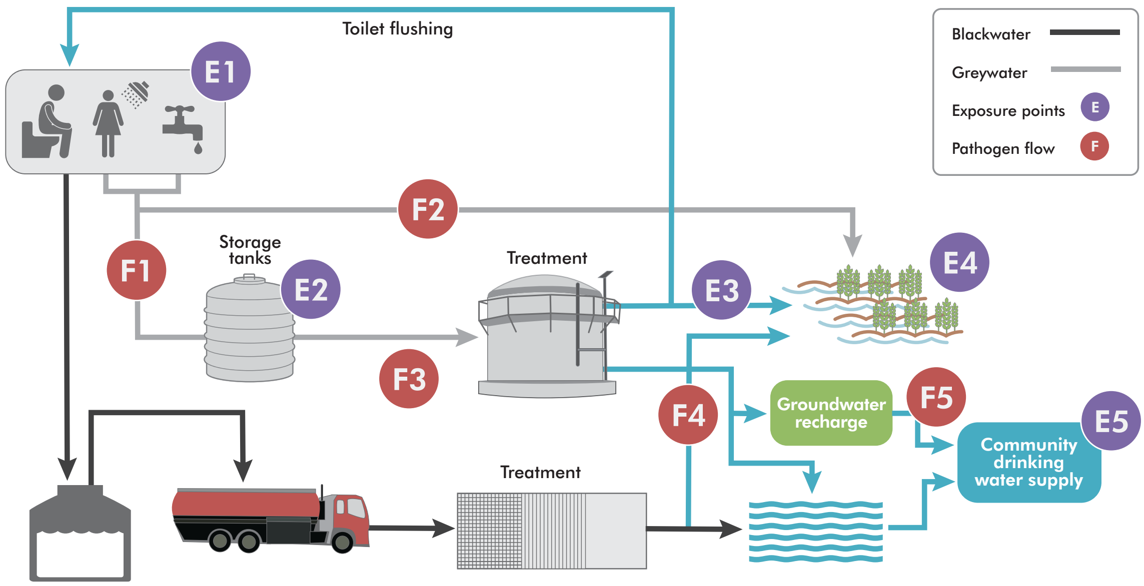
Typical scenarios for exposure to pathogens in a greywater-reuse system chain include accidental ingestion of greywater by workers; groundwater or surface water contamination with greywater; inhalation of aerosols during use of greywater for toilet flushing, crop irrigation or landscape irrigation; and consumption of crops irrigated with untreated greywater. For example, a microbial health risk assessment that was conducted for a typical source-separated greywater system in Sweden found that, despite a low faecal load, the system posed unacceptably high rotavirus infection risks (Ottoson and Stenström 2003). This underlines the need for adequate treatment in greywater recycling.

Centralized systems

Centralized wastewater systems are designed to collect and transport wastewater from households to a centralized point for treatment and disposal or resource recovery and reuse. Traditional centralized wastewater chains combine black- and greywater, with connection to large networks of sewers. They often also take in wastewater from industries and drainage. Depending on the intended application or recipient of the effluent, the choice of treatment technologies may

FIGURE 5.2

Typical pathogen flows and exposure points: on-site sanitation system with greywater recycling



E1: Users and cleaners of toilet; **E2:** Ingestion of raw greywater (workers); **E3:** Ingestion of treated greywater (workers); **E4**: Ingestion of greywater and consumption of crops (workers and consumers); **E5:** Consumption of greywater recharged water

Figure: Razak Seidu

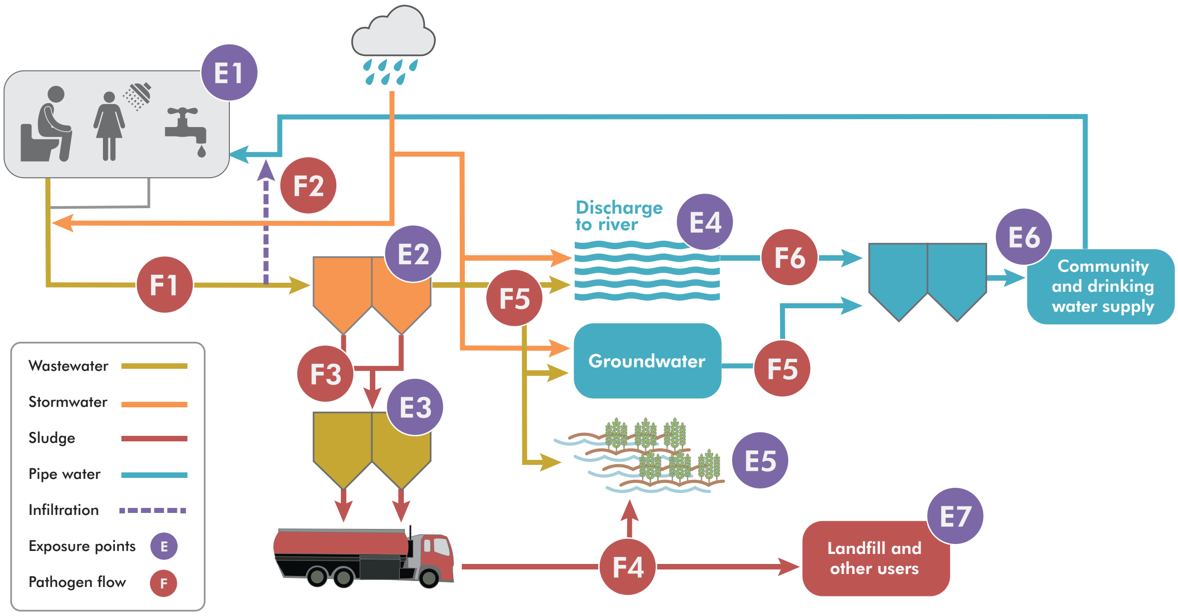
range from a simple mechanical process to an advanced combination of mechanical, microbial and chemical treatment processes. Figure 5.3 shows a centralized wastewater treatment system configuration including exposure points for the transmission of microbial pathogens.

During wastewater transport, the surrounding community can be exposed to microbial pathogens, especially during flooding or the maintenance of pipe networks. In Gaza, children under five years old living in an area with poorly constructed sewers were found to be four times more likely to be infected with *Ascaris* during winter flooding compared to those in areas without a sewer network (Smith 1993).

However, in general, communities with sewer connection are generally less likely to be exposed to pathogens than communities without. A cross-sectional study in the city of Salvador, Brazil, revealed that children aged 5–14 living in areas with sewers were between 1.2 and 1.7 times less likely to be infected with *Ascaris* and *Trichuris* than those living in areas without sewer networks. An expansion of the sewer network in Salvador to more households also reduced the prevalence of diarrhoeal disease among children by 21 per cent (Barreto et al. 2007).

In wastewater treatment plants, workers may inhale pathogens (see e.g. Fracchia et al. 2006; Westrell et al. 2004). Epidemiological studies assessing viral infection risk among workers in wastewater treatment plants have shown conflicting results. In a cross-sectional survey, no excess infection risk for Hepatitis A virus was found among plant workers in a large US city (Trout et al. 2000). In France, however, wastewater plant workers were found to be 2.2 times more likely to be infected with Hepatitis A than non-wastewater treatment plant workers (Cadilhac et al. 1996).

Figure 5.3 **Typical pathogen flows and exposure points: centralized wastewater treatment system**



E1: Users and cleaners of toilet; **E2 and 3**: Exposure to wastewater/sludge (workers); **E4**: Recreational use, e.g. swimming (users);
E5: Exposure to wastewater/sludge and consumption of irrigated/fertilized crops (workers, community and consumers);
E6: Direct or indirect consumption of potable water **E7**: Exposure at landfill site (workers and community)

Figure: Razak Seidu

5.3 Health protection in recovery and reuse

Agricultural reuse

Recovering and reusing resources from wastewater and excreta for agricultural purposes offers many opportunities to improve health through improved water and food security, along with a range of other benefits. However, this can only be considered part of sustainable sanitation and wastewater management if it is done safely. There are a range of health risks from exposure to pathogens present in excreta and wastewater that need to be avoided through appropriate management and treatment.

Wastewater irrigation
Agricultural irrigation is one of the most widespread types of water reuse. However, it is frequently unregulated and uses untreated wastewater, especially in low- and middle-income countries, which creates major health risks both for agricultural workers and consumers of the crops produced (Dickin et al. 2016).

In the case of agricultural reuse, the main groups at risk of exposure are farmers applying the wastewater or excreta-based products; consumers of crops to which wastewater or excreta-based products have been applied (particularly vegetables eaten raw); populations living in close proximity to the agricultural sites. The level of microbial health risk depends on the level, type and efficiency of the treatment the reuse products have undergone (if any).

Studies from Ghana, Vietnam, Mexico and Pakistan have revealed a high risk of helminth infection, diarrhoeal disease and skin infections among farmers using untreated or poorly treated wastewater for irrigation without protective clothing (e.g. Seidu et al. 2008; Blumenthal et al. 2001; Trang 2007; Rutkowski et al. 2007). Consumers of wastewater-irrigated vegetables can face a greater range of *E. coli* O157:H7, rotavirus, norovirus and helminth infection risks (Seidu et al. 2008; Barker et al. 2013; Seidu et al. 2013). One study estimated 0.68 episodes of diarrhoea per year associated with consuming wastewater-irrigated lettuce in urban Ghana (Seidu and Drechsel 2010). To be weighed against the microbial health risk, however, Trang (2007) found that despite the prevailing risks of helminth infection children living in an area with wastewater reuse area had significantly better nutritional status than those in areas using river water.

Less attention has been paid to the potential health risks to populations living close to wastewater-irrigated farms. One important means of exposure for these populations is aerosols from sprinkler irrigation with untreated wastewater. One study found that children living within 600–1000 m of the sprinkler wastewater-irrigated field had a two-fold excess risk of clinical enteric infection during summer months, while the average risk for the year was much lower (WHO 2006).

In order to ensure that wastewater irrigation is safe, one approach is to treat the applied wastewater sufficiently to reduce the pathogen and pollutant content to levels where the wastewater can be safely handled and crops grown with it can be eaten with only normal hygiene precautions. However, if this level of treatment is not feasible, lower-standard wastewater can be used in combination with awareness raising, stricter precautions during application and cultivation, and improved hygiene in the handling of the produce. Also, standards for food crops will be higher than for non-food crops. The US Environmental Protection Agency has elaborated comprehensive guidelines for water reuse (see below, which are based on international experiences and also partly on the WHO's guidelines for the safe use of wastewater, excreta and greywater (WHO 2006).

Source-separated faeces

In the case of a non-waterborne sanitation system, the direct use of untreated excreta in agriculture presents the most significant health risk, particularly for farmers directly engaged in the use of excreta from dry pits and consumers of excreta-fertilized crops. Several studies have found high risks of infection among both farm workers applying dried but otherwise untreated faeces and consumers of food crops grown in soil

Unsafe faecal sludge management by "froggers" in the Kibera slum, Nairobi, Kenyan. Photo: Reuters / Antony Njuguna

Part of a low-energy wastewater treatment system based around a cascade of biological stages. Biofilms of microorganisms, some living on plant roots, remove nutrients from the effluent. Photo: Organica

to which dried faeces had been applied (Westrell 2004; Trang et al. 2007; Seidu 2010; Jiménez. 2007).

However, extended storage can greatly reduce the pathogen risk from faeces. Faeces stored for 12 to 18 months, depending on climatic conditions, generally presents a minimal risk for all pathogens, except potentially some parasites (WHO 2006).

Biosolids

Digested or stabilized sludge from wastewater treatment plants is sometimes referred to as biosolids. Based on microbial content, the US Environmental Protection Agency classifies biosolids into Class A (which can be sold for public use) and Class B (for restricted use only; US EPA 2003). As with wastewater reuse, the main risk groups and exposure scenarios associated with the land application of biosolids include a) farm workers; b) populations living close to the biosolid or sludge application site; c) consumers of biosolid-fertilized food crops; and d) aquatic and other wildlife.

The risk to surrounding communities from biosolid application is unclear. Lewis et al. (2002) reported a higher incidence of disease and mortality among populations living close to sewage sludge-applied fields in Canada and the USA. The affected residents lived within 1 km of the application sites and complained about skin rashes and burning sensations in eyes, throat and lungs. However, in a national study in the USA, Brooks et al. (2005) evaluated the community health risk associated with the bioaerosols from Class B biosolids land application sites. The study took downwind aerosol samples from the loading, unloading and land application of Class B biosolids, along with background operations. The annual risk of infection was found to be below WHO target values.

A similar finding was made in Ghana, where Seidu (2010) found a low infection risk from exposure to aerosolized rotavirus during the field application of faecal sludge.

Source-separated urine

Compared with faecal sludge, the reuse of urine poses much lower health risk, in both handling and agricultural reuse. An assessment in Sweden (Höglund et al. 2012) concluded that the microbial health risk from directly ingesting urine stored for 1–6 months was acceptably low for a range of exposure scenarios. The microbial risks related to the use of urine as a crop fertilizer were quite low ($<10^{-3}$ per exposure), except for possible rotavirus infections when the urine was either unstored or stored at too low a temperature (4°C or lower). The study concluded that the health risks from source-separating and reusing urine were acceptably low, and advocated its use as a crop fertilizer.

Source-separated greywater

Greywater is generally low in pathogens, although risks may vary depending on the source of the greywater. For example, Barker et al. (2013) carried out a study in Melbourne, Australia, to assess the risks of eating home-grown lettuce that has been directly irrigated with greywater (despite government advice against the practice). The study found that the norovirus infection risk was lower from eating lettuce irrigated with bathroom greywater than from eating lettuce irrigated with laundry greywater.

However, as a rule, treatment of greywater is critical, irrespective of the source if it is to be used for irrigating vegetables consumed raw.

Potable reuse

The highest safety standards are necessary when recovered water is to be used for drinking. Studies of the microbial health risks associated with direct and indirect potable wastewater reuse schemes are limited. The few studies that have been undertaken have not shown a statistically significant association with excess disease incidence or outbreaks. An ecological study of the health risks associated with the consumption of water from the Windhoek potable reuse scheme (see the case study in Section 9.1) concluded that diarrhoeal disease prevalence was associated with socio-economic factors, but not water supply (NRC 1998). Other studies have found no significant relationship between microbial health risks and the consumption of water from direct or indirect potable reuse schemes.

The low health risk does not, however, mean that potable reuse schemes are completely immune to failures that might lead to disease outbreaks. Failure events (e.g. inadequate treatment or complete failure in a treatment step) that have triggered disease outbreaks in regular drinking water supply systems can also occur in advanced potable reuse schemes. For instance, studies have shown that many of the treatment methods in potable reuse schemes may not completely remove microbial pathogens (Gennaccaro et al. 2003; Rose et al. 1996). This means that even though there have not been any reported outbreaks, such schemes must be robust to avoid any potential failures that can significantly affect consumers.

5.4 Health risk management

Over the years several risk management approaches have been implemented to optimize sanitation systems to reduce or eliminate pathogens in wastewater; and restrict human exposure (contact, inhalation or ingestion) to pathogens in the sanitation system chain.

The most widely used health risk management approach in sanitation systems is *multi-barrier risk management.* More recently the *sanitation safety planning (SSP)* approach has been developed by the WHO to facilitate the implementation of risk management strategies by stakeholders in the sanitation sector. These risk management approaches are briefly described below with reference to specific case studies.

Multi-barrier approach

The multi-barrier approach involves interventions (barriers) to human contact with pathogens at the different potential exposure points in the sanitation chain,

Figure 5.4 **A multi-barrier approach to agricultural reuse of urine**

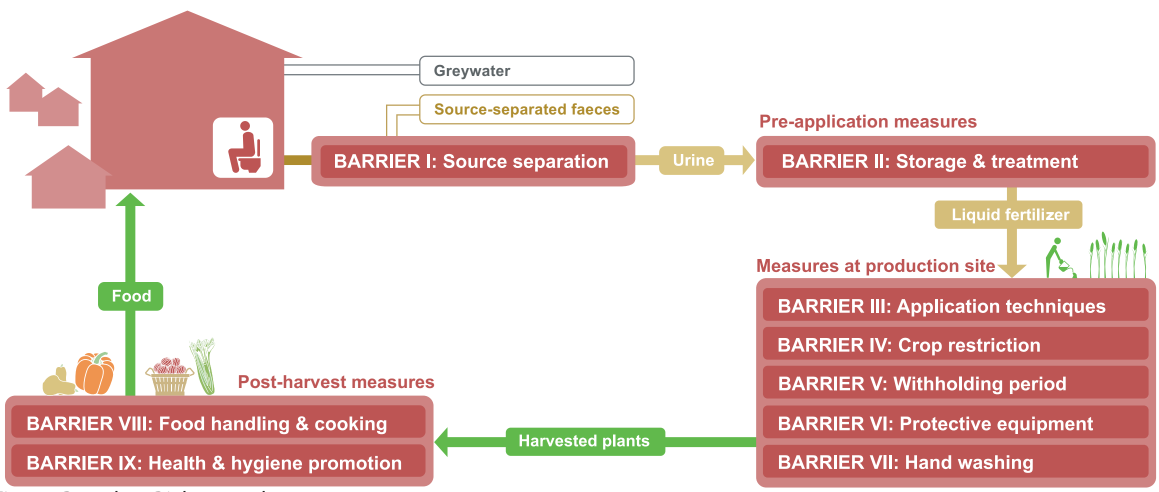


Figure: Based on Richert et al. 2010

particularly at the stages of disposal, release and/or reuse. Depending on the type of system, microbial exposure points and risk groups, the multi-barrier approach may involve a series of treatment barriers or a combination of treatment and non-treatment barriers (improved practices and behavioural and attitudinal changes) along the sanitation chain. Figure 5.4 shows a multi-barrier approach for agricultural reuse of urine.

In a multi-barrier approach, the technical treatment steps are carefully monitored and controlled to ensure consistent water quality standards and compliance with local or national guidelines. The approach has been successfully implemented in potable water reuse schemes in South Africa, Namibia (see the case study in Section 9.1), Australia and the USA.

Designing treatment according to the intended fate of the water or other fractions of wastewater (e.g. discharge into receiving waters or specific types of reuse) is commonly referred to as the *fit-for-purpose* approach. The degree of treatment is calibrated to the specific potential health (or environmental) risks in the intended use of wastewater. This approach is practised in several states in the USA and Australia, and helps in selecting cost-effective strategies (US EPA 2012a). The treatment of biosolids to Class A or B microbial quality level (see above) is another example of a fit-for-purpose approach. Table 5.2 summarizes US EPA guidelines on

TABLE 5.2 **What types of wastewater reuse might be appropriate after what level of treatment?**

	Primary treatment	Secondary treatment	Filtration and disinfection	Advanced treatment
Processes	Sedimentation	Biological oxidation and disinfection	Chemical coagulation, biological or chemical nutrient removal, filtration and disinfection	Activated carbon, reverse osmosis, advanced oxidation processes, soil aquifer treatment etc.
End uses	None recommended	Surface irrigation of orchards and vineyards Irrigation of non-food crops Restricted landscape impoundments Groundwater recharge of non-potable aquifers Wetlands, wildlife habitat, stream augmentation Industrial cooling	Landscape and golf course irrigation Toilet flushing Vehicle washing Food crop irrigation Unrestricted recreational impoundment Industrial systems	Indirect potable reuses, including: Groundwater recharge of potable aquifers Surface water reservoir augmentation and potable reuse.
Acceptable levels of human exposure	+	++	+++	++++
Cost	+	++	+++	++++

Source: Based on US EPA 2012a

TABLE 5.3 **Efficacy of treatment and non-treatment interventions at different critical points of the "farm-to-fork" chain**

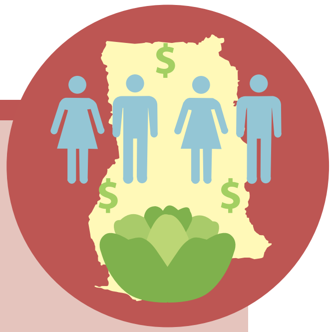
	Risk mitigation measure	Pathogen log reductiona	Comments	Primary target risk group
Treatment				
	Wastewater treatment	1.6	Pathogen reduction depends on the type and degree of treatment technology selected	Farmers exposed to wastewater Consumers of crops
On-farm options				
	Alternative land and water source	6–7	In Ghana, authorities supported urban farmers by drilling wells. In Benin farmers were offered alternative land with access to safer water sources	Farmers exposed to wastewater Consumers
	Crop restriction (i.e. no food crops eaten uncooked)	6–7	Depends on (a) effectiveness of local enforcement of crop restriction, b) comparative profit margin of the alternative crop(s)	Consumers
On-farm treatment:				
	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	Consumers and farmers
	Simple sedimentation	0.5–1	Sedimentation for ~18 hours	Consumers and farmers
	Simple filtration	1–3	Performance depends on filtration system used	
	Pathogen die-off (faecal sludge)	In line with WHO (2006)	Raw faecal sludge used in cereal farming in Ghana should be dewatered on-farm for: ≥ 60 days or ≥ 90 days depending on the application method (spread vs. pit) to minimize occupational health risk.	Farmers and people living in close proximity to sludge farms

TABLE 5.3 **Efficacy of treatment and non-treatment interventions at different critical points of the "farm-to-fork" chain** *continued...*

	Risk mitigation measure	Pathogen log reduction[a]	Comments	Primary target risk group
Method of wastewater application:				
	Furrow irrigation	1–2	Crop density and yield may be reduced	Consumers
	Low-cost drip irrigation	2–4	2-log unit reduction for low-growing crops 4-log unit reduction for high-growing crops	Consumers
	Reduction of splashing	1–2	Farmers trained to reduce splashing when watering cans are used (splashing adds contaminated soil particles to crop surfaces, which can be minimized)	Consumers
	Pathogen die-off (wastewater)	0.5–2 per day	Die-off support through irrigation cessation before harvest (value depends on climate, crop type etc)	Consumers
Post-harvest options at local markets				
	Overnight storage baskets	0.5–1	Selling produce after overnight storage in baskets (rather than overnight storage in sacks or selling fresh produce without overnight storage)	Consumers
	Produce preparation prior sale	1–2	a) Washing salad crops, vegetables and fruit with clean water	Consumers
		2–3	b) Washing salad crops, vegetables and fruits with running tap water	Consumers
		1–3	c) Removing the outer leaves on cabbage, lettuce	Consumers
In-kitchen produce – preparation options				
	Produce disinfection	2–3	Washing salad crops, vegetables and fruit with appropriate disinfectant solution and rinsing with clean water	Consumers
	Produce peeling	2	Fruits, root crops	Consumers
	Produce cooking	6–7	Options depends on local diet and preference for cooked food	Consumers

Sources: Seidu 2010; Seidu et al. 2013; Mara 2010; US EPA 2012a
[a] Log (for logarithm) reduction is a way of measuring pathogen elimination. A 1-log reduction is a ten-fold (or 90 per cent) reduction in the number of pathogens, a 2-log reduction is a 100-fold (or 99.9 per cent) reduction, and so on.

BOX 5 .1



Effectiveness and cost-effectiveness of interventions for wastewater irrigation in urban Ghana

In urban Ghana, diarrhoeal diseases associated with the consumption of wastewater-irrigated lettuce account for 12,000 DALYs, representing about 10 per cent of the diarrhoeal disease burden in the country. A study assessed several treatment and non-treatment interventions for their cost-effectiveness in reducing diarrhoeal disease among consumers of the crop. The treatment intervention included the rehabilitation of existing wastewater treatment plants to improve the microbial quality of irrigation water for farmers. The non-treatment interventions focused on the farms and post-harvest points (kitchens and restaurants where wastewater-irrigated lettuce salad are prepared); and aimed at stimulating good risk management practices at those points through a campaign.

The study found that, depending on the risk management practices used at different stages, between 41 and 92 per cent of the diarrhoeal disease burden could be averted. The average cost-effectiveness ratios were:

- On-farm non-treatment intervention: US$13/DALY averted.
- Post-harvest intervention (75% of kitchens adopting hygienic food preparation and handling): US$ 27/DALY averted.
- Combination of low-cost wastewater treatment, on-farm and post-harvest non-treatment interventions (75% adoption rate): US$61/DALY averted.

The assessment revealed that the adoption rate of the non-treatment interventions at the critical points was the most important determinant of both the effectiveness and cost-effectiveness of the interventions.

Source: Based on Seidu and Drechsel 2010; Drechsel and Seidu 2011

the treatment requirements for different types of wastewater reuse.

A multi-barrier approach based on fit-for-purpose strategies underpins microbial guidelines for wastewater treatment and disposal/reuse in many developed countries. In many low- and middle-income countries, however, the implementation of treatment barriers in the protection of public health remains an intractable challenge.

The most recent WHO guidelines (WHO 2006) advocate a combination of treatment and non-treatment barriers along the entire path from “farm-to-fork”, in order to protect public health in agricultural reuse schemes, particularly in low- and middle-income countries. In this approach, health outcome-based targets instead of water quality standards are used.

The WHO guidelines use disability-adjusted life years (DALYs) to define the health outcome-based targets. They currently define the maximum tolerable additional disease burden from reuse as $\leq 10^{-6}$ DALY lost per person per year. In areas where high levels of

Crops fertilized with treated excreta: extra precautions may be needed in food preparation. Photo: Kim Andersson

contamination are expected this translates roughly into 6–7 log units of pathogen reduction before food to which wastewater has been applied can be consumed.

Defining health outcome-based targets instead of specifying mandatory treatment steps offers authorities more options and flexibility in how they reduce the risks, especially where conventional water treatment is not possible.

Several risk management strategies have been implemented or experimented with to assess their efficacy in achieving the WHO target. Table 5.3 summarizes the efficacy of different treatment and non-treatment interventions along the farm-to-fork chain.

An optimal combination of non-treatment and treatment strategies can be both effective in pathogen reduction and cost-effective in averting disease burden per dollar invested (see Box 5.1). However, there are obstacles to implementation in unplanned reuse schemes in low- and middle-income countries. For example, farmers engaged in such reuse, as well as consumers of wastewater-irrigated crops, may have a poor understanding of the hazards and risks. Successful implementation often requires: improved understanding of the risk and benefits of the interventions; changes in long-standing traditional practices; investments; and effective local regulation.

Sanitation safety planning

The SSP approach provides a framework for developing and implementing strategies to optimize a sanitation system for public health protection (WHO 2015). It specifically provides guidelines for the identification and management of health risks along the sanitation chain; informs investments based on actual health risks; and provides assurance to authorities and the public on the safety of sanitation-related services and products.

The SSP approach is derived from the WHO guidelines for safe use of wastewater, excreta and greywater (WHO 2006). It can be adapted, however, to cover sanitation systems that are not configured for reuse purposes. The approach involves three distinct but interrelated steps: assessing the sanitation system, monitoring operation of the system; and management of the system.

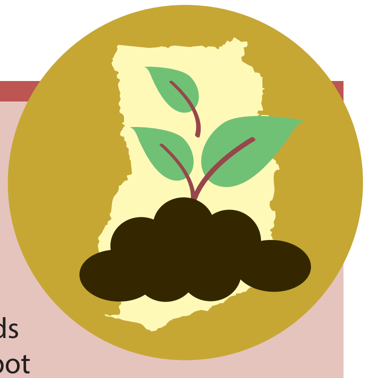
Assessment: This step involves a comprehensive assessment of the different units that comprise the sanitation system. The assessment identifies the different microbial exposure points in the system; potential hazardous events at the exposure points, including technology failure and risks related behaviour and practices; the groups exposed to risk at the different exposure points; the severity of the health risks for different risk groups; and prioritization and ranking of the exposure points.

Monitoring: Monitoring mechanisms are needed to quickly detect problems in the system and mitigate hazardous events. A monitoring regime may involve sampling and microbial analysis of treated wastewater in the case of a reuse scheme, to ensure that specific guidelines are met.

In a non-waterborne system, monitoring regimes may cover the use, containment, emptying and disposal or agricultural use of excreta. Ultimately, the outputs of operational monitoring will help system managers to decide whether new risk reduction or control measures are needed in the system.

Management: Procedures are needed to maintain the integrity of sanitation system components – and minimize microbial risks – during normal operation. There should be a plan of action and control measures to

BOX 5.2



Local guidelines for faecal sludge application in northern Ghana

In Northern Ghana, farmers applying sludge to agricultural lands employ two traditional sludge treatment methods – random spot spreading and pit containment – to process raw sludge into "cakes" for health risk mitigation, easy handling and application. Dehydration of the sludge is undertaken in the dry season (November to April) when temperatures across the northern zone of the country can reach 39º C.

Although the treatment methods are perceived to be safe by farmers, and provide an alternative option to conventional sludge treatment technologies, they are considered illegal by public health authorities. No alternative health risk reduction measures have been made available to the farmers, however, and they continue to apply sludge using the traditional methods. Varying sludge drying times ranging from 7–60 days and 90–105 days for the random spot spread and pit methods, respectively, were used by farmers.

An assessment of the two methods showed the WHO health-based target for direct exposure to rotavirus and ascaris could be achieved if sludge is dewatered for ≥ 60 days and ≥ 90 days under the random spot spreading and pit methods, respectively. This simple treatment provides farmers options of choosing between the random spot spreading method and the pit method depending on their needs. It does not require the collection and analysis of samples for microbial analysis and is therefore easy for farmers to implement and manage.

Source: Seidu 2010

mitigate potential health risks during system malfunctions.

Improving health risk management in practice

Risk management in sustainable sanitation and wastewater systems requires not just appropriate technologies but also financing, as well as appropriate behaviours from users, workers and communities. In addition, guidelines and regulations are necessary for the effective implementation of risk management strategies.

In areas where there is poor understanding of the critical microbial exposure points in the sanitation system and the potential health risks they present, it is thus crucial to invest in behavioural and attitudinal change. Here, well-designed and implemented awareness-raising campaigns and training programmes can play a significant role in improving public understanding.
Costs associated with risk management may include both direct costs, for example in technologies or materials (from a treatment plant to a pit latrine to protective clothing for workers); and indirect costs, for example related to the loss of profits due to wilting of crops (e.g. lettuce and cabbage) due to cessation of irrigation before harvest. Risk management strategies should take these costs into account and provide economic incentives or assistance such as subsidized or free treatment facilities or soft loans where there is a risk that costs could prevent implementation.

Many countries lack guidelines or regulations for the agricultural use of wastewater and other waste fractions. The current WHO guidelines provide some levvel of flexibility through the multi-barrier framework with health-based targets, described above. Implementing the guidelines for wastewater irrigation will, however, remain a daunting challenge in the short to medium term in low- and middle-income countries. Local authorities often lack the capacity to implement and monitor specific components of the WHO guidelines.

There is therefore a need for specific local and national guidelines in these countries (Seidu 2010). The national guidelines should be easily comprehensible and implementable based on existing local practices, like those proposed for traditional sludge treatment and reuse in northern Ghana described in Box 5.2. The development of the guidelines and regulations should involve broad consultation with all stakeholders, including both the potential beneficiaries and risk groups: users of sanitation facilities, users of the treated excreta and/or greywater, financial institutions, and research institutions, for example. The SSP process can help in identifying the stakeholders that should be involved.

KEY MESSAGES

- Recovery and reuse of resources in wastewater and excreta can greatly improve human health and well-being through improved food security and nutrition, and reduced burdens of water-related disease.
- There are high risks associated with the reuse of untreated or improperly treated wastewater and excreta.
- Recognizing potential risks associated with resource recovery and reuse requires an integrated perspective based on an under-standing of local exposure pathways.
- Mitigating risks to human health in sanitation and wastewater management, particularly in resource recovery and reuse, can be achieved through both technical treatment and non-technical (e.g. behavioural) measures in combination.

6. ENVIRONMENTAL SUSTAINABILITY AND PROTECTION

Inadequate management of wastewater has significant implications for environmental sustainability. When large volumes of wastewater are discharged untreated into rivers, lakes and oceans containing nutrients, toxic substances and organic matter, they can severely compromise the integrity of ecosystems (Grant et al. 2012). In addition to the harm to aquatic life, degraded ecosystems have less capacity to provide a number of important services that humans rely on such as coastal protection, water purification and food provision (Barber et al. 2011).

BOX 6.1

UNEP GEMS/Water Programme: a pioneer in water quality monitoring

The UNEP GEMS Programme was initiated in 1978 with the aim of providing global capacity for storing data on water quality from monitoring programmes. Until April 2014 it was supported by Environment Canada. It is now co-hosted in Nairobi, Germany and Ireland.

The GEMStat (www.gemstat.org) database shares surface and ground water quality data sets collected from the GEMS/Water Global Network, including more than 4,100 stations. It holds close to 4.9 million records, and the over 100 parameters that constitute the World Water Quality Assessment. It includes global data sets showing water quality trends in natural and polluted drainage systems. GEMStat is currently hosted by the German Federal Institute of Hydrology.

GEMS also has a new capacity building centre based in Ireland, supported by a consortium of Irish universities and institutes. The centre runs training workshops in developing countries in monitoring and water quality management.

Source: www.unep.org/gemswater/

While there is growing interest in ensuring wastewater treatment can mitigate environmental risks, this is a relatively recent development and still found mainly in higher-income countries.

Environmental protection efforts in the context of sanitation and wastewater management were originally focused largely on monitoring. Box 6.1 describes the UNEP GEMS/Water programme, which sought to create a global database for water quality monitoring. Increasingly, however, the focus has shifted to end-of-pipe measures to minimize harm from wastewater, which are generally technology-based, and preventive measures, including behavioural, regulatory and technology-based steps and systems-based approaches such as integrated water resources management (see Box 6.2). As the viability of various forms of recovery and reuse usually depends on waste streams having a predictable quality and composition, it can provide an added incentive (and financing) for both preventive and end-of-pipe measures that help to reduce environmental damage.

6.1 Environmental risks

Nutrients and organic matter

Nutrient contamination originates from two main sources: agricultural run-off, and the release of human and animal excreta and other biodegradable organic waste into water bodies. Excessive nutrients negatively impact the structure and functioning of freshwater and marine ecosystems by temporarily boosting the growth of certain plant species, especially algae. When the excess biomass dies, its bacterial decomposition depletes the oxygen content of the water, creating zones that are hypoxic or anoxic (i.e. with very little or no oxygen).

BOX 6.2

Integrated Water Resources Management and wastewater

Environmental protection of coastal zones and lakes or rivers requires that wastewater management is coordinated with other sectors such as agriculture, silviculture and industry. Integrated Water Resources Management can support this kind of coordination. IWRM uses the water basin as the operational scale. The concept of IWRM for entire drainage basins was developed during the 1990s, and several organizations have subsequently set up global IWRM programmes, including the Global Water Partnership (GWP) and the UN Development Programme's Capacity Development in Sustainable Water Management Network (CAP-Net).

The IWRM approach has been successfully carried out in a number of watersheds, including the North Sea, Baltic Sea, North American Great Lakes and Chesapeake Bay. In a peri-urban district of Pixian, China, IWRM planning was used to show that agricultural wastewater reuse could conserve 35 Mm of water in local rivers each year and/or significantly increase agricultural profits (Murray and Ray 2010).

This can lead to losses of critical habitats and biodiversity, including mass die-offs of fish (also referred to as "fish kills") or other fauna (Diaz and Rosenberg 2011). In addition, algae may produce toxins, sometimes known as red tides or harmful algal blooms (HABs), or may prevent sunlight penetrating the water surface, which further aggravates the oxygen deficit. Figure 6.1 shows that eutrophication is widespread and occurs in many parts of the world, representing an important global water quality challenge.

Nutrients affect different ecosystems in specific ways, so appropriate nutrient management solutions are very important. For instance, phosphorus has traditionally been the key factor in determining the primary productivity of freshwater ecosystems, thus high levels are most likely to lead to eutrophication. In coastal and marine systems, nitrogen has been the most important contributor to eutrophication (Schindler and Vallentyne 2008).

There are also significant variations in the relative importance of nutrient sources around the world. For example agricultural sources (commercial fertilizers and animal manure) are typically the primary sources of nutrient pollution in waterways in Europe and North America, while urban wastewater is often the main source of nutrients in the coastal waterways of South America, Asia and Africa. Biodegradable organic matter, such as faeces, contained in untreated wastewater can also deplete oxygen resources in water bodies and contribute to degradation of water quality and damage to aquatic life.

Promoting environmental sustainability through wastewater management has largely focused on waterborne systems. Less effort has been invested in researching more indirect impacts such as pollutants leaching into soils, for example from poorly sited pit latrines, and being passed on and concentrated through food chains. While more than 1.77 billion people use pit latrines, research to date has only focused on a few indicator contaminants (Graham and Polizzotto et al. 2013). Discharge of waste into subsoils may also generate an excess of nutrients in groundwater, which may reach toxic levels that affect human and livestock health when used as a drinking water

FIGURE 6.1 **Eutrophication impacts worldwide**

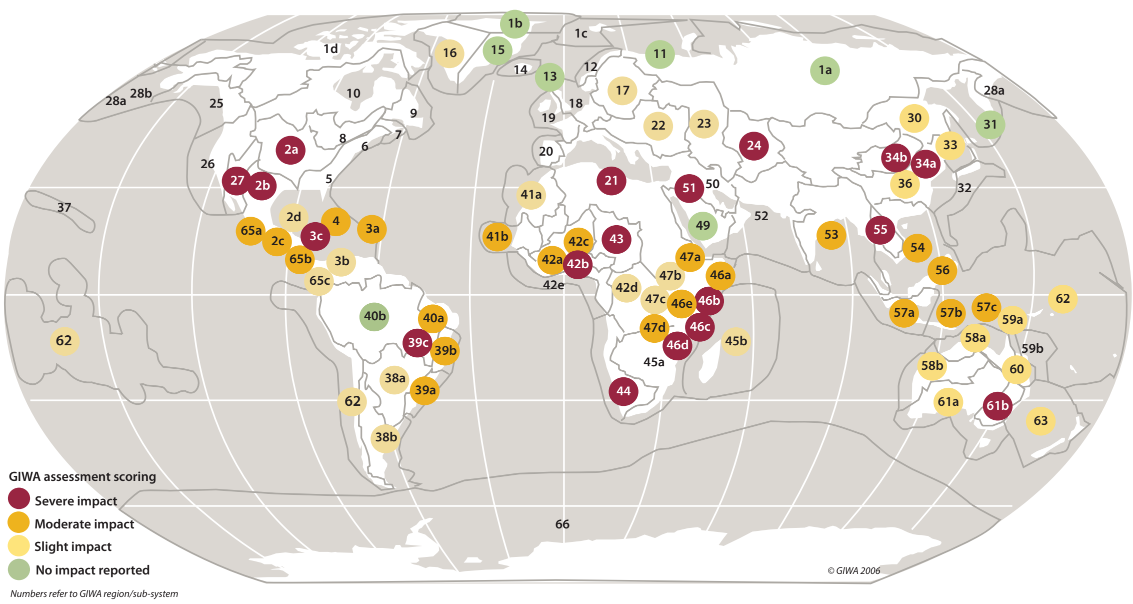


Figure: UNEP 2006

source. These environmental contamination pathways will increasingly require new research and management solutions.

Harmful substances

The impacts of hazardous substances found in wastewater on ecosystems range from acute toxic effects (e.g. ammonia leading to fish mortality) to longer-term impacts in the case of substances that persist and build up to dangerous concentrations (e.g. organic compounds such as polycyclic aromatic hydrocarbons (PAH) and plasticizers, or heavy metals such as mercury, lead and cadmium).

Emerging contaminants such as pharmaceuticals, personal care products and pesticides are also receiving increased attention due to their potential negative impacts on humans and ecosystems. Studies have shown that emerging contaminants may have developmental, reproductive and behavioural impacts on fish and other aquatic life (Holeton et al. 2011). These hazardous substances primarily impact aquatic ecosystems, although there are also potential transmission pathways via soil and food production into terrestrial ecosystems when reusing sanitation waste products and wastewater on agricultural land. Box 6.3 shows how pharmaceutical compounds in wastewater can end up in the environment. However, further research is needed to improve understanding of the transport

BOX 6.3

Pharmaceuticals in wastewater

Cumulative excretions of antibiotics, analgesics, hormones and anti-inflammatories into municipal wastewater systems may pose significant environmental risks. While understanding the full extent of potential impacts on human health and the environment requires further research, there has been a significant reaction to these concerns among the public, which presents a challenge for municipal authorities that are responsible for treating household sewage. Much like trace levels of radioactivity, public response to the identification of pharmaceutical compounds in drinking water, even if they are identified at nano- and picogram-per-litre levels, needs to be addressed. The pathways of these compounds in the environment are illustrated in the figure below.

Pathways of pharmaceutical compounds in the environment

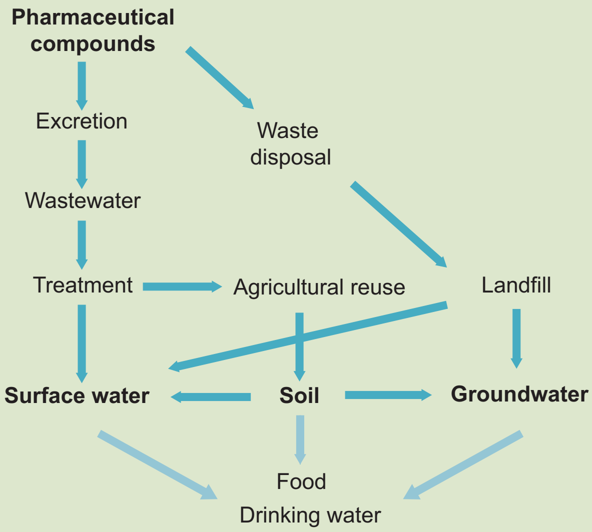


Figure: Adapted from Ternes 1998

and fate of these diverse chemicals in the environment (Luo et al. 2014).

Many existing wastewater treatment plants are not capable of eliminating such emerging contaminants, as they were not designed to do so. This is illustrated by a monitoring survey of wastewater treatment plants as part of a Chemicals Investigation Programme in the UK, which revealed that the treated effluent from more than half of the plants exceeded environmental quality standards for chemicals including PAHs, zinc and a range of pharmaceuticals (Gardner et al. 2012).

6.2 Protection responses

Technological responses

Technological approaches to reduce environmental risks from wastewater and excreta can be both preventive and end-of-pipe treatment. Different processes, or combinations of processes, are more effective at reducing different problem substances. When new contaminants appear they require new technologies, and new investments. As production and consumption patterns change, wastewater treatment and environmental protection responses must thus be able to adapt (Thomaidi et al. 2015). All of the technologies described in the case studies in Chapter 9 are designed at least in part with environmental protection in mind.

The best combination of treatment steps to include in a wastewater management system is determined by the (current and projected) characteristics of the wastewater, the substances (and pathogens) that need to be removed, and the characteristics and sensitivity of surrounding ecosystems. There are also trade-offs to be made between the efficacy of the treatment and the operating costs, energy requirements of the treatment processes, the creation of dangerous by-products and concentrated residues that then need to be handled safely (Luo et al. 2014). A lifecycle assessment approach can be useful to determine whether the environmental benefits of a particular treatment or type of resource recovery really outweigh the environmental costs (see e.g. Gallego et al. 2008).

In addition to end-of-pipe treatment, there can be upstream control of pollutants in households or within industries (including e.g. replacement of hazardous substances, on-site reuse and recycling, and modification of processes). Box 6.4 describes the potential impact cleaner production strategies can have on industrial emissions.

Environmental monitoring is an important tool for keeping track of progress in wastewater management and for follow-up on the efficiency of treatment measures. For instance, some pharmaceutical compounds that persist in surface water may be considered indicators of wastewater contamination. Recent advances in analytical techniques have made it possible to detect even trace levels of contaminants (Richardson and Kimura 2016).

Regulatory mechanisms

Tools for effective implementation of wastewater risk management strategies often include a range of regulatory frameworks. An example is the US system, centred on the 1972 Clean Water Act. This system includes water quality criteria for wastewater treatment, the issuing of discharge permits for industries and effluent regulations.

Defining what substances must be regulated is a continuous process, given the constant emergence of new compounds and materials, and uncertainty about their possible short- and long-term impacts. The European Union has chosen to address this challenge with the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) regulation, requiring companies themselves to identify and manage the risks associated with chemicals they manufacture (if they are used in Europe), and demonstrate how they can be safely used. EU member states' authorities are responsible for enforcing REACH and can restrict the use of hazardous substances (see echa.europa.eu/regulations/reach).

Understanding the types of activities generating wastewater is crucial to identify appropriate strategies to protect the environment. Industrial and commercial activities such as mining, pulp and paper, pharmaceutical production, tanneries and food processing often produce complex discharges. Many countries impose regulations on these types of activities, and require companies to treat effluent before it is discharged into combined wastewater streams. This is particularly cost-effective when the effluent contains substances that would not otherwise enter the wastewater stream: applying the necessary treatment to the entire volume of combined wastewater would make little sense. Also, many wastewater treatment methods (and resource reuse methods) use biological processes that might be adversely affected by toxic compounds.

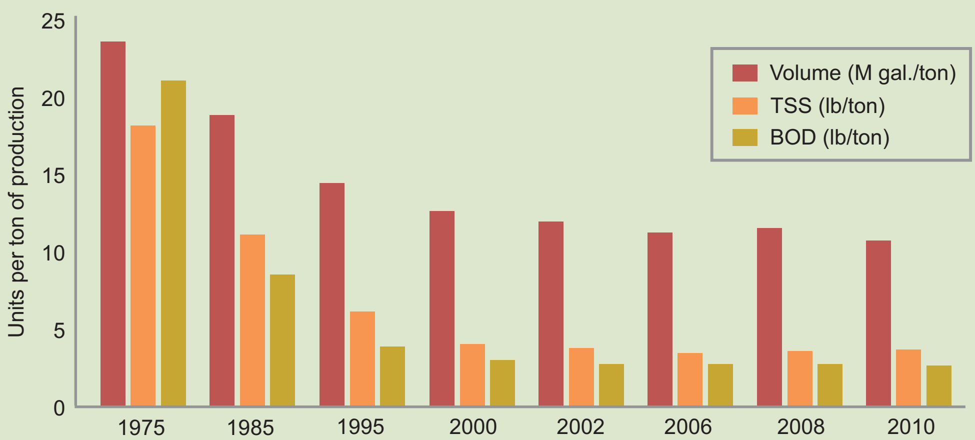
In many countries, regulations or guidelines for environmental management within

BOX 6.4

The pulp and paper industry: from dirty mills to bio-refineries

Industrial pulp and paper production has long been associated with major impacts on downstream aquatic ecosystems due to toxic compounds in effluents, largely from bleaching. Since the 1970s, however, in many places around the world the pulp and paper industry has significantly reduced wastewater volumes, total suspended solids and BOD values. In the USA, for example, between 1975 and 2010 the amount of dissolved organic material discharge that can contribute to oxygen depletion (i.e. biochemical oxygen demand) in the receiving stream was reduced by 88 per cent (see the figure below). New technologies are introducing cleaner bleaching and digestion processes that save on raw materials and decrease waste streams and toxic effluents. In addition, bio-refineries producing climate-friendly biofuels that can address the industry's emissions of greenhouse gases are being introduced (Isaksson 2015).

Effluent discharge reductions in pulp and paper mills in the USA (1975–2010)



TSS = total suspended solids;
BOD =biological oxygen demand.
All values imperial.

Figure: Based on AF&PA 2012

sanitation systems are inadequate or lacking. In particular, many countries do not have specific guidelines or regulations for the agricultural reuse of wastewater. In this case, WHO guidelines (WHO 2006) propose a flexible approach of risk assessment and risk management linked to health-based targets (see Section 5.4 and Amponsah et al. 2015).

Behavioural responses

Behavioural interventions, like awareness campaigns targeted at households to promote safe disposal of various products, can also make important contributions towards environmental protection (Malmqvist and Palmquist 2005). While individual households contribute to a smaller range of potential toxic compounds, some of these can be easily avoided through behavioural interventions and by providing alternatives for hazardous waste disposal, such as locations where people can dump paint residues. For example, to avoid elevated heavy metal content in wastewater, awareness campaigns have been used to stop people disposing of household dust in their toilets (Kim and Ferguson 1993). Sweden managed to halve the level of heavy metal contamination in wastewater between 2000 and 2013 due to a range of upstream measures, very few of them involving treatment (Finnson 2013)).

Environmental protection is generally not the first priority in the design of on-site sanitation systems or in arrangements for disposal of sludge from treatment systems, but it is important to build awareness of the associated challengesin order to encourage more sustainable behaviour.

BOX 6.5

REVAQ: certification of wastewater treatment plants in Sweden

REVAQ is a unique system that aims to support measures by wastewater treatment utilities to reduce flows of dangerous substances to wastewater treatment plants, in order to achieve sustainable reuse. REVAQ is operated by the Swedish Water and Wastewater Association, the Federation of Swedish Farmers (LRF), the Swedish Food Federation and the Swedish Food Retailers' Federation, in close cooperation with the Swedish Environmental Protection Agency.

REVAQ was launched in 2008, and by 2013 about half of Sweden's population was connected to a REVAQ-certified wastewater treatment plant, with the share steadily growing. In 2013 REVAQ-certified sludge contained almost 3000 metric tons of phosphorous, of which 1300 tons was used in agriculture. It has been calculated that if the whole Swedish population were connected to a certified plant, and acceptance of agricultural reuse were further improved, the sludge could replace 50 per cent of the mineral fertilizers currently used in Sweden.

Treatment plants can obtain REVAQ certification after a third-party audit based on four criteria: a structured work programme for improving quality, upstream activities to reduce contamination of wastewater flows, transparency about quality and treatment processes, and quality of sludge output.

Source: Persson et al. 2015

6.3 Recovery and reuse as drivers for environmental protection

Resource recovery and reuse can play an important role in addressing environmental concerns associated with wastewater. Contamination must be kept at levels that are safe enough for the planned type of reuse or recovery. Even small quantities of toxic substances, at the scale typically released by households, can make water and sludge unsuitable for reuse. They can create unacceptable health and environmental risks – as well as reducing the value of the recovered resources and the efficiency of biological processes such as biogas production or growing insect protein (see the cases in Sections 9.5 and 9.6). A the same time, treated wastewater can still contain salts, heavy metals, pharmaceuticals and other substances that accumulate in soil if used for irrigation. Thus, different reuse scenarios must be carefully managed, planned, and monitored (US EPA 2012a).

Sewage treatment plants hoping to sell reuse products, particularly treated water and sludge-based agricultural fertilizers, have a strong incentive to prevent harmful substances reaching the plants in the first place, and may include a range of upstream measures to do this as part of their business operations. The unique Swedish REVAQ system encourages this by certifying sewage treatment plants as producing sludge suitable for agricultural reuse (see Box 6.5).

From the perspectives of nutrient management and environmental protection, agricultural (or silvicultural) reuse of sludge is generally a win-win solution since the nutrients are used to boost productivity instead of being discharged into the environment and causing eutrophication. As with any use of fertilizers, however, poor management and excessive application can lead to environmentally hazardous run-off.

Finally, it is important to take environmental considerations into account when reviewing possible trade-offs and different options for reuse in a specific context. For instance, in some areas it might make more sense to use wastewater to recharge aquifers and provide a coastal barrier against saltwater intrusion (El Ayni et al. 2011) or to irrigate non-food crops rather than to treat it up to the required standard for potable reuse or irrigation of food crops. Similarly, the energy input required to achieve these standards may lead to unacceptably high GHG emissions. Alternatively, the wastewater could be reused to irrigate non-food crops (e.g. energy forests).

KEY MESSAGES

- Ecosystems impacted by discharge of untreated wastewater and human excreta have less capacity to provide a number of important services that humans rely on.
- Options to prevent the release of environmentally harmful substances include both end-of-pipe treatments and a range of cost-effective technological, behavioural and regulatory measures to prevent such substances entering waste streams in the first place.
- Sustainable sanitation and wastewater management can play a key role in limiting the release of damaging pollution, pathogens and nutrients, particularly nitrogen and phosphorus, into aquatic ecosystems.
- Resource recovery and reuse can provide incentives – and sources of financing – for keeping environmentally harmful contaminants out of treated wastes.

7. INSTITUTIONAL AND SOCIAL ASPECTS OF SUSTAINABILITY

7.1 Governance systems for recovery and reuse

Even the best-designed technical system for sanitation and wastewater management cannot be truly sustainable unless all of the responsibilities for service delivery and system management are clearly assigned, and the stakeholders are aware of their responsibilities and both able and willing to fulfil them.

This is an even bigger issue for sanitation and wastewater management systems aiming for resource recovery, as they involve an even greater diversity of actors than conventional systems, and many of these actors have no prior experience of the sector. The additional complexity of linking in new sectors and stakeholders, while also raising the bar in terms of service quality, requires something beyond conventional institutional arrangements and governance.

This chapter discusses special institutional and social challenges for a system designed for safe and efficient resource management, including recovery and reuse. It highlights management roles and responsibility and provides examples of proven solutions – both formal and informal – for reuse-enabling institutions.

The governance system for conventional wastewater management is already complicated, involving several sectors with different focus areas; for example, water discharge is regulated by one department, health and safety by another. The addition of resource recovery can introduce additional components and actors into this system. For example, agricultural reuse directly affects the farmers as well as the consumers and traders of products produced using recovered resources. It is thus particularly important to understand interactions between major components of the governance system.

Analyses of users and the public good employ a common terminology for discussing these interactions. One important distinction from a governance perspective is between the public and private "spheres", reflecting whether the interests most closely affected at different stages of the process are public goods (public health, healthy environments) or private (the interests of the different types of users and consumers); and linked to that, where primary responsibility might lie for proper functioning of the respective spheres. It should also be noted that in a rural setting, the entire chain, private and public spheres included, can be fully on-site (see Box 7.1).

Such a division is necessarily imperfect. For example, the private sphere should remain subject to public-sector regulation and support, while services in the public sphere are often carried out by private contractors. While the user interface is usually very much in the private sphere, public toilets are an example of a user interface in the public sphere. Nevertheless, the division into public-private spheres is a useful starting point for discussing the institutional and social aspects of sanitation and wastewater systems.

The private user sphere

The *private user sphere* for sanitation systems includes the parts of the service chain with which individual users have direct contact, generally covering the user interface, collection, and transportation away from the immediate household environment. The main functions within the private user sphere are waste containment and other functions to protect health and provide convenience. For on-site systems, functions such as treatment and subsequent reuse or disposal into the environment may fall within the private user sphere (subject to public regulation), while for institutional and public sanitation facilities, functionality issues will be very similar to household facilities, but ownership and responsibility will look different. In general, the individual user (e.g. household or private company) has responsibility for the functionality of the system components (often according to regulated minimum standards), which means that in most cases, initial investments and running costs for these components are the responsibility of the user. There are situations, however, where utilities manage individual systems at the household level and users pay monthly fees for the service.

The public sphere

Management of waste streams outside the household compound – mainly conveyance/

BOX 7.1

Private and public spheres in rural and peri-urban systems

The limits and functions of the private and public spheres vary between rural (and peri-urban) and urban settings. While urban areas often have centralized, piped systems to carry away wastewater, many rural and peri-urban residents rely on on-site or small decentralized systems. This means that excreta are stored on their property at least temporarily. Certain rural systems can be fully on-site; for example, households may dig a new pit when the old one is full, or use composting toilets and urine storage, with direct reuse on their own land. However, private users more often rely on external services such as for emptying pit latrines and septic tanks to maintain functionality. These services should be considered part of the public sphere, because poor functionality can impact on public health and the environment.

A challenge is often a lack of formal emptying services. This means that this functionality depends on the knowledge, capabilities and responsible behaviour of the household and/or an informal emptier. Too often, latrines are allowed to over-run, or untreated sludge is dumped in the environment. In general, more attention needs to be paid to the public sphere functionality of sanitation and wastewater systems in rural and peri-urban areas. This requires local governments to take responsibility, and establish an appropriate governance framework.

A man fishing in sewage-polluted water at the junction of the Wei and Zao rivers. Photo: Reuters / Stringer

transportation to a treatment facility, treatment and disposal – are regarded as being in the *public sphere* (see Valfrey-Visser and Schaub-Jones 2008). Functionality in the public sphere is often the responsibility of the local government, though it may contract or partner with private service providers. Poor functionality in this sphere can impact public goods and the population at large, for example through degradation of the environment and ecosystem services, or high risks to public health – particularly in urban settings.

Resource recovery and reuse may also fall within the public sphere, for example in the case of water recycling and reuse, and excreta-based energy generation, fed into public grids. This is also the case where resources are used to restore ecosystem services within the public domain.

The private re-user sphere

Finally, depending on the nature of resource recovery, the treated products from the public sphere may also move into the *private re-user sphere* of the service delivery chain. This is the case when, for example, recovered nutrients, organic matter and water are applied on private agricultural land. Products linked to resource reuse, such as foods, fuel or treated water, also return to the user private sphere when they are purchased (and consumed) by individuals. The acquisition of the recovered resource products often takes place in the public sphere; for example, distribution of recovered water that households purchase.

As with the functionality in the private user sphere, activities in the private re-user sphere also need to be regulated and supported by public entities in order to protect public health, the environment and consumers' rights. For example, procedures for applying different qualities of treated wastewater to agricultural land or urban green space need to be regulated in order to protect both agricultural workers and surrounding communities. Further along the chain, hygiene standards need to be monitored and disseminated for the sale and consumption of the resulting agricultural products.

7.2 Governing the user private sphere

Achieving functionality in the user private sphere is one of the critical and most challenging management issues for the entire sanitation and wastewater system. While private actors generally have ownership and responsibility for maintaining both the user interface and part of the collection system within their domain, they often do not understand their role within the larger system of wastewater management. In addition, the technical infrastructure within the private sphere is often chosen and purchased by the users themselves. The choice and use of technology in the private sphere, however, directly impacts on management in the public sphere, as only facilities that are properly used, cleaned and maintained regularly provide benefits.

Accordingly, there is need for communication strategies that enable mutual understanding of user needs and system functionality within both spheres. Regulators, service providers and others in charge of defining general requirements for system design in the user private sphere need to consider social aspects (such as hygiene practices and preferences, ease of cleaning, menstrual hygiene issues) in order to ensure functionality of the full service delivery chain, and especially so where resource recovery is aimed for. Source separation, in particular,

BOX 7.2

Capturing the right message: urine reuse in Niger

A project to increase fertilizer access for smallholder farmers in rural Niger shows the power of using the right message in order to motivate behavioural change. Before the project started, many believed that it would be difficult to convince the population to use treated urine as a fertilizer owing to religious and cultural taboos. Through close work with religious leaders, women's groups and agricultural assistants, however, the project found that changing behaviour – establishing urine collection and reuse at household level – was easier than anticipated. The project used a PHAST (Participatory Hygiene and Sanitation Transformation)–SARAR (for self-esteem, associative strength, resourcefulness, action planning, responsibility) sanitation and hygiene promotion methodology (see WaterAid 2013), adapted to communicate the fertilizer value of treated human excreta, in conjunction with crop trials with urine fertilizer and exchange between villages.

The main barriers to overcome were local Islamic beliefs forbidding people from handling urine, and a preference among men to squat while urinating. The solution was to collect the urine in closed jugs and apply it to the fields using gloves, thus avoiding contact with the urine. The families were encouraged to place the collection jugs in holes, thus enabling a squatting position.

Women were especially positive to the new technique since it greatly reduced odour around the family compound (previously the family urinated in the shower which drained into the street outside). From an agricultural perspective it was not difficult to convince the farmers of benefits of using urine as fertilizer. It was already well known that the fields closest to the village (where local people often defecated) produced better than other fields. The improved yields demonstrated in crop trials using urine during the project also helped to convince people. In a relatively poor area, the message that the farmers could produce their own fertilizer at a minimal price proved to be a very powerful one.

The project was implemented by CREPA (now Water and Sanitation Africa; WSA) in close collaboration with Stockholm Environment Institute and the local organization Project for the Promotion of Local Initiatives for Development in Aguié (PPILDA).

Source: Dagerskog 2010

relies on the correct design, functioning and use of components in the user private sphere. Consequently, users must be made aware of and be willing and able to follow directions for proper use, for example avoiding excess water in dry systems, and avoiding dumping chemicals or other hazardous wastes into a toilet.

There are three key aspects that should be addressed in the user private sphere in order to achieve functional reuse: appropriate drivers for proper use of a sanitation facility with reuse; technical solutions that facilitate proper use, operation and maintenance; and effective communication with users to raise awareness, create ownership and when necessary, effect behaviour change.

Promoting behaviour to facilitate reuse in the user private sphere

To facilitate resource recovery in sanitation and wastewater management, the governance system needs to create an enabling environment. An initial step is to identify the key motivations of users in investing in, and then using, a specific type of user interface. For domestic sanitation facilities, studies show that users generally desire an interaction with their system that is convenient, comfortable, clean and dignified (Cairncross 2004; Jenkins and Curtis 2005; Jenkins and Scott 2007). Additional factors can include legal requirements, improving household status, available subsidies, and protecting health and the environment.

It can be difficult to motivate users to install and correctly use a reuse-oriented system, especially if it is designed differently from the system they are accustomed to or involves additional costs such as fees or added maintenance. Strategies and management structures need to be put in place to communicate reuse benefits to individual users and ensure that they are willing to pay and use the systems properly (see Box 7.2 for a successful project in this regard).

Creating "willingness-to-pay" in private users can involve both economic and ideological drivers. In some cases, economic benefits may be felt directly in the private sphere; for example household-level biogas production, fertilizers for household gardening or agriculture, or water reuse.
However, especially in urban areas, benefits may not be felt directly by users. In such cases, it may be advisable to redistribute the system's net benefits through, for example, reductions in service fees or tax rebates. In

Demonstration of urine-diverting dry toilet prototypes, eThekwini, South Africa. Photo: Kim Andersson some cases, regulations can also be used to create economic incentives. For example, in Sweden environmental discharge regulations prohibit building houses with traditional on-site wastewater treatment technologies in environmentally sensitive areas. Building permits can, however, be obtained for certain resource-recovery systems, so land owners can upgrade or build new houses in areas where they otherwise would not have been able to do so (see the case study in Section 9.4) .

Ideological drivers aim to give users a sense of personal satisfaction when they install and properly use and maintain their system. This could be linked, for example, to a desire to protect the local environment, protect children's health, or reduce climate impacts. Increasingly, people are aware that their choices matter and they may be willing to change their consumption habits if they feel that it will make a positive difference.

Resource recovery can, of course, be a powerful driver for highly environmentally conscious users. It can also, however, motivate other users. A study in Sweden (Wallin 2014) showed desire for personal gain to be the strongest driver for reuse, followed by concerns about fairness (for example in distribution of costs and benefits). While environmental motivations lagged behind these, they were nonetheless also important for users. Thus, if all other factors are equal, environmental motives can help to change users' behaviour.

Mechanisms for two-way communication with the users are critical for the success of ideological drivers. In particular, it is important to communicate results: that is, show users that their waste is actually being reused.

User-oriented design

Only facilities that are used properly, cleaned regularly and generally maintained provide benefits. It must be remembered that the key driver in the private sphere is a positive personal experience, particularly with the toilet. No one wants to use a smelly, dirty toilet, no matter how much fertilizer it makes, or how strict the regulations are. The toilet and other parts of sanitation facilities, such as the shower, should be easy to use and clean. If routine cleaning is difficult to do there is a risk that they will not be cleaned and soon become non-functional.

An information panel to support a sustainable sanitation project in Bihar, India. Photo: Kim Andersson

Dry and source-separating toilets can be particularly sensitive to cleaning issues since excess water used for cleaning can create problems such as strong odours in dry faecal collectors or diluted urine with lower fertilizer value. Consultations with users, particularly women who traditionally are responsible for household cleaning, are strongly recommended during the design and testing of new toilets. In cases where special cleaning methods are required these will need to be clearly communicated to the users. In the case of public and institutional toilets the involvement of caretakers and janitors is clearly needed.

The user interface should be suitable for both sexes, and adapted to certain cultural norms and preferences; for example for squatting or sitting, or wiping or washing for anal hygiene. The facility should also be designed so that it is easy to use properly. If the system requires source separation, this should as far as possible be accomplished by the toilet itself and not require manual action by the users.

An additional issue for women is menstrual hygiene and how the toilet interface and facility are designed to accommodate it. For example, it will require ways of safely storing or disposing of reusable cloths/pads or disposable sanitary products, that do not interfere with the system's proper functioning. Failing to provide disposal facilities can result in blockages and rapidly filling pits/tanks as women discard used sanitary material in the toilet (House et al. 2012); alternatively, if the pads are discarded outside the toilet but not properly enclosed, they can spread pathogens. This is particularly an issue with public toilet facilities, because of the lack of surrounding private space and the risk of spreading communicable disease. However, information campaigns may also be needed to inform private households concerning the proper disposal of sanitary products.

Water availability for cleaning reusable material, as well as how this water is disposed, should also be factored into system design.

Changing behaviour and attitudes

In cases where private facilities are lacking or misused there is likely a need for both awareness raising and behaviour change. There are a number of successful tools available for promoting sanitation use. In particular, community-led total sanitation (CLTS) has been used to stop open defecation practices (Kar and Chambers 2008) and the Participatory Hygiene and Sanitation Transformation (PHAST) approach (see Box 7.2) aims at providing communities with techniques to improve their hygiene behaviour (Simpson-Herbert et al., 1997). The key messages in these tools are generally related to health and improvement of the local environment.

These methods use participatory and social marketing techniques to educate and create social pressure to change. Other marketing techniques, such as subsidies and awareness-raising campaigns, have been shown to be effective drivers for investment in and use of private household toilets. At the same time, it is crucial that the social intervention has a technical capacity component to ensure appropriate design and operation.

From a reuse perspective, it is of course important that people adopt hygienic household practices. It can, however, be harder to motivate adoption of particular reuse-oriented systems. As mentioned above, the development of a social marketing reuse programme will need to communicate the right drivers for private users. In rural settings, the fertilizer benefits of reuse can be communicated in both words and demonstrations (see Box 7.2, the case study in Section 9.3, and Andersson 2014b). Demonstration units, where future users can experience and try out different technologies is key to gaining acceptance for new technologies (see the case study in Section 9.5 and Andersson 2014c).

There is a need, however, to develop better communication tools, messages and techniques for driving behaviour change in relation to wastewater reuse. While some existing tools can be adapted for this purpose, others, such as CLTS in its current form, may actually be directly

BOX 7.3

Translating Ostrom's principles in the context of sanitation and wastewater management

Nobel laureate Elinor Ostrom suggested a number of guiding principles for successful management of common-pool resources. These principles can be broadly applied to sanitation and wastewater management as a means to set guidelines for establishing successful public institutions. In order to avoid terminological confusion in this text, common-pool resources will be referred to as "the public good" while "resources" refers to recoverable resources in wastewater flows and excreta.

Clearly define boundaries of the system, its users and the public good affected
Ostrom's principles state that there should be clearly defined boundaries for:

- users: clear and locally understood boundaries between legitimate users and non-users are present;
- the public good: clear boundaries that separate a specific public good/question from a larger social-ecological system are present.

Build responsibility for governance in multiple layers
This covers Ostrom's principle of nested enterprises, where service provision, monitoring, enforcement, conflict resolution and governance activities are organized in multiple layers of nested enterprises.

Allow users to participate in governance
This combines two of Ostrom's principles:

- collective-choice arrangements: most individuals affected by the operational rules can participate in modifying them;
- minimal recognition of rights to organize: the rights of community members to devise their own institutions are not challenged by external governmental authorities.

Match service delivery to local needs and conditions
Ostrom states that governance structures should be congruent with local social and environmental conditions.

Establish a monitoring system
Ostrom highlights the need for monitors who actively audit resource conditions and appropriator behaviour:

- monitoring users: users or individuals who are accountable to them monitor service provision to users and the users' own use of the services and system.
- monitoring a public good: users or individuals who are accountable to them monitor the condition of the relevant public good.

Apply equitable tariffs, sanctions and methods for conflict-resolution
This covers another two of Ostrom's principles, as well as the need for an equitable distribution of costs and benefits:

- graduated sanctions: sanctions for rule violations start weak but become stronger with repeat violations;
- conflict-resolution mechanisms: responsive, low-cost, local mechanisms exist for resolving conflicts among users or with officials.

Source: Adapted from Elinor Ostrom's Nobel lecture (Ostrom 2009) and Ostrom 1990

User participation in designing a toilet as part of a sustainable sanitation project in Colombia. Photo: Kim Andersson

counter-productive, since they play on disgust about human excreta, which conflicts with the idea of them as valuable resources (Kar and Chambers 2008). Some tools for analysing sanitation behaviour and designing messages for change exist, such as the SaniFOAM framework (Devine 2009). New tools and intervention strategies that apply psychological knowledge on behavioural change are needed (Mosler 2011), particularly in relation to reuse.

Awareness raising may also be necessary with regard to resource reuse *products*. For example, consumers may have concerns regarding the quality and safety of vegetables fertilized with human excreta in areas where this has not been traditionally practised. In some cases, legal frameworks reinforce this low acceptance, as in the case of European Union legislation regarding organic certification, which does not allow for fertilization with treated human excreta.

In designing resource recovery systems it will be important to identify acceptance levels for proposed products and how existing legislation may be hindering or promoting recovery. In instances where acceptance is low, communication and marketing strategies will be needed in order to increase acceptability.

7.3 Governing the public and re-user private spheres

Within the public sphere, governance and functionality of the sanitation and wastewater management system assure benefits that extend beyond the individual. A properly functioning sanitation and wastewater service delivery chain protects water sources, the living environment and public health. Water sources, the living environment and public health can be considered "common pool resources" or "public goods" – that is to say, resources from which the public benefits but the protection of which may be in conflict with private interests. For example, it may be convenient for an individual to discharge untreated wastewater (e.g. by flushing the toilet) into the public drain, but such behaviour results in a downstream public health hazard and deterioration of the receiving water body.[19]

[19] An example of the "tragedy of the commons". See Hardin (1968)

BOX 7.4

Using geography, not systems, to set jurisdictions of utilities

While institutional mandates in the water and sanitation sector have traditionally been divided up according to technologies or functions (it is especially common for a utility to cover only sewer-connected users), this approach poses a real risk of gaps or conflicts in responsibilities, which can among other things make the kind of cross-sectoral cooperation needed for resource recovery and reuse more complicated. An increasingly common approach is to instead give one institution responsibility for all sanitation and wastewater management (and potentially also management of other organic waste) within a geographic area.

In Durban, South Africa, the eThekwini municipal Department of Water and Sanitation delivers services to a range of different types of customers within municipal boundaries. The department delivers water-borne sanitation services within a defined zone. (Outside this zone, services are implemented based on the South African national free basic services policy.) On top of that, the department offers different levels of water-borne service delivery within the water-borne sanitation zone, in order to match different abilities to pay for services. Durban also has 500 informal settlements, to which eThekwini Water and Sanitation temporarily provides public toilets, showers and washing services until these settlements can be upgraded through the national housing programme.

Another example is the Water Utilities Corporation (WUC), in Botswana whose mandate to deliver water and sanitation services has recently changed as part of larger water sector reforms. WUC's previous mandate was based on maintaining and expanding (piped) water supply and sewerage networks. In practice, WUC has now taken over water supply and sanitation services from district and town councils in all incorporated towns and villages, including on-site users. Hence, its mandate is now based on geographical jurisdiction. In Dakar city, Senegal's National Sanitation Office (ONAS) is responsible for both sewer-connected sanitation and the management of on-site systems, although the utility has chosen to use private-sector participation for collection, transport and treatment of faecal sludge from on-site systems.

The interpretations of Elinor Ostrom's principles for managing common-pool resources presented in Box 7.3 provide a good framework for considering governance in the public and reuser private spheres, and is used in the following subsections.

Clearly define boundaries of the system, its users and the public good affected

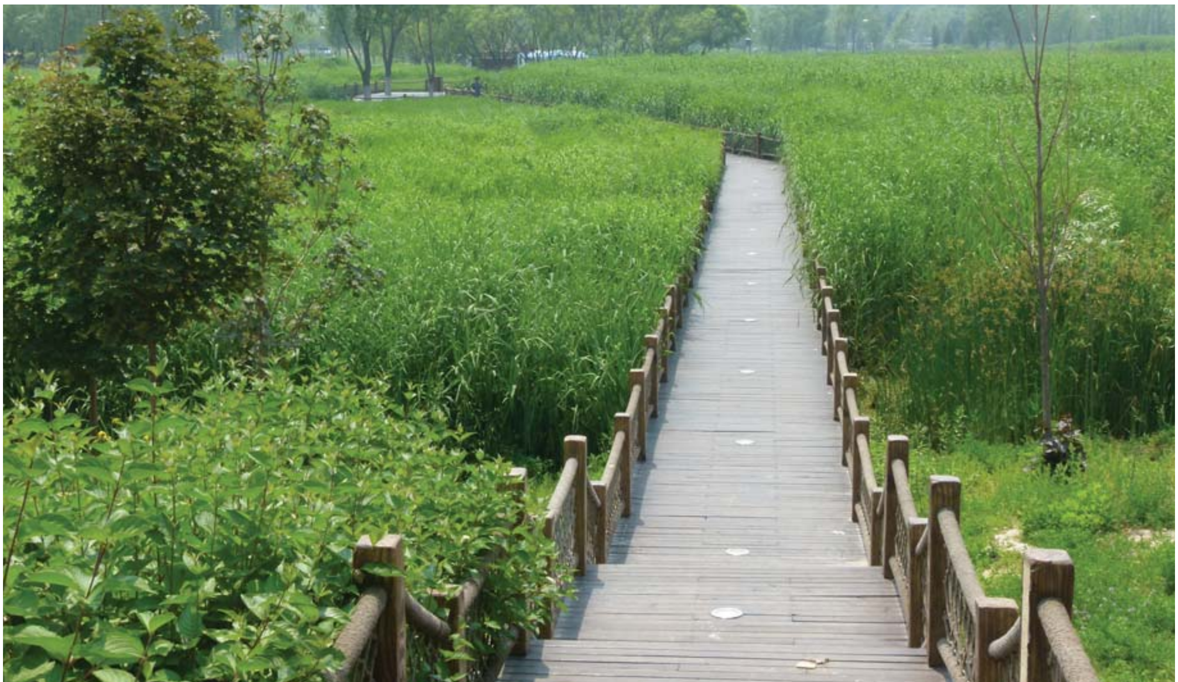
To define the governance boundaries – that is, what falls within the responsibility of a governance institution – of the entire resource recovery system, it is important to define initially the public good to be managed, and the users. Often particular public good issues drive implementation or upgrading of sanitation and wastewater systems, such as avoiding pathogen spread, pollution or eutrophication, or boosting food, water or energy security. In defining the boundaries of the public good to be served or protected, it is critical to cover the local population affected as well as the local environment or receiving waters. For example, wastewater effluent from an urban treatment plant will affect a particular recipient locally, but also have potential negative effects for users in other settlements downstream.

For sanitation with resource recovery, the public good will also have to include the final application of the recovered resource. In the case of agricultural reuse, for example, the land on which the resources are reused has to be included within the boundary of the system; for energy reuse, air quality may have to be included as a potentially affected public good.

It is also important to define the system's legitimate users. For a utility or other entity responsible for service delivery, user boundaries are defined by the customers accessing the services. Traditionally, many utilities serve only customers with sewer connections – hence the type of sanitation technology sets the user boundary. This generally works in settlements with high sewer coverage rates, including in newly developed areas. It works less well, however, in settings where the conventional sewer system covers only a fraction of the city. In many cases, citizens without sewer connections have to rely on services to support on-site systems, which often are unregulated, more expensive than sewer services, and operate under the radar of the authorities. All too often, they dispose of sludge improperly, harming water resources and the urban environment in general. Thus, for both public goods and service delivery, it makes more sense to define user boundaries geographically, instead of according to sewer connection or other technical criteria (see Box 7.4).

With the boundaries of the public good and users clearly defined, the boundaries of the entire system more easily fall into place. A sanitation or wastewater management system's boundaries are the settlement in question (including its inhabitants and physical environs) and the recipients (that is, bodies of water or land) receiving the treated waste of the treated effluents – both solid and liquid – from the wastewater and sanitation systems in that settlement.

The addition of resource recovery to the service chain complicates system boundaries, adding more (re)users and affected public goods, and leading to the additional challenge of engaging and motivating sectors normally not involved in sanitation service delivery, such as agriculture or energy. However, most forms of resource recovery



A constructed wetland in Beijing Olympic Forest Park helps to clean wastewater released to the environment, as well as providing a valuable ecosystem for birds and other wildlife, and a pleasant urban leisure facility. Photo: Claus Holzapfel and reuse affect the public good positively, for example by reducing the need for chemical fertilizers or fossil fuels.

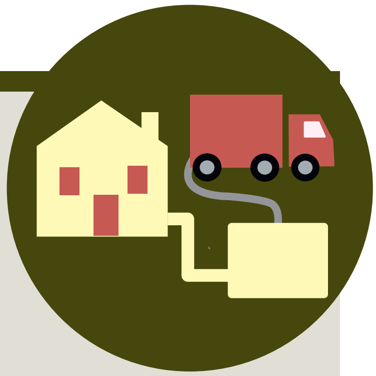
Build responsibility for governance in multiple layers

When sanitation and wastewater services include reuse, the system necessarily involves more stakeholders and thus multiple governance layers. For example, the reuser private sphere may introduce actors from the agriculture or energy sectors and their corresponding institutions.

A multi-level governance structure is often geographically organized, with local actors managing local resources while at the same time being part of a wider district or national organization. Cooperation and coordination between the different layers of governance is of course critical for success. The roles and responsibilities of organizations at all levels of governance (including public, private and non-profit sectors) should be clearly understood and respected by all (WHO 2006).

Originally, the need for nested layers of governance arose from grassroots frustration over the inability of governments to protect local ecosystem services. There are numerous examples of wastewater and sanitation service delivery reflecting this situation around the world, such as the organically developed on-site sanitation and wastewater management services described in Box 7.5. Such organizations often exist in parallel with

BOX 7.5



Organically developed faecal sludge management services, Bengaluru, India

In many cities where coverage of the conventional sewage network is limited and the city authorities offer no services to on-site sanitation customers, private entrepreneurs offer unregulated emptying services under the radar of the authorities. One such example is the megacity of Bengaluru, India, where there are many private operators. These operators empty septic tanks and pits, and transport the faecal sludge to a treatment plant in the best cases, but more often the sludge is dumped indiscriminately in the urban environment. Some operators in Bengaluru take the faecal sludge to peri-urban farmers who then reuse it in crop production.

These services have developed organically without institutional or financial support from the authorities. They operate in an institutional "grey zone" and an uncontrolled manner. As long as the services stay under the radar of the authorities they will most probably only cater to the "private good" of the sanitation service delivery chain. Control and institutional recognition are two things needed to get the public good part of the chain operational.

In order to further develop what already exists and not to break what is already functioning, it is important that authorities and service providers consider existing services and use them as a starting point when formalizing services within the public sphere of the service delivery chain. In the Bengaluru case, that would entail capitalizing on existing agricultural reuse, while making sure that reuse is conducted safely.

Source: Kvarnström et al. 2012

formally recognized services such as utilities providing connections to sewer systems. In a city, other types of service may also exist, such as services offered by local or external non-profit organizations. These informal governance structures, however, are usually unable to protect the public good since they are normally not connected to waste flow treatment systems.

Multi-level governance structures should be planned and managed from the initial development stages. Experience shows that spontaneous and free development of layered governance has clear limitations in terms of service delivery (Nordqvist 2013). An analysis of sanitation service delivery in Kampala, Uganda, found that services showed the desirable adaptive capacity, but that the provided services did not produce sustainable outcomes, either within the private or the public sphere. Better linking of property owners to a wider governance structure might improve this situation, especially with effective structures for monitoring and sanctions (see below).

The steering of layered governance needs to be even stronger for services that include reuse, given its necessary involvement of actors from other sectors, and its raising of the service delivery bar towards more sustainable services. The expansion of the governance system to also include resource recovery will require: higher investments within all responsibility spheres; and financial costs, as well as organizational implications and related behavioural change.

Improvements in service delivery, with full connection between the different elements in the service delivery chain, will not happen organically. Rather, they demand different types of incentive and instrument to steer development, such as political engagement, resource recovery policies, regulation and legislation, inter-sectoral work at the local government level, information, financial incentives available for households, external funds for service providers aiming at resource recovery, and extensive communication between stakeholders. As stated previously, however, organically developed services, which are part of existing layered governance, should be used as a starting point when firming up sanitation governance for improved public good protection and resource reuse.

Allow users to participate in governance

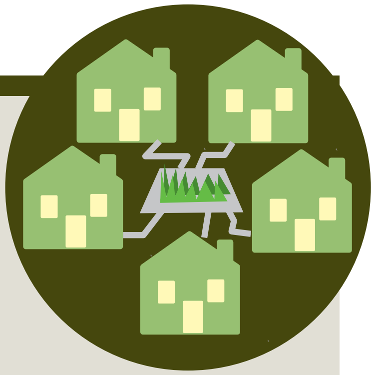
One of the fundamentals of the principles shown in Box 7.3 is that of public participation, for example involving users in setting the operational rules of the system (and having their input respected by the authorities). In a wastewater and sanitation system there is also a need for strong user participation, especially within the user private sphere. It is valuable, however, also to involve users in planning and shaping the service chain functions within the public sphere. This is particularly important in countries that lack strong institutions for service provision and system management.

In the water and sanitation sector, stakeholder participation is often seen, and promoted, as a means to understand the existing problems, create a common vision of necessary improvements across the spectrum of stakeholders, understand citizens' demands for improved services, and set realistic priorities and trade-offs in the actual context. Involving users and existing service providers in the process of formalization of service delivery can assure better customer satisfaction, compliance with use of the system and payment of fees: and ultimately a more functional system.

Increasingly, sectoral planning tools put stakeholder participation at the core of their processes. One example is the Community-Led Urban Environmental Sanitation (CLUES) process, developed at EAWAG-Sandec (Box 7.6). Another is the strategic approach to urban sanitation planning described by Tayler et al. (1999), which also involves the stakeholders and has an iterative approach. The well-established PHAST-SARAR methodology is another example. PHAST-SARAR relies heavily on participation in order to improve the sanitation situation in rural areas (see Box 7.2, WaterAid 2013 and Simpson-Herbert et al. 1997).

When service delivery also encompasses resource recovery and reuse, there is a

BOX 7.6



Participatory planning and governance using the CLUES approach

Nala is a village in Nepal with approximately 2,000 inhabitants. Before a sanitation intervention using the Community-Led Urban Environmental Sanitation (CLUES) approach for planning and implementation, Nala had poor sanitation situation, with over-full latrines and a high water table. The situation had contributed to strong local demand for sanitation improvement in an area with active local leadership and support from community groups.

The CLUES approach focuses first on household decisions about service needs, and then moves on to consider the neighbourhood, the larger settlement, and its surroundings. A sanitation plan looking at all waste streams (human excreta – in the form of blackwater or other fractions, greywater, solid waste and stormwater), as well as hygiene promotion was produced during the planning phase. The participatory multi-stakeholder process involved household surveys, identification and prioritization of user needs, and community information exchanges. In Nala the village came to a decision to implement a simplified sewerage system with an anaerobic baffle reactor and horizontal-flow constructed wetland for blackwater treatment. The users were also actively involved in the implementation stage, both in developing an action plan and in constructing the system.

Success factors in the Nala CLUES process include the strong demand for sanitation improvement, support from local leaders, and extensive user participation and ownership throughout the project. The community-level committee set up to facilitate the project's implementation has now been merged into the Nala Water Supply and Sanitation Users Committee, which is a legal entity registered with the local authority. This committee is responsible for O&M of the system. Hence, the Nala experience is a good example not only of participatory processes, but also of how users can be involved in monitoring and in shaping governance arrangements.

Source: Sherpa et al. 2013

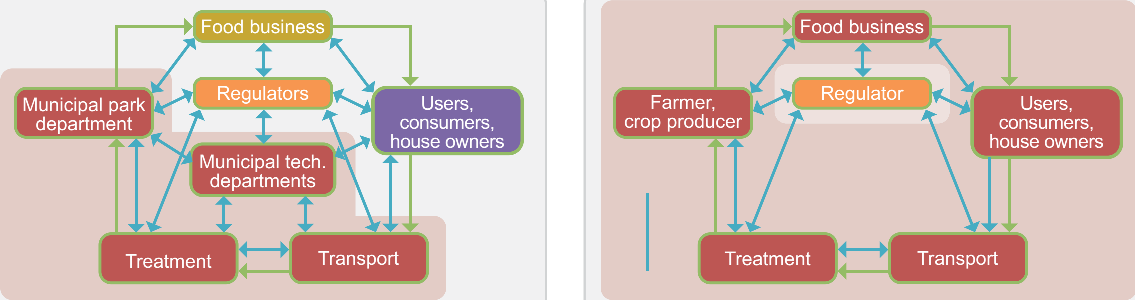
need to involve (re)users from the sectors targeted for potential reuse. It is, for example, incredibly important to involve farmers in an early phase in any project aimed at agricultural reuse, the aim being to develop trust between the sectors, and to ensure that farmers' demands are known and met, and that the service chain can be adapted to match the farming cycle. A good example of cooperation between a utility, farmers and the research community is the case of Hölö, Sweden (see the case study in Section 9.4).

A key to establishing meaningful participation and functional structures for governance is to create trust between the various actors. Especially in the case of agricultural reuse cultivating crops for human consumption, trust between the key stakeholders, including the food industry, is of utmost importance.

Establishing trust also means valuing the different kinds of knowledge that various stakeholders can bring to discussions. As noted above, informal service providers may be better placed to understand and respond to the needs of local residents yet their knowledge is not always valued as highly as that of, for example, a technical consultant.

FIGURE 7.1

Stakeholder trust and communication webs for resource recovery and reuse systems



Municipal system: A municipality that opts for resource reuse within its own sphere of influence (shaded box) has to build trust and exchange information with fewer stakeholders.

Rural system: Resource recovery and reuse in subsistence farming means easier trust and information flows; in this case, the same farmer could represent all the stakeholders except one: the regulator.

Green arrows = material flows; blue arrows = trust and information flows

Figure: based on H. Jönsson, Swedish University of Agricultural Sciences

An analysis of stakeholder relationships and levels of trust can be a critical step in achieving functional participation (see Figure 7.1). Based on this analysis, well-defined communications plans and trust-building activities can be developed to overcome areas where there is a lack of trust between stakeholders.

Match service-delivery to context

There is a widely acknowledged need to adapt governance and service delivery systems to local needs and conditions. One-size-fits-all policies and large national or regional roll-outs of wastewater technologies, regulations and approaches have been shown to be largely ineffective, and probably not the best way to achieve improved services and resource recovery (see Ostrom 2009).

In contrast, a customer service perspective allows for the ultimate adaptation to local needs and conditions. Too often, however, the local government body responsible for sanitation and wastewater focuses on infrastructure expansion rather than service delivery; sets tariffs according to political agendas rather than realistic levels for financial sustainability; and under-prioritizes O&M, all of which often lead to substandard service delivery as well as low accountability (McGregor 2005).

In many cases, developing a service delivery model that matches local needs demands internal reform of a utility or local government body in charge of service delivery. Focus needs to be shifted from engineering and infrastructure to customers and service delivery.

Achieving this shift may require implementing different management models and distributing roles and responsibilities for service delivery between different stakeholders. For example, the local government body can set a strong focus on customer service, accountability and appropriate service delivery in the contracts it signs with different types of entities.

Management responsibility can reside with:

- A public utility,
- private operator(s),
- community-based organization(s), or
- combinations of the above.

For the resource recovery step, there may or may not be a different set of service providers with whom to engage, and who in turn can be public, private or community-based. There are a number of factors that will influence the most suitable management model for a system with resource recovery. These cover the combination of operator(s) in a given context (see Figure 7.2), including:

FIGURE 7.2 **Key factors in the design of a wastewater and sanitation management system**

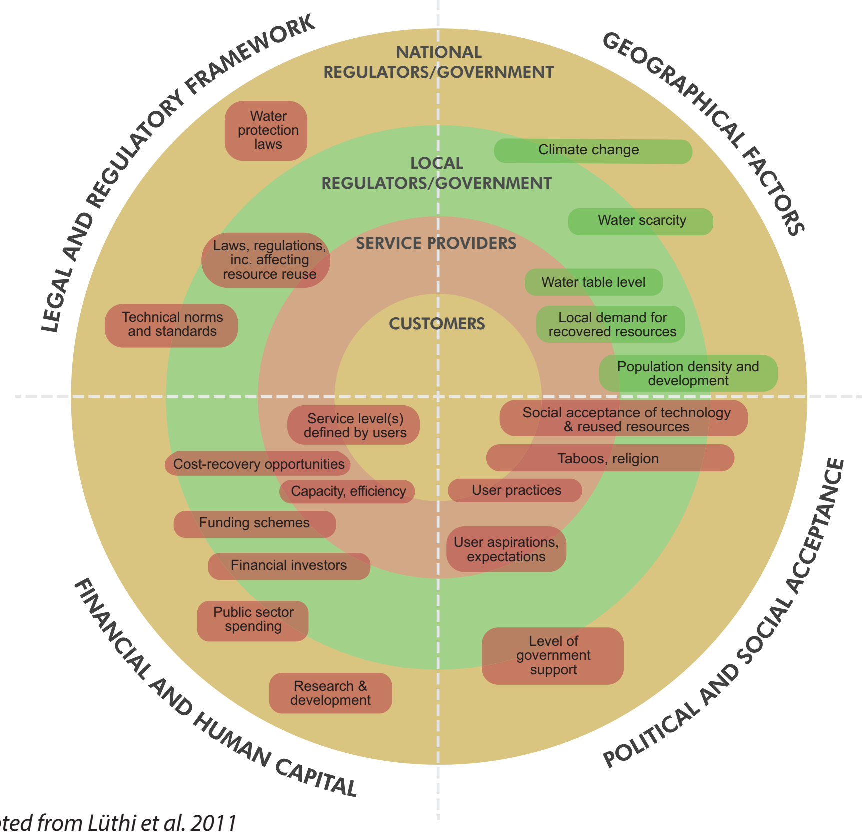


Figure: Adapted from Lüthi et al. 2011

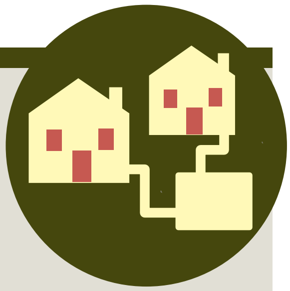
- expected and appropriate service level(s), as defined by the customers;
- service capacity and efficiency of potential service providers;
- cost-recovery expectations and possibilities;
- local demand for recovered resources;
- socio-cultural acceptance of technical solutions and recovered resources;
- existing regulation and legislation, including those impacting resource recovery; and
- government support.

The first four bullets above are all strongly linked to the local context, and are therefore crucial for deciding on a locally adapted model. Determining an appropriate management model will mean understanding the strengths and weaknesses of potential operators and asking critical questions to identify areas in which knowledge and capacity are currently lacking.

Key questions to be asked are: Do service providers have the knowledge and human capacity to operate proposed technical systems? Are there elements of the service delivery chain that can generate a profit and therefore can be outsourced to the private sector? What information or resources do the proposed reusers (e.g. farmers) need to be able to effectively use the waste product? Is there management capacity within other sectors that can be linked to this system? Answering these questions and developing solutions to fill knowledge gaps will help development of efficient service-delivery models.

The *service levels expected* by customers will strongly influence the selection of potential operators, as will the operators' capacity to deliver that service. Areas with existing sewer systems will expect to maintain a similar service standard, for example, even if it is retrofitted for resource recovery, and thus a community-based organization may not be an appropriate operator to deliver the service. The situation may, however, be different in an area where customers are used to operators coming to the house to empty on-site systems.

BOX 7.7



Service delivery associations: the SISAR and COPANOR models

Two models have been developed to meet the challenges of providing a sustainable water supply to small, isolated, communities in poor regions of Brazil: the SISAR model in Ceará state and the COPANOR model in the semi-arid Minas Gerais state. In both states, the water and sanitation service utility had difficulty properly serving isolated communities. Water and sanitation service systems had been built for these communities following participatory, demand driven planning processes, but they often fell into disrepair a year or so after construction when the social capital imparted in the planning and construction process gradually dissipated and the water users' associations that had been created consequently failed to keep the systems running.

The SISAR model has been in use for two decades. Its approach is to create a federation of water users' associations (the SISAR) in a sub-region, under the auspices of which daily operation and maintenance of the systems are carried out by the local operator but other functions which benefit from an agglomeration of scale (heavy maintenance, procurement of reagents and spare parts, water meter calibration, training of operators, billing, social capital capacity building, etc.) are centralized under the federation. Communities with a SISAR have universal provision of metered household water connections; sanitation systems include condominially designed sewers and lagoon treatment systems or communal septic tanks.

The COPANOR model was established around 10 years ago through the creation of a subsidiary of the state water utility, COPASA, which allowed for a differentiated salary structure for COPANOR staff and tariffs tailored to the reality of poor, isolated households. COPANOR provides all households with metered household connections and simplified sewerage with wastewater treatment by an upflow anaerobic sludge blanket (a kind of anaerobic digester) or lagoon system. Both SISAR and COPANOR are run like professionalized utilities, with indicator-based management and decision making, annual business plans, etc.

Source: Personal communication Martin Gambrill, lead water and sanitation specialist at the World Bank.

It is important to recognize that the capacity of potential operators will vary, and efficient service delivery may require the involvement of a combination of operators whose capacities complement each other. One efficient way to increase access to capacity is the formation of associations through which the members gain clout and negotiating power, can share resources, exchange experiences and facilitate peer-to-peer learning. Examples of this exist both for associations of utilities in Brazil (see Box 7.7.), and for faecal sludge emptying entrepreneurs' associations in Senegal and Burkina Faso (see Bassan et al. 2012).

Financing system operations is another critical aspect of functional service delivery. Sanitation systems operating with *cost-recovery* will, for example, allow for public-private partnerships for the operation of infrastructure, which could be implemented under different models. Some examples are design-build-operate contracts for treatment facilities; franchising or licensing of emptying services; or long-term contracts for treatment and reuse. Even in situations where cost-recovery is not realistic, it is possible to work with public-private partnerships by covering operating costs from the public purse. For more discussion on financing of sustainable sanitation and wastewater management systems, see Chapter 8.

In order to establish sustainable resource recovery, the most crucial factor may be the existence of *local demand for the recovered resources*. The creation and management of this demand may require the involvement of additional operators, or at least additional capacity within existing operator(s). In the case of agricultural reuse, an established cooperation between the sanitation service provider and farming community, locally available farmland and farmers is a key factor to consider. The local government body could also consider the farming community for carrying out treatment for reuse on an entrepreneurial basis.

The last three factors in determining the appropriate management in the list on source separation are related to the so-called *enabling environment*, which refers to the broader conditions and factors that are important for achieving functionality in all parts of the service chain. Matching service-delivery models to local conditions will require consideration of these broader conditions. For example, proposed technical solutions need to be socially acceptable. This means recognizing the needs of customers in the user private sphere (see Section 7.2).

The *legal and regulatory framework* should support and enable, or at least not prevent, resource recovery. This is rarely the case today. Changing these frameworks can take a long time. From a resource recovery perspective it may thus be important to look pragmatically at the existing legal and regulatory framework and identify grey areas that are open to interpretation. With bold leadership, it may be possible to push for positive change within the existing legal framework and create precedents to argue for legislative change (see Lüthi et al. 2011).

One common problem with regulatory and legal frameworks that can work against innovation is being too specific about technologies and methods, rather than the function that needs to be achieved. A good example of locally adapted regulation for on-site sanitation that has gone from being technology-prescriptive to function-based in Sweden is described in Box 7.8. Overarching EU and national regulation undoubtedly sets the scene for that case, but the local context – for example the vulnerability of receiving waters – decides what level of treatment is needed. The fact that the regulation has changed from only allowing a few technologies to actually demanding functions to be met has spurred innovation in the on-site sanitation sector in Sweden.

A final important factor is securing *political support*. There are a number of arguments that can be used to garner political support for increased reuse. These include: compliance with international targets; abating climate change; and the possibility of recovering extra costs through sales of reuse-products. In addition to economic gains, proponents of reuse-oriented systems can use ideological arguments (see Section 7.2) to convince local politicians, decision-makers and users to support these systems.

A clear communications plan should be developed which contains locally adapted messages promoting reuse and identifies target audiences for lobbying, such as key politicians, government departments, and users and other stakeholder groups.

Monitoring

Monitoring the quality of services provided, proper use of the system, and the condition of the recovered resources is critically important to ensuring that the system protects both private and public goods. There are different ways of setting up monitoring, both active and passive, but to ensure better protection of public goods it is advisable to involve users, either directly or through representative bodies. A system where users can directly report problems with service delivery is one option.

Regular inspection of system components by the service provider or an external monitoring agent is also recommended. Once again, if agricultural reuse is envisaged, it is important to involve the farming community in the monitoring. One example of user-developed monitoring and regulation is the certification system for agricultural use of sanitized blackwater and other wastewater fractions from small wastewater systems operated by the SP Technical Research Institute of Sweden (Box 7.9). The Federation of Swedish Farmers was heavily involved in setting up this system, along with municipality representatives and researchers.

The functional sanitation ladder (Figure 7.3) is a tool that can be used for monitoring of service delivery. A variation of

BOX 7.8

On-site sanitation regulation in Sweden: function-based and locally decided

In Sweden, regulations for on-site sanitation have undergone a makeover during the last decade or so, going from being technology-prescriptive to function-based. In the past, local environmental authorities, following national guidelines from 1987, only have permits for soil-based technologies (soil infiltration or sand filters) in combination with three-chamber septic tanks. This hampered technical development and made it difficult to apply new technologies in situations where the approved ones were not feasible.

In 2006, the Swedish Environmental Protection Agency published new national guidelines for on-site sanitation, which focused not on sanitation technology per se but on its function. In particular, the new guidelines emphasize the need to reduce phosphorus emissions to receiving water bodies and highlight the importance of nutrient recycling. The guidelines outline mandatory basic functions, as well as "normal" and "high" levels for health protection and environmental protection functions, which local authorities can apply depending on the local context.

One effect of these guidelines has been an explosion of new products and innovative technologies coming to market. One example is the increase in high-level water-saving blackwater systems that make it possible to reuse nutrients for farmland after sanitization. Other innovative technologies that are increasingly popular in Sweden are: (i) compact treatment plants for on-site use, (ii) filters containing highly reactive P-absorbing materials, and (iii) urine-diverting toilets as complements to conventional soil infiltration or sand filters.

The new technologies are also producing new types of wastewater fractions from households. This has spurred technical departments in municipalities to organize systems for reuse of collected fractions, and national actors are now engaging in research and development for the establishment of a functioning service chain. This is a development that reuse advocates had been trying to bring about since the mid-1990s.

the functional ladder is currently used by the NGO Welthungerhilfe (www.welthungerhilfe.de/) for monitoring the sanitation and hygiene status of partner communities. Proper use of the system can be monitored by the users themselves, community groups representing the users, or by the service providers. Individuals or organizations responsible for O&M are often well placed to monitor or provide information to monitors regarding the quality of services and correct use of the system.

BOX 7.9

Certification standards for wastewater fractions, Sweden

The SP Technical Research Institute of Sweden manages a certification system for wastewater fractions from on-site and small (<50 person equivalent) wastewater systems. The wastewater fractions must be interesting from a fertilizer perspective – for example urine, blackwater, phosphorus-precipitated sludge, phosphorus-saturated filter-bed material, or faecal sludge from dry toilets. Septic tank sludge, which has comparatively low nutrient content, is not included in this certification.

An approved certification allows the producers of fertilizer products to display the "SP" certificate. Certification guarantees traceability of the wastewater fraction from origin to the field where it is used, quality control, routine sampling, and self-monitoring. All treatment and transport has to be undertaken so that the quality of the fertilizer products is not impaired.

All certified wastewater fractions need to be treated to reduce microbial pathogens to specific limits. Wastewater fractions apart from urine, can, after sanitization, be used for cereals and other crops that go through a processing stage before consumption. Depending on storage times and temperatures, urine can be certified for use on different crops; and after one year of undisturbed storage it can be used to fertilize any crop.

Quality (including pathogen) testing of the fertilizer products is carried out by the producer, and details of the content provided on the label, along with recommended dose per ha. based on concentrations of heavy metals. The producer also has a responsibility to inform households that fertilizer is being produced from their wastewater fraction, and to educate them regarding what they should and should not flush; for example, in a blackwater-collection system it is important that water from floor mopping does not go into the toilet bowl.

Source: SP Technical Research Institute of Sweden 2012.

Apply equitable tariffs, sanctions and methods for conflict-resolution

Service tariffs should achieve congruence between the costs incurred by users and the benefits they receive (see Felice and Vatiero 2012). In other words, the distribution of costs and services should be equitable for all citizens within the service jurisdiction in question. Firstly, the tariff setting should be equitable between different types of customers. On-site customers often pay more overall than sewered customers in situations where informal service providers provide services to on-site sanitation customers, and sewered customers are served by a utility.

The second congruence step between costs and services is to apply a progressive tariff, where a higher level of service within the private good and higher consumption is connected with progressively higher costs for repeated violations. Box 7.10 presents a good example from Durban, South Africa of congruence between costs and service received.Increased compliance along the service delivery chain may require a "sticks and carrots" approach, with the service provider applying both sanctions and incentives. In the Durban case, faecal sludge emptying contractors are paid per ton of sludge delivered from on-site systems to the treatment plant, rather than a flat rate per area or number of households served. This gives the contractors an incentive to bring the sludge to the treatment plant rather than cut corners by illegally dumping it. Durban also provides another good example of incentives and sanctions in the form of its debt relief scheme. Incentives and sanctions can be applied at different levels in order to influence the use of a system. For example, a national government that wants to inspire local governments to take actions on resource recovery can provide financial incentives for those that present good plans and ideas. At the same time, local

FIGURE 7.3

Function-based sanitation ladder, with proposed indicators for monitoring

		Function	Indicators	Management needs
Environmental functions	7	**Integrated resource management**	Indicators will differ and depend on flowstreams from the full environmental sanitation system (urine, faeces, greywater, faecal sludge, wastewater as below but also including water provision, stormwater management and solid waste management and context	
	6	**Eutrophication risk reduction**	Indicators will differ and depend on flow stream from the sanitation system (urine, faeces, greywater, faecal sludge, wastewater)	
	5	**Nutrient reuse**	(i) X% of N, P, K excreted is recycled for crop production, (ii) Y% of used water is recycled for productive use	
Health functions	4	**Pathogen reduction in treatment**	Indicators will differ and depend on flow stream from the sanitation system (urine, faeces, greywater, faecal sludge, wastewater) and also whether the flowstream will be used productively afterwards or not	
	3	**Greywater management**	(i) No stagnant water in the compound, (ii) no stagnant water in the street, (iii) no mosquitoes or other vectors	
	2	**Safe access and availability**	(i) 24-hr access to facility year-round, (ii) facility offering privacy, personal safety and shelter, (iii) facility is adapted to needs of the users of the facility	
	1	**Excreta containment**	(i) Clean facility in obvious use, (ii) no flies or other vectors, (iii) no faecal matter lingering in or around latrine, (iv) hand-washing facility in obvious use with soap, (v) lid, (vi) odour-free facility	

* Note that moving up the ladder means that the functions below are also fulfilled.

Figure: Based on Kvarnström et al. 2011

BOX 7.10

eThekwini Water and Sanitation: Durban, South Africa

Congruence between costs and service provision

eThekwini Water and Sanitation is a good example of a municipal water and sanitation service provider that displays strong congruence between costs and service provision in setting water tariffs. South Africa has a policy of providing free basic services for all of its citizens. In terms of water and sanitation, all South Africans have the right to access a ventilated improved pit latrine, with free basic emptying service every five years and free minimum water access – a policy that is backed up with national funds.

In Durban, eThekwini Water and Sanitation provides the free basic services for families living in houses worth less than 250,000 rand (around US$16,700). These free services include a urine-diverting toilet and 9m$^{\text{and}}$ of water per month. The next step up the service ladder for water is a semi-pressure system with a roof tank (full pressure is achieved in the house through roof tank placement); the tariff for this service is reduced, but rises with water consumption. The third service level is full pressure, which is paid for by both household and other customers. Household customers pay a progressive tariff with the price per cubic metre of water rising with increased monthly consumption. Semi-pressure and full-pressure customers start paying the same price per cubic metre at a monthly consumption rate of 30 m^3.

Debt relief

eThekwini Water and Sanitation is also working with debt relief schemes and amnesty schemes to try to get non-paying customers back to being paying ones. The debt repayment scheme requires the customer to pay their current account in full and on time for 20 months. For each payment made on time, one-twentieth of the debt is cancelled. After 20 months there is no debt and the customer has been trained into paying a monthly fee, making it much more likely that they will be able to become a full paying customer again. If the customer stops paying, then a flow limiter is installed in the connection, taking service delivery down to the free minimum level, and the full debt is reinstated. If the connection is tampered with then it is removed and the customer has to collect water from the nearest municipal office or purchase it from a neighbour.

Conflict resolution

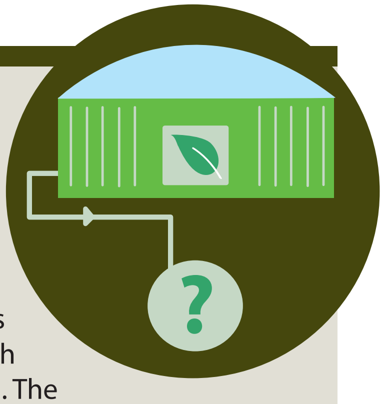
As an efficient means to continuously improve its service delivery and raise consumer satisfaction, eThekwini Water and Sanitation provides channels for customers to raise their concerns and voice appreciation, as well allowing them to influence service delivery. It also views this communication as a means to understand its customers better.

eThekwini Water and Sanitation uses user platforms continuously for resolving conflicts and explaining new corporate policies. One example where these platforms have worked well is in addressing frustration expressed by customers that the free basic service level is insufficient to serve extra guests during funerals. eThekwini Water and Sanitation has been able, through a user platform, to solve this issue amicably: households with an upcoming funeral can contact the utility, which will allow it unlimited supply for three days at a fixed reduced tariff. The platforms have also been used to address, reach agreement and adapt other policy changes that both customers and the utility can live with – for example regarding who can be registered as a customer – as well as addressing issues between eThekwini and its employees.

Based on personal communication with Teddy Gounden and Neil Macleod, eThekwini Water and Sanitation, Durban, South Africa

BOX 7.11

Building a system for resource recovery, and not using it: Kullön, Sweden



The residential area Kullön is located on an island in the coastal municipality of Vaxholm, about 50 km north of Stockholm, Sweden. The area has 250 houses, built in 2001, and has attracted mainly young, well-educated families with children. Kullön has high environmental ambitions; the environmental initiative that has attracted the most attention is the sanitation system. The wastewater treatment plant is managed by the municipally owned water company Roslagsvatten, and it is complemented by double-flush urine-diverting toilets, with separate collection of urine in tanks at neighbourhood level. The reduced discharge of nutrients to the Baltic Sea and the greater reuse of nutrients in urine help to make the system more sustainable than many conventional systems.

Hoever, there has been little or no reuse of the collected urine. Instead it has been allowed to overflow into the wastewater treatment plant. The main reasons for this are that the institutional and management aspects were not prioritized in the initial planning phase, which led to unclear roles and conflicts around responsibilities and economy. The initial capital investment for installation of the system added a little to the cost of the houses (less than 1 per cent of the houses' total cost). However, the companies selling the houses did not calculate the costs for management of the reuse system and ignored the problem; the municipality had declared that responsibility for reuse rested with the future house owners.

Kullön inhabitants were unwilling either to take responsibility for finding a farmer willing to reuse the treated urine or for the extra financial costs for O&M of a system that was initially imposed by the municipality, especially since the system was more sustainable and the proposed roles and responsibilities were in conflict with national legislation. The inhabitants approached local politicians, and the municipality decided that responsibility for reuse in fact rested with Roslagsvatten.

The process of organizing a system took several years (!) and in the meantime the separated urine from the households was still not reused. It was not until 2008 that the first urine was collected, transported, stored and reused by a farmer in a neighbouring municipality. In 2013, however, this farmer, who was under contract with Roslagsvatten, changed the focus of his agricultural practices and stopped taking the urine. Roslagsvatten subsequently could not find a new solution for collection and reuse, and the urine is once again overflowing into the local wastewater treatment plant.

Kullön clearly illustrates the need for an appropriate institutional set-up and clear responsibilities, not just technology and infrastructure, to make a sustainable sanitation system. It is also an example of costs for new, more sustainable but also slightly more expensive systems being placed in the private as opposed to the public sphere, where responsibility for the protection of public goods more properly resides.

Source: Johansson and Kvarnström 2011; and personal communication with Mats Johansson, Ecoloop, Sweden.

Decentralized plant treating hospital wastewater, Thanh Hóa, Vietnam. Photo: Flickr /frapoberlin

government can use financial incentives for households to install systems that better enable reuse.
While tariffs are important – especially to finance O&M and recover costs – the tariff system must be carefully balanced to avoid providing a disincentive for reuse-oriented behaviours and systems. Box 7.11 highlights a case where local authorities allowed service providers to charge higher user fees for urine-diverting systems.

In other municipalities, political decisions have been taken to make the management of systems with resource recovery cost-neutral compared to conventional systems. One way to do this is to cover any additional costs for the utilities and other service providers by a uniform tariff increase for users within the wastewater jurisdiction, whatever system they use.

In managing public goods there will invariably be trade-offs between different stakeholders, potentially causing conflicts. Arenas and mechanisms to resolve these conflicts should be local and public, and thereby accessible to all individuals (see Felice and Vatiero 2012). In cases where stakeholders are involved in participatory planning, the planning process itself serves as an arena for conflict resolution.

The case described in Box 7.11 initially lacked an arena for conflict resolution. An externally financed project involving national experts provided an arena for conflict resolution, which, in combination with increased local capacity, greatly contributed to establishing the reuse of urine on farmland. As the e-Thekwini case (Box 7.10) shows, user platforms can be an means of resolving conflicts arising around water and sanitation services.

KEY MESSAGES

- While a growing range of technologies are available for recovery and reuse, institutional constraints and issues of social acceptance can act as barriers to their use.
- Sanitation and wastewater management systems aiming for resource recovery require the involvement of diverse actors, many of whom are traditionally not involved in the water and sanitation sector.
- As a rule, involving new sectors and stakeholders while also increasing service quality will not happen organically, but will require innovative institutional arrangements and governance mechanisms.

8. ECONOMICS AND FINANCING

8.1 The economics of the sanitation and wastewater management gap

Inadequate sanitation and wastewater management places a heavy burden on national economies (see Chapter 2). While attempts to quantify the costs of inadequate wastewater management at global and regional estimates are rare, it has been estimated that water supply and sanitation together cost an estimated 1.5 per cent of global GDP, while regions such as South Asia and sub-Saharan Africa experience much higher economic losses: estimated at 2.9 per cent and 4.3 per cent of their GDP, respectively (Hutton et al. 2007; and see Figure 8.1). The sanitation gap across the world correlates with low GDP and consumer poverty (Rosemarin et al. 2008), underlining the fact that the gap is strongly connected to broader issues of development and inequality.

FIGURE 8.1 **Economic losses associated with inadequate water supply and sanitation by region, as percentage of GDP**

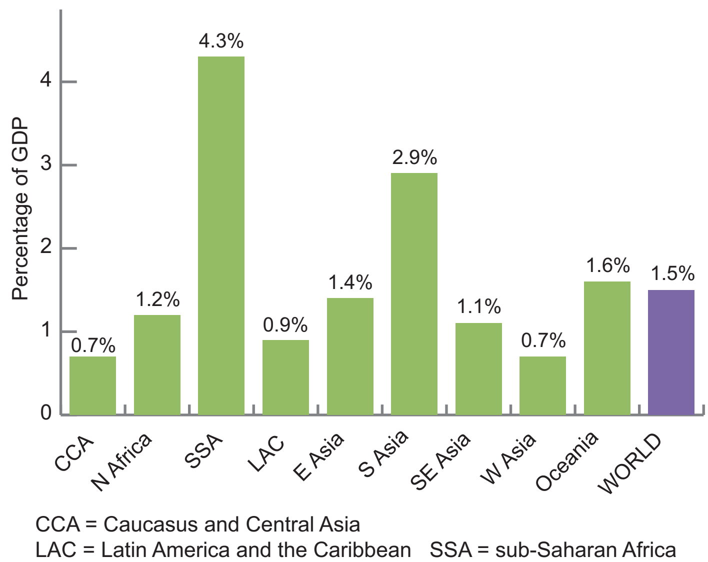


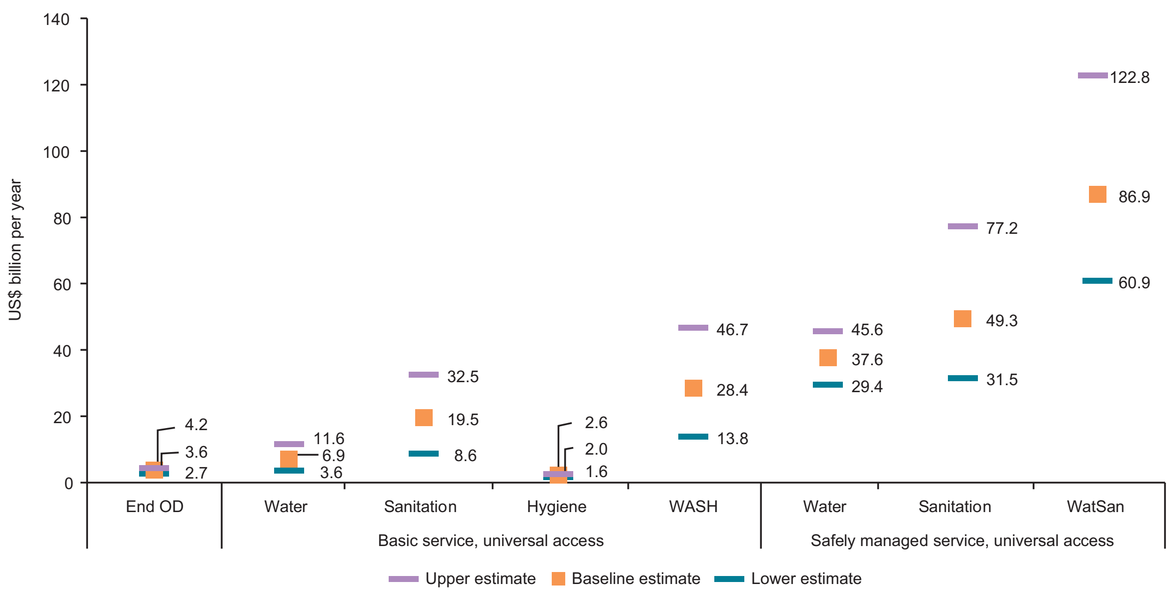
Figure: Based on Hutton 2012

What might it cost to provide the world with functioning universal sanitation coverage? The first attempt to estimate this (Hutton 2012) gave a figure of almost US$200 billion for urban capital costs during the period 2011–2015. The figure for rural investments was US$134 billion.

A new estimate for the capital investment cost of meeting the SDG targets for safe WASH (Targets 6.1 and 6.2) by 2030 is US$74–166 billion per year (Hutton and Varughese 2016). Most of this investment would need to be in rural areas, at an urban to rural ratio of about 1:1.75. In terms of percentage of GDP, the same report estimates about 0.4 per cent for "safe" services meeting the SDG targets (this does not include investments to enable resource recovery). For the regions with the greatest needs – sub-Saharan Africa and South Asia – this means capital spending up to 2% GDP and 0.85% GDP, respectively. From the same study O&M costs would run at about the same level as capital expenditures up to 2030. Thus, to achieve these SDGs globally will cost something around US$200 billion per year up to 2030. Meeting SDG Targets 6.1 and 6.2 will cost globally three times as much as providing universal "basic" WASH services, as illustrated in Figure 8.2, but this is still less than the health costs from inadequate sanitation.

Given that the costs of providing adequate sanitation are less than the health-related costs due to inadequate sanitation, and that sanitation pays for itself several times over (see Figure 8.3), the case for national investment in sanitation is strong. Nevertheless, a recent report shows that government spending on WASH stagnated between 2008 and 2014 (Martin and Walker 2015). In some of those countries where the need is greatest, spending is very low; for example, public water and sanitation expenditure averaged just 0.32 per cent of GDP during the period 2000–2008 for both urban and rural areas in sub-Saharan countries (van Ginneken et al. 2011).[20] This is well below the benchmark of 1 per cent of GDP (supplemented with another 1 per cent retrieved through cost-recovery strategies, such as user tariffs, and "community contribution") proposed by the UNDP for low-income countries with limited coverage and high levels of poverty (UNDP 2006).

FIGURE 8.2 **Annual global capital costs of different WASH service levels, 140 countries**



Note: Ending open defecation (OD), or open defecation-free, has a target year of 2025. WASH = water, sanitation, and hygiene; WatSan = water and sanitation

Figure: Hutton and Varghese 2016

[20] This can be compared with total health expenditures (not including water and sanitation) of an average of 6 per cent of GDP in sub-Saharan African countries in 2013, and an OECD average of 9.3 per cent. Figures from the WHO Global Health Expenditure Database (http://apps.who.int/nha/database/ViewData/Indicators/en.

FIGURE 8.3

Benefit-cost ratios of interventions to attain universal access to improved sanitation, by region, 2010

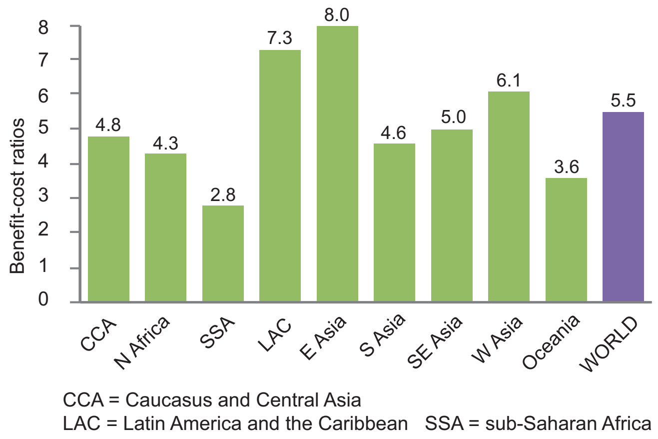


Figure: Based on Hutton 2012

8.2 Financing sustainable sanitation and wastewater management

The two main types of expenditures to consider in sanitation and wastewater provision are capital expenditures – in particular one-off investments in "hardware" items such as infrastructure, technologies, and equipment along with real estate – and recurring costs for operating and maintaining the system. There may be a range of other costs related to the factors such as regulatory reform and enforcement, quality testing of effluent, creating demand, and related aspects of development. It is essential to anticipate the costs (and benefits) along the entire system and value chain, and over the whole lifecycle of the system.

Ultimately, the main sources of finance for capital expenditure on conventional sanitation and wastewater management are public spending, external aid and cost-recovery from users. Capital investments, whether by users or in the public sphere, are often made using credit which might range from microfinance up to government bonds and corporate equity, depending on the borrower, the purpose and the availability of credit.

For system sustainability, financing must be both predictable and reliable over the long term. This is not only in order to access credit and service debts, but also to ensure the system operates efficiently for as long as possible.

Sustainable sanitation and wastewater management provide benefits for the user and for the surrounding community and society, and also often serve as part of a development strategy. However, while sanitation and wastewater management usually pay for themselves many times over (Hutton 2012), especially when there is resource recovery, many of the economic benefits are non-monetized. There will almost always remain a gap between the costs of installing and operating a system and the revenue that can be collected along the value chain. Consequently, the users or governments may be reluctant to make the investments needed to achieve the development outcome.

For these reasons, sanitation and wastewater management are often subsidized, or even paid for entirely, from the public purse or – in the case of developing countries – external aid. For example, subsidies may be used to help users purchase an improved toilet or a biogas digester, or install source-separating toilets. If subsidies are well calibrated and targeted, they can be a cost-effective way to help achieve development aims. They can also be seen as a way of paying the user for some of the more indirect societal and environmental benefits of sustainable sanitation and wastewater management.

8.3 Financing in the public sphere

External donor funding has covered – and will continue to cover – some investment in sanitation and wastewater management. Even as government spending on water and sanitation has stagnated in recent years (see above), external aid to water and sanitation almost doubled during 2000–2011, reaching nearly US$8 billion annually (OECD-DAC 2013). However, aid is generally not a good, stable basis for long-term financing of a large system, not least as aid commitments tend to be for much shorter periods than the lifetime of the system.

Also, given the investment needed to achieve universal access to adequate sanitation and wastewater management, aid is likely to be insufficient. Sustainability therefore requires at least some domestic financing. Experience in developing countries demonstrates the advantages of combining different types and sources of financing (see ISF-UTS 2014).

Capital expenditure

Capital expenditures and O&M expenditures must be made in both the private (user and re-user) and public spheres (see Chapter 7), each with different implications for financing. Costs in the public sphere might include laying and maintaining sewer networks; constructing and operating wastewater treatment facilities or centralized resource recovery plant; collection points for faecal sludge; or purchasing vehicles to transport sludge or other wastes, and keeping them running. These costs may be recovered through user tariffs, taxation or a combination of the two (along with external aid, in the case of developing countries).

Urban sanitation generally requires utility-based systems. Installing (or upgrading) sewer networks and wastewater treatment plants requires major investments, usually by government or public-private partnerships and financed by bonds or equity.

Given the scale of the investment in these cases, and the length of time it takes to recover costs, it is important to plan for future developments in the area served so that, for example, infrastructure can be easily extended to serve new communities, and treatment plants have enough capacity to cope with growing user populations. As discussed in Chapter 4, all system components need to be aligned for maximum efficiency in resource recovery and wastewater treatment. It is therefore sensible to invest in a system, including infrastructure, which is compatible with any future ambitions in this regard, even if they are not affordable now.

In the case of urine-diverting toilets, pit latrines, septic tanks, etc. that require faecal sludge, urine, food waste or other wastes to be transported away from the user's property for treatment or disposal, there may also be a need for public infrastructure (such as sludge collection points) and utilities, but most costs will be borne by private-sector suppliers, regulated (and perhaps subsidized) by the public sector. User tariffs are collected directly by the service provider or collected through taxes (especially local) and then passed on to the service provider.

Given the projected urbanization trends, particularly in areas that currently have large sanitation and wastewater management gaps, it is important to consider how rising population density might affect the economic viability of different systems when planning investments. A unique study carried out in Brazil in the early 1980s found that a shift from on-site systems to decentralized piped systems was viable as population density increased to around 200 persons per ha. (assuming users' ability to pay adequate tariffs), while centralized systems started to become economically competitive at a density of 350 persons/ha. (Sinnatamby 1983). However, on-site systems remain the most common form of sanitation in urban areas (WSP 2014).

Operation and maintenance

Failure to factor in O&M costs and only consider the initial capital investments is a common pitfall that results in systems

The wastewater treatment plant at the US military's Joint Base Pearl Harbor-Hickam has been retrofitted to capture methane gas for future energy use. Photo: Flickr / US Navy / Denise Emsley

functioning inefficiently or breaking down entirely over time. In the public sphere, O&M is usually carried out by private contractors. They may be employed or contracted by the government or utility (for example, to maintain a treatment plant or sewerage or drainage network), or directly by the user or community (for example, in the case of on-site systems, faecal sludge emptying services, community toilets or decentralized systems).

Because the services are so important for health and environmental protection, even service providers employed by the users need to be regulated, and measures put in place to ensure that service providers can and do keep operating. Subsidies and state-provided services might help to do this and to ensure that users do not get unregulated, unqualified service providers. However, this needs to be balanced against the interests of long-term financial sustainability and building the strength of this economic sector.

Subsidies can also be used to encourage service-providers to serve poor communities, or others that are not economically attractive. Traditionally, subsidies have been paid in advance, or at predictable intervals. However, an emerging subsidy model for service provision, output-based aid (OBA), ties disbursement to outputs. The service providers need to pay costs up front, often through private-sector credit, giving them a strong incentive to perform. OBA and other results-based financing (RBF) approaches are described in Trémolet (2011). Figure 8.5 shows how functions can be "packaged" for the purposes of OBA.

O&M may require capacity building for users, especially in systems that require source separation (see Chapter 4) or the operation of unfamiliar resource recovery systems such as a biogas digester or composting toilet. It is also necessary to invest in training and maintaining a workforce of specialist O&M service providers. Scientific quality testing of treated wastewater or other recovered products is another service that has to be provided.

"Software" costs

In many cases, especially where innovations such as source separation and resource reuse are being introduced, new sanitation and wastewater management systems need to be supported by investment in awareness raising, stakeholder training and demonstrations in order to build local market interest (see Chapter 7).

FIGURE 8.5 Potential ways of packaging output-based aid support along the value chain

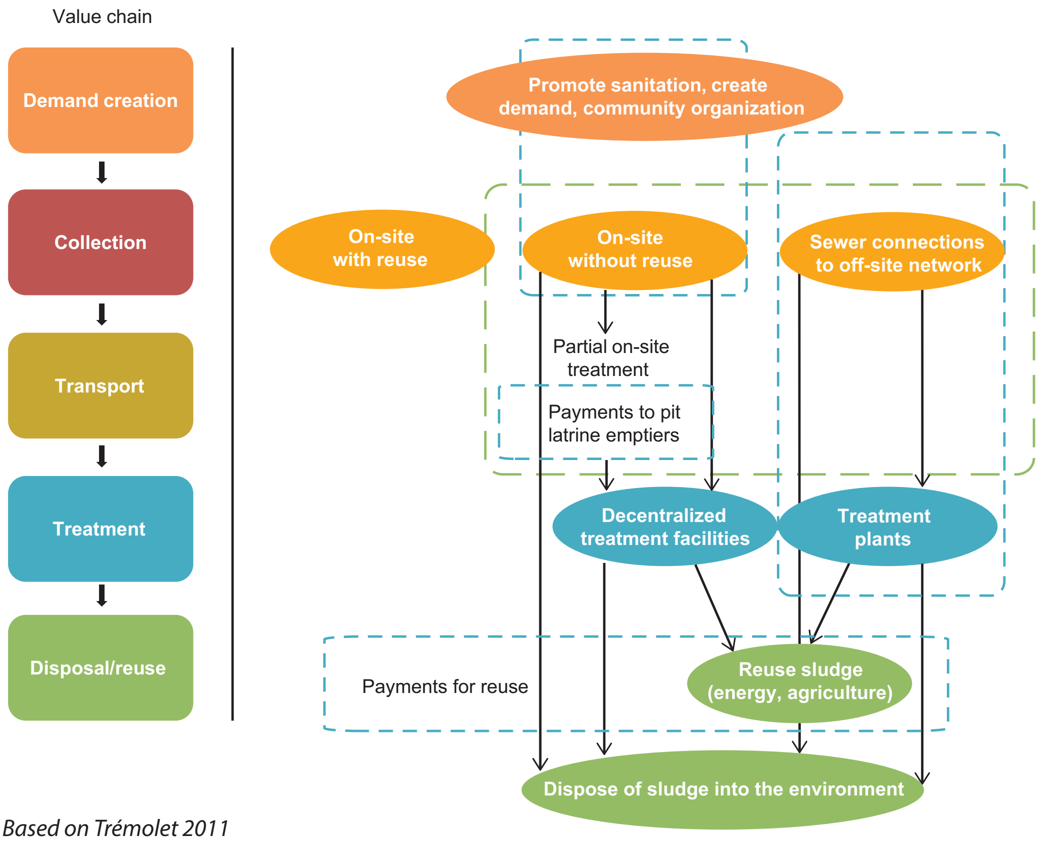


Figure: Based on Trémolet 2011

"Software" activities related to creating demand include marketing, social mobilization and product development. Marketing is commonly carried out by NGOs or community-based organizations, local government, ministries or entrepreneurs. Costs related to these activities include staff salaries and transport costs for marketing, along with the cost of developing and producing marketing materials. Similarly, product development by sanitation entrepreneurs, universities or engineering firms implies both staff and capital costs (see Trémolet 2011).

The successful Community Health Club (CHC) concept, which centres on building community members' awareness of and demand for healthy practices, including improved sanitation and hygiene, is an example of an approach aiming to build demand for sanitation within a broader development approach (Waterkeyn and Waterkeyn 2013).

8.4 Financing in the private sphere

Costs in the private sphere can include installation and maintenance of toilets or other user interfaces; excavating and maintaining septic tanks or other collection and storage tanks; accessing services to remove faecal sludge (Chowdhry and Koné 2012), collected urine or food waste; or, in another part of the cycle, the means to reuse recovered resources.

In planning financing arrangements that include investments by users, it is important to assess users' ability and willingness to pay (including to use credit for capital investments). This should take into account potential savings and income at the household level from installation, and – especially in the case of on-site systems – resource recovery and reuse. A careful accounting of these savings and returns can also help households to access credit.

In poor rural areas, it can be challenging to persuade users to invest in new on-site systems, especially when they currently practise open defecation. Many past government- and donor-supported projects have provided systems free of charge. However, this is not a sustainable model given the scale of the gaps in adequate sanitation. Experience also suggests that a sense of ownership is often an important incentive for users to properly use systems once installed, so approaches should aim to build sufficient demand that users are willing to make at least some investment.

Regarding willingness to pay (and the perceived utility of the investment to the users), various strategies can be employed to increase demand. Some of these were mentioned above – marketing, developing products that meet users' needs and expectations (while still fulfilling the desired functions), awareness-raising etc. Another is demonstration endeavours to let potential users observe the benefits for themselves. For example, in a rural sanitation project in Bihar, India, community members set up a demonstration field test growing the same crops with either urine or chemical fertilizer, and hosted visitors from nearby communities, local government and research institutions (Andersson 2014b). A composting toilet was also installed in a popular environmental education centre for demonstration and learning purposes (Andersson 2014c).

One advantage of longer-term, community development-oriented approaches such as CHCs is that the communities can install systems once there is sufficient demand, helping to ensure a sense of ownership. The reliability of the system and the perceived value of the services it provides to users will help to increase local demand and willingness to pay.

Microcredit is proving valuable in rural projects, which have previously had difficulty attracting commercial credit. The Financial Inclusion Improves Sanitation and Health programme (FINISH; http://finishsociety.org/) has applied micro-financing and output-based aid to achieve an integrated model that addresses both the demand and supply sides of the sanitation challenge in India (Post and Athreye 2015). The initiative helped more than 400,000 households gain sanitation access between 2009 and the beginning of 2015. Some more examples of innovative financing schemes are described in Box 8.1.

Urine-based fertilizer and composted faeces packaged for commercial sale. Photo: Kim Andersson

BOX 8.1

Examples of innovative financing schemes and their basic features

UN Capital Development Fund – supports microfinance institutions, banks, cooperatives and money transfer companies to ensure that suitable financial products (savings, credit, insurance, payments and remittances) are available to individuals – notably the "unbanked" – and micro-enterprises as well as small and medium enterprises. Financial products are made available at a reasonable cost, and on a sustainable basis, to overcome economic shocks, ensure smooth consumption, and provide educational and entrepreneurial investments to enable the transition out of poverty (see www.uncdf.org).

Microcredit schemes providing loans to small enterprises and households. An example is WaterCredit, provided by the organization Water.org (see water.org/solutions/watercredit)

The Philippine Water Revolving Fund uses a way to increase the pool of financing available to the water sector by leveraging limited public funds with ODA and private sector financing. An important lesson has been that private financing coupled with public funds can drive sector-wide transparency, efficiency and accountability in an apolitical and objective manner; the rules of the game to access commercial loans help drive broad water sector reform (see Paul 2011).

The Clean Water State Revolving Fund is a federal US partnership that provides communities a permanent, independent source of low-cost financing for a wide range of water quality infrastructure projects, including wastewater management and reuse (see www.epa.gov/cwsrf).

This project in Bihar, India, tackled the financing issue by providing the concrete substructure for flood-resistant toilets, while households were responsible for building the superstructure. Photo: Kim Andersson

8.5 Financing implications of recovery and reuse

Improving sanitation and wastewater management leads to diverse direct and indirect benefits for society, and these benefits increase in value with more ambitious investment in sustainability terms (see Figure 8.6). As pointed out in the previous chapters, wastewater and excreta can be seen as an economic asset. However, the indirect, external returns are rarely included in cost-benefit analyses, not least because it is difficult to ascribe them confidently to a sanitation or wastewater investment, and they do not produce direct monetized returns (without innovative cost-recovery mechanisms).

In conventional systems, the direct monetized returns will never cover the total costs of installation and O&M. However, resource recovery and reuse can transform the economics of sanitation and wastewater management from household up to municipal level. They bring additional environmental, social and economic benefits that can be clearly linked to the investment, including through the sale of commercially viable reuse products such as biogas, fertilizers and irrigation water, and their value to society can be included in the overall financial calculation as revenue or benefit (ISF-UTS 2014).

A study comparing the pros and cons of different types of sludge treatment – aerobic and anaerobic digestion, natural and mechanical dewatering and composting – found that anaerobic digestion with energy recovery had both the lowest costs *and* the lowest environmental impacts (Ghazy et al. 2011). However, scale can make a difference: in wastewater treatment plants designed to serve populations smaller than 90,000, drying beds were more cost-effective in Egyptian conditions.

Resource recovery and reuse can offset the costs of sanitation and wastewater management systems – sometimes

FIGURE 8.6 **Ladder of increasing value propositions related to wastewater treatment based on increasing investments and cost recovery potential**

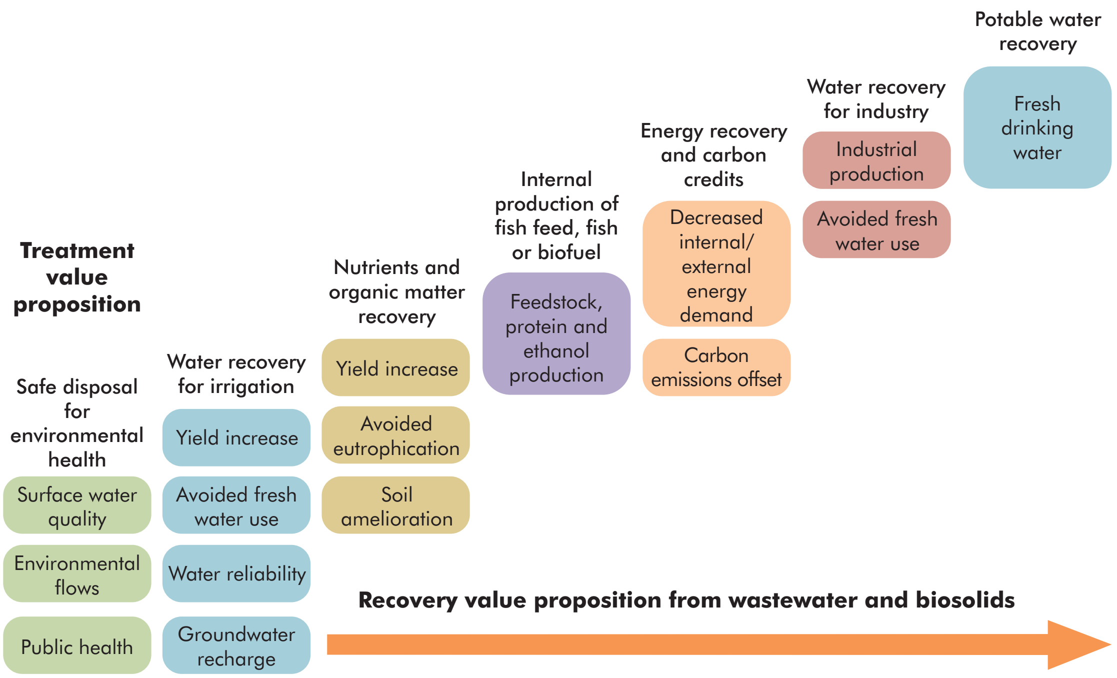


Figure: Based on Wichelns et al. 2015

substantially. Energy recovery is often particularly economically attractive, not least because the energy needed for processes in conventional wastewater treatment can represent half the total operating costs (for more on energy needs in wastewater treatment, see Lazarova et al. 2012; Long and Cudney 2012). Biogas recovery from sludge can be made even more efficient by breaking up the sludge during the anaerobic digestion process.

This is clearly illustrated by the good benefit-to-cost ratio in the case of the Käppala sewage treatment plant in Sweden, which has installed two systems to break up sludge: the Krima disintegration system, and the Grubbens deflaker (see Figure 8.7). Table 8.1 illustrates an attempt to categorize the different costs of installing and operating a system with resource recovery. However, one of the main arguments in favour of resource recovery and reuse is its potential economic benefits in terms of costs that are offset and new sources of revenue, productivity and livelihoods. For example, in contexts where it is necessary to reduce nutrient loads reaching recipient waters, source separation of nutrient-rich urine (see Section 4.4) can significantly reduce wastewater treatment costs in centralized waterborne systems. This has a demonstrated potential to halve capital expenditure and reduce operating expenditure by 25 per cent (Maurer 2013).

Storage tanks for source-separated urine, El Alto, Bolivia. Photo: Kim Andersson

FIGURE 8.7

Cost-benefit analysis for adding sludge processing technologies to boost methane production from sewage sludge, Käppala sewage treatment plant, Sweden

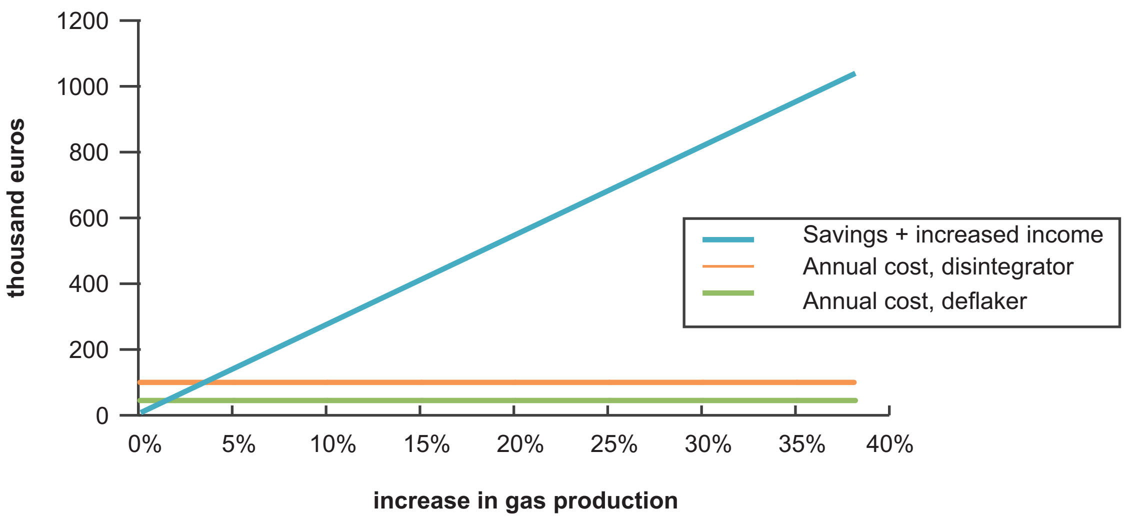


Figure: Based on Sundin 2008

TABLE 8.1 **Major costs of wastewater reuse systems**

System segment	Major cost elements	
	Physical facilities and associated costs	*Other costs*
Wastewater generation	Pre-treatment (especially by industry) to prevent constituents toxic to humans or crops being discharged into sewers	Source control regulatory system
Sewage collection system	Construction, operation and maintenance costs for pipes, pump stations	
Wastewater treatment for discharge or reuse	Construction, operation and maintenance costs for treatment facilities	Regulatory system to set treatment or effluent quality standards and to monitor treated water quality, worker protection
Additional wastewater treatment for reuse	Construction, operation and maintenance costs for treatment facilities	Regulatory system to set treatment or effluent quality standards and to monitor treated water quality, worker protection
Untreated wastewater or reclaimed water distribution system	Construction, operation and maintenance costs for pipes, canals, water storage	
Reuse site	Construction, operation and maintenance costs for pipes, canals, meters or water measurement devices, valves, irrigation equipment; re-plumbing of existing sites to separate potable from non-potable pipes	Additional water purchase to leach salts from soil, worker protection, negative effects on farm production and income, education of local residents, groundwater monitoring, regulatory surveillance
Effluent discharge system	Construction, operation and maintenance costs of pipes	Regulatory surveillance

Source: Winpenny et al. 2010

These costs and benefits naturally vary depending on a wide range of contextual factors. Table 8.2 shows a tool developed by Winpenny et al. (2010) to estimate the many costs and benefits for different stakeholders in a given context. There are both costs and benefits for all, and costs are shared along the value chain. It is always important not to overlook the positive impacts of effluent reuse when costing out capital and operation expenses, as a possible investment incentive. An illustrative financial feasibility study was carried out for a system in the Po valley in Italy with agricultural reuse of treated wastewater (Verlicchi et al. 2012).

Improved wastewater treatment was needed to address urgent challenges linked to recurrent drought and eutrophication in an environmentally sensitive area. The planned system included a constructed wetland in the public park surrounding the treatment plant to "polish" the treated effluent up to agricultural reuse standards and simultaneously provide recreational space. The study concluded that, taking into account factors such as net present value, benefit-cost ratio, pay-back period, and internal rate of return, the project was financially feasible. Most of the benefits were non-market in nature.

TABLE 8.2 **Financial benefits and costs of effluent reuse for major stakeholders**

Stakeholder	Benefits	Costs	Key factors
Central government	Avoided cost of major inter-state freshwater projects or other new major infrastructure	Initial capital cost of project; net fiscal cost of transfers and compensation paid to other stakeholders	Delineation of fiscal and financial responsibilities between different layers of administration; water pricing policy; access to external funding; mandatory health and environmental standards (e.g. EU)
State governments, regional water authorities	Revenues from sale of bulk fresh water to cities; fiscal revenues from further development of urban and rural areas due to greater water security	Capital funding of schemes and O&M costs; purchase(*) of effluent from municipal WWTPs; any fiscal transfers entailed	Division of financial and fiscal responsibilities between central, regional and local governments; local environmental and public health regulations
Municipal utilities	Avoided costs of alternative water solutions; savings in effluent treatment costs; Extra revenues * from urban water sales; reduced pollution charges	Capital and operating costs of new facilities and infrastructure; costs of public health measures and restrictions on amenity	Tariff policy for effluent and fresh water; apportionment of costs between users and authorities;** degree of current and future urban shortages
Farmers	Greater reliability of effluent; savings in abstraction and pumping; savings in fertilizer; increase in yields and sales revenue	Cost of produce restrictions; reduced amenity, reflected in price of land	How much of project cost borne by and recovered from farmers; alternatives available, e.g. own groundwater; price charged for effluent, compared to that of fresh water; ability to sell existing water entitlement; severity of produce restrictions

In using this table to estimate benefits and costs of a reuse system, it is important to distinguish between one-off investments (e.g. capital investments) and recurring costs (such as for operation and maintenance (O&M).

** Note that in most European countries water cannot be sold, but the costs can be recovered.*
*** According to EU policy all costs must be included in final price.*

Source: Winpenny et al. 2010

A case from Spain with agricultural reuse of treated (but not separated) wastewater (13.2 million m³ per year) resulted in even higher benefits in relation to costs (Heinz et al. 2011). Overall, the benefits were calculated to outweigh the costs by €9.5 million per year. Two important factors were savings: in the cost of pumping irrigation water from rivers, and in purchasing fertilizer.

Tsinghua University carried out a comprehensive cost-benefit analysis comparing a conventional sanitation system with an on-site reuse system installed in an urban apartment complex as part of a project led by Stockholm Environment Institute (Figure 8.8). The project installed urine-diverting dry toilets in every apartment of a new block (3,000 inhabitants) in Erdos, northern China.

Using a social discount rate of 8 per cent, the on-site reuse system was found to be more economically viable than the conventional one (Rosemarin et al. 2012). The benefits of the reuse system included water savings, recycling of nutrients from the excreta, and reuse of wastewater, and amounted to approximately US$20,000 per year, which was approximately twice those from the conventional system. External benefits were, however, approximately US$2 million per year: 35 times the figure for the conventional system.

It is also notable that the construction costs of the reuse system were twice as high as for the conventional system, partly as the system was so novel, and there were few similar experiences to learn from. The construction costs for such a reuse system are likely to fall as the technologies become more mature, and benefit from increased policy support. It was suggested that support mechanisms might include a water rights system, incentives for reduced wastewater discharge, and a rational wastewater tariff.

8.6 Sanitation and wastewater management in a development context

In many developing countries, wastewater management and sanitation form part of a larger development need, along with community and household improvements such as better housing, drainage, energy services, land-use reform/zoning, healthcare, food security, employment, literacy, community governance, tax systems and others. However, often water and sanitation investments are not well integrated with other development priorities, which can cause project inefficiency and even failure. Financing sanitation and wastewater management without integrating it with these other development areas can be counterproductive.

In both the North and the South, the water and sanitation sector is commonly financed with subsidies. However, these subsidies overwhelmingly target urban

FIGURE 8.8 **Compartments included in the cost-benefit analysis comparing on-site reuse sanitation system with a conventional system for the Erdos project**

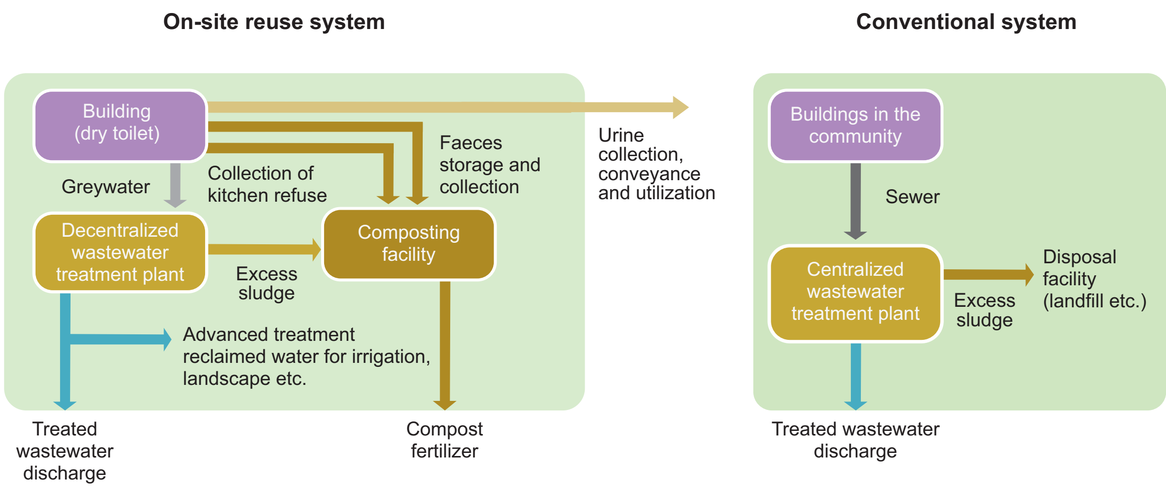


Figure: Based on Rosemarin et al. 2012

A combined heat and power plant that recovers energy (heat and electricity), potable water and ash from faecal sludge and other combustible waste. Photo: Flickr / SuSanA Secretariat / Janicki Bioenergy

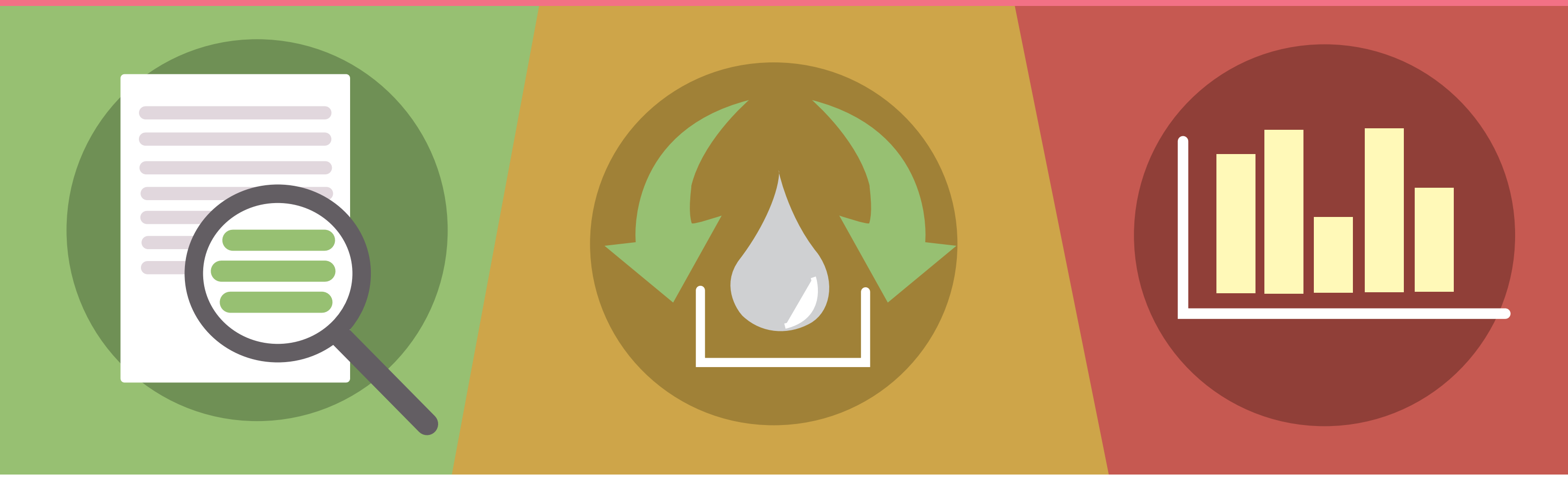
centres, while rural areas and informal peri-urban areas (where the majority of systems, when they exist, are on-site) receive much lower levels. For the sector to take on a more resilient role requires comprehensive development in terms of urban and peri-urban infrastructure, and at the same time deep-rooted O&M and management capacities. Without this balanced approach we are likely to see recurrent and frequent failures (European Court of Auditors 2012).

At the same time, in many rural areas, support needs to be strongly linked to rural development, land tenure, and agricultural extension and health services. The dilemma surrounding financing universal WASH, and sanitation in particular, is thus rooted in development itself, and the sector cannot be isolated, costed out and financed on its own.

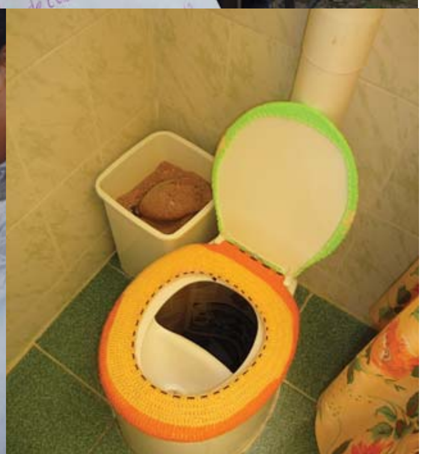
KEY MESSAGES

- The direct and indirect benefits that can be obtained from sustainable sanitation and wastewater management systems are many times greater than the investments required.
- Safe WASH services are affordable if consumer demand can be stabilized and supply capacity for both capital and O&M can be increased within a context of broader development.
- Innovative financing mechanisms can be considered to address the significant financing gap for sustainable sanitation and wastewater systems.
- Resource recovery and reuse can change the economics of sanitation and wastewater investment, providing both monetized returns and broader societal and environmental benefits with indirect economic value.

9. SHOWCASING TECHNICAL SYSTEMS FOR SAFE RESOURCE RECOVERY



This section presents some successful resource reuse and recovery solutions that are being implemented in various parts of the world. The descriptions focus on technologies, but also try to set out key issues and lessons in relation to other aspects of sustainability.



Members of an indigenous community in Munchique, Colombia, participate in designing a sanitation system (top) and learn to make their own urine-diverting toilets (left) for home use (right). Photos: Kim Andersson

CASE STUDY 9.1

Photo: Wingoc

RESOURCE RECOVERED:
Potable water

WASTE STREAM:
Municipal sewage

TYPE OF REUSE:
Drinking water supply and aquifer recharge

TREATMENT:
Multiple barriers with chemical treatment and filtration

TOTAL VOLUME OF RECYCLED WATER:
5.8 million m^3/year

Reclaiming water from municipal sewage: New Goreangab Water Reclamation Plant, Windhoek, Namibia

For more than 45 years, the city of Windhoek in Namibia has reclaimed potable water from municipal sewage. The New Goreangab Water Reclamation Plant, completed in 2002, made the process even more efficient and should help the city meet rising water demand into the future.

The population of Windhoek is about 350,000, growing annually at a rate of around 5 per cent. The city relies on surface water (dams fed by ephemeral rivers) and groundwater (borehole water) for water supply. Rainfall is erratic, totalling around 370 mm a year, while the potential surface evaporation rate is approximately 3,400 mm/year. Windhoek thus suffers frequent water shortages.

Roughly 700 km separates the city from the nearest perennial river, the Okavango, to the north-east, while the Namibian Atlantic coastline (2,650 km) is approximately 300 km away. As a consequence, Windhoek has implemented an integrated water resource management strategy with the aim of securing supply by a combination of water savings, water reclamation, water banking (managed groundwater recharge) and water pollution control.

The system

Using advanced multi-barrier treatment processes, the New Goreangab project is able to consistently produce potable water that meets all required drinking water standards from secondary-treated sewage piped municipal sewage. Reclaimed water constitutes up to 35 per cent of the water supplied to the households. No health problems have ever been reported, and safety has been verified by epidemiological studies. This has been achieved, moreover, in a country with limited technical and financial resources. Despite its success and obvious utility, Windhoek's direct potable water reclamation from sewage remains unique in the world.

The plant can treat 21,000 m³ of secondary treated sewage per day. It uses at least two removal processes for each contaminant that could be harmful to human health or aesthetically objectionable. Industrial and other potentially toxic wastewater streams are separated from the main municipal wastewater stream.

Results

Since 1997, the Windhoek municipal authorities have practised water banking by recharging the local aquifer with potable water – a mix of purified water from the Goreangab plant with conventionally treated drinking water. The water injected into the aquifer is fit for human consumption.

The total volume of water that had been banked in this way up to 2013 was 3.3 million m³. The capacity is being further expanded in order to provide water over extended drought periods of up to three years, covering up to 60 per cent of the expected water demand by 2020. Very strict water quality guidelines are enforced to prevent deterioration of groundwater quality and additional treatment steps prior to injection prevent clogging of the aquifer by controlling biodegradable dissolved organic carbon.

The total annualized costs of purifying water at the plant is €0.95/m³, of which €0.75/m³ is O&M costs. User tariffs for the recycled water are linked to consumption, and range from €0.75/m³ to €2.3/m³.

Sources: Lahnsteiner et al. (2013); personal communication with John Esterhuizen, General Manager, Windhoek Goreangab Operating Company (Pty) Ltd (WINGOC); and the WINGOC website (http://www.wingoc.com.na/).

CASE STUDY 9.2

Photo: UNSPLASH/Oliver Wndel

RESOURCE RECOVERED:
Non-potable water

WASTE STREAM:
Domestic non-kitchen greywater

TYPE OF REUSE:
Greywater reused for toilet flushing, outdoor floor/patio washing, garden irrigation, within each equipped apartment building

TREATMENT:
On-site for each building, including anaerobic steps followed by aeration, decanting, filtration and chlorination

EXAMPLE NET WATER SAVING:
432 m³/month/building

Greywater reuse in individual apartment buildings, Vitória, Brazil

Background

Water scarcity is a reality in several Brazilian cities, where supply is threatened by problems with both the quantity and the quality of the water, while demand is growing fast. At least 19 metropolitan areas, including the homes of a third of the population, are at risk of water supply collapse.

A range of drinking water conservation practices have been implemented in the largest Brazilian cities, including both voluntary water savings and wastewater recovery and reuse. In the metropolitan area of Vitória, several apartment blocks have instituted building-level greywater reuse. This relies on on-site systems, collecting source-separated greywater, minimally treating it, and then making it available for various non-potable uses, including flushing toilets, washing public spaces and garden irrigation. Some buildings are able to save up to 30 per cent of potable water as a result.

This practice illustrates the advantages of source separation: as faeces and urine (along with kitchen greywater) are diverted, smaller on-site treatment plants are adequate to make the remaining greywater safe for non-potable reuse, and they can operate more stably and release fewer by-products.

The system

The buildings are fitted with two independent piped water supply systems: one from the mains for drinking water and one for recovered greywater. The drinking water supplies showers, sinks, washing machines and tanks.

The greywater generated from these uses is carried to the building's greywater treatment plant. Following treatment, the recovered water enters the second water supply system, which feeds toilet cisterns and dedicated taps. Blackwater and kitchen sink greywater are channelled directly to the sewerage network.

The treatment plants produce only a small amount of liquid sludge, which can be released directly into the sewer. Several indicators of treated greywater, such as pH, turbidity, residual chlorine and E. coli content, are measured monthly to ensure they are within safe limits, and the treated water is low-risk, according to WHO standards. Moreover, the treatment plant and immediate environment represent a small risk for bacterial transmission, chiefly via aerosol routes for personnel carrying out maintenance work.

Results

In the 30-apartment Royal Blue condominium block, the first to have a greywater reuse system installed, the system has produced a large surplus of water for reuse. The consumption (91 litres per day) accounts for about 32 per cent of the available water, leaving a surplus of around 68 per cent that is not used in the building. The potential for increased reuse could mean even greater savings of drinking water in the future. At present, the untreated greywater is released through a bypass system into the public sewer. The system produces a net water savings of 432 m^3/month.

The monthly costs associated with the greywater treatment plant are related to O&M, energy, removal of sludge and laboratory analysis. Spending on O&M is approximately US$260 per month for the entire 30-apartment building. The cash flow based on costs and revenues from the installation and operation of the reuse of greywater system becomes positive in 103 months, which means that in 8.5 years the amount invested will be recovered, based on current operation practices. Greywater reuse in buildings is still a very recent development in Brazil. The absence of a legal framework contributes to uncertainty among the various stakeholders involved. Nevertheless, given the obvious economic and practical advantages, implementation has been expanding quickly across the country.

Source: Bazzarella 2005; and Gonçalves, da Silva and Wanke 2010.

CASE STUDY 9.3

RESOURCE RECOVERED:
Non-potable irrigation water and nutrients

WASTE STREAM:
Municipal sewage

TYPE OF REUSE:
Agricultural and silvicultural irrigation

TREATMENT:
Centralized; mechanical screens, oxidation ponds, chlorination, filtration

Farming in a semi-desert with water and nutrients from sewage: Gerga, Sohag Governorate, Egypt

Background

Sohag Governorate is a semi-desert region in Upper Egypt with around 4.5 million inhabitants. A two-year experiment (2013-2015) in a farm outside the city of Gerga in Sohag demonstrated the potential benefits of reusing treated sewage wastewater to irrigate and fertilize crops on otherwise dry and infertile soils, simultaneously relieving pressure on scarce water resources and helping to meet growing demand for food. The 2.5-acre farm was managed by the Cairo-based Holding Company for Water and Wastewater, in collaboration with UNEP and the Italian Ministry for Environment, Land and Sea.

The project is part of the country's plan to use treated sewage in the cultivation of timber trees, as well as for agricultural development and urban expansion in desert regions. Crops such as white figs, pomegranate, sunflower and hibiscus were chosen in April 2013 for harvest in the summer, and broad (fava) beans, lentils and chickpeas were planted in the winter season of September 2013. Subsequent harvests also included olives.

The system

The farm was located close to the Gerga municipal wastewater treatment plant. Treated water was stored in a reservoir and delivered by pipeline to the experimental farm, then applied to the crops using drip irrigation. The experimental farm's total requirement was about 2.35 litres per second, and trees and crops were irrigated for up to 5.5 hours a day, depending on water demand.

The treated wastewater showed itself to be a competitive substitute for nutrients for the chosen crops. Analysis found that the heavy metals content was high for root or bulb crops such as potatoes, sweet potatoes, carrots, turnips, onions and garlic. However, it was within both Egyptian national and European standards for irrigation of leaf or stem food crops. For the cultivation of fruit crops those with a thick skin such as citrus and pomegranate were chosen. Industrial wastewater was source-separated and thus did not enter the waste stream.

Results

As well as demonstrating the technical feasibility of this system, the project had wider aims. It raised awareness and educated farmers not only with regard to agricultural questions but also concerning economic, social and health issues related to the dangers of using untreated wastewater for food crop production as compared to the benefits of using safer treated wastewater. The project showed that it is important to consider distances between farms, treatment plants and groundwater wells (additional sources of water) when planning and deciding study locations – proximity means feasibility.

The study also engaged scientists and other specialists to look at the most suitable soil types (preferably light sandy soil textures with deep profiles in desert regions) and crops for sewage wastewater reuse in the specific local climatic conditions and in relation to the degree of sewage treatment and water salinity. A survey was also taken of the potential markets for the crops.

The expansion of drinking water delivery to underserved areas will increase wastewater volumes, thus providing more opportunities for building in reuse strategies from the start. Another lesson learned in Gerga is that institutional collaboration needs to be further emphasized and the appropriate state agencies need to be involved in such projects.

Source: HCWW 2014.

CASE STUDY 9.4

Photo: Kim Andersson

RESOURCE RECOVERED:
Combined water and nutrients

WASTE STREAM:
Household blackwater

TYPE OF REUSE:
Treated blackwater used as liquid fertilizer for crop and biomass production

TREATMENT:
Decentralized, with liquid composting and urea treatment in a plant adjacent to the cropland

Reuse of household blackwater in agriculture, liquid composting technology, Hölö, Sweden

Background

The decentralized blackwater system at Hölö, Sweden, is a joint initiative by the municipal utility, the farming community and researchers. Hölö is located in an area of Södertälje municipality, south of Stockholm. It has a relatively low population density. Prior to the project, about 40 per cent of the existing on-site sanitation systems were malfunctioning, causing discharge of contaminated wastewater. Severe eutrophication of two nearby lakes led to a freeze on building permits, to prevent wastewater from adding to the problem.

As a result, a decentralized wastewater management scheme was implemented, with resource reuse on nearby farmland – reducing the need for synthetic fertilizers, and thus the associated eutrophication, and avoiding the discharge of contaminated wastewater. The project took a whole-system approach, installing special toilets and tanks at household level, organizing transportation and treatment, with a view to safe reuse. It was supported by municipal policy.

The system

At the household level, the blackwater system is either a very low flush (max 0.6 l./flush) or vacuum toilet, to reduce blackwater volume and dilution. The toilets are connected to a household tank. Greywater is treated and infiltrated at household level. Households pay a fee to the municipal utility for collection of the blackwater by tanker truck, which transports it to a treatment plant designed to serve 500 to 700 households. The plant is managed by a local farmer, who receives technical and financial support for O&M from the utility. After treatment, the blackwater is stored in a 1,500 m^3 tank until it is reused.

The liquid fertilizer produced from Hölö treatment plant meets the newly developed Swedish certification standards for wastewater fractions for reuse from on-site and smaller wastewater treatment systems (see Box 7.9). Initial quality tests showed elevated values for copper, but this was easily corrected by replacing some brass faucets at the treatment plant. The reusing farmers also have complementary environmental protection features in their farms, such as protective zones around watercourses to reduce nutrient leaching, which have proved effective in preventing the release of pharmaceuticals.

Results

The liquid produced provides a complete fertilizer input for 40 ha. of cultivated land. The initiative has achieved its primary purpose – reduced eutrophication of lakes and coastal waters – more cost-effectively than expansion of the centralized sewer system could have done. Environmental restrictions have spurred technical development of the blackwater treatment, which is now patented by the utility, and the process produces a popular certified liquid fertilizer that can be spread using conventional farming equipment. Effective public-private entrepreneurial arrangements between utility and farmer are another benefit to have come out of the initiative.

Source: Personal communication with K.A. Reimer, Södertälje Municipality, and A. Kalo, Telge Nät, Sweden.

CASE STUDY 9.5


Photo: Kim Andersson

RESOURCE RECOVERED:
Combined water and nutrients

WASTE STREAM:
Source-separated household faeces, urine and greywater

TYPE OF REUSE:
Treated urine used as liquid fertilizer, composted faeces used as solid fertilizer in crop production after treatment. Greywater used for ornamental and kitchen garden irrigation

TREATMENT:
Decentralized storage of urine and vermicomposting of faeces. Greywater pre-treated in a grease trap before reuse

Decentralized excreta management and local greywater reuse in a peri-urban community: El Alto, Bolivia

Background

District 7 of El Alto city, Bolivia, is an example of a growing peri-urban community lacking public sewerage infrastructure and with a problematic water supply (shortages and rationing on weekends). These problems are due to increasing water demand from a growing population, and are likely to be aggravated by the continued shrinking and anticipated disappearance of Andean glaciers, which currently provide a significant share of freshwater supply. Water conservation is thus an important climate change adaptation measure.

This project was initiated in 2008 by the national Fundación Sumaj Huasi. More than 1,200 families, mainly from the Aymara indigenous group who migrated to El Alto from rural villages, installed the systems. Sumaj Huasi aimed to improve quality of life in the communities, and put strong emphasis on social processes such as capacity building, demonstration gardens, and frequent follow-up visits.

The systems installed by the project collect and treat urine and faeces separately, for resource recovery and agricultural reuse. Faeces is composted with worms (vermicomposting), while urine is treated by storage. Greywater from basins and showers is channelled to small constructed wetlands in the household's garden, with ornamental and edible plants. Testing found that both water and excreta products were safe to reuse, including for food production.

In the first phase of the project, excreta-derived fertilizers were used in demonstration gardens. As more families have had systems installed, the growing volume of fertilizer produced has opened up potential for large-scale treatment and reuse. The excreta-derived fertilizers (vermicompost and treated urine) have been found to be even more nutrient-rich than organic fertilizers commonly used in the region (such as cow manure), as evidence by both nutrient testing and crop yields. Potato yields from plants fertilized with human vermicompost and urine were double those of plants fertilized with cow manure.

The system

The household systems installed by the project include urine-diverting dry toilets, to minimize water use. The UDDTs have a single vault, in which faeces is collected in 100-litre plastic containers and urine in 20-litre jerry cans. The containers are collected using pick-up trucks, and transported to the common treatment plant. Faecal matter is vermicomposted for eight to nine months using red Californian earthworms (*Eisenia fetida*).

The households are responsible for the appropriate use and cleaning of the toilets, and for moving the containers with faeces and urine to the street outside the house on scheduled collection days. Appropriate use includes applying a layer of sawdust over the faeces after defecation, and a small quantity of water after urinating. Sawdust is easy to find in the area and costs about 5 Bolivianos (US$0.65) for a 20 kg bag (sufficient for about one month).

The project also installed showers and hand-washing/laundry basins for improved hygiene. The greywater captured from these is pre-treated in site-built grease-traps before being channelled to the constructed wetlands. Currently, about 8 tons of solids (faeces and sawdust) and 22,500 litres of urine are collected each month and processed at a common treatment plant. To overcome challenges for handling and reuse posed by these large volumes, a number of different strategies have been tried, such as storing urine directly in the field before cultivation.

Results

The construction cost per sanitary unit was $795. Of this, $620 was covered by the Swedish International Development Cooperation Agency (Sida) and Sumaj Huasi, and households contributed labour and other in-kind contributions. A monthly fee scheme has been piloted, in which each household pays around 10–20 Bolivianos ($1.30–2.60) per month to cover collection and transport costs. The decentralized system has proved cost-effective compared to centralized systems and the fertilizer products offer significant boosts to agricultural production.

A general positive health impact has been confirmed in the community. The prevalence of acute diarrhoeal disease has fallen by 23 per cent, according to epidemiological studies in the intervention area. Analyses of treated faeces show that parasite content is within WHO-recommended limits. The water saving due to the installed UDDTs is estimated at 108 m^3 per day in the project area.

Experience in the project indicates that key factors in the high acceptance rate have included the comprehensive social process, an integrated WASH approach, and, in particular, the collection and external management of the excreta.

Sources: Suntura and Sandoval 2012, Fundación Sumaj Huasi 2015.

CASE STUDY 9.6

Curitiba. Photo: Flickr/Francisco Anzola

RESOURCE RECOVERED:
Nutrients and organic matter

WASTE STREAM:
Municipal sewage, including lime added during treatment

TYPE OF REUSE:
Agriculture (food and non-food crops) and reforestation

TREATMENT:
Anaerobic treatment, with secondary treatment consisting of aeration, stabilization ponds or percolating filters. Sludge dewatered and treated with lime

Reuse of sewage sludge in agriculture, Paraná State, Brazil

Background

Sanitation Company of Paraná (Sanepar) runs 234 wastewater treatment plants serving over 7 million people in the state of Paraná, Brazil. Since 2002, agricultural use has been the final disposal method for the sewage sludge generated in the Metropolitan Area of Curitiba (RMC) and in the region of Foz do Iguaçu. After 2007, steps to implement the process in other regions began, and after 2011 this practice was implemented throughout the state.

The treated sludge has been used for green manure crops, mulberries, rye, coffee, sugarcane, barley, citrus, beans, corn, soybeans, grass and eucalyptus and pine reforestation.

The system

One aspect of the treatment at the plant is disinfection of sludge through prolonged alkaline stabilization. In this process, the sludge's pH is raised to 12 by adding large quantities of lime. This means that the treated sludge can act as a soil acidity corrector, representing further savings for the farmers. Industrial wastewater is separated at source and treated separately.

After laboratory testing to ensure a batch of processed sludge meets the regulatory standards, it is made available to farmers registered in the programme. The farmers must produce suitable crops and in areas appropriate for this sort of reuse. The sludge application rate is based on the crop's soil and nutritional needs. If necessary, supplementary fertilizer is added. Farmers receive technical advice, and sign a special agreement certifying they are aware of the requirements and guidance for proper use of the material, and commit to follow them. The treated sludge is supplied free to the farmers.

The agricultural reuse of sewage sludge follows the criteria and procedures established in national and state regulatory measures. These set a maximum limit for pathogenic agents and inorganic contaminants. The monitoring of organic substances in the sludge is also required, but these do not have to adhere to maximum concentration limits. The observed levels of pathogens found in the sludge meet all the requirements of the related regulation – Resolução Sema 021/09. The inorganic substance levels remain under the limits of the regulation 90 per cent of the time.

Results

From 2011 to 2013, 104 farmers benefited in farming areas in 41 municipalities, an average of 65 km away from a treatment plant. The reuse of sludge in Paraná provides benefits to the farmers (based on replacement of NPK fertilizers and lime application) amounting to US$110/ha. In 2011–13, reused sludge supplied 90 per cent of the limestone, 69 per cent of the nitrogen, 83 per cent of the P_2O_5, and 35 per cent of the K_20 demand in Paraná.

The sewage sludge has received a favourable reception among farmers in the state and the approach holds great promise. The project's expansion has been a major challenge for Sanepar, as sludge recycling was not an operational goal from the start of system design. Thus, improvement of infrastructure and capacity building are necessary. Other complications include logistics of transporting the sludge, uneven demand around the year (concentrated in two growing seasons), and the high number of rainy days, which can make application difficult. The programme also encountered difficulties contracting laboratory analysis services with the required infrastructure and technical capacity. The project has also highlighted a need to update national regulations, which presently impose an overly bureaucratic and burdensome process not applicable to local conditions.

Sources: Andreoli et al. 2001, Bittencourt 2014, Souza et al. 2008.

CASE STUDY 9.7

Photo: Flickr / N. Khawaja

RESOURCE RECOVERED:
Biogas, nutrients, soil conditioner

WASTE STREAM:
Human excreta, greywater, livestock manure, food waste and crop residues

TYPE OF REUSE:
Cooking, lighting and heating (biogas) and agriculture (food and non-food crops)

TREATMENT:
Anaerobic fermentation of organic matter, followed by composting of the remaining sludge

On-site systems for biogas and fertilizer: China

Background

Since the 1970s, China's biogas development programme has spread across the country, primarily in rural communities. Some 40 million biogas fermenting units have been built with government subsidies. The concept goes back to the rural development policies initiated by Mao Zedong during the 1950s to provide renewable energy to farming communities. There was major expansion in 2003–2012, with a cumulative investment of US$4.5 billion, impacting about 100 million people.

The system

Human excreta are transferred by pour-flushing from toilets to the airtight fermentation tank, where they are mixed with other organic waste from the household and farm. Their carbon content is digested anaerobically by methanobacters, producing methane gas that can be collected for use as a household energy source, mainly for lighting and cooking. Once digestion is complete, the accumulated sludge is transferred from the digester to an aerated composting site, resulting in a nutrient-rich soil improvement agent.

Several digester models have been deployed. Most of those for household use have a volume of 6, 8, or 10 m^3 and are designed to last for 20 years; however, success depends on careful operation and maintenance, since the systems are biological. It also depends on an adequate supply of organic material. It is unclear from reports how many of the installed units are actually in use, with estimates ranging from 30 per cent to 90 per cent.

Results

In 2013, China produced more than 15 billion m³ of biogas, producing energy equivalent to 25 million tons of coal or 11.4 per cent of the national natural gas consumption. Also, biogas digesters produce 410 million tons of organic fertilizer per year, reduce CO_2 emissions by 61 million tons, and generate benefits worth ¥47 billion (US$7.3 billion at 2012 exchange rates) in cost savings and income, according to the Ministry of Agriculture. Nevertheless, questions have been raised about whether the heavy government subsidies for the programme (provided for initial installation, and regardless of the wealth and income of the household) have encouraged installation of systems that have not subsequently been properly used and maintained. A lack of maintenance services has proved a bottleneck.

Biogas production from excreta and other organic waste provides several economic and environmental benefits for rural communities, including a clean and low-cost energy alternative to fuelwood, charcoal and fossil fuels, and a low-cost source of safe plant nutrients and soil conditioner. Health benefits range from improved indoor air compared to cooking with charcoal and wood, to containment of excreta and animal manure.

Source: Zuzhang 2013.

CASE STUDY 9.8

Black soldier fly. Photo: Dunstan Adongo

RESOURCE RECOVERED:
Organic matter, nutrients, protein

WASTE STREAM:
Livestock manure and human faecal sludge from urine-diverting toilets

TYPE OF REUSE:
Livestock feed and agricultural inputs, plus industrial oils

TREATMENT:
Faecal sludge taken to central treatment plant where black solider fly larvae feed on sludge and reduce the mass of the treated material and pathogen load

Livestock protein feed from faeces with black soldier fly: eThekwini, South Africa

Background

One key barrier to safe management of faecal sludge is the lack of economic incentive. In many areas, pit latrine emptying services are not available, or households face high costs for emptying and disposing of faecal sludge as the costs of removal cannot often be fully covered by selling the products. Processing faecal sludge using black soldier fly (*hermetia illucens*) larvae offers a new and potentially financially sustainable approach to managing waste, as the mature larvae are a good source of protein and fat for animal feed. Black solider fly larvae can consume large amounts of waste, reducing the dry matter content of manure by up to 58 per cent and that of municipal organic waste by up to 70 per cent.

While black soldier fly larvae technology has been used with swine, chicken and cattle manure, it has not yet been used to manage human excreta on a large scale. In eThekwini municipality, South Africa, a cost-effective faecal waste processing plant using the technology is under development through a public-private partnership. The aim is to process faecal waste removed from urine-diverting toilets in 80,000 households.

Faecal waste can be used to feed insect larvae due to its high organic content. Larvae of the black soldier fly are a particularly good option because the resulting larval biomass is a high-value product. This provides a source of income for communities or local entrepreneurs. Urine collected from the diverting toilets, along with process residues from the black soldier fly technology, can be safely used as agricultural fertilizers and soil conditioner after further treatment.

Adult black solder flies are not disease vectors and are not considered a nuisance fly species because they only feed on fat stores from their larval stage. The larvae also reduce the dry mass of faecal waste and reduce *E. coli* and salmonella pathogen loads, thus decreasing the risk of disease transmission. However, if treatment residues are to be used as fertilizers for food crops, an additional treatment step is recommended.

Next steps

More research needs to be conducted on the ability of black soldier fly larvae to consume human waste, including wastes from different latrine types, with different physical and chemical characteristics. Potential risks resulting from bioaccumulation of heavy metals and contamination by pathogens need to be assessed for biomass that enters the human food chain thus creating possible regulatory obstacles to using larvae as animal feed.

Sources: Lalander et al. 2013, Banks et al. 2013 and Alcock 2015.

10. CONCLUDING REMARKS

Transforming sanitation and wastewater management is critical to shifting the world onto a sustainable development path. This transformation has many dimensions: it is not only about closing the major gaps and inequalities that still exist in provision and access, but also about ensuring that what is provided meets the economic, social and environmental criteria for long-term sustainability. And the transformation of sanitation and wastewater management needs to happen urgently, given the rapid growth in populations and urban centres and the challenges to water, food and energy security anticipated in the coming decades.

The transformation requires a fundamental change in perceptions about what sanitation and wastewater management are for, and about the value of excreta and wastewater. Sanitation and wastewater management are currently seen as ways of disposing of dangerous waste products in a way that protects human, and to an extent ecosystem, health. Sustainable sanitation and wastewater management, in contrast, belong to the circular economy paradigm, as ways of "closing the loop" and recovering and reusing valuable resources. The "wastes" become inputs to productive processes, particularly agriculture, but also energy production, water saving and supply, and potentially many other processes.

The transformation cannot be achieved simply by replicating the old, unsustainable models, even as a "bridge" to more sustainable sanitation and wastewater management systems. These are long-term investments, and there is a real danger of "lock-in". As far as possible, investments today should be in sustainable systems that are designed and operated for safe and efficient resource recovery.

Designing such system requires a whole-system perspective. From a technological point of view, this means that all technologies in the system are complementary. But system sustainability is not only about the right technologies. For example, separating different waste streams at the source – urine, faeces, greywater etc. – can facilitate safe recovery of resource. For it to work, it needs not only user interfaces that allow this separation, but also means of storing, transporting and treating them separately. It also depends on the interfaces being properly used and maintained, so the users must have both the knowledge and the will to do so. There must be demand for the recovered resources, and for crops grown with them (in the case of agricultural reuse). There must be businesses providing maintenance and other services. And regulations and institutional set-ups need to promote the particular type of reuse. Poor functioning in one stage undermines the sustainability of the whole system.

Sustainable sanitation and wastewater management systems must also be designed for the specific local geographic, social, cultural, economic and environmental conditions; there are no one-size-fits-all sustainable sanitation systems. Hard experience has shown clearly that sustainability is not in the technology itself, but in how it matches the needs and constraints of the specific context.

Design also needs to take in the time dimension; the changes that may come during the lifetime of a typical system. It makes practical and economic sense to plan and invest with an eye to the long-term future – for example urban expansion, the consolidation of unplanned peri-urban communities, future pressures on resources, and climate change impacts.

Sustainability in a sanitation and wastewater system also depends on its ability to coper with natural and man-made hazards and disasters. Systems that break down or malfunction during disasters are often responsible for a large share of mortality and sickness in their aftermath. In this respect, sustainable sanitation and wastewater systems are an integral part of disaster resilience.

The economic case for investment in improved sanitation is already well established. Just the savings and dividends from increasing productivity and reducing mortality and sickness from communicable disease ensure that such investments pay for themselves several times over. But systems built for resource recovery and reuse can provide even greater economic benefits, creating jobs and even whole new business sectors and domestic markets. Depending on the context, making scarce resources, particularly water, fertilizer and clean energy in the form of biogas, available for society can lead to gains in productivity in sectors such as community development, transportation, agriculture, aquaculture and forestry.

The know-how and the capabilities to make good, sustainable investments are available. This book has presented a diverse selection of technical and institutional solutions that have been tried and tested around the world, and there are many more worth showcasing. Sanitation and wastewater management designed for resources recovery is an area of rapid technological innovation, and there is a need for ever greater technological cooperation, learning and knowledge sharing.

As a final note, it is important to realize that the challenges are not confined to the "developing world" where provision is currently poor. While most wealthy cities and countries have well-developed sanitation and wastewater management systems, they are rarely suited to resource recovery, and often use huge amounts of energy and water (especially treated drinking water). Many will need to adapt or even replace their existing systems. Throughout history, advances in sanitation and wastewater management have gone hand in hand with some of the greatest steps in human development. Sanitation and wastewater management could once again play a crucial, even catalytic, role in realizing the sustainable development vision of the 2030 Agenda.

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