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Cost-Effectiveness Analysis of Interventions for Diarrhoeal Disease Reduction among Consumers of Wastewater-Irrigated Lettuce in Ghana

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Abstract

Interventions proposed and implemented for the mitigation of diarrhoeal diseases associated with wastewater reuse in agriculture have received little, if any, comparative assessment of their cost-effectiveness. This chapter assesses the costs, outcomes and cost-effectiveness of the so-called 'treatment' and 'non- or post-treatment' interventions as well as a combination of these for wastewater irrigation in urban Ghana using an approach that integrates quantitative microbial risk assessment (QMRA), disability-adjusted life years (DALYs) and cost-effectiveness analysis (CEA). The cost-effectiveness ratios (CERs) for the treatment and non-treatment interventions assessed ranged from US$31/DALY to US$812/DALY averted. Risk-reduction measures targeting farming practices and the basic rehabilitation of local wastewater treatment plants were the most attractive interventions with a CER well below the threshold of US$150/DALY, sometimes considered as the upper limit for a health intervention to be cost-effective in developing countries. All combinations associated with the basic rehabilitation of the treatment plants, with either on-farm or post-harvest interventions or both, resulted in CERs within the range of US$40/DALY to US$57/DALY. However, the CERs for the construction

of a new wastewater treatment plant either as an independent intervention or in combination with on-farm and post-harvest interventions were unattractive in view of health-risk reduction for wastewater irrigation. Although attractive, the CERs of non-treatment options are largely dependent on compliance (adoption) by farmers and food vendors. In this regard, the CER increased by almost fivefold when the adoption rate was only 25 per cent by farmers and food vendors; but was attractive as long as adoption rates did not fall below 70 per cent. On the other hand, the success of the treatment option depends on the functionality of the treatment plants which is not without challenges in a country like Ghana. Thus, this chapter stresses the need for a balanced risk-management approach through a combination of treatment and non-treatment interventions to hedge against failures that may affect CERs at any end. While this chapter provides a contribution to the debate on interventions for health-risk mitigation in wastewater irrigation, more case studies would be useful to verify the data presented here.

INTRODUCTION

Irrigation with raw, diluted and treated wastewater for vegetable production is increasingly becoming a central component of the urban food matrix in many countries due to depleting freshwater resources, increased demand for fresh vegetables and the need to reuse water based on a deeper understanding of sustainability issues. The benefits of the practice are many and encapsulate social, economic and environmental returns that dovetail neatly into food security, freshwater conservation and sustainable wastewater management. At the same time, wastewater irrigation can serve as a conduit for severe and sometimes fatal health consequences with a cost to society greater than its benefits if not undertaken in a safe manner. Many of the infectious pathogenic organisms of viral, bacterial, protozoan and parasitic origins implicated in gastroenteric diseases are present in wastewater and may be transmitted via the consumption of wastewater-irrigated vegetables. A review of several wastewater-irrigation studies worldwide showed clear evidence of direct correlations between the consumption of wastewater-irrigated vegetables and the occurrence of gastroenteric diseases including diarrhoea (Blumenthal and Peasey, 2002).

To reduce the health risk associated with wastewater irrigation while optimizing its benefits, a multi-pronged approach that progressively reduces microbial health hazards has been proposed by the most recent World Health Organization (WHO) Guidelines for wastewater irrigation (WHO, 2006). This approach to health-risk management appreciates the diverse and disparate socio-cultural, technical and institutional dynamics of wastewater irrigation and thus postulates a wide range of flexible and locally specific health-risk barriers. This is of particular importance where the main conventional risk barrier, i.e. wastewater treatment, does not sufficiently work, as in most developing countries. Here, so-called 'post-treatment' or 'non-treatment' options gain significance (see Chapter 2). These comprise measures for risk reduction along the farm to fork pathway, such as drip-kit irrigation or vegetable-washing.

Several of these health-risk barriers have been explored in different geographical areas in terms of their efficacy in view of risk reduction and, in some cases, their feasibility of implementation, acceptability and potential sustainability. One of these cases is Ghana. In urban Ghana, where wastewater irrigation is common and poses a significant health risk (Seidu et al., 2008), non-treatment interventions at the farm and post-harvest points have been explored in different cities, on farms, in markets and in street-food restaurants (see references in Drechsel et al., 2008). These studies, together with others elsewhere (WHO, 2006), have shown that a significant risk reduction is also possible where public health cannot yet rely on conventional wastewater treatment, especially if different options are combined. However, decisions as to which intervention to implement have largely accounted for only the efficacy of the interventions in terms of reduced bacterial counts or helminth eggs, without rigorous analysis of the health gains and cost-effectiveness.

An approach that has been used to address this gap is cost-effectiveness analysis (CEA). The approach provides a framework for the assessment of interventions in terms of their costs per standardized health benefit measured in DALYs averted (WHO, 2003). This approach, although widely used to assess water and sanitation interventions, is yet to be applied to wastewater irrigation to rigorously assess the different interventions proposed in the 2006 WHO Guidelines. This chapter presents the first attempt at applying a holistic CEA framework that integrates the health gains in terms of diarrhoeal disease reduction and cost of treatment and non-treatment interventions associated with wastewater irrigation in urban Ghana.

Description of interventions

Both intervention types, treatment and non-treatment, were considered in comparison with the common (baseline) practices of wastewater irrigation, independently and in combination. For the non-treatment option a variety of improved practices were tested at different critical control points, i.e. on the farm, in markets and in kitchens of the street-food sector, in terms of their ability to reduce faecal coliforms and helminth eggs on vegetables mostly eaten raw (Drechsel et al., 2008). Chapters 10 and 12 in this book provide more details on this. For the promotion of these practices the International Water Management Institute (IWMI) and national partners suggested a 36-month campaign.

The campaign targeted farmers using wastewater for irrigation and street-food kitchens selling wastewater-irrigated salads as part of common urban fast-food dishes. For the CEA, the on-farm and off-farm components of the campaign were assessed separately and in combination. The campaign was largely based on social marketing, incentives and education (see also Chapter 16), and included improved irrigation practices such as cessation of irrigation, drip irrigation and improved overhead irrigation at the farm level, as well as more effective vegetable-washing practices at the post-harvest level.

A set of possible interventions was compiled at the farm and fast-food restaurant level, taking into account different possibilities and constraints at different locations. As some practices will have a higher applicability and adoption potential at one site than another their average risk reduction was used in the analysis presented here. Thus, in the assessment, the specific improved practices were categorized into two groups, on farm and post-harvest respectively, with no further distinctions between the different interventions. Aside from those 'non-treatment' options, the IWMI project carried out an inventory of all 70 (largely dysfunctional) wastewater treatment plants (WWTP) in Ghana to analyse, among things, their costs of rehabilitation. Nine smaller wastewater treatment plants with minor technical problems were selected for rehabilitation across five major cities in Ghana where wastewater irrigation is practised, each meeting the following criteria:

- The treatment plant had farmland available for irrigation purposes.
- Wastewater irrigation is undertaken in the town/city where the treatment plant is located.
- The readiness and willingness of local regulatory authorities and managers of the plant to use wastewater for irrigation.
- The cumulative area would be large enough to absorb the large majority of farmers currently using untreated wastewater.

In addition to the rehabilitation option, the ongoing construction of a smaller new wastewater treatment plant in Legon, Accra[1] (with a theoretically possible large-scale irrigation component) was assessed, using official cost estimates. Finally, all possible combinations of treatment and non-treatment options were assessed.

METHODS

An integrated approach combining QMRA, DALYs and CEA was applied to estimate quantitatively the health effects and cost-effectiveness of the interventions. For this, the QMRA framework presented by Haas et al. (1999) was followed while DALY estimations were based on Murray (1994). The cost-effectiveness of the interventions was constructed following the WHO guide to cost-effectiveness analysis (WHO, 2003). A detailed description of the methodology is presented as follows.

Health-risk assessment

Hazard identification

All diarrhoea-causing pathogenic organisms of viral, bacterial, protozoan and parasitic origins are present in wastewater and can be transmitted via the consumption of wastewater-irrigated vegetables. In Ghana, studies on the microbial hazards in wastewater have so far been limited to faecal coliforms and helminths (Amoah et al., 2007; Obuobie et al., 2006). However, epidemiological investigations of diarrhoea prevalence have consistently detected a wide range of pathogenic organisms including rotavirus (Reither et al., 2007), (non-typhi) *Salmonella* and *Cryptosporidium* (Adjei et al., 2004) suggesting that these organisms can potentially be found in the wastewater used for vegetable irrigation. Therefore, for this assessment, we chose rotavirus, *Cryptosporidium* and *Salmonella* respectively as representative organisms for the viral, protozoan and bacterial infections and diarrhoea cases.

Rotavirus has been used as a representative organism in health-risk assessments associated with wastewater irrigation in Ghana (Seidu et al., 2008) and elsewhere (Hamilton et al., 2006; Mara et al., 2007; Shuval et al., 1997). (Non-typhi) *Salmonella* has been found in street-salad vegetables potentially irrigated with wastewater (Mensah et al., 2002). It is also a major cause of foodborne diseases worldwide and has been used as a representative organism for bacterial infections in a risk-assessment study (Gerba et al., 2008). *Cryptosporidium* has also been used as a representative organism in quantitative microbial risk studies (Mara et al., 2007) and is widely associated with diarrhoeal diseases worldwide.

As indicated above, none of these organisms has been directly investigated and detected in wastewater in Ghana. Therefore, their concentrations in irrigation wastewater were determined by extrapolation using ratios (pathogenic bacteria/virus/protozoan to indicator bacteria) ranging from a conservative $1{:}10^5$ to the least conservative $1{:}10^6$ and $1{:}10^4$ to $1{:}10^5$ were used to predict the concentration of rotavirus and *Salmonella* in wastewater respectively (Gerba et al., 2008). For *Cryptosporidium,* a range of $1{:}10^6$ to $1{:}10^7$ (Mara et al., 2007) was used. For the wastewater treatment options, the faecal coliform concentrations reported for domestic wastewater in Ghana (Awuah et al., 1996) were used. For the non-treatment interventions (farm and post-harvest improved practices), the reported concentration of faecal coliforms in stormwater drains in Ghana (Keraita and Drechsel, 2004; Obuobie et al., 2006) and on crops (Amoah et al., 2007) were used. To account for uncertainty, the reported faecal coliform concentrations in the wastewater were assumed to follow a lognormal probability distribution (Table 13.1).

Exposure assessment, dose-response and risk of infection

Exposure to the pathogenic organisms for each of the interventions was modelled for wastewater-irrigated lettuce by accounting for the reductions in faecal coliforms

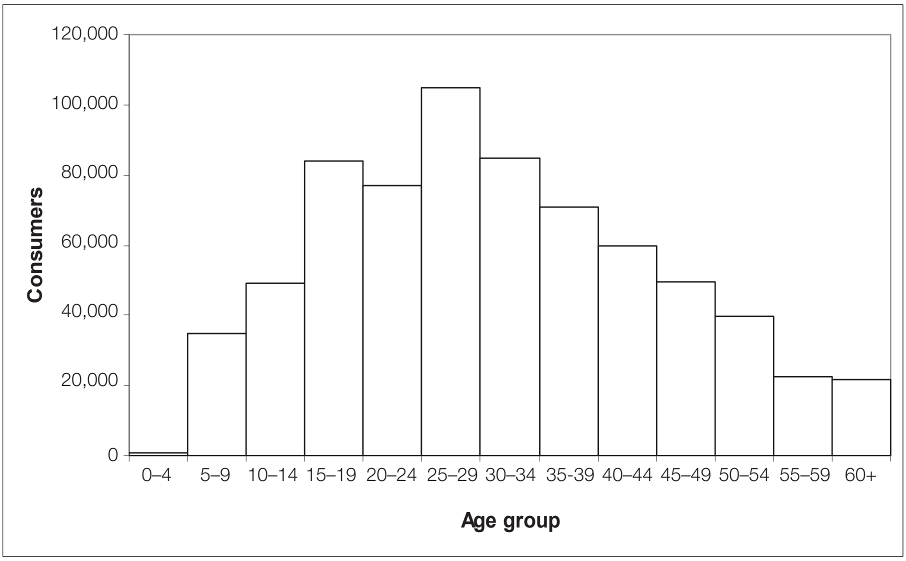

Figure 13.1 *Projected distribution of wastewater-irrigated lettuce consumer population in urban Ghana*

attributable to each of the interventions using the probability distributions in Table 13.1. The exposed consumer population was estimated from surveys of restaurants and food vendors serving wastewater-irrigated lettuce salad by following the distribution-consumption path described by Amoah et al. (2007) and was approximately 700,000 per day in Ghana's five largest cities where urban fast food is common (IWMI, 2009). From this survey and an earlier study (Obuobie et al., 2006), it was found that consumers in the streets of Accra and Kumasi, on average, ate about 13g of lettuce salad three times per week, resulting in an annual consumption of 1.87kg per person (IWMI, 2009). Since response to various pathogenic organisms is age-dependent, this was accounted for by stratifying consumers of lettuce at restaurants and fast-food vendors. Figure 13.1 shows a standardized age-cohort distribution of the exposed consumer population.

The dose of organisms D_i ingested by consuming irrigated lettuce was determined as:

$$D_i = Q_i \,.\, V_i \,.\, V_c \,.\, 10^{-n} \qquad 13.1$$

Q_i is the mass of lettuce consumed per meal (g); V_i is the volume of irrigation water left on lettuce after harvest (ml g^{-1}); V_c is the concentration of pathogens per volume of wastewater (number of pathogens g^{-1}); and n log unit reduction in pathogens associated with the interventions. V_i was assumed to be between 10.8ml

Table 13.1 *Efficacy of treatment and non-treatment interventions*

Concentration of faecal coliforms in irrigation water source	Interventions	Log_{10} reduction	References	Probability distribution used for reduction in faecal coliforms
Treatment options: Domestic wastewater	Wastewater treatment plant	3–6	WHO (2006)	Triangular (3, 4, 6)
Lognormal (10^8, 10^8)[a]		2–3	Hodgson (2000); Awuah et al. (1996)	
Non-treatment options:	On farm: Cessation of irrigation	0.65–0.66 per day	Drechsel et al. (2008)	Uniform (2, 3)[c]
Stormwater drain wastewater	On farm: Overhead irrigation at <0.5m	2–2.5	Drechsel et al. (2008)	
Lognormal (10^6, 10^8)[b]	On farm: Drip irrigation	3–4	Drechsel et al. (2008)	
	Post-harvest: Washing of vegetables with only clean water (cold water for 2 min)	1–1.4	Drechsel et al. (2008)	Uniform (1, 2)
	Post-harvest: Washing of lettuce with clean water and disinfectant	2.1–2.2	Drechsel et al. (2008)	

[a] Awuah et al. (1996).
[b] Obuobie et al. (2006) and Keraita and Drechsel et al. (2004).
[c] A maximum of 3 log unit reduction instead of 4 log was taken to account for problems of clogging associated with the use of drip kits by farmers in Ghana.

and 15ml (Mara et al., 2007; Seidu et al., 2008), a range based on the 10.8ml reported by Shuval et al. (1997).

For the dose-response relationships, the beta-Poisson dose-response model (which assumes the pathogen-host survival probability to vary according to a beta distribution) was used for rotavirus and *Salmonella* (non-typhi), as it best describes the dose-response relationships for both organisms (Haas et al., 1999) in human feeding trials involving rotavirus (Ward et al., 1986) and *Salmonella* of several strains (McCullough and Eisele, 1951a; 1951b; 1951c). For *Cryptosporidium* the single hit exponential dose-response model (which assumes constancy of the pathogen-host survival probability) best describes its dose-response relationship obtained from human feeding trials (DuPont et al., 1995; Haas et al., 1999). In the case of a single exposure, the beta-Poisson and exponential dose-response models are respectively expressed as:

$$P_{i\,(d)} = 1 - \left[1 + \left(\frac{D_i}{N_{50}}\right)\left(2^{\frac{1}{\alpha}} - 1\right)\right]^{-\alpha} \qquad 13.2$$

$$P_{i\,(d)} = 1 - e^{-(rD_i)} \qquad 13.3$$

$P_{i\,(d)}$ is the probability of becoming infected by ingesting D_i number of organisms, N_{50} is the median infection dose representing the number of organisms that will infect 50 per cent of the exposed population; and α and r are the dimensionless infectivity constants. For rotavirus, N_{50} and α are 6.17 and 0.253 respectively; for *Salmonella*, N_{50} is 23,600 and α is 0.3126; and for *Cryptosporidium* r is 0.0042 (Haas et al., 1999). We estimated the annual risk of infection for the organisms by accounting for the dose and frequency of consumption presented above using the formula:

$$P_A = 1 - (1 - P_{i(d)})^{156} \qquad 13.4$$

P_A is the annual risk of infection and $P_{i\,(d)}$ is as described above. All the models were constructed in Microsoft Excel and calculated with Monte Carlo simulation at 10,000 iterations using the @ Risk 4.5 (Palisade Corporation) software add-on to Excel.

Diarrhoea morbidity, mortality and Disability-Adjusted Life Years

Epidemiological data on the transition from infection with the selected pathogenic organisms to disease (mild or severe) or death are lacking for Ghana. Therefore, studies undertaken in other regions were relied on. For rotavirus, it was assumed that after infection 10–15 per cent are asymptomatic, while 85–90 per cent develop diarrhoea of which in Ghana 12 per cent of the cases are severe, with the rest suffering mild diarrhoea leading to full recovery. From the severe diarrhoea cases it was assumed that 5 per cent die (Havelaar and Melse, 2003).

Rotavirus diarrhoea-related disease is common among children. However, some studies have also reported the incidence of diarrhoea among adults infected with rotavirus. A rotavirus outbreak study among college students has reported that of the 83 cases of rotavirus infection, 93 per cent had diarrhoea with a full recovery (Fletcher et al., 2000). In another study of children with rotavirus in 28 families, 18 of 54 adult family members exposed to rotavirus developed evidence of infection, and all but four had diarrhoea (Grimwood et al., 1988).

Based on this, it was assumed that the severe diarrhoea cases and deaths can occur mainly in the consumer age groups of 1–14 years (i.e. over and above the widely reported key age group of 0–5 years who, from our survey, are not frequent consumers of street food served with wastewater-irrigated lettuce) and those over 60 years. The choice of this wide range, including those in the over 60 age group, was to account for potential outbreak incidence. It was further assumed that the other age groups (15–60 years) will develop mild diarrhoea with full recovery.

For *Cryptosporidium* infection, it is known that in developed countries, 71 per cent of infected immunocompetent persons develop gastroenteritis, while population-based outbreak studies and volunteer experiments report relapses of diarrhoea in 40–70 per cent of patients (Havelaar and Melse, 2003). The only well-documented *Cryptosporidium*-related mortality is the waterborne disease outbreak in Milwaukee where four deaths were reported out of 400,000 diarrhoea cases (Mackenzie et al., 1994). For the purposes of this study, it was assumed that 70 per cent of those infected with *Cryptosporidium* following consumption of lettuce will develop diarrhoea with a mortality rate of 0.1 per cent, to reflect the potentially high mortality rates in developing countries (Havelaar and Melse, 2003).

For *Salmonella*, studies based on the FoodNet database (Kennedy et al., 2004; Voetsch et al., 2004) were used. From these studies, it was estimated that 50.3 per cent and 49.7 per cent of consumers infected with *Salmonella* non-typhoid will develop bloody and non-bloody diarrhoea respectively. From the bloody diarrhoea cases, it was assumed that 20 per cent will be hospitalized as severe cases for an average of three days with a 0.6 per cent fatality rate (Kennedy et al., 2004; Voetsch et al., 2004).

To ascertain the efficacy of the interventions in comparison with the status quo, the burden of morbidity and mortality of the diarrhoeal disease cases resulting from the infections under each of the interventions was estimated using the DALY approach. DALY combines years of life lost by premature mortality with years lived with a disability, standardized using severity or disability weights (Murray, 1994). The approach was first introduced in the *World Development Report* (World Bank 1993) and was revised in 1996 for the *Global Burden of Disease* studies (Murray and Lopez, 1996). For each of the pathogenic organisms, the DALYs/year were calculated using the equation:

$$\text{DALYs} = \text{YLLs} + \text{YLDs} \qquad 13.5$$

YLL is the number of years of life lost due to mortality and YLD is the number of years lived with a disability, weighed with a factor between 0 and 1 for the severity of the disability or disease.

YLLs and YLDs were derived using the equations:

$$YLLs[r, K, \beta] = \frac{KCe^{ra}}{(r+\beta)^2}\{e^{-(r+\beta)(L+a)}[-(r+\beta)(L+a)-1]-e^{-(r+\beta)a}[-(r+\beta)a-1]\} + \frac{1-K}{r}(1-e^{-rl}) \qquad 13.6$$

$$YLDs[r, K, ß] = D\{\frac{KCe^{ra}}{(r+ß)^2}\{e^{-(r+ß)(L+a)}[-(r+ß)(L+a)-1]-e^{-(r+ß)a}[-(r+ß)a-1]\} + \frac{1-K}{r}(1-e^{-rl})\} \quad 13.7$$

K = age weighting modulation factor; C = constant; r = discount rate; a = age of death; $ß$ = parameter from the age weighting function; L = standard expectation of life at age a.

For rotavirus the severity indexes of mild diarrhoea and severe diarrhoea were taken as 0.1 and 0.23. For *Cryptosporidium* and *Salmonella,* 0.067 was used as the severity index for watery diarrhoea cases. Bloody *Salmonella*-related diarrhoea was accounted for with a severity index of 0.39 (Havelaar and Melse, 2003). All mild and severe diarrhoea cases lasted seven days while the very severe cases with blood lasted 5.6 days based on bloody diarrhoea associated with *E. coli* O157 (Havelaar and Melse, 2003). Deaths resulting from all the diarrhoea cases irrespective of the organism involved had a severity index of 1. A standard life expectancy of 60 years (GSS, 2002) across all the age groups with a standard age-weighting modulation factor ranging from 0 to 1 was used, and the parameters $ß$ and C were set at 0.04 and 0.1658 respectively (Murray, 1996). The DALY model for the interventions was constructed and simulated in Excel and discounted at 3 per cent annually (WHO, 2003).

Costing interventions

The ingredient approach, which totals all the inputs as the products of their respective quantities and values, was used to estimate the cost of the interventions. For the suggested three-year campaign (IWMI, 2009) targeting farmers and fast-food vendors/restaurants, all relevant stakeholders including the Ghana Social Marketing Foundation, Ministry of Food and Agriculture (MOFA) and the Food and Drugs Board (FDB) were interviewed to get a feasible cost-assessment for the campaign.

For the nine treatment plants selected for rehabilitation, a facility assessment survey was carried out by local sanitation consultants to elicit information on the inputs/materials required for a basic (low-cost) upgrading towards effective operation (IWMI, 2009). In the case of the new wastewater treatment plant all costs were obtained from the appraisal reports of the African Development Bank-funded Accra Sewerage Improvement Project (ASIP) (IWMI, 2009). All cost streams obtained for the different interventions were separated as capital or recurrent. All cost items for the various interventions including their components are summarized in 2008 US dollars (Tables 13.2–13.3). Capital costs were annualized and recurrent costs discounted over three years for the non-treatment campaign and ten years for the treatment interventions. For comparability across regions, capital and recurrent costs for the interventions were annualized and

Table 13.2 *Summary of costs for non-treatment options (national campaign)*

Intervention	Component	Cost (US$) (36 months)	Total Cost (US$)
Campaign reaching all vegetable *farmers* in five major cities	Programme Management & Administration	300,000	1,100,000
	Training and Materials	440,000	
	Enforcement/Follow-Up	260,000	
	Marketing Study	100,000	
Campaign reaching all vegetable *street-food vendors/restaurants* in five major cities	Programme Management & Administration	310,000	1,820,000
	Training/Social Marketing	1,050,000	
	Enforcement/Follow-Up	240,000	
	Marketing Study	220,000	
Total			2,920,000

Source: IWMI (2009)

Table 13.3 *Summary of costs of two 'treatment' options*

	Selected Plants	Cost (US$)
1) WWTP Rehabilitation Restricted rehabilitation of core functions of selected plants with agricultural lands	Roman Ridge, Accra	5,500
	PRESEC, Accra	48,500
	KNUST, Kumasi	50,000
	Asafo, Kumasi	7,000
	Pantang, Accra	20,000
	Kamina Barracks, Tamale	20,000
	UCEW, Winneba	25,000
	Ankaful WWTP	25,000
	Volta Star WWTP, Juapong	17,000
	Total	**218,000**
	Total annual O&M incl. staff labour for all 9 plants	+333,000
2) Construction New construction of a small treatment plant with sewer rehabilitation and extension (part of the already funded and ongoing ASIP project)	University of Ghana, Accra:	
	Sewer (re)connection	16,500,000
	Ponds and pumping station	6,700,000
	Total	**23,200,000**

Source: IWMI (2009)

discounted at 3 per cent as the base case and at rates of 0 per cent and 6 per cent for sensitivity analysis (WHO, 2003). To account for uncertainty around the cost estimates, the triangular probability distribution was fitted to all the capital and recurrent costs by taking the minimum and maximum likely values at +/– 20 per cent, respectively.

Cost-effectiveness

Cost-effectiveness of the interventions was modelled with the TreeAge ProHealth Suit Software (www.treeage.com) (Robberstad et al., 2007). The average cost-effectiveness ratios (CER) were calculated in US$ per DALY (i.e. the cost incurred for each DALY averted by the intervention) as well as the incremental cost-effectiveness ratios (ICER) (i.e. the additional cost needed for each additional unit of DALY averted resulting from investment in the intervention rather than its comparator) after accounting for the DALYs averted for each of the interventions in relation to the status quo (no intervention scenario). An expansion path analysis, based on the ICER, was also made to highlight dominated interventions (i.e. interventions that are both costly and less effective than their comparators) and for the ranking of the interventions. All costs and DALYs averted were discounted at 3 per cent as baseline with further sensitivity analysis at 0 per cent and 6 per cent, as suggested by the WHO. The cost-effectiveness ratios were compared with a cut-off value of US$150/DALY averted, which was used for many years as a rough economic evaluation criterion by which a health intervention in a developing country is considered cost-effective (World Bank, 1993). All interventions with cost-effectiveness ratios of < US$150/DALY were considered cost-effective while those > US$150/DALY were classified as unattractive.[2]

Sensitivity and uncertainty analysis

A one-way sensitivity analysis was also made to ascertain the effects of variations in the discount and campaign adoption rates as well as costs on the CER and ICER. The CER and ICER were calculated for each of the interventions by varying the discount rate for costs and benefits (DALYs) from 0 per cent to 6 per cent. As the calculations were based on a successful campaign with 100 per cent adoption, the sensitivity analysis was used to address lower adoption rates. Adoption rates of 25 per cent and 75 per cent representing pessimistic and optimistic scenarios respectively were assessed for the on-farm and post-harvest interventions. For the costs, as stated above, triangular distributions were applied for both the capital and recurrent costs with minimum and maximum values at 20 per cent below and above the most likely value, calculated from the ingredient approach (Robberstad et al., 2007). From the triangular distributions, 10,000 Monte Carlo simulations were made and CERs calculated. From these iterations mean CERs with 95 per cent confidence intervals were derived for each of the interventions.

RESULTS

Infection risks, diarrhoea cases and DALYs

The annual infection risk associated with the consumption of lettuce salad irrigated under the current wastewater-irrigation and post-harvest practices across the country showed a high viral infection risk. The median viral infection risk was of a magnitude of 10^{-1} per person per year (pppy) while those of bacterial and protozoan were 10^{-5} pppy indicating that the risks of bacterial and protozoan infection given the current wastewater irrigation practices met the WHO tolerable infection risk of 10^{-4} pppy. These infection risks resulted in 477,258 self-limiting (mild) diarrhoea cases, representing 0.68 episodes per consumer per year. This falls outside the range of diarrhoea incidence of 0.8–1.3 pppy for all ages in developing countries, but approximates the global average diarrhoea incidence of 0.7 pppy (Mathers et al., 2002). Of the 0.68 diarrhoea episodes, about 14 per cent and 0.1 per cent were severe and fatal respectively and translated into 12,016 DALYs annually, representing 0.017 DALYs pppy. This figure represents nearly 10 per cent of the WHO-reported DALYs occurring in urban Ghana due to various types of water- and sanitation-related diarrhoea (Prüss-Ustün et al., 2008).

Effectiveness of interventions

The assessment shows that 41–92 per cent of the total DALYs (related to the consumption of wastewater-irrigated salads) can be averted through the different on-farm and post-harvest interventions (Figure 13.2). A campaign targeting improved farm practices could avert up to 92 per cent of the DALYs while up to 74 per cent could be averted through interventions in the street-food sector. Also, the rehabilitation of the nine selected WWTPs with farmland nearby and well distributed over the country could allow a high DALY reduction of 82 per cent if farmers would agree to move to those sites. Building a new WWTP (independently of its level of sophistication and cost) would certainly be very effective in its treatment but could not accommodate all farmers (even in Accra, with the greatest amount of irrigated urban farming) and supply all required vegetables. Thus, it would only avert in the best case 44 per cent of the annual DALYs. Combined non-treatment options (on farm, off farm) or non-treatment options and the rehabilitation of the nine WWTPs would in all cases increase the health benefit by averting 94 per cent of the DALYs, which is not much more than the farm interventions alone if they are broadly adopted.

Cost-effectiveness of interventions

As presented in Table 13.4, the CERs ranged from US$31/DALY to US$812/DALY on average. Based on the rough CER benchmark of US$150/DALY, the

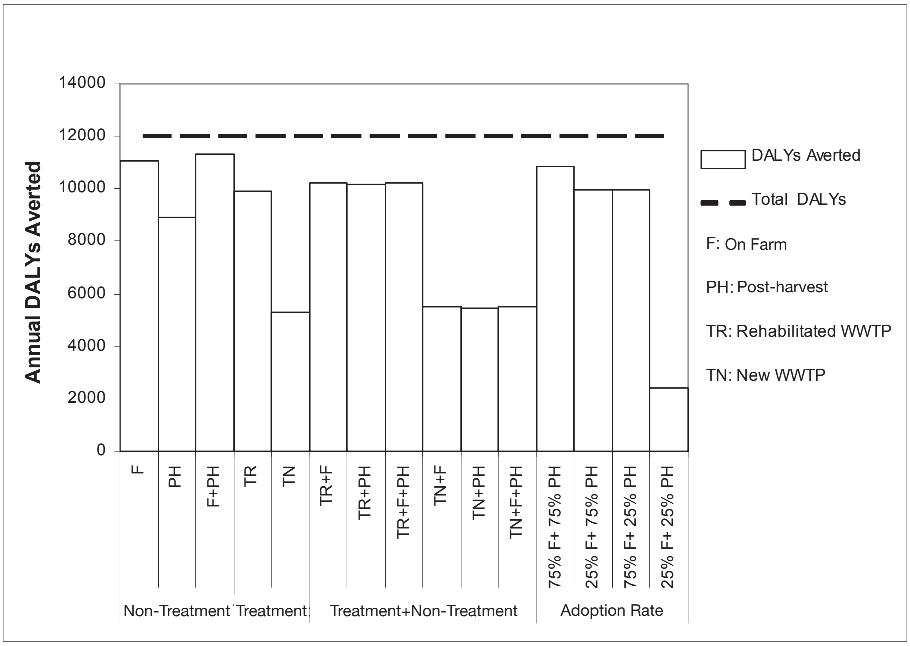

Figure 13.2 *DALYs averted by interventions*

most cost-effective interventions are those targeting health-risk reduction at the farm level (CER of US$31/DALY). Also, the low-cost rehabilitation of a larger number of existing but underperforming WWTPs well distributed over urban Ghana can be very cost-effective. These two options demand that farmers either adopt safer irrigation practices or move to sites with safer (treated) water. Also combining both options to offer farmers more choices is still very cost-effective (US$40/DALY) and so is the multiple-barrier approach combining low-cost rehabilitations, on-farm interventions and post-harvest (street-food) interventions. This is important as it offers more options and security for risk reduction while only marginally increasing the costs per DALY averted.

Only the construction of new WWTPs could not be considered as cost-effective in view of health-risk reduction related to wastewater-irrigated salads. The reason is not only the low coverage but the high costs, even of simple pond systems, if sewer connections are planned. Thus, increasing the number of new plants to cover all land needed for satisfying the current demand for salad greens would even decrease the CER despite averting all DALYs. This also applies to any non-treatment intervention combined with construction of a new WWTP.

The high cost-competitiveness of the WWTP rehabilitation is due to the limited investments needed to get the selected systems working again; the costs

Table 13.4 *Cost-effectiveness ratios of interventions*

Interventions	CER (US$/DALY)	
	Mean	CI (5–95%)
Non-Treatment Options Campaign		
100% adoption rate (AR) on farm	31	27–35
100% AR post-harvest	67	58–76
100% AR on farm + post-harvest	83	72–95
25% AR on farm + 75% AR post-harvest	95	82–108
75% AR on farm + 25% AR post-harvest	94	81–107
25% AR on farm + 25% AR post-harvest (pessimistic scenario case)	394	340–447
75% AR on-farm + 75% AR post-harvest (optimistic scenario case)	87	75–98
Treatment Options		
Rehabilitation of selected urban WWTPs	31	27–35
Construction of one new WWTP with household connections	786	678–893
Combined Options		
Rehabilitation + on farm	40	34–45
Rehabilitation + post-harvest	48	41–54
Rehabilitation + on farm + post-harvest	57	50–65
Construction + on farm	771	666–877
Construction + post-harvest	798	689–907
Construction + on farm + post-harvest	812	702–924

are even lower than the funds required for a national campaign on non-treatment options. However, as mentioned before, this option assumes no further costs on sewer to household connections and that the farmers move to those sites with treated wastewater. Where this would increase their transport costs, incentives will be needed to ensure that farmers do not maintain their current high-risk plots.

Even though the CERs provide significant information regarding the efficacy of interventions, they cannot be used to rank the interventions without considering resource constraints. Therefore, an expansion path, based on the incremental cost-effectiveness of the interventions, was undertaken by first ranking all the interventions in terms of their effectiveness. Figure 13.3 shows the expansion path for the interventions given that there is no resource constraint. The associated incremental cost-effectiveness analysis shows that the most cost-effective path for the implementation of possible interventions is from the rehabilitation of the WWTPs to on-farm interventions to a combination of on-farm and post-harvest interventions. All other interventions were completely dominated, i.e. resulted in negative incremental effects against a comparator.

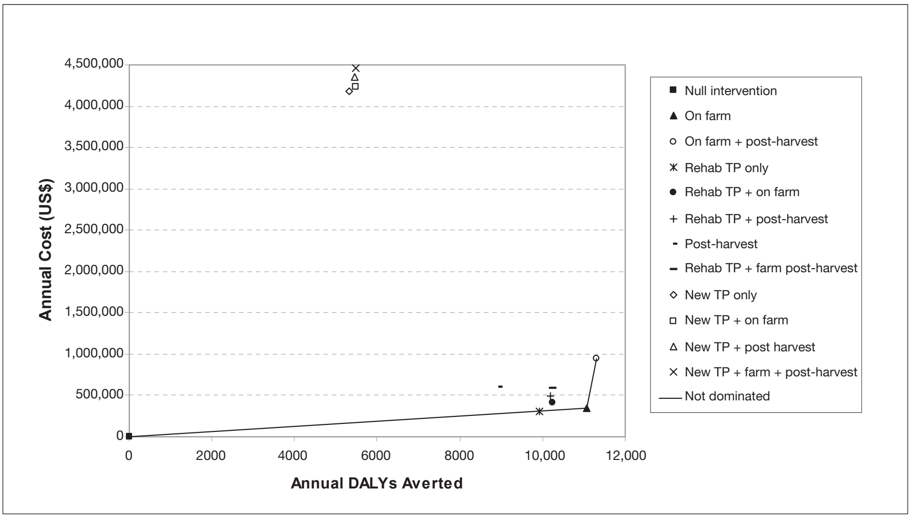

Figure 13.3 *Expansion path showing dominated interventions*

Sensitivity and uncertainty analysis

Discounting the cost and health benefits at 0 per cent and 6 per cent significantly affected the average CER, but this did not affect the ranking of the interventions in terms of incremental cost-effectiveness ratios (results not shown). Also, there was a remarkable effect of the campaign adoption at the farm and post-harvest sectors on the overall effectiveness and, hence, the cost-effectiveness of the interventions (Figure 13.2 and Table 13.4).

Generally, the relationship describing this phenomenon was exponential. Given the pessimistic scenario where only 25 per cent of farmers and food vendors adopted the improved practices of the campaign, only 20 per cent of the DALYs lost were averted, resulting in a CER of US$394/DALY, which is more than twice the benchmark CER and thus making the campaign unattractive. The optimistic scenario representing 75 per cent adoption of improved practices across the farm and post-harvest sectors averted about 90 per cent of the DALYs, leading to a CER of US$87/DALY. This shows that significant health gains can still be made cost-effectively at marginal non-compliance rates of up to 25 per cent for the optimistic scenario in this study across the farm and post-harvest sectors. Further calculations based on the exponential relation show that a maximum non-compliance (non-adoption) rate of about 30 per cent across the farm and post-harvest sectors could still make the campaign attractive in view of the US$150 benchmark.

Discussion

The assessment has shown that the consumption of wastewater-irrigated lettuce is likely to significantly contribute to cases of diarrhoea and DALYs with a disproportionate impact on children. The results were compared with the EU-funded SWITCH project which used QMRA to assess the disease burden associated with contaminated piped drinking water, flooding, playing in open storm water drains, swimming at urban beaches and occupational contact with faecal matter in Accra (Lunani et al., 2009). It was found that for the same urban area and population the consumption of wastewater-irrigated vegetables appears to be the second highest in risk after children exposed to an open stormwater drain (IWMI, 2009).

Mensah et al. (2002) found a wide range of pathogenic organisms including *Staphylococcus aureus* in street-food salad in Accra and concluded that the lettuce and cabbage used in the preparation of the salad were potentially irrigated with wastewater and/or fertilized with poorly composted manure. In the same study, poor hygiene practices by street-food vendors serving salad were also implicated in the microbial contamination of the salad served. This study, together with others (Amoah et al., 2007; Obuobie et al., 2006; Seidu et al., 2008), stressed the importance of on-farm and post-harvest practices as control points for the reduction of the health hazards associated with wastewater irrigation.

As the results indicate, health-reduction measures at these points have the potential to avert a high number of DALYs and are cost-effective as well. Nevertheless, the sensitivity analysis showed the importance of strategies that support the adoption of non-treatment options as non-compliance of more than 30 per cent rendered the campaign increasingly unattractive in terms of costs and health gains.

Thus, strategies that ensure a consistent increase in the adoption of improved practices are vital. In this regard, constraints including the additional labour requirements (e.g. farm ponds) or investment needs (e.g. drip kits) of some of the improved practices, or risk of lower yields due to cessation of irrigation or furrow irrigation (see Chapter 12) have to be taken into account in the design of incentive systems and effective campaign programmes. A framework combining incentive systems, education, social marketing and regulations to achieve a high adoption rate as well as practical examples from participatory on-farm research are discussed in Chapters 16 and 17.

It should be stressed that the assessment here generally reflected an endemic situation, accounting for variations in the pathogenic organisms in the stormwater-drain irrigation water with probability distribution functions. These distributions did not account for an epidemic or outbreak situation. In an outbreak or epidemic situation, where the concentration of pathogenic organisms in the irrigation water is significantly elevated, even an adoption of 70–75 per cent may not reduce the total DALYs significantly as an elevated incidence of diarrhoea and DALYs could occur in a cluster of consumer population not affected by the intervention.

Given the sensitivity of the CERs of the non-treatment interventions to farmers' and vendors' adoption rates, it would not make sense to select a single critical control point. It is thus proposed that both treatment (rehabilitation of wastewater treatment plants for wastewater treatment) and non-treatment interventions (on-farm improved irrigation practices and post-harvest washing practices by fast-food vendors) be combined to increase the probability of DALY reduction while only marginally decreasing the CER. In this regard, a combination involving the basic rehabilitation of the nine Ghanaian wastewater treatment plants together with both or either of the non-treatment options will not only reflect best the 'multi-barrier' approach promoted by the WHO (2006) but also provide some safety against potential failures in the suggested campaigns.

It is, for example, uncertain whether the probability of behaviour-change will be higher among farmers than vendors or vice versa. To increase the probability of success, it is thus recommended to address both groups.

In the CEA of interventions to reduce health risks related to wastewater-irrigated vegetables, those involving the construction of a new wastewater treatment plant were less attractive. Despite the small size of the plant, a major cost factor in the Accra case was the rehabilitation and construction of household connections which dominated the actual pond construction by a factor of three to one.

However, WWTPs might be cost-effective in terms of other reduced health risks (e.g. if underground sewers replace open drains), household support and/or environmental protection, which are not considered here. There is also no question about the effectiveness of WWTPs for pathogen and diarrhoeal disease reduction (Barreto et al., 2007; Kolahi et al., 2009; WHO, 2006). It is therefore recommended to be, on the one hand, location- and case-specific, but on the other, to carry out a more encompassing cost-effectiveness assessment that includes all locally relevant diarrhoeal-related risk factors that may be impacted by the construction of a WWTP and other benefits of WWTPs.

The estimated CERs for the interventions presented here are comparable with those of other water, sanitation and hygiene interventions worldwide, which range from US$3.35–$20/DALY for hygiene behaviour-change to up to US$6,396/DALY for improved urban water supply and sanitation systems (Table 13.5). The comparison shows that the non-treatment options as well as low-cost rehabilitation of existing treatment plants can be as cost-effective as the promotion of hand-washing or water chlorination. Also, the estimated CER for the non-treatment (on-farm and post-harvest practices) and basic rehabilitation of treatment plants for vegetable irrigation compares favourably with an estimated cost-effectiveness ratio of US$516/DALY for the reduction of diarrhoea associated with the coverage of stormwater drains in Accra (IWMI, 2009). However, due to the fact that these CERs have been arrived at via different methodologies, such comparisons should be used with caution. On the other hand, we may be relatively confident that

Table 13.5 *CER of interventions for diarrhoeal disease reduction*

Intervention	CER (US$/DALY)	
	Mean	Range
Hygiene behaviour-change campaign	–	3–20
Chlorination at household level	–	46–266
Solar disinfection	54	40–74
Ceramic filtration	125	83–59
Basic sanitation (pit latrine) construction and promotion	≤ 270	–
Basic sanitation (promotion only)	11	–
Water supply via hand pumps/stand posts	94	–
Water supply via house connection	223	–
Oral rehydration therapy	1062	132–2570
Rotavirus immunization	2478	1402–8357
Cholera immunization	2945	1658–8274
Improved rural water supply and sanitation	1974	–
Improved urban water supply and sanitation	6396	–
A campaign leading to 75% adoption of safer irrigation and vegetable-washing practices[a]	87	75–98

Source: Cairncross and Valdmanis (2006); Clasen and Haller (2008); Hutton and Haller (2004); Keusch et al. (2006); Lvovsky (2001); [a]this study

an intervention with a CER of US$45/DALY is better than another one with US$450/DALY (Clasen and Haller, 2008).

The assessment applied QMRA to estimate health risks from extrapolated microbial hazards. The extrapolation of the empirically analysed thermotolerant coliform bacteria to the different pathogenic organisms remains, however, only an estimate based on the best available transfer functions; this may result in an underestimation or overestimation of the health risks with the accompanied DALYs and hence the CERs. The study of Donkor et al. (2008), for example, shows that in view of *E. coli* O157:H7, our assessment might be on the safe side. Such uncertainty surrounding the estimates has been accounted for by providing the 95 per cent confidence interval (CI) around the mean CER, to provide policy-makers with an opportunity to better assess intervention options on a continuum. However, a more rigorous study based on epidemiological investigations of the interventions and their associated impact on diarrhoea is needed to further validate the QMRA results and CERs arrived at in this assessment.

Conclusions

The health risk associated with wastewater irrigation in terms of diarrhoea cases and the associated DALYs can be significant. This study has demonstrated that by implementing on-farm and post-harvest interventions, both independently and in combination, the DALYs could be significantly reduced in a very cost-effective way. Although these interventions are attractive, their implementation and subsequent cost-effectiveness relies significantly on the adoption rates by farmers and vendors in the fast-food sectors. It is thus suggested that these interventions be well promoted, taking advantage of tangible or intangible incentives and combined with the rehabilitation of wastewater treatment plants where this is possible at low cost, to ensure, by an only marginally decreased CER, the best allocation of scarce resources. The study also suggests that the construction of new wastewater treatment ponds and related sewer systems is much less cost-effective in terms of public-health-risk reduction from the (limited) perspective of wastewater irrigation. Further studies looking at other 'non-treatment options', as well as the larger impact of treatment plants, are recommended.

NOTES

1 Based on a set of anaerobic, facultative and maturation ponds with a planned intake of 6424m^3/day.
2 In more recent literature, other criteria are used, for example based on the GDP of a country. The Commission on Macroeconomics and Health classifies interventions that have a cost-effectiveness ratio of less than three times GDP per head as cost-effective (CMH, 2001).

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