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Assessing and Mitigating Wastewater-Related Health Risks in Low-Income Countries: An Introduction

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Abstract

In and around urban areas pollution of natural water bodies is on the rise. As a result, wastewater irrigation is an increasingly common reality around most cities in the developing world. For reasons of technical capacity or economics, effective treatment may not be available for years to come; therefore, international guidelines to safeguard farmers and consumers must be practical and offer feasible risk-management options. This chapter provides an introduction to microbiological hazards. These can be addressed best in a step-wise risk assessment and management approach starting with wastewater treatment where possible, and supported by different pathogen barriers from farm to fork. A major change in the most recent WHO Guidelines for the safe use of wastewater, excreta and greywater in agriculture and aquaculture (WHO, 2006) agriculture is the focus on a holistic approach to achieving health-based targets, instead of prescribing irrigation water-quality threshold levels that are often unattainable. The health-based targets should not be read as absolute values but as goals to be attained in the short, medium or long term depending on the country's technical capacity and institutional or economic conditions. Local standards and actual implementation should progressively develop as the country moves up the sanitation ladder. While health-risk assessments are recommended to identify entry points for risk reduction and

health-based targets, the Guidelines also offer shortcuts in situations where research capacities and data are constrained.

Introduction

The agricultural use of treated, partially treated or untreated wastewater[2] or surface water contaminated with wastewater is common. An estimated 20 million hectares worldwide are irrigated with wastewater, more of it with untreated than treated wastewater (Jiménez and Asano, 2008; Scott et al., 2004). This misbalance in favour of untreated wastewater will continue to increase as long as the pollution of streams, by effluents from growing urban populations is not matched by treatment facilities. The increasing global scarcity of good-quality water will turn wastewater irrigation from an undesirable phenomenon into a necessity wherever agricultural water demand is not met by supply. This is not only the case in drier regions, but anywhere where farmers seek land and water to address market demand. Common examples are urban and peri-urban areas in most developing countries where clean water sources are hardly sufficient even to meet domestic demand.

The use of untreated wastewater, or polluted water in general, poses risks to human health since it may contain excreta-related pathogens (viruses, bacteria, protozoan and multicellular parasites), skin irritants and toxic chemicals like heavy metals, pesticides and pesticide residues. When wastewater is used in agriculture, pathogens and certain chemicals are the primary hazards to human health by exposure through different routes (see Table 2.1). These exposure routes are mainly contact with wastewater (farmers, field workers and nearby communities) and consumption of wastewater-grown produce (consumers). In addition, contamination may be due to poor post-harvest handling that can also lead to cross-contamination of farm produce.

This chapter and most other sections of this book target microbiological hazards, while chemical hazards are addressed in Chapter 6 and Chapter 11.

Exposure routes for health hazards from wastewater irrigation

The causative agents of excreta-associated infections are released from infected persons (or animals in some cases) in their excreta. They include pathogenic viruses, bacteria, protozoa and helminths of which are released from the bodies of infected persons (or animals in some cases) in their excreta (faeces or urine). The pathogens eventually reach other people and enter either via the mouth (the faecal-oral pathway, e.g. when contaminated crops are eaten) or via the skin (contact with infective larvae, e.g. hookworm infection and schistosomiasis).

Table 2.1 *Examples of different kinds of hazards associated with wastewater use in agriculture in developing countries*

Hazard	Exposure route	Relative importance
Excreta-related pathogens		
Bacteria (for example *E. coli*, Vibrio cholerae, *Salmonella* spp. *Shigella* spp.)	Contact; Consumption	Low–high
Helminths (parasitic worms)		
• Soil-transmitted (*Ascaris*, hookworms, *Taenia* spp.)	Contact; Consumption	Low–high
• *Schistosoma* spp.	Contact	Nil–high
Protozoa (*Giardia intestinalis*, *Cryptosporidium*, *Entamoeba* spp.)	Contact; Consumption	Low–medium
Viruses (for example hepatitis A virus, hepatitis E virus, adenovirus, rotavirus, norovirus)	Contact; Consumption	Low–high
Skin irritants and infections	Contact	Medium–high
Vector-borne pathogens (*Filaria* spp., Japanese encephalitis virus, *Plasmodium* spp.)	Vector contact	Nil–medium
Chemicals		
Heavy metals (for example arsenic, cadmium, lead, mercury)	Consumption	Generally low
Halogenated hydrocarbons (dioxins, furans, PCBs)	Consumption	Low
Pesticides (aldrin, DDT)	Contact; Consumption	Low

Source: Adapted from WHO (2006)

Occupational exposure

The most affected groups are farm workers due to the duration and intensity of their contact with wastewater and contaminated soils (Blumenthal and Peasey, 2002; WHO, 2006). For instance, in Haroonabad, Pakistan, prevalence rates for hookworm infection as high as 80 per cent have been reported for farmers (mainly male adults) using untreated wastewater (van der Hoek et al., 2002). Epidemiological studies of farmer groups using wastewater have produced overwhelming evidence of the high risk of helminth infections. This has resulted in the strict WHO guideline value of ≤1 egg per litre of irrigation water (WHO, 2006). Nevertheless, recent epidemiological studies conducted among rice farmers in Vietnam using wastewater found significantly more evidence for increased diarrhoea and skin problems than for the risk of helminth infections (Trang et al., 2007a, b).

Contradictions may occur between actual risks and perceived ones. Wastewater farmers themselves seldom associate infections and diseases with their irrigation practice (Rutkowski et al., 2007), which may jeopardize efforts towards their adoption of risk reduction measures by them (see Chapter 17). It also highlights the need to educate farmers about the risks they face when using wastewater for irrigation. There are arguments based on economic impact studies as well, that the financial gains from agricultural production using wastewater irrigation can allow farmers to pay for medication to treat helminth infections (Bayrau et al., 2009). More on integrating economic impacts into risk analysis is presented in Chapter 7.

Other than helminth infections, recent studies from Vietnam and Cambodia have attributed skin diseases such as dermatitis (eczema) to contact with untreated wastewater (van der Hoek et al., 2005; Trang et al., 2007c). A study conducted in the Kathmandu Valley, Nepal, showed that more than half of 110 farmers interviewed using wastewater had experienced skin problems (Rutkowski et al., 2007). The reported skin problems included itching and blistering on the hands and feet. Similar problems were reported by rice farmers along the Musi River in Hyderabad, India, and urban vegetable farmers using wastewater in Ghana (Buechler et al., 2002; Obuobie et al., 2006). Nail problems such as koilonychias (spoon-formed nails) have also been reported but this is specifically associated with hookworm infections which cause iron deficiency (anaemia) damaging the formation of nails (van der Hoek et al., 2002). Studies conducted in Vietnam did not find an association between the risk of eye ailments (conjunctivitis or trachoma) and wastewater-related exposure but recommended more studies to determine if there is a link between skin infections and particular water pollutants (Trang et al., 2007c).

Consumption of irrigated produce

In relation to consumption-associated health risks, the primary concern is about vegetables eaten uncooked e.g. in raw salad dishes (Harris et al., 2003). Several studies including a prospective cohort study (Peasey, 2000), an analytical descriptive study (Cifuentes, 1998) and several descriptive studies including one done in Jerusalem (Shuval et al., 1984) have shown higher *Ascaris* infections for both adults and children consuming uncooked vegetables irrigated with wastewater. Studies on the impact related to diarrhoeal diseases from consumption of contaminated vegetables have been published and reviewed extensively (Beuchat, 1998; Harris et al., 2003).

The *Escherichia coli* strain enterotoxigenic *E. coli* (ETEC) is often associated with diarrhoea (travellers' diarrhoea) in developing countries (Gupta et al., 2007). In addition, viral enteritis (especially norovirus and rotavirus) and hepatitis A are the most commonly reported viral infections from vegetable consumption (Lindesmith et al., 2003; Seymour and Appleton, 2001). Several diarrhoeal outbreaks have been associated with wastewater-irrigated vegetables (Shuval et al., 1984; WHO, 2006). However, in developing countries it is often a challenge to attribute diarrhoeal outbreaks to specific exposure routes due to other contributing factors including poor hygiene, sanitation and reduced access to safe drinking water.

Diseases associated with wastewater use in agriculture

Not every hazard will end up causing illness and different hazards and exposure pathways will result in different disease burdens. The relative importance of health hazards in causing illness depends on a number of factors. The ability of infectious agents to cause disease relates to their persistence in the environment, minimum infective dose, ability to induce human immunity, virulence and tency periods (Shuval et al., 1986). Thus, pathogens with long persistence in the environment and low minimal infective doses that elicit little or no human immunity and having long latency periods (for example helminths) have a higher probability of causing infections than others. According to this, helminth infections, where endemic, pose the greatest risks associated with wastewater irrigation. Risks from most chemicals are thought to be low, except in localized areas with large industrial wastewater generation. Diseases associated with exposure to chemicals (aside from acute symptoms such as skin rashes, etc.), such as cancer, are harder to attribute to wastewater use in agriculture. This is because workers may be exposed to complex mixtures of chemicals in the wastewater and long latency periods before the disease symptoms appear, making it difficult to attribute the disease to any one specific exposure route or causal factor.

The diseases of most relevance differ from area to area depending on the local status of sanitation and hygiene and the level to which wastewater is treated prior to use in agriculture. Table 2.2 provides examples of the burden of some diseases of potential relevance to wastewater use in agriculture. Most of these excreta-related illnesses occur in children living in poor countries. The disease burden is measured in disability-adjusted life years (DALYs),[3] which is increasingly becoming an essential unit in comparing disease outcomes from different exposures. More details on the use of DALYs are given in the following chapters. Overall, the WHO estimates that diarrhoea alone is responsible for nearly 3 per cent of all deaths and 3.9 per cent of DALYs worldwide (Prüss-Ustün and Corvalan, 2006). Diarrhoea is indeed a disease which can be largely attributed to environmental factors (88 per cent, WHO, 2009), such as unsafe drinking water, poor hygiene and sanitation, and the consumption of pathogen-contaminated crops.

The question of how much of the disease burden can be attributed to poor sanitation, unsafe drinking water, poor hygiene and, in particular, to the consumption of wastewater-irrigated vegetables remains a challenging one. There are not many comparative studies and those that exist only look at either waterborne or foodborne pathways. Wastewater-irrigated food links both categories, but more importantly, many factors are interwoven and not mutually exclusive. The large number of confounding factors makes any specific attribution to wastewater use difficult. One way to address the challenge is via microbiological risk assessment considering location-specific exposures.

Table 2.2 *Global mortality and DALYs due to some diseases of relevance to wastewater use in agriculture*

Disease	Mortality (deaths/year)	Burden of disease (DALYs)	Comments
Diarrhoea	1,682,000	57,966,000	99.7% of deaths occur in developing countries; 90% of deaths occur in children; 94% can be attributed to environmental factors.
Typhoid	600,000	N/A	Estimated 16,000,000 cases per year.
Ascariasis	3000	1,817,000	Estimated 1.45 billion infections, of which 350 million suffer adverse health effects.
Hookworm disease	3000	59,000	Estimated 1.3 billion infections, of which 150 million suffer adverse health effects.
Lymphatic filariasis	0	3,791,000	Mosquito vectors of filariasis (*Culex* spp.) breed in contaminated water. Does not cause death but leads to severe disability.
Hepatitis A	N/A	N/A	Estimated 1.4 million cases per year worldwide. Serological evidence of prior infection ranges from 15% to nearly 100%.

N/A = not available.
Source: Prüss-Ustün and Corvalan (2006); WHO (2006)

Tools for risk assessment

Assessment of risks mainly relies on data from microbiological analysis, epidemiological studies and/or quantitative microbial risk assessment (QMRA), the latter being a prospective assessment rather than extrapolation from evaluations. Traditionally, microbial analysis and epidemiological studies have been extensively used in evaluating risks in wastewater-irrigated agriculture, especially among affected farmers. A number of epidemiological studies in this area have shown higher prevalence of infections in the exposed population compared to unexposed populations. The studies have also clearly associated levels of pathogens in irrigation water to infection levels (Blumenthal and Peasey, 2002). Nevertheless, from the perspective of possible risk to society or planned agricultural wastewater irrigation, the epidemiological approach has limitations in that it is relatively expensive and it does not meet the need of the public, governments and other stakeholders to obtain health-risk estimates before the commissioning of projects. QMRA is increasingly used for this purpose, giving a prospective risk assessment for the wastewater irrigation situation at hand (Hamilton et al., 2007). Contributions and limitations of the main assessment tools are shown in Table 2.3. Detailed

Table 2.3 *Data used for the assessment of health risks*

Type of study	Contributions	Limitations
Microbial analysis	• Determines concentrations of different excreted organisms in wastewater or on products. • Provides data on pathogen die-off rates. • Can help to identify sources of pathogens. • Used to link pathogen to infection/disease.	• Expensive unless indicators are used. • Collection of samples may be time-consuming. • Needs trained staff and laboratory facilities. • Obtaining laboratory results takes time. • Lack of standardized procedures for the detection of some pathogens or their recovery from food products. • Recovery percentages may show high variability. • Some methods do not determine viability.
Epidemiological studies	• Measure actual disease in an exposed population. • Can be used to test different exposure hypotheses. • Can be applied to chemical risk assessments.	• Expensive. • Bias can affect results. • Large sample sizes needed. • Ethical clearance needed. • Need for balance between power of study and its sensitivity.
QMRA	• Can estimate very low levels of risk of infection/disease. • Low-cost method of predicting risk of infection/disease. • Facilitates comparisons of different exposure routes. • Principles can also be applied to chemical risk assessments.	• Exposure scenarios can vary significantly and are difficult to model. • Validated data inputs are not available for every exposure scenario. • Predicts risks from exposure to one type of pathogen at a time.

Source: Adapted from WHO (2006)

descriptions on microbiological risk analysis and risk analysis tools are presented in the following chapters in this volume.

GUIDELINES FOR WASTEWATER IRRIGATION IN DEVELOPING COUNTRIES

While some countries, especially more developed ones, have national guidelines addressing wastewater use in agriculture, the best known international guidelines are those produced by the UN, in particular the WHO. To protect public health and facilitate the rational use of wastewater and excreta in agriculture and aquaculture, WHO developed the document *Reuse of Effluents: Methods of Wastewater Treatment and Public Health Safeguards* in the early 1970s. This first normative document from the WHO in the field of wastewater use was developed in the absence of good epidemiological studies and borrowed essentially a low-risk approach from the USA (Carr, 2005). In 1976, it was complemented by the FAO's Irrigation and Drainage Paper 29 which addressed the water-quality challenges of salinity and specific ion toxicity (FAO, 1976). The WHO publication relied on water thresholds, i.e. critical pathogen levels in the irrigation water (100 coliforms $100ml^{-1}$) which should not be exceeded, and gave best practice recommendations on how to treat the water to achieve this quality standard (Havelaar et al., 2001).

In the two decades following the publication of these documents, the use of wastewater in agriculture expanded in many arid and semi-arid countries. This trend and the health and safety questions concerning this practice became driving forces for conducting a number of epidemiological studies. (A thorough review of epidemiological studies was prepared by Shuval et al., 1986.) As epidemiological evidence was compiled it became clear that the initial WHO publication needed to be revised and the following additional issues needed to be considered (Carr, 2005):

- Overly strict water-quality standards were impossible to achieve in many situations and were therefore often ignored, rendering the Guidelines useless.
- Guidelines needed to include risk-management approaches that would complement available treatment processes or could be used in the absence of wastewater treatment to reduce health risks.

Based on these considerations a second edition of the WHO Guidelines was published in 1989 (Mara and Cairncross, 1989). The FAO's Irrigation and Drainage Paper 47 followed in 1992, building on the 1989 Guidelines while also addressing issues specific to irrigation such as managing salinity (FAO, 1992). Both guidelines have been very influential and many countries have adopted them, in some cases with adaptations. In view of pathogenic threats, both reports emphasized the need for appropriate wastewater treatment before use and for water-quality criteria that are easy to monitor.

In 1997, the FAO's 'Water Report no. 10' challenged the application potential of the WHO water-quality standards, as adequate treatment facilities sufficient to help meet these standards could well be a decade or more away (FAO, 1997). This publication stressed the need for additional, interim measures, in particular crop restrictions. With increasing knowledge about and tools for risk assessments (such as QMRA), the development of the DALY concept and the increasing emphasis on critical control points to achieve food safety, the WHO joined forces with the FAO and started another historic revision of the WHO Guidelines. The revised edition was to include more information about how to define tolerable risks to society based upon the actual disease situation in any given country, with a stronger emphasis on local opportunities but also limitations to achieve risk reduction (Carr, 2005).

A major change was the shift from critical levels of microbial contamination of irrigation water to health-based targets (WHO, 2006). In addition to the challenge of achieving water quality-based targets (especially in those countries where the burden of associated illness is highest), another weakness was that water quality-based thresholds hardly helped to address food contamination taking place from sources other than irrigation. The suggested alternative was to reduce the risk, especially for consumers of wastewater-irrigated crops, wherever there is an opportunity along the production and marketing chain. This can be wastewater treatment, safer irrigation practices, only growing crops that are eaten fully cooked and washing crops as part of food preparation. Using a combination of these preventive measures, it will be possible to approach the health target values which are set at the end of the chain, i.e. at the point of consumption, similar to the concept of food-safety objectives (CAC, 2004). This target is calculated based on the pathogen reduction from the initial crop contamination level and can be expressed in DALYs averted. The emphasis on 'targets' means that these values should not be read as absolute values but as goals to be attained in the short, medium or long term depending on the country's technological, institutional or financial conditions (Sperling and Fattal, 2001).

In order to better package the Guidelines for appropriate audiences it was decided to present them in separate volumes:

- Volume 1: Policy and regulatory aspects;
- Volume 2: Wastewater use in agriculture;
- Volume 3: Wastewater and excreta use in aquaculture;
- Volume 4: Excreta and greywater use in agriculture.

The Guidelines can be downloaded from www.who.int/water_sanitation_health/wastewater/gsuww/en/index.html. Shorter, related fact sheets and policy briefs for different stakeholder groups can be found at www.who.int/water_sanitation_health/wastewater/usinghumanwaste/en/index.html.

APPROACHES FOR MITIGATING RISKS FROM WASTEWATER IRRIGATION

Conventional options and their limitations in developing countries

Wastewater treatment in designed plants or pond systems has long been considered the ultimate solution for reducing risks in wastewater-irrigated agriculture.

Wastewater treatment as a risk-mitigation measure has therefore been widely studied and documented in both developed and developing countries (Hammer and Hammer, 2008; Mara, 2004; Metcalf and Eddy, 2002; Patwardhan, 2008). Questions are being raised, however, about the effectiveness of conventional treatment systems in removing pathogens that are of particular concern in many developing countries and also about some emerging organic chemical compounds, such as pesticides and their residues, pharmaceutically active compounds and endocrine disrupting substances. Indeed, most conventional systems have two treatment systems: primary treatment where suspended solids and organic matter are removed; and secondary treatment for removing biodegradable organics. Tertiary level treatment may also be available, but the aim of tertiary treatment is removal of nutrients and toxic compounds (Metcalf and Eddy, 2002). So, conventional treatment systems are designed mainly to address environmental concerns and not human health risks. This was further shown by a review of more than 20 studies conducted for the WHO for the third edition of its Guidelines. The review showed wide variations in the effectiveness of log unit removals of various pathogens by different conventional treatment processes (WHO, 2006).

The processes involved in several conventional treatment systems, except stabilization ponds, are difficult and costly to operate in developing-country contexts as they have high energy requirements, need skilled labour and also have high installation, operation and maintenance costs (Carr and Strauss, 2001). This perhaps explains the high number of dysfunctional treatment plants and low general levels of wastewater treatment in developing countries of less than 1 per cent in sub-Saharan Africa, about 35 per cent in Asia and 14 per cent in South America (WHO and UNICEF, 2000). A survey in Ghana, for example, reported that only 10 per cent of the reported 70 treatment plants and faecal sludge stabilization ponds are still operating as planned, most of them belonging to larger hotels (IWMI, 2009).

Innovative changes are therefore necessary for conventional wastewater treatment to continue to be seen as a realistic health-risk mitigation option in developing countries. In recent years, some of these changes have included research towards re-engineering conventional wastewater treatment systems to make them more appropriate for irrigation, by optimizing the water and nutrient contents in treated wastewater effluents, as discussed in Chapters 14 and 15. Studies have also focused on developing systems which are more efficient in pathogen removal and nutrient conservation. Here, a focus on systems that use low-rate biological processes, such as pond systems, has been promoted, as discussed in Chapters 8 and 9. There is also a growing research emphasis on biosolids, especially developing risk-mitigation measures for faecal sludge use in agriculture, as well as on outsourcing treatment to the farm level (see Chapter 10).

Non-conventional options and the multiple-barrier approach

Considering the apparent limitations of implementing conventional wastewater treatment systems in many developing countries at present, the third edition of the WHO Guidelines recommends the use of the 'multiple-barrier approach'. The approach draws from the Hazard Analysis Critical Control Point (HACCP) concept promoted by the *Codex Alimentarius* initiative and is based on targeted interventions at key control points along the food chain to achieve a food-safety objective (CAC, 2004). Critical control points (which can be important pathogen barriers) can be found along the whole chain of events from wastewater generation to the preparation of the vegetables served for consumption. The approach therefore covers both conventional and non-conventional wastewater treatment methods as well as other health-protection measures to meet health targets, be it for the farmer or consumer. Non-conventional wastewater treatment methods include the use of low-cost systems such as on-farm ponds, sedimentation traps and biosand-filters while health-protection measures include improved irrigation methods, like drip irrigation, cessation of irrigation before harvesting and produce-washing (Keraita et al., 2008). In some parts of the 2006 edition of the Guidelines, these different options are grouped as 'treatment' and 'non-treatment' options with 'treatment' covering all conventional wastewater treatment systems (see Chapters 8 and 9) and 'non-treatment' options including all other possible practices and measures, especially on farm and in the post-harvest sector (see Chapters 10 to 12). Table 2.4 provides an overview of different health-protection measures and where they can be applied in the food-production chain.

STRENGTHS AND WEAKNESSES OF DIFFERENT APPROACHES FOR RISK REDUCTION

All critical control points or possible 'barriers' have strengths and weaknesses. A key factor of the main groups of 'treatment' and 'non-treatment' (also known as 'post-treatment') options is that they require particular settings to work. Wastewater treatment has a marginal impact in many developing countries due to limited coverage, under-resourced institutions, limited human capacities and severe financial challenges. Post-treatment options, on the other hand, require farmers, traders or food caterers to adopt safer practices, often without any obvious or direct personal or business benefit. In the context of low-income countries with limited public education and awareness of food-safety issues, non-treatment options are thus not the panacea where wastewater treatment is missing or fails, and actually require particular efforts in terms of awareness creation, incentives and regulations as described in Chapters 16 and 17.

Post-harvest treatment and handling of fresh produce often cannot eliminate pathogens without compromising the attractiveness and physical quality of the

Table 2.4 *Overview of health-protection measures*

<table>
<tr><th>Health-protection measures</th><th>Location</th><th>Examples</th><th>Protected groups</th><th>Chapters in this book</th></tr>
<tr><td rowspan="2">Treatment options</td><td>Pre-farm</td><td>Municipal wastewater treatment plants (e.g., waste stabilization ponds, constructed wetlands)</td><td rowspan="2">Farming communities and consumers</td><td>8, 9</td></tr>
<tr><td rowspan="5">On farm</td><td>On-farm treatment systems (e.g., sedimentation traps or tanks, simple ponds, sand-filters)</td><td rowspan="5">10, 17 (microbiological control measures)
11 (chemical control measures)</td></tr>
<tr><td rowspan="5">Post-treatment (or non-treatment) options</td><td>Protective clothing, including gloves, and footwear</td><td>Farming communities only</td></tr>
<tr><td>Safer collection and application of wastewater (e.g. low-cost drip irrigation, splash reduction, reduced helminth egg uptake from sediments)</td><td>Farming communities and consumers</td></tr>
<tr><td>Imposing a minimum period of no irrigation immediately prior to harvest (to promote pathogen die-off)</td><td rowspan="3">Consumers only</td></tr>
<tr><td>Crop restrictions (to exclude e.g. crops eaten uncooked or grow only non-edible crops)</td></tr>
<tr><td>Off farm (post-harvest sector)</td><td>Produce-washing, disinfection, peeling and/or cooking</td><td>12, 16</td></tr>
</table>

produce (Beuchat, 1998) unless the product is always consumed after cooking. Thus, it appears most feasible not to rely on only one barrier or option but to combine different barriers from wastewater treatment to on-farm and off-farm measures (see Chapters 10 and 12).

So far, the use of the multiple-barrier approach in wastewater-irrigated agriculture has not been systematically studied in a variety of different settings. However, a review conducted for WHO based on some limited studies shows that this approach appears to be feasible (Table 2.5). For example, in the WHO Guidelines, a pathogen reduction of 6–7 log units is used as the performance target for unrestricted irrigation to achieve the tolerable disease burden of $\leq 10^{-6}$ DALYs per person per year. For monitoring purposes, log unit pathogen reductions are

Table 2.5 *Pathogen reductions achievable by selected health-protection measures*

Control Measure	Reduction (log units)	Comments
Wastewater treatment (primary + secondary)	1–4	Reduction usually achieved by wastewater treatment depending on the type and functionality of the treatment system.
Drip irrigation used for:		
Low-growing crops	2	Root crops and crops such as lettuce that grow just above, but partially in contact with, the soil.
High-growing crops	4	Crops, such as tomatoes, fruit trees, the harvested parts of which are not in contact with the soil.
Pathogen die-off	0.5–2 per day	Die-off on crop surfaces that occurs between last irrigation and consumption. The log unit reduction achieved depends on climate (temperature, sunlight intensity, humidity), time, crop type, etc.
Produce-washing with water	1	Washing salad crops, vegetables and fruit with clean water.
Produce disinfection	2–3	Washing salad crops, vegetables and fruit with a weak, often chlorine-based disinfectant solution and rinsing with clean water.
Produce peeling	1–2	Fruits, cabbage, root crops.
Produce cooking	6–7	Immersion in boiling or close-to-boiling water until the food is cooked ensures pathogen destruction.

Source: Adapted and modified from WHO (2006)

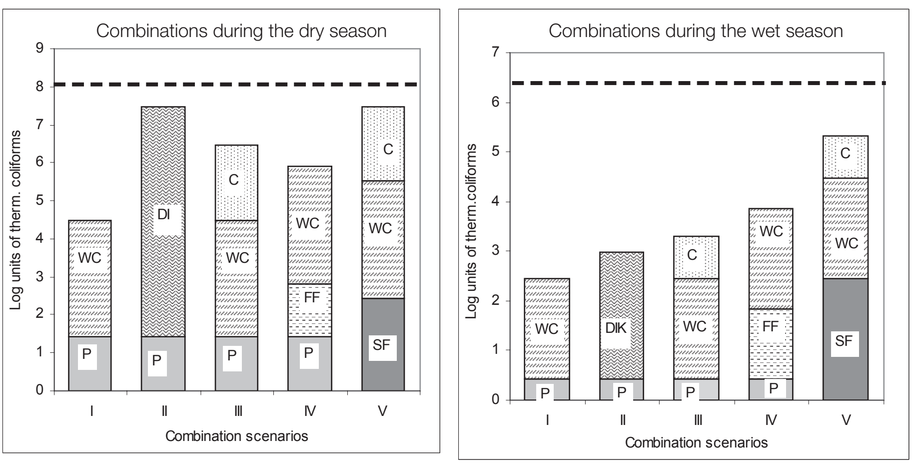
not measured via actual pathogen numbers, but by the reduction in numbers of a pathogen indicator organism, which is in most cases *E. coli*. As Table 2.5 demonstrates, combining minimal wastewater treatment, drip irrigation and washing vegetables after harvesting can easily achieve a 6 log unit reduction.

ACTUAL FIELD ASSESSMENTS OF RISK-REDUCTION OPTIONS

The increased complexity of the 2006 WHO Guidelines means that they are sometimes perceived as less user-friendly. The concerns relate to the more complex health-based targets and the need to perform risk assessments, including the DALY concept. Although the Guidelines ask for a certain sequence of steps to be followed, their application should not be limited to situations where all steps can be taken. Where a risk assessment, like QMRA, is not possible for reasons of missing data or research capacity and a local performance target for irrigation cannot be calculated, it is recommended to combine options as shown in Table 2.5 aiming at a cumulative pathogen reduction of 6–7 log units where the irrigation water is likely to be contaminated with pathogens and used on crops to be eaten raw (see also Chapters 3 and 5). In countries where achieving this log reduction in the local socio-economic context is not feasible, alternative national health-based targets can be established, under the condition that their implementation procedures are strictly monitored and the targets are incrementally improved towards the globally recommended one. Lower log reductions can also be targeted where crop restrictions are possible (see Chapter 3).

Another limitation of studies conducted so far on non-conventional or 'non-treatment' options, and in particular the multiple-barrier approach, is their restricted geographical extent (WHO, 2006). Even where research has progressed over the years, as in Ghana, it is still another step to implement the research (IWMI, 2009). In Ghana, the studies have focused on the adaptation of known but also on locally developed farm-based and off-farm measures. These include the cessation of irrigation before harvesting, safer water collection and application, safe irrigation methods, sand-filters, on-farm sedimentation ponds and post-harvest measures such as various indigenous vegetable-washing methods (see Chapters 10 and 12). These studies showed that low-cost measures have the potential to reduce pathogens, especially if they are developed with the user and can be used in combination so as to have a cumulative effect (Drechsel et al., 2008). However, their success depends largely on the adoption rate which requires an appropriate analysis of possible economic and social incentives (see Chapter 16).

Figure 2.1 shows a number of combination scenarios that were discussed in the studies of farm-based options in Kumasi, Ghana (Keraita, 2008). Scenario



P = sedimentation ponds, WC = improved use of watering cans, SF = sand filter, FF = fabric filter, DI = Drip kits; C = cessation, ------- usual contamination levels on vegetables in Kumasi

Figure 2.1 *Feasible combinations of farm-based interventions and achievable reduction of thermotolerant coliforms on lettuce leaves in Kumasi, Ghana*

Source: Keraita (2008)

I reflects the most farmer-friendly option as it only entailed modifications of existing technologies. Although this option gives the lowest aggregate reduction in contamination levels, it is still a significant one for both the dry (4.5 log units) and wet (2.5 log units) seasons, if other barriers are available. Generally, the suggested combined intervention measures show very good performance during the dry season, but not in the wet season due to rainfall, shorter duration of sunshine and generally lower temperatures. As this was a location-specific study, similar trials elsewhere are encouraged.

Conclusions

In and around four out of five cities in the developing world, wastewater in treated, raw or diluted form is used in irrigated agriculture. Even if the areas are small, these farms are often specialized in producing highly perishable cash crops with a significant market share (Raschid-Sally and Jayakody, 2008). It is important to recognize that in many situations where wastewater is used in agriculture, effective treatment of wastewater may not be available for many years to come. International guidelines must therefore be practical and offer feasible risk-management solutions that will maximize health protection and facilitate the beneficial use of scarce resources. To achieve the greatest benefits to health, the third edition of the WHO Guidelines provides tools, methods and procedures to set health-based targets that can be achieved with different pathogen barriers from the wastewater source to the consumption of wastewater-irrigated food. This multiple-barrier approach should be implemented with other health measures such as health education, hygiene promotion and the provision of access to safe drinking water and adequate sanitation.

There are still many open questions for research and application, some of which are outlined in the last chapter of this volume. In order to properly interpret and apply the guidelines in a manner appropriate to local conditions, a broad-based policy approach is required that will include legislation as well as positive and negative incentives to support the adoption of good non-treatment or post-treatment practices. Efforts to expand the treatment of wastewater are important and need to accelerate. The current WHO Guidelines can support local, national and international standard-setting bodies in their efforts to develop their own procedures and protocols on how to achieve the recommended health-based targets. The procedures will differ between and within regions according to differences in technological, institutional and financial conditions. While the health-based targets will remain a given in any specific context, local standards and actual implementation should progressively develop as the country moves up the sanitation ladder.

NOTES

1 The opinions expressed in this chapter are those of the authors only and do not necessarily reflect the policies and positions of the World Health Organization.
2 The term 'wastewater' as used in this book covers wastewater of different qualities, ranging from raw to diluted, generated by various urban activities (see Chapter 1).
3 The DALY concept allows one to quantify the contribution to the 'burden of disease' from mortality, disability, impairment, illness and injury. One DALY can be thought of as one lost year of healthy life and is calculated as a combination of (1) years of life lost (YLL) as a result of premature mortality and (2) equivalent healthy years of life lost as a result of disability (YLD). The burden of disease therefore measures the gap between current health status and an ideal situation in which every one lives into old age free of disease and disability. See http://en.wikipedia.org/wiki/Disability-adjusted_life_year and www.who.int/healthinfo/global_burden_disease/en/index.html.

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