14. Health Risk Management for Safe Vegetable Irrigation

Pay Drechsel, Bernard Keraita, Philip Amoah and Hanna Karg

This chapter presents approaches tested in Ghana to mitigate wastewater irrigation-related risks for consumers and farmers from microbial contamination. The recommended interventions follow the WHO approach concerning multiple barriers along the food chain. Factors that could support the uptake of safety measures are discussed.

14.1 Health Risk Management in Wastewater Irrigation

Different approaches have been proposed for risk mitigation. For a long time, conventional wastewater treatment was regarded as the ultimate risk mitigation measure (Asano and Levine 1998). This approach puts a strong emphasis on the use of water quality standards in wastewater irrigation systems and strict regulations as done in most high-income countries. However, the most recent World Health Organization (WHO) guidelines for wastewater irrigation recommend a shift from water quality standards to so-called 'health-based' targets which can be achieved along a chain of multiple risk reduction measures from wastewater treatment to safer irrigation to hygienic marketing and food preparation in the kitchen. The health-based targets thus describe the allowed risk level at the moment of consumption (WHO 2006). This new approach shifts the emphasis across the food chain from the farm and water to actual exposure. There are good reasons for this:

a) In most low-income countries with insufficient wastewater collection and treatment it is unrealistic to achieve and maintain theoretical water quality standards, while weak regulations cannot prevent hundreds or thousands of farmers from using water from polluted streams.
b) There can be significant food contamination on and off farm, even where clean irrigation water is used, thus a multiple risk barrier from 'farm to fork' is generally recommended and a standard practice around the globe (the Hazard Analysis and Critical Control Points [HACCP] approach).

WHO is thus suggesting that risk barriers are placed at critical control points from wastewater treatment (if available) to food consumption, aiming at maximum risk reduction. A generic example of these barriers is shown in Figure 14.1.

The WHO (2006) guidelines use the DALY[1] approach to define the health-based target. This is currently a tolerable additional disease burden of $\leq 10^{-6}$ DALY loss per person per year, which translates in areas where high contamination is expected roughly into 6-7 log units of pathogen reduction, which the barriers have to achieve before food intake. This new approach of health-based targets offers authorities more options and flexibility for reducing risks especially where conventional water treatment is not possible. However, as the multiple barrier approach is more complex to implement and understand than setting up water quality thresholds, thresholds remain globally the predominant thrust of wastewater re-use guidelines, especially in those countries which can afford high treatment standards and have no challenges in using water quality criteria as a monitoring tool.

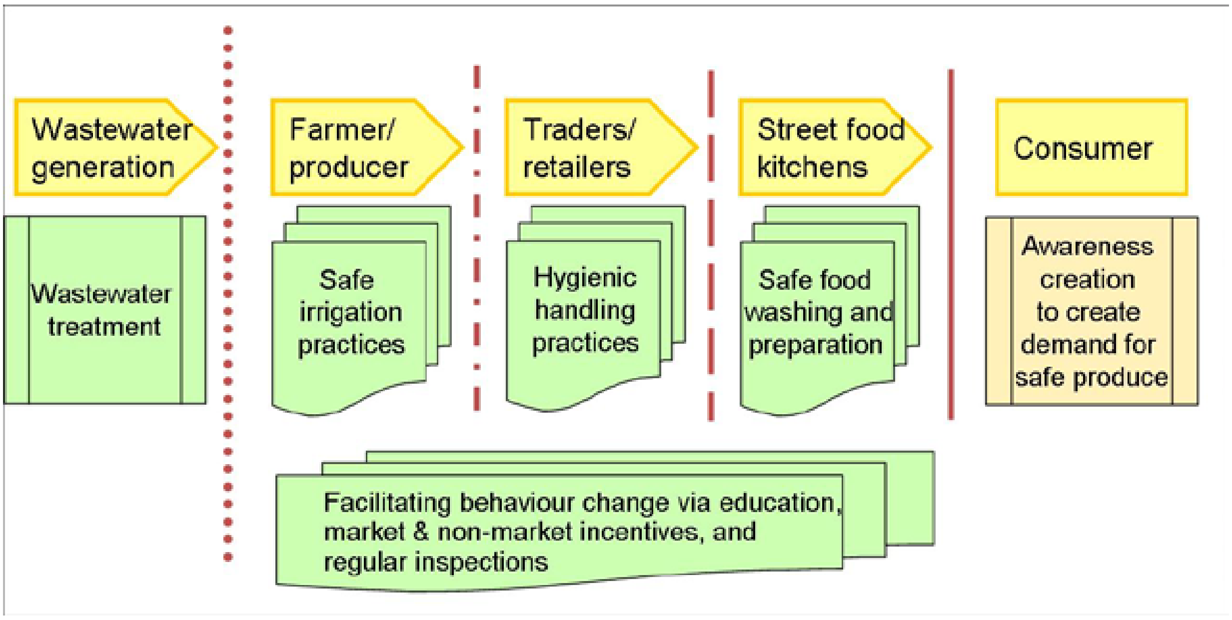

FIGURE 14.1. The multi-barrier approach for consumption-related risks along the food chain as applied in wastewater irrigation (Amoah et al. 2011).

14.2 Risk Management Strategies – An Overview

As mentioned above, the ideal option is to increase the coverage of safe wastewater collection (on site via septic tanks and of off site through sewerage) and to have the collected **wastewater appropriately treated** before it enters streams and other waterbodies used for vegetable irrigation.

[1] The disability-adjusted life year (DALY) is a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death. The 10^{-6} threshold is based on the United States Environmental Protection Agency's acceptance level of an annual cancer risk, and is probably conservative, i.e. stricter than appropriate (Mara 2011).

However, as outlined in chapter 6, it will still take considerable time and investments for this to happen in most parts of Africa at a relevant scale. However, depending on the location, there are options where new or rehabilitated treatment plants could directly improve water quality for farming sites nearby.

Another strategy for farmers and extension officers is to explore access to **safer water sources**, which could mean tap water or groundwater, or change of the current plots to others where safer water is available. In Cotonou, Benin, for example, the authorities recognized the contribution of urban agriculture and allocated new parcels of land to urban farmers outside the city with unpolluted shallow groundwater. In Accra, the Ministry of Food and Agriculture was exploring options for groundwater use in urban agriculture areas irrigating with water from city drains. Both efforts had mixed success. In Benin, farmers did not appreciate the longer distance to the urban markets and tried to keep their current sites, while in Accra, most groundwater appeared to be too saline for most crops (Drechsel et al. 2006).

When irrigation projects are either well organized, or where laws are strongly enforced, the classical risk mitigation measures are **crop restrictions** to ensure that wastewater is not used to irrigate high-risk crops, such as leafy vegetables that are eaten raw. Research in Mexico, Chile and Peru has shown that this is possible but it is only a viable proposition for farmers when the crops allowed under the restrictions are of similar profitability, i.e. in higher demand than the banned ones, and for public health if restrictions can actually be enforced (Drechsel et al. 2002). It is doubtful that such an approach would be successful in the context of Ghana where leafy salad greens achieve the best revenues. However, public awareness campaigns (such as through the media) might steer consumers' demand for safer crops and influence farmers' decision making.

WHO's **multiple barrier approach** supports an array of further options for the management of risks from pathogens on farm, in markets and in kitchens (Table 14.1). For example, combining (i) a minimal (low-cost) wastewater treatment (1-2 units pathogen reduction), (ii) drip irrigation (2-4 log units pathogen reduction) and (iii) washing vegetables after harvesting (1 log units pathogen reduction) can achieve 4-7 $\log_{10}$ unit pathogen reduction. Most of these estimates however need:

- Field testing and implementation of the suggested measures;
- The actual verification of the cumulative risk response;
- A strategy for monitoring the acceptance and effectiveness of such practices.

The verification of the cumulative risk reduction of subsequent pathogen barriers is important as in theory different barriers might affect the same group or size of pathogens and not those remaining.

TABLE 14.1. Health-protection control measures and associated pathogen reductions

Control measure	Pathogen reduction (log units)	Notes
A. Wastewater treatment	6-7	Pathogen reduction depends on type and degree of treatment selected.
B. On-farm options		
Crop restriction (i.e., no food crops eaten uncooked)	6-7	Depends on (a) effectiveness of local enforcement of crop restriction, and (b) comparative profit margin of the alternative crop(s).
On-farm treatment:		
(a) Three-tank system	1-2	One pond is being filled by the farmer, one is settling and the settled water from the third is being used for irrigation
(b) Simple sedimentation	0.5-1	Sedimentation for ~18 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	2-log unit reduction for low-growing crops, and 4-log unit reduction for high-growing crops.
(c) Reduction of splashing	1-2	Farmers trained to reduce splashing when watering cans used (splashing adds contaminated soil particles to crop surfaces which can be minimized).
Pathogen die-off (cessation)	0.5-2 per day	Die-off between last irrigation and harvest (value depends on climate, crop type, etc.).
C. Postharvest 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 fruit with clean water.
	2-3	(b) Washing salad crops, vegetables and fruit with running tap water.
	1-3	(c) Removing the outer leaves on cabbages, lettuces, etc.
D. In-kitchen produce preparation options		
Produce disinfection	2-3	Washing salad crops, vegetables and fruit with an appropriate disinfectant solution and rinsing with clean water.
Produce peeling	2	Fruits, root crops.
Produce cooking	5-6	Option depends on local diet and preference for cooked food.

Sources: EPHC/NRMMC/AHMC (2006); WHO (2006); Amoah et al. (2011).

Reductions expressed in percent or as log units are however only meaningful if used in combination with start and end concentrations. Box 14.1 tries to illustrate this.

BOX 14.1. Log reductions and percentages (Amoah et al. 2011)

- A reduction of 1 log unit from 10^7 to 10^6 (or from 7 to 6 logs) for example, removes 90% of the original coliform count. Two log reductions represent 99% and 3 logs 99.9%. This appears to be an impressive result, but from the initial 10^7 perspective the remaining coliform counts in the example are with 10^4 (10,000 coli bacteria) still 10 times above the level of 1,000 counts (10^3) per 100 ml of irrigation water which is the common upper limit for unrestricted irrigation (WHO 1989).
- A reduction of 6 helminth eggs from– on average – 6.8 to 0.8 eggs represents a reduction by less than 1 log unit or 88% of the original count and although 88% looks less impressive than 99.9% in the example above, a final count of 0.8 eggs matches the WHO (1989) recommended egg count in irrigation water (less than one viable egg per liter).

14.3 Options to Improve Urban Sanitation and Wastewater Treatment

In general, improved urban sanitation and wastewater treatment will lead to cleaner urban water streams; hence farmers will have safer water to use in their farms. While current statistics on wastewater management are gloomy, there are many efforts to improve the situation. For example, in Accra, the Accra Sewerage Improvement Project (ASIP), which is supported by the African Development Bank (AfDB) was approved in 2006. The project constructed two waste stabilization pond-based sewage treatment plants at the Densu Delta (about 5,900 m^3/day) and Legon (about 6,400 m^3/day) accompanied by extension of sewer network coverage. The existing household connections were rehabilitated while more than 4,000 new houses were connected. The project will also build more than 140 new public toilets and 37 septage/night soil reception holding tanks (AfDB 2005). Such efforts could be accompanied by improved waste and storm water management as suggested for example for Kumasi (http://www.urbandesignlab.columbia.edu/?pid=garden_city_kumasi).

To support the sustainability of treatment plants, Murray and Drechsel (2011) analyzed the conditions of the existing plants in Ghana and posed key questions that could lead to improving the wastewater treatment sector (Table 14.2). These questions are intended to raise awareness among stakeholders about key drivers of the viability of treatment plants in a context like Ghana's, and to foster informed decisions – including their impacts on environmental and public health – related to the rehabilitation and new design of treatment plants.

TABLE 14.2. Proposed guiding questions to improve sanitation infrastructure design, policy and management.

Question	Rationale
Governance	
Is there 'political will' to give waste treatment and safe disposal appropriate priority?	While recognizing that financial limitations do not give governments in low-income countries the flexibility needed to support all development goals equally, and that sanitation especially is often the largest cost factor in municipal budgets, there should be a clear commitment to keep treatment plants (TPs) under all circumstances operational and to prevent untreated sewage being redirected into waterbodies.
Do the institutions in charge have the capacity and positive track record of maintaining TPs? If not, what could be done to enhance and sustain their capacity?	Decentralization efforts in Ghana shifted the responsibility of many TPs to the municipal and metropolitan authorities that had no qualified staff and budget resources to cope with the new responsibility. Despite the fact that also most other operators have extremely poor track records, donor agencies are starting new projects.
Technology selection	
What is the (actual/expected) frequency of electrical power cuts? (This includes cuts due to inadequate power supply and inability to pay electricity bills in time)	If electricity supply proves to be, or is expected to be, sporadic, technology choices must be capable of providing waste treatment also in the absence of power. Ideally, treatment technologies should have no electricity demand, like waste stabilization ponds (WSP), but at the very least should be adaptable. A trickling filter is an example of a technology that is *not* adaptable. Aerobic systems (e.g. activated sludge systems) will only provide suboptimal treatment when aerators are off. Critical pumps should be connected to stand-by generators.
Operation and maintenance	
How many people must a maintenance request pass through? What is the average response time for a repair to be made? Are there shortcuts depending on the required budget and (emergency) situation?	Repairs or other maintenance needs at treatment facilities were often found to be prolonged due to inefficiencies in the protocol for authorizing such requests. There should be sound justification for each individual or entity involved in the authorization process such that the system is as streamlined and responsive as needed. For ad hoc or emergency requests there should be simplified procedures or step-wise financial authorization limits. This also requires a related budget and environmental laws with sufficient power to give this budget and repairs highest priority.
Based on the existing or intended treatment scheme, what is the recommended number of person hours per day for an operator at a facility?	All wastewater and fecal sludge treatment technologies require some form of active operation and maintenance (O&M) for optimal function as they face permanent and continuous inflow. Treatment plant staffing decisions should be informed by the demands of the technologies in place.

What is the expected sludge accumulation and recommended removal frequency for the treatment scheme?	Excessive sludge accumulation has a debilitating effect on the performance of treatment technologies. Importantly, accumulation rates differ for wastewater versus fecal sludge treatment, and also vary among technologies. Conventional aerobic treatment tends to generate more sludge than anaerobic treatment and WSPs. A sludge management protocol that is commensurate with the requirements of the technology and sewage source is critical for treatment efficacy.
What is the annual investment in maintenance compared to the replacement value of the wastewater treatment plant and environmental damage?	As a rule of thumb, a minimum of 3% (and up to 6%) of the replacement value of infrastructure should be invested in annual maintenance. Deferred maintenance can significantly decrease the lifetime of a facility and inhibit treatment efficacy. Donors of treatment plants should set up contractual securities or support if they expect that national partners will provide the required maintenance. The observed provision of spare part support over two years after TP commissioning might be too short.
Financial scheme	
What is the user fee collection in comparison to O&M costs?	Complete O&M cost recovery may not be possible from user fees alone; however, fees can be an important component of a sustainable operating budget. The user fees that can be realistically charged and collected should inform the selection of technologies.
What is the percent of users who pay for service compared to the percent of users who receive a formal bill?	The importance of an institutionalized billing process in the sanitation sector must not be underestimated. User fee collection can only be as reliable as the billing scheme, and willingness to pay is shown to be correlated with the professionalism and transparency of the billing process.
Incentives and accountability	
What is the market demand for productive end-use options of wastewater, fecal sludge and treatment byproducts?	It is possible that designing or rehabilitating sanitation facilities for re-use of wastewater, fecal sludge and treatment byproducts can provide further leverage contributing to cost recovery at the facilities by creating economic demand for the treated products. Further, incorporating re-use into the treatment process can lower costs by decreasing treatment and/or disposal requirements.
What are the environmental and health trade-offs of an underperforming or defunct treatment plant?	Environmental and/or public health concerns were not given any weight in the observed cases of treatment failure, despite open discharge of wastewater or fecal sludge in densely populated urban areas. This common 'plan B' of open discharge if the designed system fails should no longer be the convenient option, but should result in disciplinary action and punitive fees above what is required to actually solve the problem.
Monitoring and control	
Which independent agency in charge of human or environmental health could regularly monitor the system? Does this agency have an enforced anticorruption code?	In most observed cases, the operating agencies and in particular the local 'caretakers' did not reveal that their TPs had any problems. Divergence of raw sewage flows into rivers occurred on company premises largely invisible to the public. Control systems with regular (unannounced) field visits are required as part of any risk management plan.

Source: Murray and Drechsel (2011).

Indeed, if all wastewater generated is adequately treated before it reaches farms, then the quality of irrigation water for direct and indirect agricultural re-use would meet standards and health risks would only be limited to postharvest practices. Several reviews show various wastewater treatment options which can meet quality standards needed for crop irrigation (Norton-Brandão et al. 2013; WHO 2006). Table 14.3 shows various wastewater treatment practices and the ranges of pathogen removal. In low-income countries, where pathogens are the main concern, low-rate process technologies such as pond systems are well suited for pathogen reduction (Scheierling et al. 2010). For the control of **chemical contaminants** more sophisticated treatment is required, but this should ideally happen at the source, like an industrial plant.

TABLE 14.3. Log unit reduction or inactivation of excreted pathogens achieved by selected wastewater treatment processes**.**

Treatment process	**Log unit pathogen removal**			
	Viruses	Bacteria	Protozoan (oo)cysts	Helminth eggs
Low-rate biological processes				
Waste stabilization pounds	1-4	1-6	1-4	1-3[b]
Wastewater storage and treatment reservoirs	1-4	1-6	1-4	1-3[b]
Constructed wetlands	1-2	0.5-3	0.5-2	1-3
High-rate processes				
Primary treatment				
Primary sedimentation	0-1	0-1	0-1	0-<1
Chemically-enhanced primary treatment	1-2	1-3	1-2	1-3
Anaerobic up-flow sludge blanket reactors	0-1	0.5-1.5	0-1	0.5-1
Secondary treatment				
Activated sludge + secondary sedimentation	0-2	1-2	0-1	1-<2
Trickling filters + secondary sedimentation	0-2	1-2	0-1	1-2
Aerated lagoon + settling pond	1-2	1-2	0-1	1-3
Tertiary treatment				
Coagulation flocculation	1-3	0-1	1-3	2
High-rate granular or slow-rate sand filtration	1-3	0-3	0-3	1-3
Dual-media filtration	1-3	0-1	1-3	2-3
Membranes	2.5->6	3.5->6	>6	>3
Disinfection				
Chlorination	1-3	2-6	0-1.5	0-<1
Ozonation	3-6	2-6	1-2	0-2
Ultraviolet radiation	1->3	2->4	>3	0

Adapted from WHO (2006).

14.4 Farm-based Risk Management Measures for Pathogens

Low-cost Water Treatment Technologies for Pathogen Removal

In Ghana, shallow dugout ponds (usually less than 1-meter (m) deep and 2-m wide) are widely used in irrigated urban vegetable farming sites. In most cases, shallow dugout ponds are used as storage reservoirs into which surface runoff and wastewater effluents are channeled. Refilling frequency of drums and reservoirs depends on their volume and daily water needs. During the storage of water and gradual use in irrigation, sedimentation takes place, like in water storage and treatment reservoirs (WSTRs), although the extent of pathogen removal will be lower depending on the length of the undisturbed retention time. Studies conducted in Ghana showed that these ponds are very effective in removing helminths (reduced to less than 1 egg l^{-1}) when sedimentation is allowed for two to three days (Keraita et al. 2008c; Keraita et al. 2014).

Reductions can be achieved with better pond designs (deeper, wedge-shaped pond beds) and training farmers on how to collect water without stirring up sediment in the pond (Keraita et al. 2008c; see Figure 14.2). In addition, measures that can enhance sedimentation, for example, using natural flocculants such as *Moringa oleifera* seed extracts in the ponds, seem to be promising in Ghana (Sengupta et al. 2012). Furthermore, use of additional measures that influence pathogen die-off such as sunlight intensity, temperature and crop type can help in lessening the pathogen load in irrigation water (Silverman et al. 2014).

FIGURE 14.2. Water fetching without stepping in the pond and whirling up sediment (photo: B. Keraita)

In addition to the sedimentation ponds, slow sand filtration systems are ideal in treating irrigation water. Sand filters remove pathogenic microorganisms from polluted water by first retaining them in the filtration media before they are eliminated (Stevik et al. 2004). The typical pathogen removal range reported by WHO is 0-3 log reduction units and 1-3 log reduction units for bacteria and helminths, respectively (WHO 2006). Our research in Ghana using column slow sand filters achieved between 98.2 to 99.8% of bacteria removal, equivalent to an average of 2 log reduction units 100 ml^{-1}. In addition, 71 to 96% of helminths were removed (Keraita et al. 2008b). This removal was significant but not adequate as irrigation water had very high levels of indicator organisms.

In Ghana, farmers use different forms of sieves, but mostly use folded mosquito nets over watering cans to prevent particles like algae, gravel and organic particles from entering the watering cans. Studies of this kind of simple filter systems show about 1 log unit removal for bacteria and 12 to 62% for helminths when a nylon textile as a sieve is used (Keraita et al. 2008b, 2010). Further modifications could be done to increase removal rates, because these are the systems that many farmers find easier to adopt. Clogging is a limitation when using sand filters, however proper choice of filtration media (i.e. right uniformity coefficient and effective size configurations) can reduce the problem.

Irrigation Methods

Based on health impacts from wastewater, WHO has classified irrigation methods into three distinct categories: flood and furrow, spray and sprinkler, and localized irrigation methods, such as drip kits (WHO 2006). Flood and furrow irrigation methods apply water on the surface and pose the highest risks to field workers, especially when protective clothing is not used (Blumenthal et al. 2000). Spray and sprinkler are overhead irrigation methods and have the highest potential to transfer pathogens to crop surfaces, as water is applied on the edible parts of most crops. They also promote wide movement of pathogens through aerosols. Localized techniques such as drip and trickle irrigation offer farm workers the best possible health protection and also ensure minimal pathogen transfer to crop surfaces because water is directly applied to the root (Pescod 1992).

However, localized techniques are comparatively the most expensive and are also prone to clogging as polluted water has high particulate levels. They can reduce contamination on crops by 2-4 log units (WHO 2006). Nevertheless, recently introduced low-cost drip irrigation techniques (Figure 14.3), like bucket drip kits from Chapin Watermatics, USA and International Development Enterprises (IDE-India), have more potential for use and adoption in low-income countries (Kay 2001). Studies done in Ghana using bucket drip kits show massive reduction in contamination (up to 6 log units), especially during the dry season (Keraita et al. 2007a). These studies from Ghana also demonstrated that the traditional watering can system could be modified with a ‘rose’ at the spout of the can so as to diminish splashing of contaminated soils to the crops, which in turn would reduce crop contamination.

FIGURE 14.3. Low-head drip irrigation kit (Note: crop spacing in this experiment is not according to farmers' needs). Photo: B. Keraita

Withholding Irrigation Prior to Harvesting

In West Africa, IWMI tested the effectiveness of withholding irrigation (cessation) a few days before harvest to allow pathogen die-off on crop surfaces due to exposure to sunlight and drying-out of surfaces as recommended by Shuval et al. (1986). The results from the field trials in Ghana in the sunny dry season showed an average daily reduction of 0.65 $\log_{10}$ units of thermotolerant coliforms and 0.4 helminth eggs 100 g^{-1} of lettuce (Keraita et al. 2007b). While the lower coliform counts can be attributed to die-off, lower egg counts could be attributed to fewer additions over the days without irrigation. The studies showed that cessation was not appropriate during the wet season due to lower temperatures and soil (and bacteria) splashing from rainfall. On the other hand, the die-off studies were limited to farms, while natural die-off after harvesting can add a further reduction of 0.5-2 log units day^{-1} unless new contamination is added (WHO 2006). The greatest limitation of this measure at the farm level is the loss of crop yield under the hot conditions in Ghana. In the Ghana studies, for the daily pathogen reduction obtained, the corresponding losses were 1.4 t ha^{-1} of fresh weight (Keraita et al. 2007b). Assuming a yield of 10-15 t ha^{-1}, three days without water can result in a 30 to 40% income loss which is a major adoption deterrent for farmers. In cooler climates, such as Addis Ababa, irrigation frequency is much lower and it is possible to plan for several days minus water without any significant loss of yield.

14.5 Postharvest Risk Management Measures for Pathogens

Many vegetable traders like to clean the vegetables they harvested on the spot in the locally available irrigation water (Figure 14.4). This practice has to be addressed as it would undermine any risk reduction efforts by farmers (Hope et al. 2008). Alternative options are washing the vegetables off-farm where safe water is available.

FIGURE 14.4. Removing dirt from lettuce straight after harvest on farm (photo: IWMI)

Washing and Peeling of Vegetables at Markets

While studies on internalization of pathogens from wastewater irrigation are limited, there is a general consensus that most pathogenic contamination occurs on the surface of crops and surface cleaning is an important risk mitigation measure (Ilic et al. 2010).

Only few crops (such as carrots and cucumber) grown in our study locations in West Africa could be peeled to reduce the attached pathogen load, at kitchens or in markets. Most of the irrigated crops are leafy vegetables like lettuce, cabbage and spring onions, or 'fruity' vegetables like green pepper and tomatoes. In the risk reduction studies, we adapted produce 'peeling' to the removal of outer leaves for vegetables like cabbage and lettuce. Akple (2009) showed that the simple removal of ('bad-looking') outer vegetable leaves in markets reduced the coliform counts by 0.5 log units (lettuce) to 1 unit (cabbage) without exceeding a weight loss of the crop of 10%. Further peeling would significantly increase safety but also reduce the size of the crop and its market value unless the peeling is carried out at home. Studies on the impact of peeling on crops such as onions, carrots and cucumber are encouraged.

At markets in warm climates, produce sellers sprinkle water or wash vegetables periodically to keep them looking fresh, so that they can sell them at a higher price. However, many markets in low-income countries have no running water and produce sellers have to rely on water that they buy from tankers. Due to costs, and in some cases unavailability, the same water (usually in buckets and bowls) is used to wash or refresh vegetables for the whole day. In Kumasi, few studies have been carried out to assess the effects of this practice on crop (de)contamination (Owusu 2009; Akple 2009). Owusu (2009) assessed levels of fecal coliforms on spring onions over five washing cycles (1 kilogram [kg] of onions in each washing cycle) in a bucket of water as commonly done by vegetable sellers in Kumasi. The study showed a sharp decrease in fecal coliform levels after the first washing, from about 5

log_{10} units 100 g^{-1} to less than 1 log_{10} unit/100 g^{-1}. However, subsequent washing cycles (cycle 2-5) recorded again an increase in contamination, with the fifth cycle showing similar fecal coliform levels as those recorded on unwashed spring onions (about 5 log_{10} units). In essence, produce sellers should change the water more often or stop washing after the first cycle; however, this will affect the physical appearance of the produce, resulting in a lower price. Alternatively, washing with the same water should be done only once, but this depends on local water availability and might have cost implications.

Produce Disinfection in Kitchens

Amoah et al. (2007a) tested some popular disinfection practices in laboratory conditions to assess their effectiveness in reducing fecal coliform levels. Lettuce, the most commonly grown urban vegetable in Ghana, was used. Results are presented in Table 14.4.

The assessment showed that, irrespective of the method used, washing vegetables reduced fecal coliform levels in lettuce, however, the levels varied significantly and common concentrations of salt or vinegar, for example, appeared to have little impact. Pathogen removal through disinfection was largely influenced by contact time, concentration and the type of disinfection. Similar results were obtained for related studies done to disinfect cabbage and spring onion (Akple 2009). Table 14.4 shows recommended options like potassium permanganate (available in local pharmacies and markets) or bleach which is a very common vegetable disinfectant in Francophone West Africa (so-called ‘Eau de Javel’).

Vegetable washing was also recommended in view of pesticides, although some are hydrophobic and can only be removed with soap. For crops that can be peeled, like tomatoes, the removal of the skin was recommended. This was considered the best option as with a melting point over 100^{o}C, even boiling could not remove some pesticides (Obuobi et al. 2006).

14.6 Chemical Contaminants

There are management options for smallholder farmers in developing countries to address the challenges and risks of exposure to heavy metals or excessive salts through irrigation water. These measures include soil- and water-based interventions as well as changes in crops and crop varieties (Simmons et al. 2010).

TABLE 14.4. Effect of selected disinfection methods on fecal coliform levels on lettuce in West Africa.

Method	Log reductions	Comments
Dipping in a bowl of water	1.0-1.4	- Increased contact time from a few seconds to 2 minutes improves the efficacy from 1 to 1.4 logs. - Not very efficient compared to washing with other sanitizers. - Not very effective for helminth eggs if washing has to be done in the same bowl of water. - Warming the water did not result in different counts.
Running tap water	0.3-2.2	- Comparatively effective compared with washing in a bowl, also for helminth egg removal. - Increased efficacy only with increased contact time from a few seconds to 2 minutes. - Limited application potential due to absence of tap water in poor households.
Dipping in a bowl with a salt solution	0.5-2.1	- Salt solution is a better sanitizer compared to dipping in water if the contact time is long enough (1-2 minutes). - Efficacy improves with increasing temperature and increasing concentration, however, high concentrations have an aging effect on the appearance of some crops like lettuce.
Dipping in a bowl with a vinegar solution	0.2-4.7	- Very effective at high concentrations (>20 ml l^{-1}) but this could have possible negative effects on taste and palatability of the washed vegetables and will also be too expensive. - To achieve best efficacy and keep the sensory quality of the product the contact time should be increased to 5-10 minutes. - Efficacy is improved even at low concentration if carried out with a temperature over 30 ºC.
Dipping in a bowl with purple potassium permanganate solution	0.6-3.0	- Most effective at higher concentrations (200 ppm), a temperature of 30ºC or higher and a contact time of 5-10 minutes. - Higher concentration dyes washed vegetables purple which requires more water for rinsing or may raise questions of a negative health impact.
Dipping in a bowl with a solution containing a washing detergent (OMO™)	1.6-2.6	- Significant reductions could be achieved with 5-10 minute contact time. - Residual perfumes and soap taste might affect the consumer's sensory perception - As OMO contains surfactants which could affect health, thorough rinsing is required.
Dipping in a bowl of water with added household bleach	2.2-3.0	- Tested dosages (commercial bleach) resulted in 165-248 µS cm^{-1} salinity (= concentration indicator). - Effective with 5-10 minute contact time, and widely used in Francophone West Africa. - May pose health risks if dosage is not well explained and too high.
Dipping in a bowl of water containing chlorine tablets	2.3-2.7	- Effective at 100 ppm but tablets not commonly available in some West African countries. - Effect of higher concentrations on efficacy not tested.

Source: Amoah et al. (2007a), modified.

Compared to interventions suggested for pathogens, the options remain however limited and it is not possible to provide (for most of these measures) details on their general effectiveness in terms of health risk reduction which will largely depend on local contamination levels, current practices and site conditions, as well as spatial and temporal factors; thus careful risk assessment and monitoring are required. This is a challenge as the required analytical capacity to analyze heavy metals, for example, and in particular organic contaminants is seldom adequate in developing countries, like Ghana. It is therefore important to support the enforcement of legislations separating industrial from domestic wastewater streams or other water source potentially used for irrigation, and to treat any chemical effluent at its source.

Where contaminated water is used, the contaminant might not enter the food chain if the affected crop functions as a health risk barrier, which is the case for certain heavy metals (see chapter 9). In other cases, farmer and authorities might have no other choice than to go for nonedible crops (for instance biofuel) or to zone the areas for nonagricultural land use (Simmons et al. 2010).

14.7 Options to Support Uptake of Safe Practices

The adoption of safe practices by key actors means that farmers, produce sellers and those who prepare food in households and street restaurants need to change their behavior and routine practices. However, although experience shows that conventional awareness rising and training in improved safety practices is important, both are not a guarantee for any behavior change and practice adoption (Drechsel and Karg 2013). Indeed, for most risk mitigation measure, the related actors will need to make an 'investment'. The investment can be in different forms such as (i) increased labor, (ii) some capital or operational costs, (iii) loss of space and yield or (iv) other inconveniences from behavior change. To support this investment, it is important to understand what could trigger behavior change and/or which incentive systems are needed to trigger and maintain it (Frewer et al. 1998). This critical area for implementing the multibarrier approach is not addressed in the current WHO (2006) guidelines.

Some specific factors that could enhance adoption of risk mitigation measures are given below.

Economic incentives: Studies show that people are more likely to adopt innovations for direct economic returns on investments (Frewer et al. 1998). The adoption of safer irrigation practices should then potentially help farmers and traders to sell more or sell at higher prices.

However this will only happen if consumers show risk awareness and are willing to pay more for safer produce. Where this is the case, producer groups should be encouraged to sell their products outside the existing marketing channels to avoid mixing-up with unsafe produce. This could be done by linking farmers directly to large consumers like hotels and demarcating specific selling points in markets and supermarkets (see chapter 11).
Economic incentives can also come from the public sector, for example through subsidies or soft loans for key actors to adopt safer practices or rewards for those that have already adopted them. For this to happen, local authorities need to understand the overall benefits of safer practices to society, as well as the overall costs. A quantification of such costs and benefits and demonstration that benefits are higher than costs will help to justify this public support. A supporting measure can be economic disincentives, such as taxes or fines for noncompliance with mutually-agreed on safety measures.

Enabling farmers to visualize the risk: To encourage behavior change, key actors need to be aware of the risks of wastewater irrigation and the benefits of adopting safer practices. This awareness concerns consumers like traders and producers (Amoah et al. 2009). The importance of awareness to increase demand and willingness to pay for safer products has been discussed in the previous section. A particular challenge of pathogenic risks is their invisible nature which makes it difficult for the key actors to (i) be aware of the risks and (ii) to assess the effectiveness and quantify the impacts of suggested risk mitigation measures. Risk visibility would greatly facilitate risk perceptions and encourage adoption of safer practices. While many actors like farmers and produce sellers in low-income countries use physical indicators such as color, dirt and odor to assess the cleanliness of the produce, these physical indicators do not always correspond with microbiological indicators[2]. Scientists need to work with farmers to validate physical indicators or combinations of physical indicators that can indicate levels of microbiological contamination at the farm level (Keraita et al. 2008a; Amoah et al. 2009). Key actors will also like to 'see the impacts' of the risk mitigation measures before changing from their original practices to new ones. In this regard, participatory approaches as used in many farming experiments could help key actors to compare new practices with old practices in their own environments before making choices.

Social marketing: Social marketing seeks to induce a target audience to voluntarily accept, modify or abandon behavior for the benefit of individuals, groups or society as a whole

[2] An innovative tool for visualizing 'invisible' threats is the Glitterbug™ (www.glitterbug.com).

(Siegel and Doner-Lotenberg 2007). This could be an important tool for adopting risk mitigation measures in low-income settings where economic (market) incentives are limited by low-risk perceptions among customers (Drechsel and Karg 2013).

Even if health considerations are not valued highly in the target group, social-marketing studies can help to identify valuable related benefits, including indirect business advantages (such as attracting tourists), improved self-esteem and a feeling of comfort or respect for others. Studies must look for supportive core values that trigger the adoption of innovative approaches. For example, if a feeling of being ‘advanced’ can be associated with using vinegar rather than salt for vegetable washing, or drip kits compared to watering cans , then the social-marketing messages and communication strategies should re-inforce these existing positive associations (Karg and Drechsel 2011).

Land tenure security: Concentration of population and economic activities in cities results in very limited land availability and intense competition for its use in and around urban areas. Besides, and especially in Ghana, there is often uncertainty regarding the ownership of land (see chapter 13). In general, market forces push up land price and landowners will seek maximum revenue (rent) from their plots which makes farming noncompetitive. That we still see many hectares under agriculture is the result of informal farming on plots with low housing value (flood-prone zones and so forth) or where agriculture is tolerated as a transitional occupancy, especially on so far unused governmental or institutional land. Both forms have in common a very weak land tenure security which was often mentioned by farmers as a key risk factor for their livelihoods (see chapter 10). An incentive such as better tenure security could facilitate farmers’ interest in investments in structures that have positive health impacts, such as small-scale wastewater treatment ponds. Municipalities may adopt a variety of approaches to securing land for horticulture, including regularization of informal titles, or promoting urban farming on public land (such as terraces along urban rivers). Similar incentives are possible for street food restaurants, which are often more informal than formal.

Training and extension: Another key factor for the correct application of safer practices and compliance over time is having trained and qualified actors. Extension services and research-extension linkages will have a significant role to play. The current curriculum of urban extension officers is not much different from the one for rural extension and modules on exotic vegetable production or irrigation with polluted water sources are needed. Training materials (also for trainers) supporting food safety on and off farm have been prepared for example by IWMI and FAO (Box 14.2) and can be used within larger training programs like farmer field schools (see chapter 11) for urban and peri-urban producers (e.g. FAO 2007).

BOX 14.2. Training and awareness materials on wastewater irrigation and food safety developed by IWMI, FAO, KNUST and UDS in Ghana.

- On-farm practices for the safe use of wastewater in urban and peri-urban horticulture. A FAO training handbook for farmer field schools. www.fao.org/docrep/016/i3041e/i3041e.pdf
- On-farm treatment options for wastewater, greywater and fecal sludge. www.iwmi.cgiar.org/Publications/wle/rrr/resource_recovery_and_reuse-series_1.pdf
- Safer irrigation practices for reducing vegetable contamination in urban sub-Saharan Africa: An illustrated guide for farmers and extension officers. www.iwmi.cgiar.org/Publications/Books/PDF/Farmers_Guide-Low_res-Final2.pdf
- Improving food safety in Africa where vegetables are irrigated with polluted water. Awareness and training video for staff of street restaurants. http://youtu.be/DXHkQE_hFg4 *
- Good farming practices to reduce vegetable contamination. Awareness and training video for wastewater farmers and extension officers. http://youtu.be/Aa4u1_RblfM *

* The two videos listed here also on the CD which is part of this publication.

Laws and regulations: Karg and Drechsel (2011) identified regulations as an important external factor to institutionalize new food-safety recommendations so as to provide the legal framework for compliance monitoring via both incentives (e.g. certificates) and disincentives (e.g. fees). To integrate improved food-handling practices into institutional structures, inspection forms can be updated, inspectors and extension officers can be trained and pressure can be applied to farmers and caterers to enhance compliance. However, regulations should not be based on imported (theoretical) 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 behavior change, whereas promotional and educational activities are usually limited to a specific time frame.

Effective communication: To be useful, knowledge (whether it is farmers' innovations, latest research findings or pressing policy issues) must be effectively shared amongst people and institutions. It is important to understand the information pathways (like media) used by key actors, such as farmers, produce sellers and those who prepare foods in households and street restaurants, who should adopt risk mitigation measures, so that effective communication channels are selected to reach the target groups. For example, a pilot social marketing study in Ghana showed that it is more likely that innovations spread from farmer to farmer through social networks than through any external facilitation (Keraita et al. 2010). Farmers prefer field demonstration and/or learning-by-doing. This also verifies the importance of encouraging actors' own experimentation because it promotes knowledge generation, as well as self-monitoring and evaluation. However, it is pertinent for the implementation process to recognize the wider system within which key actors operate. The wider system, made up of institutions, regulatory bodies and in- and output markets can have a significant positive or negative influence on key actors' decision making, while this is often ignored by scientists.

14.8 Conclusions

Developing risk mitigation measures in line with the WHO-recommended multi-barrier approach offers a variety of options to achieve a realistic chance for the management of pathogenic risk along the food chain deriving from informal wastewater irrigation in low-income countries. Improving urban sanitation and wastewater treatment remains however central to address also chemical contaminants and to safeguard the natural environment.

Where treatment capacity is weak, this chapter has demonstrated the potential of additional pathogen barriers tested in actual field studies in Ghana. The studies have shown that farm and postharvest risk mitigation measures can contribute to preventing contamination and supporting decontamination of vegetables grown with highly-polluted water. Although the effectiveness of *individual* measures may not be sufficient to safeguard public health, measures can be used in combination to complement each other (multiple barriers) in order to achieve acceptable risk levels. Combinations can be accomplished within and between operation levels, i.e. farms, markets and households. The measures presented, though not exhaustive, allow for flexibility to adaptation in different locations. Equally important are however the discussed factors, incentives and strategies that could foster adoption of safety practices, as risk awareness per se is still low and thus also market demand for safe produce.