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PRODUCTIVE AND SAFE USE OF URBAN ORGANIC WASTES AND WASTEWATER IN URBAN FOOD PRODUCTION SYSTEMS IN LOW-INCOME COUNTRIES

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Introduction

Rapid urbanization in developing countries raises the challenges of urban food supplies and management of the waste flows from urban households and markets. Large amounts of municipal solid waste, human excreta and wastewater are produced, which mostly end up in non-engineered landfills or polluting the urban environment, especially in low-income countries where sanitation infrastructure is less developed. Wastewater and many organic wastes are nutrient rich and can be productively used in intra- and peri-urban agricultural systems, enhancing the resilience of the urban metabolism.

However, productive reuse of waste faces a variety of challenges. These range from securing cost recovery for up- and out-scaling successful examples of planned reuse to the acceptance of safety practices within the informal reuse sector in urban and peri-urban areas. Opportunities for addressing the first challenge include more attention to business models which can build on different value propositions beyond 'water' or normal 'composting', and for the second challenge they include more attention to social marketing options, private-sector engagement and incentive systems for catalysing behaviour change towards the adoption of safety practices.

A shift in thinking about solid and liquid waste

Cities are hungry and thirsty and there are enormous hubs of consumption of all kinds of goods including food. This in turn makes them major centres of generation of food waste. If this waste remains in the urban environment or its landfills,

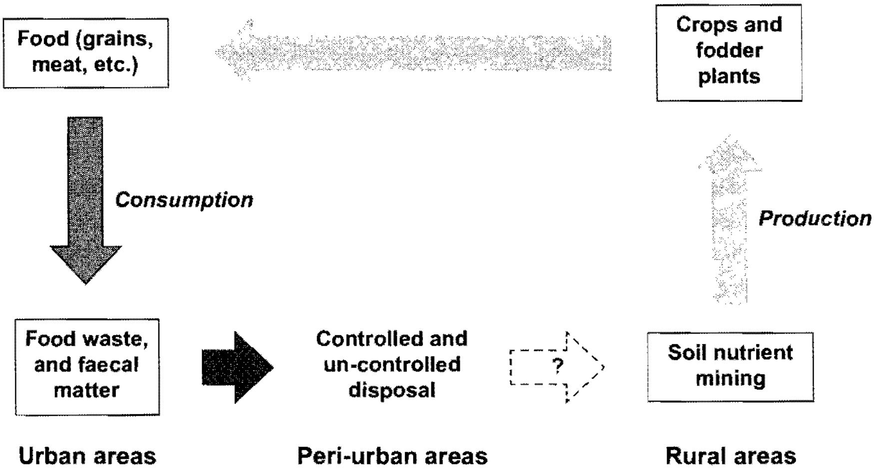

FIGURE 7.1 Urban and peri-urban areas as vast nutrient sinks
Source: authors.

cities will also become vast sinks for the resources, like crop nutrients, while rural production areas face degradation of soil fertility (Figure 7.1). The same applies to nutrient-rich wastewater discharged from households (excreta, urine and grey water), and commercial and industrial establishments, which could also be mixed with storm water as may be present.

Given the value of the resources hidden in waste, and the environmental burden of a business-as-usual scenario in growing cities, there is need for a paradigm shift. For example, in solid waste management, there is increasing advocacy to a shift in the behaviour of the public towards the 'three Rs', i.e., 'Reduce, Reuse and Recycle' (UNEP 2011). Social science research is re-conceptualizing waste from 'risk, hazard or dirt' towards 'resources, values, assets and potentials' (Moore 2012). In wastewater management, a clear shift from nutrient removal to nutrient recovery is taking place with treatment facilities shifting from waste disposal to resource conservation (Murray and Buckley 2010). This conceptual thinking of 'design for reuse' or a 'reverse water chain approach' considers the ultimate fate of the water as the design base for the urban water chain, including treatment and upstream issues (Huibers and van Lier 2005).

This thinking has been strengthened through an increasing focus on dry sanitation systems, especially ecological sanitation systems, in regard to the managing of human faecal matter. Ecological sanitation is based on three principals: (i) preventing pollution rather than attempting to control it afterwards, (ii) sanitizing urine and faeces (excreta), and (iii) using safe products for agricultural purposes (Winblad and Simposon-Herbert 2004). There is also increasing efforts for using faecal waste and other organic waste in energy production through biogas schemes.

The modern dry sanitation systems facilitate the transport of faeces and potential resource recovery through the 'drop-store-sanitize-and-reuse' approach in a controlled environment which conventional approaches like 'drop-and-flush' or 'drop-and-forget' of sewered systems or pit latrines, respectively, do not support (Rautanen and Viskari 2006). These newer approaches incorporate the 'three Rs' thinking across scales for increasing the resilience of urban areas, and society at large. A change in thinking is not only a possibility but, in many cases, a 'must' as limited water resources do not allow flush sewer systems while some resources like phosphorus are non-renewable, and especially poorer countries will be the first to feel increasing fertilizer prices (Mihelcic et al. 2011).

Resource recovery ideally starts at the household level. Supported by public awareness, households reduce their waste collection fees by separating, for example, old glass, used paper, plastic waste and organic kitchen residues into dedicated collection systems. Where space and regulations allow, backyard composting of kitchen residues for urban farming is encouraged. For grey water from kitchens and bathrooms and black water from toilets, local reuse options, e.g., via urine diverting toilets, are being explored, although for the large majority of urban households the conventional target remains the removal of faecal matter from household premises through the sewer system.

In most developing countries, collection of wastewater and solid waste and the separation of different solid waste streams are still a major challenge, resulting in severe pollution of water bodies. Less than 10% of the urban population in sub-Saharan Africa, about 3% in South-East Asia and 31% in South Asia are connected to any wastewater collection system (Lautze et al. 2014). Collection of solid waste does not require expensive infrastructure but shows a similar picture with South Asia and Africa ranking lowest with 65% and 46% collection rates, respectively (Hoornweg and Bhada-Tata 2012). The remaining waste is a severe public health hazard. As most households are poor, waste management cannot rely on fees and taxes to finance its operations. In fact, expenditure on waste management often takes up to half of the municipal budget and even then is seldom enough to cope with waste generation, especially in the low-income high-density parts of the city which are difficult to access. The possibility of increasing household fees is not only limited by poverty, but also due to low education, resulting in limited environmental awareness and responsibility. If collection fees are raised, households are likely to start dumping their waste in the street or drains.

In low-income countries, increasing collection coverage is the highest priority in most local authorities, much more so than introducing resource recovery activities, which often remain at pilot scale. However, recycling takes place, but is more poverty-driven than done for environmental reasons, with landfill scavenging and e-waste burning for metal recovery being popular examples. However, an increasing number of entrepreneurs are engaged in activities such as commercial plastic recycling, and the reuse of organic residues for various purposes.

While urban and peri-urban food production and especially food safety clearly suffer from poor sanitation, urban farmers do often take advantage of underutilized solid and liquid waste resources. This may be food waste from agro-industrial production, such as cotton husks or poultry manure, composted market-waste, domestic wastewater or faecal matter.

In this context, we need to consider two waste 'streams': the waste that is managed and on its way to treatment or disposal; and the waste that bypasses formal systems, leaking out or never getting there in the first place (Drechsel et al. 2011). This chapter will focus on both streams in developing-country contexts (though there are many similarities with developed countries), and the related challenges and opportunities for the productive and safe use of urban organic wastes and wastewater. While there are several reuse options, from industrial reuse to the production of potable water, in the context of this publication, agricultural reuse, especially in intra- and peri-urban farming, will be the focus.

With the emergence of intensive – high input, high output – urban and peri-urban food production systems, which are often a direct response to changing diets in urban areas, we see an increasing interest in water reuse and alternative fertilizer making use of different types of waste (Box 7.1).

BOX 7.1 FORMS OF URBAN WASTE OF VALUE IN AGRICULTURE

Urban waste can be solid, partially solid (e.g., manure, sludge) or liquid (grey water), organic or inorganic, recyclable or non-recyclable. Of interest to urban agriculture as a source of nutrient and organic matter is the organic fraction of municipal solid waste (MSW) and agro-industrial waste, and as a source of water and nutrients also domestic wastewater. For example, at least 50% of urban solid waste is biodegradable and hence of immediate interest in recycling. Wastewater on the other hand is often already used, directly where water is scarce or indirectly if mixed with other water sources. Typical types of waste commonly used in urban farming are:

1 **Solid waste:** Domestic and market wastes, food waste including vegetable and fruit peelings, and charcoal ash. This also includes waste from institutions and commercial centres.
2 **Horticultural and agricultural waste:** Common especially in high-income areas: garden refuse, leaf litter, cut grass, tree cuttings, weeds, animal dung, crop residues, waste from public parks, etc.
3 **Agro-industrial waste:** Waste generated by abattoirs, breweries, timber mills, poultry farms, food processing and agro-based industries.
4 **Sludge and biosolids:** Human faecal matter from septic tanks and treatment plants.
5 **Wastewater:** Typically, it is estimated that 70–80% of total water supplied for domestic use leaves the household as wastewater. However, high wastewater collection is not always successful because of the low coverage of sewer.

Source: Cofie et al. 2006; modified.

Resources in urban organic waste and wastewater

Municipal solid waste (MSW)

Current global MSW generation levels are approximately 1.3 billion tons per year ($Btyr^{-1}$), and are expected to increase to approximately 2.2 $Btyr^{-1}$ by 2025. This represents a significant increase in per capita waste generation rates, from 1.2 to 1.42 kg $person^{-1}day^{-1}$ in the next 15 years (Hoornweg and Bhada-Tata 2012). In sub-Saharan Africa, approximately 62 million tons of MSW are generated per year. Per capita waste generation is generally low in this region, but spans a wide range, from 0.09 to 3.0 kg $person^{-1}day^{-1}$, with an average of 0.65 kg $capita^{-1}$ day^{-1}. In the MSW stream, waste can be organic and inorganic, and generally categorized organic, paper/cardboards, plastics, glass, metals, textiles and other materials (see Figure 7.2).

Of most relevance to urban food production systems is the organic waste, which is most commonly used to improve soil productivity. In general, the organic fraction is the largest one within domestic waste (Figure 7.2). According to Hoornweg and Bhada-Tata (2012), low-income countries have an organic fraction of 64% compared to 28% in high-income countries. The potential benefits of organic waste recycling are particularly in reducing the environmental impact of disposal sites, in extending existing landfill capacity, in replenishing the soil humus layer and in minimizing waste quantity (Zurbruegg and Drescher 2002).

In a comprehensive review on MSW use in agriculture, Hargreaves et al. (2008) described the positive effects of MSW on the biological, physical and chemical soil properties. The review showed that MSW has high organic matter

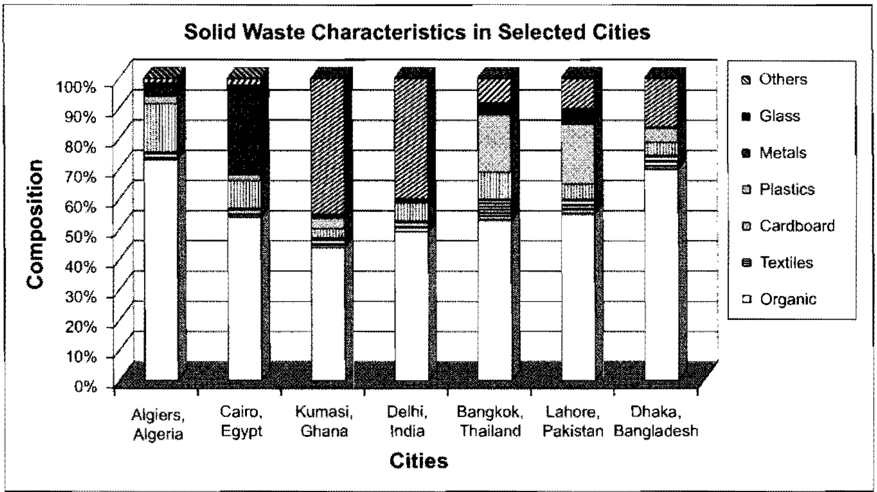

FIGURE 7.2 MSW characteristics in selected cities

Source: Cofie et al. 2006.

content, limited amounts of nutrients and low bulk density. Once composted, these characteristics can influence, in particular, the physical properties of soils by increasing the soil C/N ratio, water-holding capacity, etc. In view of biological properties, the review showed a general improvement on soil microbial health through increasing organic biomass, increasing soil aeration and accelerating the activities of enzymes which help in the transformation of nutrients. Reduced soil acidity and – depending on the type of waste or supplements – the addition of nutrients was identified as a possible beneficial effect on soil chemical properties.

Other benefits adapted and summarized from Hoornweg et al. (1999), with particular reference to organic waste composting, are that it:

- Reduces overall waste volume, transport costs and landfill lifetime.
- Enhances recycling and incineration operations by removing moist organic matter from the waste stream.
- Promotes environmentally sound practices, such as the reduction of methane generation at landfills.
- Is flexible for implementation at different levels, from household efforts to large-scale centralized facilities; i.e., can also be started with very little capital and operating costs.
- Addresses possible health impacts from faecal matter due to the composting (sanitizing) process.
- Can integrate existing informal sectors involved in the collection, separation and recycling of wastes, and contributes to the 'green economy' of a city.

However, despite these benefits, current MSW management practices show very small proportions of MSW being recycled and/or composted. This ranges from over 30% in some high-income countries to as low as less than 2% in low-income countries (see Table 7.1). On average, only 1.5% of MSW is

TABLE 7.1 Global MSW disposal practices (by income levels of the countries)

	High income (%) Total = 588.05 million tons	*Upper middle income (%) Total = 135.78 million tons*	*Lower middle income (%) Total = 55.32 million tons*	*Low income (%) Total = 3.76 million tons*
Dumps	0	33	49*	13
Landfills	43	59	11	59
Compost	11	1	2	1
Recycled	22	1	5	1
Incinerated	21	0	0	1
Other	3	6	33	25

Note: * including China.

Source: adapted from Hoornweg and Bhada-Tata 2012.

composted in low- and middle-income countries. The reasons for these low shares are as various as the theoretical benefits. More than a decade ago, Hoornweg et al. (1999) had already identified six common challenges preventing compost initiatives from going to scale: (i) inadequate attention to the biological process requirements like under tropical climates; (ii) over-emphasis placed on electricity-demanding and often fragile mechanized processes rather than labour-intensive operations; (iii) lack of vision and marketing plans for the final product – compost; (iv) poor feed stock which yields poor-quality finished compost, for example, when contaminated by heavy metals; (v) poor accounting practices which neglect the fact that the economics of composting rely on externalities, such as reduced water contamination, avoided transport and disposal costs, etc.; and (vi) difficulties in securing finances since the revenue generated from the sale of compost will rarely cover processing, transportation and application costs.

Although there are an increasing number of success stories, as documented for example in the *Urban Agriculture Magazine* Vol. 23 (www.ruaf.org), an over-reliance on technical approaches and lack of business thinking was reconfirmed also in more recent studies. Based on experiences from composting projects in Africa, Drechsel et al. (2010) identified as a key constraint that the composting gains in terms of reduced transport volumes and cost are seldom made available to (run) the composting unit due to poor coordination among involved institutions and the lack of an enabling institutional (e.g., private–public partnership) framework. While, for example, city authorities stress that composting is most welcome as a means to reduce waste volume and transport costs, the savings remain inaccessible to the private compost plant operator. However, in many situations, and especially for larger cities, these 'savings' would be a higher benefit (revenue stream) than the actual compost sales. The situation might be very different for smaller towns where agricultural demand might surpass waste supply.

The importance of transport costs derives from the increasing problems of city authorities to find community-supported landfill sites in the city vicinity, while local communities are less reluctant to accept a compost station (Drechsel et al. 2010). From this point of view, compost stations should be planned as close as possible to the points of waste generation, and from the sales perspective as decentralized as possible to support farmers' access to the product. Knowing customers' locations and demand, the corresponding daily production of compost, transport and operation and maintenance (O&M) costs, it is possible to determine the optimal number of decentralized compost (and transfer) stations to minimize costs.

Possible market segments go beyond intra- and peri-urban crop production and include landscaping, housing sector, coffee and tea plantations, forestry, etc. As long as the reuse market is not fully assessed, cost recovery for compost

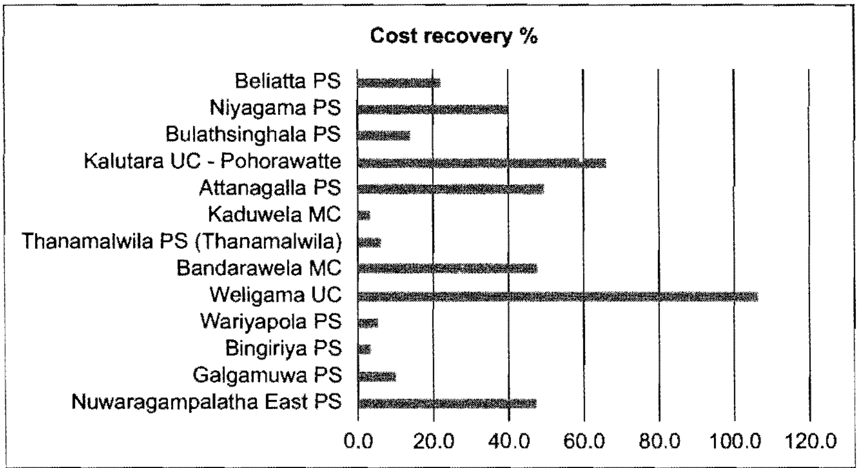

FIGURE 7.3 Range of O&M cost recovery among selected compost plants in Sri Lanka
Source: Fernando et al. 2014.

production will remain small, and any compost business will have to be based on subsidies based on transport and landfill cost saving.

Based only on compost sales, cost recovery can vary in wide margins, as the Pilisaru project in Sri Lanka has shown. More than 110 compost plants were set up under the first project phase, with an average cost recovery of less than one-third of the O&M costs (Figure 7.3). The average value hides the fact that several compost plants produced far less compost than planned (reducing also the O&M cost), although several accepted more waste than they were designed for, targeting more volume reduction than the production of a marketable product (Fernando et al. 2014). However, some plants in Sri Lanka performed well and even achieved profits (Otoo and Drechsel 2015). This was interesting, as almost all MSW compost plants in the country are owned by the public sector. Thus the differences between poor- and well-performing stations could not be easily attributed to management, technology or regulatory differences, allowing cross-case analysis. A typical reason for difference in performance related to different expertise and knowledge about local markets and the emergence of private–public partnerships.

Human excreta

Human excreta are the final 'food waste' and a key component of domestic waste production. Like animal manure, they are an excellent fertilizer, and richer in organic matter with essential plant nutrients such as nitrogen, phosphorus and potassium than the average organic MSW. The use of human excreta as a fertilizer dates back to many centuries. For example, Chinese were aware of the benefits of using excreta in crop production more than 2,500 years ago, enabling them to sustain more people at a higher density than any other system of agriculture (Lüthi et al. 2011). Even in many European cities, fertilization of farm lands continued into the middle of the 19th century as farmers took advantage of the value of nutrients in excreta to increase production, and urban sanitation benefited as they used farming lands as a way of treatment and disposal (Lüthi et al. 2011). The practice only stopped due to the need to manage possible health risks within increasingly dense human settlements.

It has been shown that the nutrient content of human waste collected in a year is approximately equal to what has been eaten during the year (Drangert 1998). Each year, a human excretes up to 500 litres of urine and 50 to 180 kg (wet weight) of faeces, depending on water and food intake (Drangert 1998). These contain about 4 kg of nitrogen, 0.6 kg of phosphorus and 1 kg of potassium, with variations depending on protein intake (Drangert 1998; Jönsson et al. 2004). Phosphorus (P) recovery from excreta is of particular importance due to the fast depletion of phosphorus reserves (see Box 7.2).

BOX 7.2 THE NEXT INCONVENIENT TRUTH – PEAK PHOSPHORUS

Phosphorus is an essential nutrient for all plants and animals. About 80% of mined phosphate rock, the main source of phosphorus, is used in fertilizers, thus making it very vital for the world's agriculture sector. Today, about 90% of phosphate rock reserves are found in only five countries and the largest commercially recoverable reserves are found in three countries – China, United States and Morocco/Western Sahara. The US Geological Survey reports that phosphate rock reserves are running out and that phosphate rock extraction will peak around the year 2030. The extraction rate of phosphate rock in the United States (US) peaked 15 years ago and present forecasts show that the US will deplete its reserves within 30 years. Globally, phosphate rock reserves are estimated to be depleted within 75–100 years. Being a non-renewable resource, phosphorus cannot be manufactured from alternative sources. Therefore, there is need for agricultural reforms and innovative and sustainable strategies to recover phosphorus from human, animal and other organic wastes for use in agriculture.

Source: Rosemarin et al. 2009.

While most of the organic matter is contained in faecal matter, most of the nutrients (88% of the nitrogen, 67% of the phosphorus and 71% of the potassium) are found in urine (Heinonen-Tanski and van Wijk-Sijbesma 2005) in forms that are readily available for crops. Organic matter from decomposed faeces can also serve as a soil conditioner, improve soil structure, increase water-holding capacity, and can reduce pests and diseases while neutralizing certain soil toxins like heavy metals (Esrey et al. 2001). An important benefit from recycling excreta is the reduction of environmental pollution and degradation of water quality from uncontrolled dumping of faecal sludge.

Following the promotion of urine-diverting toilets, extensive field trials conducted both in tropical and temperate climates have shown increase in yields from using human excreta compared to when the soils are unfertilized. Jönsson et al. (2004) reviewed various field experiences regarding agricultural yields on using human excreta in agricultural production. Despite very promising agronomic results, the reuse of faecal matter (excreta and urine) is facing various challenges from the cost of toilets separating the resources, to limitations based on perception or health regulations, or the logistics of transportation where households do not have the opportunity of on-site reuse. More progress has been achieved in view of urine and its high phosphorus content. Modern technologies allow the recovery of high percentages of P before it starts damaging pipes and valves in wastewater treatment systems through unwanted precipitation. This results in significant savings for treatment operators by reducing the use of chemicals otherwise needed to remove the crystals. Enterprises specialized in P recovery thrive on these savings while the generated P fertilizer (struvite) is still struggling to move beyond selected niche markets given the lower price of natural rock phosphate (Otoo et al. 2015).

Wastewater

For reasons of simplicity, and in comparison with safe freshwater sources, the term 'wastewater' is commonly used in the literature on urban and peri-urban agriculture, although the water quality varies in very wide margins from raw wastewater to diluted wastewater to grey water and polluted stream water. These differences might even be larger than between treated and untreated wastewater, as what is called treated in one country might still be considered unsafe in another one. In general, treated wastewater reuse is more common in developed countries while a ten-time larger area is irrigated with diluted or raw wastewater in developing countries and emerging economies (Scott et al. 2010). The most direct benefits of wastewater use in urban food production systems can be the nutrients in the water, especially in raw wastewater, but otherwise it is the water itself, or more precisely the reliable and low/no cost supply of water where and when freshwater is not available. A typology of different common reuse scenarios is attempted in Table 7.2.

TABLE 7.2 Typology of water reuse

Type	*Value addition to the resource*	*Farmer pays?*	*Commonly seen in (examples)*	*Reuse-based business model*
1. **Direct** use of **untreated** wastewater	None, except for facilitation of water access (canals). Water use can be considered a land treatment	Seldom as usually illegal, but if then, e.g. for land near wastewater channel	Pakistan Mexico Vietnam Peru	Where resources are scarce, farmers might pay for access to land or wastewater (which could support wastewater collection, basic treatment or health care)
2. **Indirect** use of **untreated** wastewater	Dilution and natural treatment depending on distance between source and use	Wastewater is diluted and not perceived as wastewater	India Ghana Mexico China	Water perceived as natural water with low willingness to pay. Business model could request for safety measures against market or tenure incentives
3. **Direct** use of **treated** wastewater	Provision of water safe for agricultural use through treatment	For provision of treated wastewater (but see right for inverse cash flow)	Tunisia Egypt USA Australia Chile Israel	Several revenue options: Payment for access to safe wastewater, or farmers are paid for swapping freshwater with wastewater, or savings in freshwater use pay for reuse system
4. **Indirect** use of **treated** wastewater	Provision of safe water through treatment before mixing with surface water or for groundwater recharge	As above, if water users know about treatment and appreciate it	Jordan Spain Mexico USA	Water often perceived as natural water limiting farmers' willingness to pay. Otherwise also water swap models are possible exchanging freshwater against treated wastewater

Source: Evans et al. 2013; modified.

Undiluted wastewater has nutrients that can significantly contribute to crop growth and improving soil fertility. It is estimated that 1,000 m^3 of municipal wastewater for irrigating one hectare can contribute 16–62 kg total nitrogen, 4–24 kg phosphorus, 2–69 kg potassium, 18–208 kg calcium, 9–110 kg magnesium and 27–182 kg sodium (Qadir et al. 2007). In Mexico's Mezquital (Tula) Valley, wastewater irrigation provides 2,400 kg of organic matter, 195 kg of nitrogen and 81 kg of phosphorus ha^{-1} yr^{-1}, contributing significantly to crop yields (Jimenez 2005). Larger crops and reduced growth periods in wastewater irrigated fields are also reported from Dakar, Senegal, which is attributed to the nutrients in wastewater (Faruqui et al. 2004).

Wastewater not only adds nutrients to soil, but can also amend soils through its organic matter content (biosolids or stabilized sludge) (Christie et al. 2001). Compared to freshwater, there is a significant body of literature showing advantages for soils and yields under wastewater irrigation, although many comparative assessments are not free from shortcomings (Drechsel, Danso and Qadir 2015). In Guanajuato, Mexico, the estimated cost for farmers for replacing the nitrogen and phosphorus loss through wastewater treatment was estimated at US$900 ha^{-1} (Scott et al. 2000).

Making an asset out of wastewater appears as a necessity especially where farming faces increasing water competition from the urban and industrial sectors. Other than availability and its low price, many farmers use wastewater because it is reliable, allowing year-round production, hence giving a strong competitive advantage during the dry season. Studies conducted in Hubli–Dharwad showed that wastewater allowed farming to be done in the dry season when farmers could sell their produce at 3–5 times the kharif (monsoon) season prices (Bradford et al. 2002). Reliability of wastewater also allows for multiple cultivation cycles and flexibility of crops planted (Raschid-Sally et al. 2005). In Haroonabad, Pakistan, the reliability and flexibility of untreated wastewater supply allow farmers to cultivate even-priced, high-value and short-duration crops (van der Hoek et al. 2002). In Ghana, the reliability of free wastewater allows urban farmers to intensify vegetable production to multiple cycles year-round. Similarly in Dakar, Senegal, untreated wastewater allows 8–12 harvests per year, compared to 5–6 harvests per year when farmers had no access to wastewater (Gaye and Niang 2002).

Where wastewater reuse is formally promoted and culturally acceptable, a critical question concerns the viability of the wastewater treatment facility and reuse scheme. The main challenges in this regard are the commonly low revenues from the sale of treated wastewater especially where already freshwater is subsidized. In this situation not only the financial gains but also economic benefits for the society should be considered as well as other possible value propositions and revenue streams from wastewater treatment, which might benefit farming or other sectors (Figure 7.4).

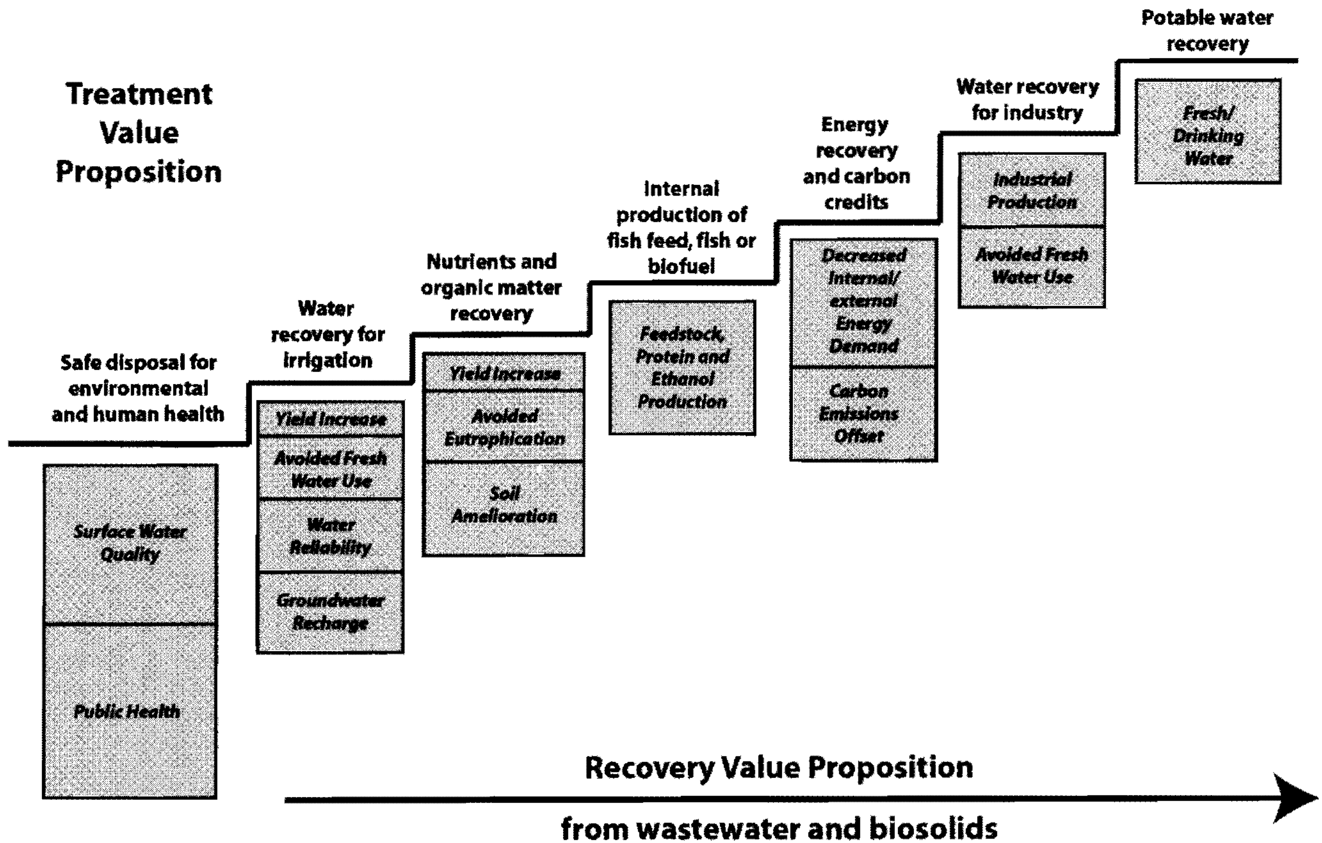

FIGURE 7.4 Value propositions related to water, nutrient and energy recovery from wastewater

Source: Rao et al. 2015.

Concerns of using solid and liquid waste in urban food production systems

Productive use of urban waste and wastewater faces a number of challenges from institutional and technical obstacles like the required treatment capacity, to the distance between waste/water generation and the agricultural market, as intra-urban farming can usually only absorb a small amount of the waste generated, making this farming sector not the major target for effective volume reduction or cost recovery. However, the largest concerns resource recovery, and reuse is facing possible risks for human and environmental health, especially where waste products are used in food production (Table 7.3). Depending on their origin, solid and liquid wastes can carry harmful chemicals and, when mixed with human faecal matter, also pathogens, potentially causing various diseases. In low-income countries, with only emerging industrial production, emphasis is laid on pathogens, since people in these countries are most affected by diseases caused by poor sanitation such as diarrhoeal diseases and helminth infections (Prüss-Ustün and Corvalan 2006). The situation changes in transitional economies with increasing industrialization and is again different in high-income countries, where infections from pathogens are largely under control while chemical pollution like heavy metals, and so-called emerging pollutants (e.g., residues of antibiotics) are of significant public concern.

While data on pathogens and heavy metals are frequently reported from irrigated urban agriculture, emerging contaminants are so far more difficult to analyse in low-income countries and data are rare (e.g., Asem-Hiablie et al. 2013; Amoah et al. 2014; Keraita et al. 2014).

TABLE 7.3 Common uses of different types of waste and related concerns

Type of waste	*Common use in low-income countries by farmers in urban and peri-urban areas*	*General concerns/risks*
MSW – Food waste	• Food waste fed to animals, deposited on nearby dumps, used in community composting and vermicomposting	• Direct feeding of household livestock is probably rather low-risk compared to livestock roaming streets • Low chemical risk as farmers know contents but community compost heaps could be harmful to children when playing around the heaps and attract rodents and other disease vectors

(*Continued*)

TABLE 7.3 (Continued)

Type of waste	*Common use in low-income countries by farmers in urban and peri-urban areas*	*General concerns/risks*
MSW – Mixed waste	• Farmers collect formally or naturally composted waste from decentralized dumping sites and apply it to fields; other stakeholders might use formally composted waste in parks or for landscaping	• Pathogens – when insufficiently composted which pose health risks to waste handlers, farmers, produce consumers and children playing near or on dumping sites • Toxic substances – such as heavy metals could cause soil and crop contamination • Glass splinters, plastics – cause physical harm to handlers
Human excreta – faeces, urine and faecal sludge	• Normally disposed of via toilets or latrines, but in some regions also used raw or after storage in farming • In urine diversion toilets, urine can be separated from faeces and used after storage, often diluted	• High risk from pathogens, especially in faeces and faecal sludge if not well handled and treated before use or use on low-growing crops • If sludge derives from treatment plants (sewage sludge) also high probability of chemical contaminants. This is significantly less the case for sludge of on-site systems like septic tanks (septage) • Foul smell and flies • Negative public and authority perceptions on using excreta for crop production and aquaculture
Wastewater	• In water-scarce countries, used formally as a source of irrigation water (often after some level of treatment) or informally without treatment • In more humid countries with poor sanitation, wastewater is disposed to drains and urban water streams which farmers might use in crop production	• High risk of exposed groups (farmers, produce traders and consumers, children playing in wastewater irrigated sites) from pollutants if not well-managed. • These pollutants can include pathogens, salts, metals/metalloids, residual drugs and other organic contaminants, also dependent on the water source • Smell (concern is lower than that of excreta) • High concentration of chemicals can also affect crop growth and productivity • Negative public and authority perceptions on using especially untreated wastewater for irrigating vegetables

Source: adapted from Keraita et al. 2006.

Safe and productive use of solid and liquid waste

While composting has, across many cultures, a long tradition, awareness, perceptions and acceptance of the use of treated wastewater, urine or faecal matter vary with the development stage of the society, and can be a very dynamic process which makes social feasibility studies, close participation of target groups, and trust-building essential components of successful reuse programmes (Drechsel, Mahjoub and Keraita 2015).

On the other hand, where reuse already takes place in the informal sector, a favourable economic benefit and limited risk awareness can jeopardize the introduction of risk-mitigation measures (Karg and Drechsel 2011). However, where markets or farmers are aware of risks, the range of technical options for conventional and/or farm-based treatment has been established (e.g., Koné et al. 2010; Libhaber and Orozco-Jaramillo 2013; Keraita et al. 2015).

The following sections will discuss experiences, challenges and opportunities for resource recovery from MSW and wastewater.

Increasing the value of composting and co-composting

Composting the organic fraction of MSW is seen as one of the most successful methods of preventing organic waste materials to end on landfills, while creating a valuable product at relatively low cost that is suitable for agricultural purposes (Wolkowski 2003). The benefits are not only attributed to increased soil fertility, but as mentioned above also to economic and environmental factors, such as costs associated with landfilling and transportation, decreasing use of commercial fertilizer imports, etc. (Hargreaves et al. 2008).

Success stories of MSW composting range from community-level projects to large-scale composting (Otoo and Drechsel 2015). An often-cited example is the 1995 established 'Waste Concern' which, since 2009, has managed to treat in Dhaka city more than 100,000 tons of waste, is tapping into carbon credits as an additional revenue stream and which, between 2001 and 2006, has produced compost in the larger Bangladesh area worth more than USD 1 million in local currency (www.wasteconcern.org).

These success stories on compost do not, however, rely only on urban farming, especially in larger cities, for reasons concerning compost quality and quantity (Danso et al. 2008), such as quality and quantity, as follows:

a) ***Quality:*** Urban farmers with a sufficiently high willingness to pay for compost (allowing compost stations to break even) are those producing for the urban market, not subsistence farmers. Commercial crops are often of short rotation, like exotic vegetables, which need most of all a nitrogen fertilizer, less an organic soil ameliorant. Even on sandy soils where compost can help retain soil water, farmers complained about additional labour as the compost first of all absorbed the water and required more irrigation. In addition, these premium customers often have poor tenure security and seek a more short-term fertilizer supply than a long-term soil ameliorant.

b) ***Quantity:*** Urban waste management is usually only interested in embarking on composting if this can reduce a significant volume of the waste. To start a compost station for saving, for example 3% of its transport volume, is usually not worth the effort. However, most intra- and peri-urban farming systems can hardly absorb any larger amounts of compost. A detailed market assessment by IWMI in Kumasi and Accra (both in Ghana) found that, of the organic waste which is collected and not otherwise used, if composted, less than 1% could be absorbed across all intra- and peri-urban farming systems if the willingness to pay should cover compost operational production costs. It was only in smaller cities with less waste generation, like in Tamale (also Ghana), that up to 5% was possible, and higher percentages can be expected from towns. But also in a city like Accra, the percentage can increase up to 20% if, for example, the non-agricultural demand, like from the housing sector, is considered.

If resource recovery is the target, and not only waste-volume reduction, then it is important to produce a high-quality product which can be attractive and competitive for different market segments. One possibility is to 'boost' the fertilizer value and attractiveness of the MSW compost (Figure 7.5), for example, through (i) co-composting organic MSW with dewatered but nutrient-rich urban faecal sludge or other nutrient-rich waste products; (ii) further enriching the compost with inorganic fertilizer, rock phosphate or urine to create a 'fortified' organo-mineral material tailored to market needs; and (iii) pelletizing the compost to reduce its bulkiness and to create a product similar in its appearance and handling to an inorganic fertilizer (Adamtey et al. 2009; Nikiema et al. 2014; Figure 7.6).

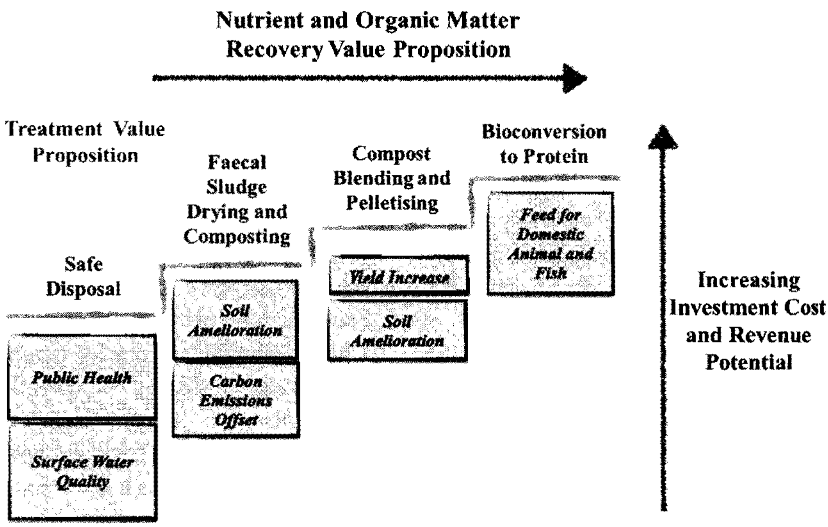

FIGURE 7.5 Value propositions for nutrient and organic matter recovery and reuse from septage from household-based sanitation systems

Source: Otoo et al. 2015.

FIGURE 7.6 Pellets of MSW-faecal sludge co-compost
Source: IWMI.

These options can also be combined with due care that any related increase in production costs is matched by the willingness to pay of the targeted customer segments, and remains competitive to alternative (and sometimes subsidized industrial) fertilizer.

Pelletized and un-pelletized co-compost is being tested for its safety for selected soils and crops, including vegetables and cereals in field and greenhouse trials. In most cases, the product proved to be competitive to inorganic fertilizer as for maize and cabbage[1] (Figure 7.7). While long-term trials are still needed to match more soils and crops with different types of pellets, farmers' interest and willingness to pay (WTP) for the product has been confirmed in very different cultural contexts, like Vietnam, Uganda, India, Bangladesh, Ghana and Sri Lanka (IWMI, unpublished). A market survey conducted, for example, in Kurunegala (Sri Lanka), where a co-composting pilot station started in 2014 its operations, showed a high WTP for nutrient-rich pelletized co-compost with a common WTP of Rs.17–20 per kg, which is 70–100% higher than what is normally paid for MSW compost (Fernando et al. 2014).

However, although the concepts of co-composting and compost pelletizing do not require any technical proof of concept anymore, related advanced compost stations remain few and research continues to be needed to capture customer feedback to adjust the technical process for market satisfaction.

Another option for increasing the value of organic waste as shown in Figure 7.5 is the use of the Black Soldier fly larvae *(Hermetia illucens)*, which feeds on organic matter, such as faecal sludge and organic wastes, and leapfrogs the

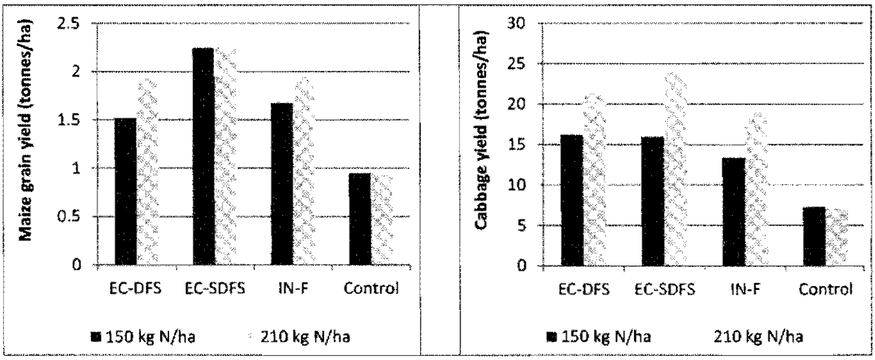

FIGURE 7.7 Maize and cabbage yields with different nitrogen (N) rates
Source: after Impraim et al. 2014.

nutrient extraction via crops by directly generating high-value protein and fat, which can be marketed for poultry, duck, pig and fish feed (Diener et al. 2014).

Increasing the safety of wastewater use

For wastewater irrigation, the focus has always been on reduction of health risk. This applies to the introduction of formal reuse schemes as well as to the challenges of already ongoing informal reuse. For formal schemes the additional challenge is cost recovery.

Due to the common shortfall in wastewater collection and treatment, WHO (2006) recommends a multi-barrier approach which decentralizes the responsibility of safeguarding public health along the food chain from production to consumption (see Figure 7.8). This approach is similar to the Hazard Analysis and Critical Control Points (HACCP) concept for food safety, which has been adopted in many developed countries. The advantage of multiple barriers is the additional security if one barrier fails. A typical example is 'crop restriction', which was successfully introduced, e.g., in Chile, Jordan or Mauritius, while farmers in other countries might ignore them due to market demand and their need to generate profits for sustaining their livelihood.

To determine how much safety is needed, WHO guidelines recommend the so-called health-based targets. These targets need to be realistic, measurable, based on scientific data and feasible within local conditions. Examples of health-based targets can be:

- Health-outcome targets (e.g., tolerable burdens of disease).
- Water-quality targets (e.g., guideline values for chemical hazards).

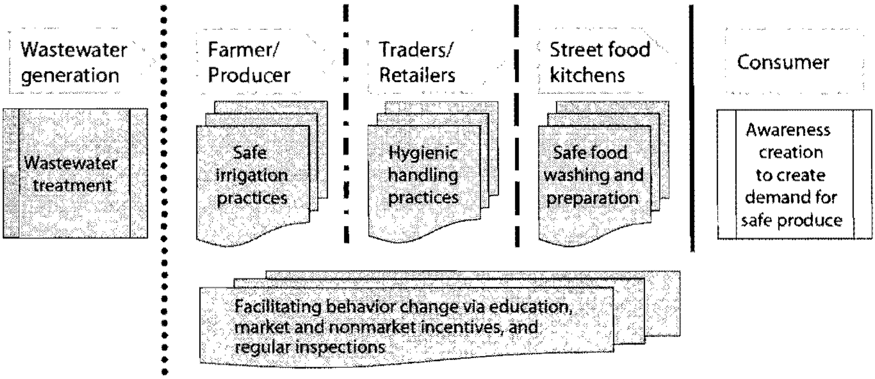

FIGURE 7.8 The multiple-barrier approach for consumption-related risks along the food chain as applied in wastewater irrigation

Source: Amoah et al. 2011.

- Performance targets (e.g., reductions of specific pathogen levels).
- Specified technology targets (e.g., application of defined treatment processes).

Looking at a risk scale from 1 to 7 with 1 being safe and 7 presenting the worst-case scenario, then a common management option is to assume the worst case and aim at maximum risk reduction of 6 units down to 1, which can be cumulative from one barrier to the other.

Table 7.4 shows some examples of the strength of some risk reduction. Some options, like cooking irrigated crops, are very powerful on their own, and can achieve 6 units, but do not fit every crop and diet. It might thus be safer to support several alternative barriers which in combination can achieve the targeted 6 units, like through combining (i) a minimal (farm-based) wastewater treatment (1–2 units pathogen reduction), (ii) drip irrigation (2–4 units pathogen reduction), and (iii) washing vegetables after harvesting, which can reduce in addition 2–3 units (Amoah et al. 2011; Drechsel and Keraita 2014).

Compared with other options for health risk reduction, including the construction of wastewater treatment plants, these on-farm or off-farm-based interventions are highly cost effective (Drechsel and Seidu 2011).

The advantage of the multi-barrier approach became obvious through the disastrous earthquake that afflicted Chile in early 2010. It affected, according to WHO, the only chlorine-producing plant in Chile, and two weeks later 30,000–40,000 cases of diarrhoea were reported from the North where chlorine is used as a single safeguard in agricultural production systems based on wastewater irrigation (R. Bos, pers. communication).

TABLE 7.4 Examples of risk-reduction barriers and effectiveness in pathogen removal

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

Note: * log units of pathogen reduction

Sources: EPHC-NRMMC-AHMC 2006; WHO 2006; Amoah et al. 2011.

Influencing perceptions and behaviour on the use of urban waste

With respect to the promotion of waste reuse, two common situations prevail: (i) the introduction of reuse as a coping strategy to water shortage and (ii) the trajectory of already ongoing informal reuse to formal reuse to facilitate the adoption of safety measures. Both situations require social acceptance and behaviour change. While the informal use of waste products is a common practice in low-income countries, the largest challenge is the transformation of the practice into one that does not put public health in jeopardy. This concerns especially the production for urban markets, where along the food chain the number of people at risk is continuously increasing. For urban Ghana, for example, it was estimated that up to 2,000 urban vegetable farmers produce salad greens consumed eventually by up to 800,000 urban dwellers every day (Table 7.5).

TABLE 7.5 Estimated number of urban farmers, street food kitchens, and urban consumers along the lettuce and cabbage value chain in Ghana based on survey and sector data

Urban farmers producing lettuce and cabbage	*Street restaurants offering salad side dishes*	*Daily consumers of salad side dishes in Ghana cities*
Ca. 1,700–2,000	Ca. 3,600–5,300	Ca. 500,000–800,000

Source: Drechsel et al. 2014.

The situation where *treated wastewater* is being introduced as an alternative water source is more common in countries with established treatment capacity and freshwater shortage, like in the MENA region, Australia or USA. In these cases, negative perceptions can be a key constraint, while cost recovery is a key challenge. Where public perception is positive, the right business plan can, however, combine several revenue streams for a high cost-recovery rate as the example of the Drarga plant near Agadir in Morocco shows. The municipality collects sewage fees to recover its O&M costs and designed the plant to generate additional revenue from the sale of (i) treated wastewater to crop farmers, (ii) reed grass from the constructed wetlands, (iii) sludge compost, and (iv) methane gas from energy recovery (Rao et al. 2015). Although not all of these components have been implemented so far, a noteworthy innovation in this case is that all sales revenues and revenues from the water and sewage tariff and connection fee are deposited into a special account, independent of the main community account to serve solely the wastewater treatment plant. This special arrangement is a response to common bottlenecks in public financing of O&M costs like spare parts which contributed to the breakdown of about 70% of the wastewater treatment plants in the country (Choukr-Allah et al. 2005).

The compliance with food safety measures is a common reality in more developed countries where the HACCP approach has been adopted. In low-income countries where *untreated wastewater* use dominates, the adoption of farm or off-farm based safety measures still requires its proof of concept as so far the WHO

2006 Guidelines have not been implemented in any low-income country. Feasibility studies for such an implementation showed that the likely success will depend on a number of internal and external factors such as risk awareness and risk perceptions (not only of producers but also of the market), peer pressure, incentives, or the possible need for investments in terms of additional space, labour or capital which could affect, e.g., time allocation or the profit margin (Drechsel, Mahjoub and Keraita 2015). As behavioural change is a complex subject and often underestimated as an 'educational' challenge, it can be slow or of short duration (Karg and Drechsel 2011).

Another potential shortcoming in addressing behavioural change is an underestimation of the wider system within which key actors operate, like institutions, regulatory bodies, media and in- and output-market agents, which can have a significant influence on key actors' decision making (Figure 7.9):

FIGURE 7.9 Behaviour change support factors

Source: authors.

- ***Awareness creation:*** It is important to understand that behavioural change can hardly be achieved through educational means and awareness creation alone, while both have, however, an important supporting role. A pilot social marketing study in Kumasi showed that it is more likely that safe practices spread from farmer to farmer through social networks than through external facilitation, although the reason was not the absence of contact with extension officers. Farmers preferred, however, field demonstrations and/or learning by doing.

A particular communication challenge in countries with limited public-risk awareness is the invisible nature of most risk carriers, like pathogens (Amoah et al. 2009; Keraita et al. 2007, 2010).

- ***Incentives:*** Studies show that people are most likely to adopt innovations for direct economic returns on investments (Frewer et al. 1998). However, this will only happen if consumers are willing to pay more for safer products. But, in low-income countries, where risk awareness might be low and no dedicated marketing channels for safe produce exists, economic incentives from the public sector (subsidies, credit access, tax reductions, etc.) based on likely savings in the health sector, or indirect economic incentives like tenure security, could be considered. For public support, a quantification of costs and benefits would help justify the intervention (FAO 2010). A particular incentive for compliance is fear of going out of business. In Ghana, for example, farmers experienced significant pressure from media when using wastewater (Drechsel and Keraita 2014).
- ***Social responsibility:*** Private-sector involvement can facilitate a shift towards safety. Out-grower schemes supplying wholesale or supermarkets might be urged to comply with, e.g., a 'responsible sourcing policy' or any other type of 'sustainable agricultural code of conduct' which the private-sector demands from its own policy perspective and/or reasons of international competiveness and branding.
- ***Social marketing:*** Where economic incentives might not work due to low risk awareness, social marketing strategies could help identify valuable benefits in support of behaviour change, similar to hand-wash campaigns. Studies must identify positive core values that can trigger the target audience to voluntarily accept, modify or abandon behaviour for the benefit of personal and or public health (Drechsel and Karg 2013).
- ***Laws and regulations:*** Regulations are an important external factor to institutionalize safe and productive reuse practices for compliance monitoring, and to provide the legal framework for both incentives (for example, certificates, tenure arrangements) and disincentives (such as fees). However, regulations should not be based on imported standards, but rather on locally feasible standards that are viewed as practical and are not prone to corruption. In this way, regulation and institutionalization may contribute to ensuring the long-term sustainability of behaviour change, whereas promotional and educational activities are usually limited to a specific time frame.

Conclusion

There are many good reasons, including financial and economic gains, for the recovery of resources from liquid and solid waste. In this regard, it is no surprise that the productive use, especially of wastewater in urban agricultural systems, is already a common reality. However, the reason is not only water scarcity but also, especially in low-income countries, water pollution, making it difficult for farmers to find clean water sources. The resulting use of polluted water is mostly charged in the informal sector, resulting potentially in significant health risks for farmers and consumers.

Wastewater treatment to reduce the volume of polluted water discharged into water bodies will remain the most powerful means to address this concern. However, the costs of comprehensive wastewater collection and treatment are often prohibitive in developing countries where, so far, most investments are more 'upstream', targeting water supply. As a result, the generation of untreated wastewater will continue to increase and it is essential that authorities give attention to the food safety along those food chains, depending on irrigated urban and peri-urban agriculture.

The multi-barrier approach recommended by WHO (2006) is addressing this situation in low-income countries. However, the approach is relying on behaviour change, which is not without challenges, and the implementation of related concepts, like HACCP, is so far limited to more-developed countries with treatment capacity, risk awareness and regulations which allow compliance monitoring. Moreover, in such countries, public health relies significantly on wastewater treatment and the institutional capacities and incentives to maintain its technical functionality. In low-income countries with limited treatment capacity, public health will have to rely solely on the adoption of safety practices by farmers and food traders, which requires significant efforts to increase public risk awareness to eventually create market incentives for safer food production. Till this is achieved, officials must determine the best ways to motivate and/or regulate farmers, food vendors and consumers to buy into the multi-barrier approach. Successful strategies will probably include combinations of financial and non-financial incentives, as well as regulations and awareness campaigns that enhance understanding of the potential harm involved when safe practices are not adopted. Supporting policies and related education will be milestones in this process, but might not be sufficient on their own to trigger behaviour change (Drechsel and Karg 2013).

Where treatment plants are in place and reuse is formally organized, the ideal situation is that farmers pay for the water to contribute to the recovery of the operational costs of the treatment facility. In most situations, the direct revenues from selling treated wastewater are, however, very small, given that freshwater prices are usually subsidized and the wastewater has to be sold even cheaper. However, there are options to increase the value of the wastewater and also business models to maximize cost recovery, or to reverse the cash flow and pay farmers for accepting treated urban wastewater while renouncing their freshwater rights for urban development (Otoo and Drechsel 2015).

In view of organic waste and faecal sludge, especially from on-site sanitation facilities, composting and co-composting offer low-cost means for pathogen destruction and risk minimization. The resulting organic product is a well-accepted soil input with a long tradition of use. An important benefit is reduced transport costs through the reduction of the waste volume. If in addition, revenues from compost reuse are targeted, then a professional business approach will be needed to move with customer-specific value propositions' organic waste recycling from the traditional appearance of a household- or community-based initiative to scale. The customers will certainly include urban and peri-urban farmers but, even more so, other sectors interested in organic matter, if the target is to effectively reduce the urban waste volume.

Note

1 EC-DFS: Enriched compost of dewatered faecal sludge; EC-SDFS: Enriched co-compost with sawdust faecal sludge; IN-F: inorganic fertilizer (i.e., ammonium nitrate, supplemented with muriate of potash and triple super phosphate); Control: soil only. Application rates: 150 and 210 kg of nitrogen per hectare.

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