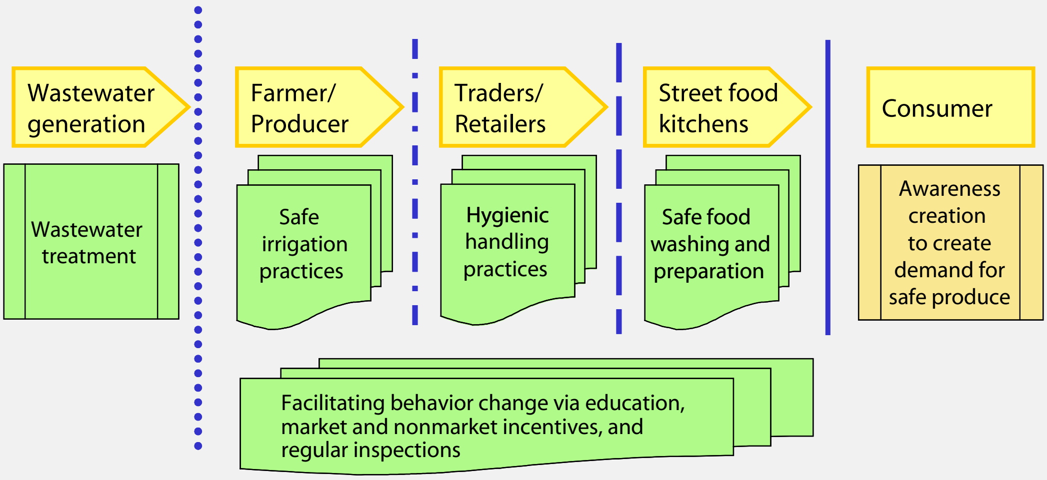
IWMI RESEARCH REPORT

141

Low-Cost Options for Reducing Consumer Health Risks from Farm to Fork Where Crops Are Irrigated with Polluted Water in West Africa

Philip Amoah, Bernard Keraita, Maxwell Akple, Pay Drechsel, Robert C. Abaidoo and Flemming Konradsen



International Water Management Institute

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Cover picture by IWMI shows the multi-barrier approach to safeguard public health from wastewater treatment to farm, market, kitchens and consumers.

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Projects

This report draws from several projects carried out in Ghana and neighboring countries over the last 5 years.

- Impact of Wastewater Use in Urban and Peri-Urban Agriculture in Three Ghanaian Cities
- Safeguarding Public Health Concerns, Livelihoods and Productivity in Wastewater Irrigated Urban and Peri-urban Vegetable Farming
- The Impact of Wastewater Irrigation on Human Health and Food Safety among Urban Communities in the Volta Basin – Opportunities and Risks
- Safe Food despite Wastewater Irrigation: A Knowledge-Sharing Approach to Safe Food
- Improving Productivity and Reducing Health Risks in Wastewater Irrigation
- Nontreatment Options for Safe Wastewater Use in Poor Urban Communities
- Wastewater Irrigation and Public Health: From Research to Impact - A Roadmap for Ghana
- Managing Water for the City of the Future
- Cities Farming for the Future

Collaborators

The following organizations collaborated in the production of this publication.

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IDRC CRDI — International Development Research Centre (IDRC)

CGIAR Challenge Program on Water and Food (CPWF)

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World Health Organization (WHO)

Food and Agriculture Organization of the United Nations (FAO)

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European Commission (EC)/International Fund for Agricultural Development (IFAD) CGIAR Programme

Resource Centres on Urban Agriculture and Food Security (RUAF)

Contents

Acronyms

CGIAR	Consultative Group on International Agricultural Research
CPWF	CGIAR Challenge Program on Water and Food
CREPA	Le Centre Régional pour l'Eau Potable et l'Assainissement à faible coût, Burkina Faso
DALY	Disability-Adjusted Life Year
FAO	Food and Agriculture Organization of the United Nations
HACCP	Hazard Analysis and Critical Control Points
ICT-KM	Information and Communications Technology and Knowledge Management Program
IDE	International Development Enterprises
IDRC	International Development Research Centre, Canada
IFAD	International Fund for Agricultural Development
IWMI	International Water Management Institute
KNUST	Kwame Nkrumah University of Science and Technology, Ghana
KSinR	Knowledge Sharing in Research (ICT-KM Program)
PVC	Polyvinyl Chloride
UDS	University for Development Studies, Ghana
USEPA	United States Environmental Protection Agency
VIPP	Visualization In Participatory Programmes
WHO	World Health Organization

Summary

This report is based on research carried out over the last 5 years in West Africa, particularly in Ghana. The research aimed at developing appropriate intervention measures to reduce health risks posed to consumers from pathogens in domestic wastewater used raw or diluted for irrigation in urban and peri-urban vegetable farming. A variety of methods for participatory action research were used, where various key stakeholders at different levels were actively involved in identifying, testing and assessing intervention measures. Some components of the study have been published in journals earlier, but it is only in this report that all components are included and discussed together in one comprehensive synthesis.

At farm level, the studies showed that sedimentation ponds and filtration techniques like sand filters could reduce the number of helminth eggs to acceptable levels in both dry and wet seasons. However, these interventions could not reduce fecal coliforms to acceptable levels. Among various irrigation methods, low-head bucket drip kits achieved high removal levels of up to 6 log units of fecal coliforms on vegetables. Removal rates for fecal coliforms were usually higher during the dry season. Low sunshine intensities, and splashing of contaminated soils from the use of watering cans and rainfall reduced the effectiveness of interventions during the wet season. To avoid splashing induced by watering cans, simple modifications on their use like lowering the watering height and using a rose on the mouth of the watering can reduced contamination levels on vegetables showing how simple adjustments can lead to significant contamination reduction. Cessation of irrigation was effective on longer durations and in the dry season but withdrawing from irrigating affected the physical quality and yields of vegetables, leading to low acceptance of this possible intervention by farmers. Suggestions to reduce consumer health risks by growing different crops as well as to use mostly alternative safer water sources like groundwater at the existing farming sites were unsuccessful.

The tested market-based interventions had generally less impact on the contamination carried over from the farm, like through the support of microbial die-off but they remain important to prevent new or additional contamination. At the consumer level, the removal of outer cabbage leaves and vegetable washing proved most successful. Washing lettuce, especially with recommended sanitizers and longer contact time, reduced bacterial contamination by around 3 log units, while most washing methods commonly used in Ghana proved to be of little efficacy. There are also alternative and more cost-effective sanitizers used in Francophone West Africa, which could be introduced in Ghana.

To protect the consumer according to the health-based targets suggested by WHO, combining intervention measures at different levels appear most promising. Their actual impact will however depend on their adoption rate. Possible strategies to enhance adoption should be based on social marketing, education, market and nonmarket incentives, and inspections. In the context of a low-income country like Ghana where wastewater treatment has a low coverage and does not protect public health, these findings show that a range of alternative options exist that can significantly reduce the risks from contaminated vegetables in line with the WHO wastewater use guidelines (WHO 2006).

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Introduction

The increasing food demand in many cities in low-income countries due to the rise in urban populations is accompanied with a shift in diets towards processed (fast) food (CTA 2005). In West Africa, the largely informal street food sector is responding to this phenomenon. A study in Accra, Ghana, found that 32% of the household budget went to purchase street foods; half of this budget went to food purchases for children. The percentage was even higher among the poor (Maxwell et al. 2000). The resulting business is good. There are about 60,000 street food vendors in Accra with a combined annual turnover of $[1]100 million (SADAOC 2002; Tomlins 2006).

As a small component of usually rice-based meals, raw salads consisting of leafy exotic vegetables, like lettuce (*Lactuca sativa*), cabbage (*Brassica oleraria*), and spring onion (*Allium cepa*) constitute one of the modern and increasingly common fast food dishes. In Accra, about 800-1,000 farmers are specialized in providing these vegetables which are consumed by over 200,000 Accra residents daily as part of their street food while it is not common to consume raw salads at home (Obuobie et al. 2006; Amoah et al. 2007a).

As many exotic vegetables are easily perishable, and there is hardly any refrigerated transport and storage, they are grown preferably closest to the markets. In many West African cities, up to 90% of vegetables consumed are grown within or near city limits (Drechsel et al. 2006). Leafy vegetables generally have high water requirements and need to be irrigated on a daily basis; therefore, vegetable farming requires constant availability of water, especially in the climate of West Africa. In most cases, however, farmers have no option other than using polluted water sources, as clean water sources are rare in the urban vicinity or unreliable while expensive. A recent survey in Ghana revealed that only 13% of the about 70 decentralized wastewater and fecal sludge treatment plants work approximately as designed and that even if all would work, less than 10% of the urban wastewater would be treated (Murray and Drechsel Forthcoming). This situation appears to be common in and around three out of four cities in the developing world, where wastewater without any significant treatment is used for irrigation purposes (Raschid-Sally and Jayakody 2008).

While wastewater contains many plant nutrients, it can also contain contaminants, like heavy metals. In the West African context, where industrial development is still very limited, and most wastewater is used after strong dilution, more attention is given to excreta-related diseases (Drechsel et al. 2006). Poorly treated or untreated wastewater has high levels of pathogenic

[1]In this report, $=US$.

microorganisms such as bacteria, viruses, parasitic worms and protozoa, and some of them can cause harm in smallest numbers (Blumenthal et al. 2000). The most affected groups are consumers of wastewater irrigated produce and farmers who are in contact with wastewater. Quantitative microbial risk assessment studies indicated a significant threat for farmers and consumers (Seidu et al. 2008) with an annual loss of about 12,000 Disability-Adjusted Life Years (DALY) in Ghana's five major cities due to wastewater contaminated vegetables (Seidu and Drechsel 2010).

This practice has therefore raised public health concerns and is one of the reasons many policymakers are reluctant to support irrigated urban and peri-urban agriculture. Nevertheless, with investments in water supply outpacing those in wastewater treatment, the use of polluted water is expected to continue. Provided it could be made safe, it could actually contribute to resource recovery, an increasingly important topic given the implications of climate change and general water scarcity. Appropriate strategies for reducing health risks are therefore an absolute and urgent necessity to make the practice beneficial and more sustainable. In West Africa, the national authorities are well aware of the challenge offered by wastewater use in agriculture. Ghana's National Irrigation Policy which had cabinet approval in 2010 is the first national policy in Africa which recognizes the challenge in a constructive way and encourages research on safe irrigation practices for irrigated urban and peri-urban agriculture where polluted water is used.

While conventional wastewater treatment has been widely acknowledged as the ultimate measure for reducing health risks from polluted water, wastewater treatment levels in many developing countries remain extremely low, with more than 90% of the wastewater being discharged untreated into water bodies (UNEP and UN-Habitat 2010). Recognizing this limitation, there is increasing advocacy for other measures which could be more appropriate or at least complementary for risk reduction in developing countries. For example, in its revised 2006 wastewater reuse guidelines, WHO adopted a multiple-barrier approach by combining different health protection measures to meet required health-based targets at the consumer level (WHO 2006). This opened the way to target - in line with the Hazard Analysis and Critical Control Points (HACCP) concept - a variety of entry points where health risks occur or can best be mitigated before the food is consumed (Figure 1). In Ghana, a number of research institutions and universities supported by FAO, CPWF, IDRC and WHO have been working with farmers and other stakeholders to explore, develop and test risk reduction measures where vegetables are irrigated with highly polluted water. The main emphasis was put on safety measures from farm to fork, i.e., those protecting consumers of salad greens, of which the findings of the last 5 years are summarized in this research report.

The report is a follow-up to a comprehensive situation analysis in the same cities (Amoah et al. 2005, 2007a; Keraita et al. 2003; Obuobie et al. 2006) and the West African subregion (Drechsel et al. 2006), which highlighted water and crop contamination levels and the potential risks for consumers, and described farmers' livelihoods, gender aspects, cropping systems, farming and irrigation practices, and the institutional context.

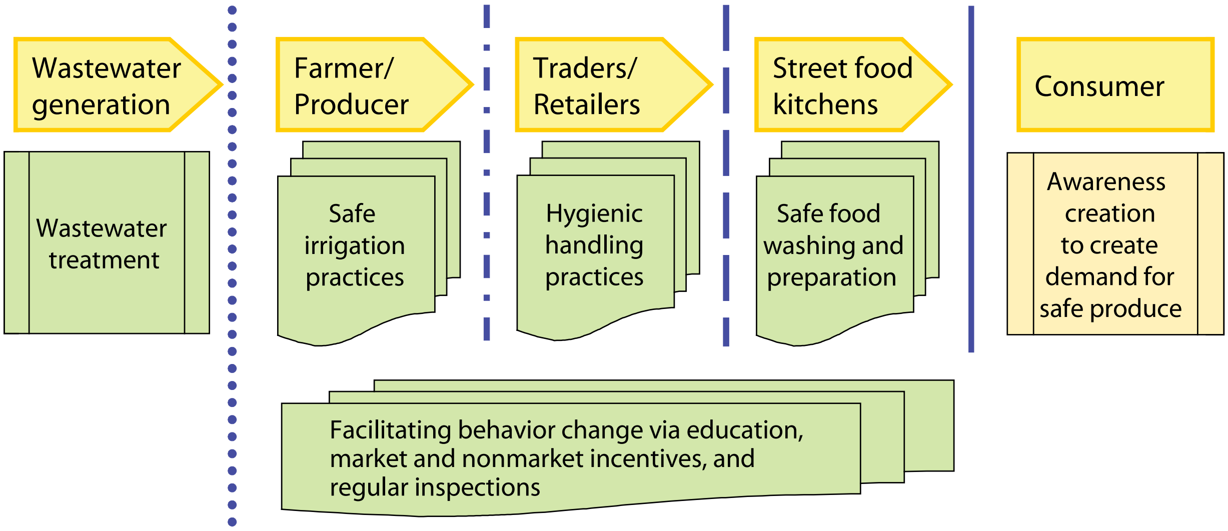

FIGURE 1. Multi-barrier approach to consumer health risk reduction.

Methodology

The Study Area

Most studies were conducted in the two largest cities in Ghana: Accra and Kumasi, and some in Tamale. In these cities vegetables are grown year-round. Although precipitation is relatively high in this region (800 to 1,400 millimeters [mm]) farmers of exotic leafy vegetables water their crops every non-rainy day. In peri-urban areas, many farmers grow vegetables only in the dry season, but maize in the rainy season.

Kumasi is the second largest city in Ghana with a population of about 1 million in 2000. In Kumasi, about 40 hectares (ha) of farmland are distributed around five major sites and many minor sites which are cultivated throughout the year by about 600 farmers. As exotic vegetables need irrigation under the given climate, all these sites are located along urban streams or drains or near shallow wells in inland valleys.

In Kumasi, two vegetable production sites (Gyenyase and Karikari) were chosen for farmer participation on farm trials. The Gyenyase site is the largest urban vegetable-growing site in Kumasi, with a total land area of about 6 ha with dugouts close to smaller streams while farmers at the Karikari site used water from household drains. The main crops grown at these sites are lettuce, cabbage and spring onion. Levels of fecal coliforms in the irrigation water usually vary between 5 and 9 log units 100 ml^{-1} and helminth eggs between 1 and 6 l^{-1}. Among the identified eggs most belonged to *Ascaris lumbricoides*, followed by *Schistosoma* spp., *Strongyloides stercoralis*, *Trichuris trichiura* and with the lowest frequency in *Taenia* spp. (Table 1). Depending on the species these can lead to intestinal obstruction, vomiting, stomach pains and diarrhea as well as anemia through loss of blood in the victim's stools and urine.

TABLE 1. Types of helminth eggs on cabbage sampled from farm, market and street kitchen (n = 369).

Types of helminth eggs identified	Mean number of helminth eggs per 100 grams (g)			
	Farm	Market	Kitchen	Total
Ascaris lumbricoides	11.4	7.8	1.4	20.6
Schistosoma species	4.8	4.2	0.7	9.7
Strongyloides stercoralis	0.5	6.0	-	6.5
Taenia species	0.4	-	-	0.4
Trichuris trichiura	-	2.3	-	2.3
Total	17.1	20.3	2.1	39.5

Source: Akple 2009.

In 2000, Accra, the capital city of Ghana, had a population of about 1.7 million, and between 47 ha (wet season) and 162 ha (dry season) of inner-city vegetable cultivation, engaging about 800-1,000 farmers. Also on most sites in Accra water from storm water drains and highly polluted streams is used. The vegetables for the washing trials were collected from a site in Dzorwulu, which is one of Accra's suburbs with a total farm area of about 12 ha under vegetable production by over 300 farmers. Most of the farmers use water from the Onyansa stream, which receives gray water from the surrounding communities. Other farmers obtain water from household gray water drains. Although most of this water is actually gray water from kitchens and bathrooms, the fecal contamination levels are in the same range as stated above for Kumasi. A very few farmers in Accra use piped water which is however not a reliable source. These sites and the situation in Tamale are described in Obuobie et al. 2006.

Organization of the Study

The research focused on three entry points: a) farm-based measures, b) market-based measures, and c) street-restaurant-based measures to determine effective methods for the reduction of pathogens, using fecal coliforms and helminths as indicators. The focus was set on street food restaurants and not households as in Ghana raw salads are not common at home, but widely served as a component of rice based dishes in the street food sector (Amoah et al. 2007a). The studies were followed by a CGIAR-supported Knowledge Sharing in Research (KSinR) project, which supported a dialogue between farmers, traders, kitchen staff, researchers, and the local extension service of the Ministry of Food and Agriculture. These accompanying studies tried to explore possible adoption constraints and drivers for recommended interventions for reducing health risks (Amoah et al. 2009).

Options Tested in Farmers' Fields

Identification of Farm-based Risk Reduction Interventions

After explaining the challenges of crop contamination with fecal matter and its implications for farmers' and consumers' health, the approach of the Visualization In Participatory Programmes (VIPP) was used to identify measures which a) farmers alone, and b) farmers and researchers together suggested to use to minimize health risks. These addressed the quality of irrigation water as well as of fresh poultry manure. The VIPP approach combines techniques of visualization with methods for interactive learning (Rifkin and Pridmore 2001). Farmers wrote feasible measures for risk reduction on large multicolored paper cards of different shapes and sizes large enough to be seen by the whole group. Farmers who could not write were helped to do so by others present but care was taken by facilitators to minimize influence. After displaying the cards, discussions started among farmers for clarifications, which led to identification of additional measures; all called here primary measures (Table 2). After a presentation of risk reduction measures mentioned by WHO (2006) further measures (secondary measures) were generated from joint discussions by farmers and the research team.

The discussion in this report will focus on consumer risks, as farmers, in general, did not see a significant occupational health risk or accepted any self-protection measure (Obuobie et al. 2006).[2]

Field Trials

Sedimentation ponds: Farmers entering ponds to fetch water whirl up helminth eggs already settled in the sediment. To assess the effect of sedimentation on removal of microbial organisms, or in other words, to assess the impact of fetching water without disturbing the sediment, water samples were taken when ponds were settled, or disturbed/unsettled, and from sediments. Samples from settled water were taken early in the morning before farmers used the ponds; samples from unsettled water were taken during irrigation, i.e., after manual water fetching with watering cans. Sediment samples were taken after fetching water from the bottom of the ponds. To establish sedimentation rates, four ponds with characteristics similar to ponds farmers normally use were constructed for controlled monitoring. Each pond was 1 meter (m) wide, 1 m long and 0.6 m deep, which is typical in the area. Initial filling for all ponds was done from the same water source for uniformity. The ponds were not used for normal irrigation and only disturbed according to the protocol when taking the samples for laboratory analysis. Details are provided in Keraita et al. 2008a. Sampling followed standard procedures (APHA-AWWA-WEF 1998).

Filtration techniques: To assess the efficacy of simple water filtering devices, sand filters were made from cylindrical PVC pipes of 0.17 m diameter and 1.4 m length, sealed at the lower end. Outflow points were positioned about 0.1 m from the lower end and raised with a hose pipe to create a constant water layer on the top of each filter (Muhammad et al. 1996). The constant water layer enhances biofilm growth and prevents the filter media from drying. Locally available sand, commonly used in construction, was used as the filtration media after being manually washed and thoroughly mixed to make trials comparable. Three media depths of 0.5 m, 0.75 m and 1 m, referred in this article as Filter 1, 2 and 3, respectively, were used. A gravel layer 0.2 m thick

TABLE 2. Measures identified by farmers to reduce health risks from contaminated crops.

Source of contamination	Primary measures[a]	Secondary measures[b]
Irrigation water	Provision of safer irrigation water like groundwater Protection of water sources Treating water with chemicals Filtration of irrigation water	Leaving water in irrigation sources to settle and not stepping inside Applying water to roots not on leaves Using right amounts of water Cessation of irrigation days before harvesting Planting crops not eaten raw
Soil	Treat soils	Reducing splashing of soils on vegetables
Manure		Better timing of manure application and using right amounts Using well-composted manures

[a] Measures identified by farmers only.

[b] Measures identified following discussions with researchers.

[2]Most farmers of exotic vegetables do not consume their own produce, unless indirectly as a component of street food.

was underlain on each filter for drainage. Each filter had a plastic bucket reservoir of 40 liters (l) with an outlet tap to regulate flow into the filters. The reservoirs were raised to allow influent to flow by gravity. The sand filters were set up in a one hectare vegetable farm in urban Kumasi and water used for irrigation (household wastewater, mainly gray water) was used as influent. Simple fabric filters were made from cotton cloth, nylon cloth and mosquito netting and attached to a water reservoir (WHO 2002; Morel and Diener 2006). Water for filtration (influent) was taken from irrigation water sources used in two major vegetable farming sites – Gyenyase and Karikari – in Kumasi. For each site, one source of water was used as influent for all the three filters. More details are provided in Keraita et al. 2008b.

Comparison of Irrigation Methods

Different ways of irrigation can result in different pathogen-crop contact and also affect the ability of the water to splash (contaminated) soil particles on the crop. In these trials three systems – watering cans, bucket drip irrigation kits and furrow irrigation – were compared as follows:

Watering cans: Use of watering cans is the most common irrigation method followed by farmers in the subregion (Drechsel et al. 2006; Figure 2). An average can has a capacity of 15 l. The average cropping density is 15 lettuce plants m^{-2}, which was also used in this experiment. Each watering can plot was about 20 m^2, a size which varies between farms. Aside from using the watering cans as common practice control, different can equipments (with and without rose [sprayhead]) on the spout, with and without mesh filter over the inlet) and ways of can holding (different heights) were compared.

Bucket drip irrigation kits: Drip kits were initially introduced in Ghana by FAO but, without any local supplier, did not find use among smallholders. With some local universities exploring self-made drip kits, the system was considered in the study giving the low contact

FIGURE 2. Farmers irrigating high beds with watering cans (with water spreading roses) at the Gyenyase vegetable growing site in Kumasi (Photo credit: Bernard Keraita).

between dripping water and the crop parts above the soil surface. With the local kits still in the test phase, home garden micro-irrigation kits fitted with micro-tube emitters were accessed through International Development Enterprises (IDE). Each kit was originally designed to cover an area of 4 m by 5 m, had two laterals which were 5 m long spaced 1 m apart with emitter spacing of 0.6 m. One kit had a total of 32 micro-tube emitters and each emitter supplied water to two lettuce plants. This gave a cropping density of 3.2 lettuce plants m^{-2} which appeared in our pilot trials as too low for a comparative study and to attract farmers' attention. Modifications were made to increase densities by adding two more laterals and extra emitters to reduce emitter spacing to 0.3 m. This raised the cropping density fourfold. Water was supplied by a plastic bucket of 40 l and was filtered by a cotton cloth supplied with the kits. The bucket was raised 1 m high and supported by a simple wooden structure.

Furrow irrigation: Furrow irrigation can reduce the crop-water contact and is common where gravity flow is possible. In the experimental study, each plot had four parallel furrows spaced about 0.5 m apart following the standard design of furrows in sandy soils. Lettuce was planted on each side of the ridges making eight rows and each row had 30 lettuce crops. Irrigation water was applied to furrows, which had a gradient of about 0.3%. Furrow plots measured 3 m X 8 m. The average cropping density obtained was 10 lettuce plants m^{-2}.

Plots for irrigation methods were randomized in three blocks, each having all three methods. They were adjacent to each other, separated by a walking path of about 1 m width to avoid cross-contamination. Four planting replications were conducted each in the dry and wet seasons. Three lettuce samples were collected from each plot by cutting off lettuce leaves randomly on each plot, making a total of 216 samples. To avoid cross-contamination, each sample from each plot was packed into a sterilized polythene bag and different sterilized gloves were used for each plot. More details are provided in Keraita et al. 2007a, 2010.

Cessation of Irrigation before Harvest

In the study area, leafy vegetables like lettuce are usually irrigated even on the day of harvest. As each day without watering allows natural pathogen die-off, especially for bacteria and viruses, treatments were designed with 2-day intervals for up to 6 days between the last watering and harvesting. The variations were irrigating till harvesting day (T0), with cessation 2 days before (T2), 4 days before (T4), and 6 days before (T6). Treatments were randomized in four blocks, with each block having four treatment plots. Each treatment plot was about 10 m^2. Three farmers (denoted by A, B, C) were involved in the trials. Two farmed on one site (A, B), and one (C) on another. During the dry season, each farmer conducted four repeated sequential trials and two repeated sequential trials during the wet season. Farmers were restricted to using the same water source for all the four blocks during each repeated sequential trial. Altogether 576 samples were collected. For a further understanding on survival of indicator organisms on lettuce in the wet season, six lettuce samples, each weighing about 200 g, were taken randomly after every 2 days for up to 18 days since the last irrigation was done. In addition, altogether 90 inner and outer lettuce samples were also taken to quantify differences in levels of contamination. Further details are provided in Keraita et al. 2007b.

Options Tested in Markets

There are different ways of handling vegetables during and after harvest. These different handling procedures were observed and then compared to determine how far they affect the pathogen load carried over from the farm. In a similar participatory approach as on the farm, common practices were discussed in view of consumer risks and possible interventions. This was supported by laboratory analyses (Abaidoo et al. 2010). Some of the treatments tested in Kumasi are described in Table 3 below. The crops under investigation were again spring onion, cabbage and lettuce.

TABLE 3. Handling methods and proposed interventions.

Handling procedure	Current practice	Tested interventions
Vegetable display	Depending on type, vegetables are displayed (Figure 3) - on the bare ground, - on old maize bags on the ground (cabbage/spring onion), - in a larger bowl without changing refreshing water (lettuce)	Display in well-aerated basket or placed on table In the same bowl but with changing the refreshing water every 2 hours
Storage	Stored after harvest in bags and sold the following day	Stored in well-aerated basket overnight
Removal of outer leaves	Outer leaves not removed (cabbage) Outer leaves removed (a few sellers)	Outer leaves removed in the laboratory to determine the effect under controlled conditions
Cutting cabbage into smaller units	Cutting with bare hands	Cutting with gloves on
Washing	Vegetables not washed before display (most sellers)	Washing vegetables with clean water (with/without disinfectant)

Source: Modified from Abaidoo et al. 2010.

To analyze the possible effects of different clientele and market environments on crop quality, samples were collected in markets serving low-, middle- and high-class dwellers. This was, however, only an indicative pilot as the number of similar markets did not allow any meaningful repetitions and statistical design.

Vegetable samples from the treatments described in Table 3 were collected and analyzed by students from KNUST for contamination levels of fecal coliform and helminth eggs.

(a)

(b)

FIGURE 3. Vegetables displayed (a) on the ground (Photo credit: Philip Amoah), and (b) above the ground (Photo credit: Maxwell Akple) in Ghanaian markets.

Options Tested in Street Food Restaurants

Exploratory Surveys on Vegetable Cleaning in Seven West African Countries

An exploratory survey in 11 cities in West Africa targeted a cross section of 210 restaurants of different standards and about 950 randomly selected household consumers. The cities were Cotonou, Porto-Novo and Sèmè-Podji (all Benin), Ouagadougou (Burkina Faso), Niamey (Niger), Lomé (Togo), Bamako (Mali), Dakar (Senegal), and Accra, Kumasi and Tamale (Ghana). With the exception of the Ghanaian cities, the survey was commissioned to the Centre Régional pour l'Eau Potable et l'Assainissement à faible coût (CREPA). City selection was based on intensity of wastewater-irrigated urban vegetable production and proximity of markets for irrigated crops (see Drechsel et al. 2006). Data collection was mainly by both structured and semi-structured questionnaire interviews supplemented by direct observation by trained interviewing teams (Klutse et al. 2005; Amoah et al. 2007b). To harmonize the survey in the various countries, terms of reference and questionnaires were developed, pretested and discussed with the various city teams. Interviews were conducted in the different communities in the cities to cover a broad spectrum of the population. Sites within the city were stratified based on wealth (high, medium, and low class areas). The purpose of the interviews was to assess the general risk awareness and identify prevalent washing methods used for pathogen decontamination of vegetables during preparation for consumption, be it at home or in (street) restaurants.

Efficacy Trials for Common and Modified Methods of Vegetable Washing

The trials were based on the results of the stakeholder survey and targeted the variety of practices used for washing vegetables in the subregion as well as efficacy-increasing modifications. Laboratory analyses were conducted to determine the impact of these practices on decontamination of fecal coliform and helminth eggs. Samples for the selected decontamination methods were exposed to different concentrations of the applied sanitizers (salt, vinegar, bleach, OMO™, potassium permanganate and chlorine tablets) reflecting those commonly in use as well as lower and higher concentrations. The effect of selected factors (e.g., sanitizer concentration, pH and contact time) was also determined. Details are described in Amoah et al. 2007b.

The vegetable samples (cabbage, spring onion and lettuce) derived from wastewater-irrigated farms in Accra were randomly collected in sterile polyethylene bags and transported on ice to the laboratory where they were pooled and homogenized. Vegetable samples used for each of the microbial decontamination trials came from the same pool of lettuce and the original contamination level with fecal coliforms and helminth eggs was determined using the same standard methods (see below). Each test was replicated 10 times.

Analysis of Adoption Constraints

For all suggestions to improve common practices or any new practice, the research team used observations, interviews and other knowledge-sharing methods (Amoah et al. 2009) to understand the perception and adoption potential of the concerned stakeholders (farmers, marketers and kitchen staff) and to assess if the improved practices require more or less capital, land, labor or specific knowledge for their implementation and long-term adoption. Students applied, for example, for internship over several weeks in street restaurants. Their task was to assist restaurant staff while observing hygienic and food safety behavior as well as constraints to improvements where common practices did not meet standards as defined, e.g., by WHO (www.who.int/foodsafety/en).

Laboratory Analysis of Fecal Coliforms and Helminth Eggs

Local laboratory capacity allowed analyzing fecal coliforms as a common pathogen indicator and helminth eggs. The Most Probable Number (MPN) method was used to determine fecal coliform counts in water and vegetable samples (APHA-AWWA-WEF 1998). Ten grams of lettuce samples were aseptically cut into a stomacher bag and washed in a pulsifier (Microgen Biproducts Ltd, Surrey, UK). This was followed by tenfold serial dilutions, and a set of triplicate tubes of MacConkey broth supplied by MERCK (Darmstadt, Germany) was inoculated with subsamples from each dilution and incubated at 44 ^{0}C for 24 to 48 hours (APHA-AWWA-WEF 1998). The number and distribution of positive tubes (acid or gas production or color change in broth) were used to obtain the population of coliform bacteria in water samples and vegetables from the MPN table. Helminth eggs were enumerated using the USEPA modified concentration method (Schwartzbrod 2001) and identified using the WHO Bench Aid (WHO 1994). In this modification, all species of helminth eggs were enumerated after 50 g of the lettuce samples were washed in 2 l of tap water using the pulsifier.

Handling and Analysis of Data

Most multiple data comparisons were based on two-way ANOVA using randomized blocks (GENSTAT-32 for Windows; VSN International Limited; Rothamsted Experimental Station) while t-tests were used for one-to-one comparisons. The target was to determine if the treatment resulted in any reductions of log units (fecal coliforms) or helminth egg counts (WHO 2006). Fecal coliform and helminth egg counts were normalized by log 10 transformations for analysis of variance. Scatter plots were made using SPSS 11.0.1 for Windows (SPSS Inc., Lead Technologies). The t-test (for both single sample and two independent samples) was used to test significance of difference between mean fecal coliform levels on different vegetables and in irrigation water from different urban sources. Other data analyses, graphs and tables were carried out using Microsoft Excel.

In this report, most results refer to lettuce (*Lactuca sativa*), specifically the bunching cultivar which is commonly grown in the study locations. This cultivar has a large leaf surface area exposed to the environment, which has a higher likelihood for deposition of pathogens from contaminated water. On the other hand, in the dry season, it is likely there is a higher rate of pathogen die-off due to its high exposure to the environment.

Results

Farm-based Interventions

Risk awareness: In all study cities, farmers encountered numerous constraints in producing vegetables, ranging from low tenure security to access to seeds, water and markets.[3] Despite heavily polluted water sources, issues of water quality were only mentioned in Accra, by one in five farmers. About two-thirds of the 138 farmers interviewed in Accra expressed satisfaction with the sources of water they use, which are mostly highly polluted streams and drains, due to their continuous flow and free supply. Less than 5% of farmers referred to possible nutrients in the water. Ten percent of the farmers mentioned the possibility of skin irritation/diseases and bad odor, while more than 70% were of the opinion that there had never been any noteworthy risk to themselves or to the consumers. Less than 20% of the farmers wear temporary protective clothing, mainly boots (Obuobie et al. 2006).

[3]This might sound strange given farmers' location in the city, but is based on gender specific roles. Most vegetable farmers are men while women control the marketing of most vegetables (Hope et al. 2009).

TABLE 4. Indicator organisms in ponds under different conditions.

Location	Pond condition	No. of samples	Fecal coliforms (log of MPN 100 ml^{-1})	Helminths (No. of eggs l^{-1})
Karikari	Settled	36	7.83 ± 0.54	1.3 ± 0.8
	Unsettled	36	9.26 ± 0.53	4.9 ± 0.9
	Sediment	36	Not determined	10.0 ± 1.1
Gyenyase	Settled	36	5.57 ± 1.21	1.0 ± 0.7
	Unsettled	36	6.61 ± 1.18	4.3 ± 0.9
	Sediment	36	Not determined	9.4 ± 1.2

Storage ponds: Effects of sedimentation on levels of indicator organisms in irrigation water. Levels of helminth eggs and fecal coliforms in settled ponds, unsettled ponds and sediments at the pond beds are shown in Table 4. Levels in both indicator organisms were slightly higher at Karikari due to the use of household effluents. However, the location differences were not statistically significant. Wider variations were recorded in levels of fecal coliforms in ponds at Gyenyase than at Karikari. The variations could be due to surface runoff collected in ponds at Gyenyase, especially when it rains.

A strong difference was observed for the reduction of helminth eggs between the disturbed and undisturbed water in the pond, showing that the night rest allowed most eggs to settle in the sediment.

On average, a difference of about 1.0-1.5 log units of fecal coliforms per 100 milliliters (ml) was obtained between settled and unsettled ponds. The levels in settled and unsettled ponds were significantly different for helminth eggs at Karikari and Gyenyase.

Removal of indicator organisms by sand filters. Table 5 shows the removal rates of fecal coliforms and helminth eggs for the three sand filters over the monitoring period of 2 months. The influent used for the three filters was the same with an average fecal coliform level of 7.3 log units per 100 ml and 5.7 helminth eggs per liter. The levels of both indicators in the influent had no wide variations since the influent came from the same irrigation water source and was fetched in each trial on the same day at the same time. Box 1 gives some explanation on how to read the data.

On average, sand filters showed better removal rates for helminths (down to less than 1 egg) than fecal coliforms. Other than the cloggedfilters, between 98.2 and 99.8% of fecal coliforms, equivalent to an average of 2 log units 100 ml^{-1} and 71-96% of helminths were removed. However, high removal rates for both indicators were recorded for filter 1 on day 50 and day 60. This was because they clogged before sampling was done. This is also shown by the low levels of flow rates, which were less than 0.15 m/day. Consideration was not made for effluents from clogged filters during statistical analyses. Removal of both indicators by each of the three filters was significant at level 0.01. However, removal by the different filters for both indicators was not significantly different. This shows that filtration media depth, at least for the range of 0.5 to 1.0 m, has no significant influence on the removal of indicator organisms.

There was a general improvement in effluent quality with time, more so with levels of thermotolerant coliforms. Removal rates of thermotolerant coliforms for all filters had positive and significant correlations with filtration duration at the *0.05 level* (2-tailed), unlike helminth eggs which dropped quickly below 1 egg (only filter 1 was significant). This implies that the effluent quality from sand filters is likely to improve over the tested time span in regard to the removal of thermotolerant coliform, which is clearly not the case for helminth eggs, probably because these are removed by physical action and not by the biofilm.

Additional tests were carried out with fabric filters such as nylon textile. These support the

TABLE 5. Removal rates of indicator organisms by sand filters (N=12 samples per filter per sampling day).

Filter sand depth	Days after installation	Effluent flow rate (m/day)	Fecal coliforms (log MPN 100 ml^{-1})		Helminth eggs (No. of eggs l^{-1})	
			Mean	% removal	Mean	% removal
	Influent	-	7.31±0.18[c]	-	5.7±0.5	-
Filter 1[a]	0	3.67	5.41±0.15	98.70	1.8±0.3	71.20
	10	3.46	5.30±0.13	98.95	1.3±0.4	79.20
	20	2.77	5.28±0.10	99.54	0.9±0.4	82.00
	30	2.35	5.14±0.15	99.38	0.6±0.2	89.56
	40	2.16	4.98±0.10	99.31	0.5±0.3	91.30
	50[b]	0.13	2.67±0.13	99.99	0.1±0.2	98.26
	60[b]	0.09	2.09±0.19	99.99	0.0±0.1	100.00
Filter 2	0	6.34	5.39±0.11	98.71	1.5±0.5	76.00
	10	3.89	5.37±0.13	98.77	0.8±0.5	87.20
	20	2.55	5.33±0.15	98.49	0.6±0.5	88.00
	30	2.82	5.26±0.09	99.19	0.8±0.5	86.09
	40	2.15	5.05±0.13	99.19	0.5±0.4	91.30
	50	2.17	4.96±0.17	99.52	0.5±0.2	91.30
	60	2.36	4.87±0.13	99.67	0.7±0.1	88.80
Filter 3	0	6.98	5.54±0.15	98.18	1.6±0.4	74.40
	10	4.02	5.44±0.21	98.56	0.6±0.4	90.40
	20	3.63	5.17±0.14	99.65	0.3±0.4	94.00
	30	3.77	5.11±0.18	99.43	0.7±0.6	87.83
	40	1.63	5.02±0.22	99.24	0.2±0.3	96.52
	50	1.87	4.90±0.21	99.58	0.5±0.5	91.30
	60	2.15	4.73±0.10	99.76	0.8±0.4	87.20

[a] Filters 1, 2 and 3 had sand depths of 0.5, 0.75 and 1 m, respectively.
[b] Clogged filters.
[c] Standard Deviation.

Box 1. Log reductions and percentages.

Reductions expressed in percent or as log units are only meaningful if used in combination with start and end concentrations.

- A reduction, e.g., from 10^7 to 10^6 (or from 7 to 6 logs), represents a reduction by 1 log unit or 90% of the original coliform counts. Two log reductions represent 99% and 3 logs 99.9%. This looks like an impressive result, but the remaining coliform counts in the example are still 4 logs (10,000 coli bacteria) which is 10 times the level of 1,000 counts (10^3) per 100 ml of irrigation water which WHO recommended formerly as the upper limit for unrestricted irrigation (WHO 1989[4]).
- A reduction of 6 helminth eggs to - on average - 0.8 eggs represents a reduction by less than 1 log unit or 87% of the original count and although 87% looks less impressive than 99.9% in the example above, a count of 0.8 eggs matches the recommended egg count in irrigation water (maximum 1 egg per 1,000 ml; WHO 1989).

[4]It is actually less than one viable egg per liter. Most eggs analyzed in our studies were not viable.

removal of debris from the wastewater including some pathogens adsorbed to organic matter resulting in a water improvement of 12-62% for helminth eggs and 78-96% for fecal coliforms, i.e., about 1 log unit (Keraita et al. 2008b). *Microbiological quality of lettuce under different irrigation methods*. Levels of indicator organisms obtained during the dry season are shown in Table 6. In both dry and wet seasons fecal coliforms and helminth egg populations on lettuce were highest on plots irrigated with watering cans and lowest under drip irrigation. In the dry season, vegetables on plots with drip irrigation had no helminths, and fecal coliforms were less than 1 log unit 100 g^{-1} of lettuce. The impact of the irrigation method on indicator organism levels was more pronounced during the dry than in the wet season. For instance, while plots with drip irrigation had an average of 2.4 log units of fecal coliforms 100 g^{-1} of lettuce lower than where water cans were used in the wet season, their difference during the dry season was 6.1 log units 100 g^{-1} of lettuce. On average, lower levels of indicator organisms were recorded during the dry than in the wet season. Treatments for both indicators in both the dry and wet seasons were significantly different ($p<0.001$). Three-quarters of all eggs were *Ascaris lumbricoides*.

TABLE 6. Counts of fecal coliforms and helminth eggs on lettuce irrigated by different irrigation methods (N=36 samples per irrigation method per season).

	Irrigation method	Fecal coliforms (log of MPN 100 g^{-1})		Helminths (No. of eggs 100 g^{-1})	
		Mean	95% CI	Mean	95% CI
Dry season	Can	6.53	6.41 - 6.64	0.6	0.4 - 0.8
	Furrow	5.29	5.22 - 5.37	0.5	0.3 - 0.6
	Drip	0.47	0.22 - 0.71	0.0	0.0 - 0.1
Wet season	Can	8.21	8.08 - 8.34	1.5	1.3 - 1.7
	Furrow	7.79	7.67 - 7.91	1.0	1.0 - 1.3
	Drip	5.65	5.56 - 5.75	0.6	0.4 - 0.8

Note: CI = Confidence level in this and other tables.

Effects of using watering cans with caps (roses) and watering height. Results obtained from trials on three typical heights of watering when using watering cans and from testing using watering cans with and without roses are shown in Table 7. Increasing watering height when using watering cans, whether capped with a rose or not, increased both fecal coliforms and helminth counts on lettuce and differences were significant ($p<0.001$). The mean difference in pathogen levels on lettuce irrigated from the highest and lowest watering heights tested was 1.5 log units 100 g^{-1} for fecal coliforms and 1.3 helminth eggs 100 g^{-1}. Using capped watering cans reduced counts of both indicator organisms at each level in both seasons. The average difference between the capped and uncapped watering cans was about 1 log unit for fecal coliforms and one helminth egg 100 g^{-1} of lettuce in both dry and wet seasons. Combined effects showed that an average reduction of 2.5 log units for fecal coliforms and 2.3 helminth eggs 100 g^{-1} could be achieved if farmers use watering cans with capped outlets and raise them not more than 0.5 m high when irrigating compared to using watering cans with no capped outlets raised more than 1 m high.

TABLE 7. Levels of fecal coliform counts and helminth eggs on lettuce irrigated using watering cans from different heights (N=30 samples per irrigation height per season).

	Irrigation height (m)	Fecal coliforms (log of MPN 100 g^{-1})				Helminths (No. of eggs 100 g^{-1})			
		Capped[a]		Uncapped[b]		Capped[a]		Uncapped[b]	
		Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Dry season	< 0.5	4.69	4.57 - 4.81	5.43	5.16 - 5.70	0.3	0.1 -0.5	1.1	0.6 - 1.5
	0.5 - 1.0	5.37	5.00 - 5.75	5.68	5.42 - 5.95	1.0	0.8 - 1.3	1.6	1.3 - 1.9
	> 1.0	5.94	5.57 - 6.32	7.77	7.36 - 8.18	1.6	1.3 - 1.9	2.6	2.1 - 3.0
Wet season	< 0.5	6.45	6.32 - 6.59	7.52	7.38 - 7.67	0.7	0.4 - 1.1	1.4	0.9 - 2.0
	0.5 - 1.0	6.64	6.50 - 6.78	7.69	7.53 - 7.85	1.5	1.1 - 1.9	2.0	1.6 - 2.4
	> 1.0	7.73	7.63 - 7.82	8.47	8.34 - 8.61	1.4	1.1 - 1.7	2.9	2.5 - 3.3

[a]Capped - watering cans used in irrigation were fitted with roses at the outlets.

[b]Uncapped - watering cans used had no roses at the outlets.

Effects of cessation of irrigation before harvesting on pathogen populations and yield of lettuce. Under the given climate, farmers usually irrigate until harvesting day, which was taken as a control. Levels of indicator organisms obtained during the dry season are shown in Table 8. There were generally lower fecal coliform and helminth counts with an increase in the number of days between the last irrigation and harvest. Differences were significant (p<0.01-0.001) between treatments including control for both indicators. Results also show that final levels of indicator organisms on lettuce depended on the initial contamination levels. For instance, lower levels of fecal coliforms were recorded on lettuce after 6 days for farmer C than for both farmers A and B, who also had higher levels of crop contamination at the start.

Cessation trials for spring onion and cabbage confirmed the same trend. Four days of cessation of irrigation achieved on cabbage a coliform reduction of 1 log unit and on spring onion of 2 log units.

As a reduced water supply also affects water uptake, the fresh weight (and related appearance), especially of leafy vegetables, was recorded (Table 9). The data show a steady reduction in the weight after cessation of irrigation. The impact was significant in the dry season while differences were smaller and only significant when reaching 6 days without irrigation in the wet season.

TABLE 8. Mean levels of fecal coliforms and helminth eggs on lettuce (N=72 samples per cessation interval per season).

	Days without watering	Fecal coliforms (log of MPN 100 ml^{-1})			Helminth eggs (No. of eggs l^{-1})		
		A	B	C	A	B	C
Dry season	0	6.32 (0.40)	6.76 (0.42)	5.62 (0.74)	2.3 (0.5)	2.2 (0.6)	2.7 (0.5)
	2	5.19 (0.61)	5.62 (0.70)	3.96 (0.83)	1.6 (0.4)	1.6 (0.6)	2.1 (0.4)
	4	3.97 (0.44)	3.96 (0.52)	2.56 (0.63)	0.8 (0.5)	0.8 (0.5)	1.3 (0.4)
	6	2.63 (0.27)	2.65 (0.48)	1.81 (0.64)	0.3 (0.4)	0.2 (0.0)	0.4 (0.2)
Wet season	0	8.58 (0.33)	8.06 (0.52)	7.82 (0.72)	1.5 (0.6)	1.6 (0.5)	1.8 (0.5)
	2	7.67 (0.44)	7.07 (0.81)	7.50 (0.64)	1.1 (0.5)	1.2 (0.5)	1.2 (0.4)
	4	6.60 (0.50)	6.91 (0.55)	6.91 (0.72)	0.5 (0.2)	0.8 (0.5)	0.7 (0.4)
	6	6.62 (0.41)	6.41 (0.46)	6.21 (0.95)	0.2 (0.0)	0.3 (0.2)	0.3 (0.1)

Notes: A, B and C denote farmers involved in the trials. Values in parentheses are standard deviations.

TABLE 9. Impact of increasing time between the last irrigation and harvest on fresh weight of lettuce (n=36 samples per cessation interval per season).

	Cessation time (days)	Mean fresh weights (kilogram [kg] m^{-2})					
		A		B		C	
		Mean	95% CI	Mean	95% CI	Mean	95% CI
Dry season	0	2.79	2.74-2.85	2.84	2.81-3.87	2.74	2.71-2.77
	2	2.47	2.42-2.53	2.48	2.44-2.52	2.44	2.41-2.46
	4	2.11	2.04-2.17	2.20	2.16-2.24	2.18	2.14-2.23
	6	1.87	1.83-1.92	2.00	1.96-2.03	1.92	1.88-1.95
Wet season	0	3.04	2.98-3.09	2.96	2.86-3.06	2.50	2.41-2.59
	2	3.01	2.93-3.09	2.90	2.80-3.00	2.39	2.32-2.46
	4	3.05	3.00-3.10	2.80	2.70-2.90	2.36	2.29-2.44
	6	2.93	2.89-2.96	2.73	2.62-2.83	2.35	2.25-2.45

Note: A, B and C denote farmers involved in trials.

As described earlier, levels of lettuce contamination in these trials were also higher during the wet season than in the dry season. For instance, start concentrations (day 0) were on average about 2 log units 100 g^{-1} of fecal coliforms higher during the wet season than during the dry season. The reduction, especially of the coliform indicator, was much better in the dry than in the wet season: In the wet season, fecal coliform levels were reduced by an average of 1.7 log units and helminths by 1.4 eggs 100 g^{-1} after 6 days of cessation of irrigation. In the dry season, an average total reduction of nearly 4 log units 100 g^{-1} for fecal coliforms and 2 helminth eggs 100 g^{-1} were recorded.

Market-based Interventions

Risk awareness. Risk awareness among vegetable traders varied significantly between the cities. While half of the sellers in Accra had heard about possible health risks, only about 10% did so in Kumasi and Tamale. Irrigation with water from drains was regularly identified as one possible risk factor but without ability to specify what type of disease or symptoms it might cause. Higher risk awareness in the capital city Accra was probably caused by higher media attention to the risks of irrigated urban agriculture (Obuobie et al. 2006).

The comparison of markets serving different income groups showed a fecal coliform decline of about 1 log unit on lettuce and spring onion from low- to middle- to high-class markets. Also the number of helminth eggs on spring onion was lowest on the upper-class market, while the analyzed cabbage samples did not show a significant difference. Easier water access and a trend of changing the water used for vegetable cleaning more frequently was earlier reported by Drechsel et al. (2000) from the same upper-class market in Kumasi. As a key reason for the different behaviors, sellers referred in that study to pressure from their customers to provide visually clean produce.

Removal of outer leaves. 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 10% (Table 10). Further peeling would significantly increase safety but also reduce the size of the crop.

TABLE 10. Effect of removing outer leaf on decontamination of cabbage on indicator organisms (N=45; *source*: Akple 2009).

Removal of outer leaves (proportions in weight %)	MPN thermotolerant coliforms 100 g^{-1} (Log 10 geometric mean)	Helminth eggs 100 g^{-1} (arithmetic mean)
0	5.66 (± 0.15)[a]	2.4 (± 0.3)
10	4.67 (± 0.12)	1.5 (± 0.2)
20	3.82 (± 0.19)	0.8 (± 0.1)
30	1.24 (± 0.62)	0.0 (± 0.0)
45	0.00 (± 0.00)	0.0 (± 0.0)

[a]Values in parentheses are standard errors.

Some sellers cut heavy cabbage crops into smaller units. Pieces cut with bare hands in the market compared with those cut under hygienic conditions showed significantly higher fecal coliform counts of up to 2 log units while helminth numbers remained unchanged (Akple 2009).

Market display and storage. Displaying cabbage or spring onion either on bare ground, on an old sack, in baskets, bowls or on a table over a working day did not significantly change pathogen levels from the high initial levels. However, among different overnight storage options, natural die-off was positively influenced where spring onion or lettuce was kept in well-aerated baskets compared to fertilizer bags (>1 log difference).

Washing displayed crops. While some crops are sprinkled to appear fresh, others crops on display are washed periodically. As clean water is usually in short supply, most traders fetch water once a day. Where clean water was used in a bowl for 2 minutes, coliform counts on lettuce and spring onion decreased by 1-2 log units and helminth eggs by about 50% or more. With running tap water, pathogen reduction was doubled in the laboratory; however, it is not realistic to assume traders could clean their crops at the often only water source.

Where the same water was used over the day to wash crops, the positive effect of washing decreased (Figure 4). Initially, fecal coliform numbers on bulbs of spring onion decreased, but then increased continuously (ρ=0.001) from the second to the fifth washing cycle. After washing a total of 5 kg spring onion bulbs (in five cycles at 1 kg per cycle) in the same water, coliform counts on the crops did not change anymore through washing.

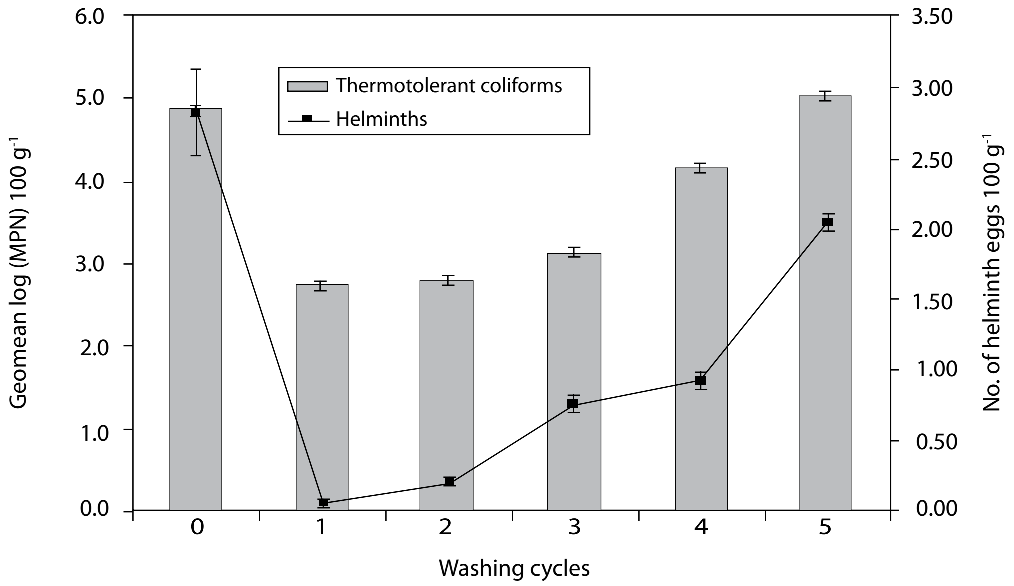

FIGURE 4. Effect of continuous washing cycles of spring onion bulbs in the same water (n=54; Owusu 2009).

Interventions for Street Food Restaurants

Risk awareness. There was generally a high level of awareness of potential health implications from consuming unwashed raw vegetables. This translated into a corresponding high level of application of risk mitigation measures, ranging from water to sanitizers in all the cities of the exploratory survey conducted across West Africa. The understanding of the kind and magnitude of risk and of appropriate risk mitigation measures however varied largely in and between the cities and, in particular, between the Francophone country group and Ghana (Amoah et al. 2007b).

Methods used for washing vegetables by food vendors and consumers before consumption. In the Francophone cities, 56-90% of the households and 80-100% of the street restaurants used some kind of disinfectant for washing leafy vegetables to be eaten raw, while in the other cases only water was used. The most common disinfectants used in restaurants were bleach (*Eau de Javel*[5]) (55%) and potassium permanganate (31%), followed by salt/lemon or soap (both 7%). In households, the prevalent use was bleach (50%), followed by potassium permanganate (22%), salt (14%), and water only (12%). Every second respondent rinsed the leaves after washing. In contrast, the use of bleach and potassium permanganate was both practically unknown as food disinfectants in Ghana. In the lower socioeconomic classes in the selected Francophone cities there was a clear tendency to use only water or water with salt, soap or lemon juice while in the middle- and upper-class households and restaurants, the use of bleach or permanganate appeared to be prevalent.

In Ghana, various salt and vinegar concentrations are used besides cleaning in water only (Table 11). Salt is preferred to vinegar because it is cheaper (Rheinlaender 2006).

[5]The French term *Eau de Javel* is used here in its generic sense as it is common in Francophone West Africa, i.e., not related to any bleach brand, including the one with the same name. Where the brand has been used in the text the symbol of the trade mark has been added.

TABLE 11. Vegetable washing methods practiced in Accra, Kumasi and Tamale.

Vegetable washing method	Accra (N=235)	Kumasi (N=117)	Tamale (N=100)
	Percentage of respondents		
Tap water in a bowl (no sanitizer)	28	18	9
Running tap	0	0	34
Salt solution	40	61	55
Vinegar solution	30	21	2
Potassium permanganate solution	2	0	0

Efficacy of sanitizers in relation to time, concentration and temperature on fecal coliform populations. Washing vegetables irrespective of the method used reduced fecal coliform levels in lettuce. Under a contact time of 2 minutes, log reductions ranged from 1.4 to 2.2 units, while reductions were much lower when vegetables were washed for less than 10 seconds (Table 12).

Using running tap water for 2 minutes can achieve log reductions of 3-4 units as tested on cabbage and spring onion, while for the larger surface area of lettuce, 1-2 log units were counted. However, running tap water is not a common feature in most locations of street restaurants.

Sanitizers used in a bowl of water are an alternative way to reduce contamination. A log reduction of about 2 units required however a higher NaCl solution (35 parts per million [ppm]) than is commonly used. However, at this concentration the lettuce leaves became soft, losing their quality. Alternatively, the efficacy of salt (and vinegar) solutions increased significantly between 1 to 2 log units, when the temperature of the solution was increased from 25 to 40 ºC.

Vinegar appeared significantly more effective than salt, although again not in the low concentrations commonly used. With a threefold increase in vinegar concentration of up to 21,400 ppm it was possible to drop the pH below 2.8 where coliform counts decreased by 4.5 log units to marginal counts even under a low contact time of 20 seconds.

At a lower vinegar concentration (12,500 ppm), increasing contact time from 2 to 5 or 10 minutes, significantly ($p<0.05$) increased its efficacy. For example, holding lettuce leaves for 10 minutes at this concentration reduced fecal coliform populations by about 3.5 log units (Table 12). Significant fecal coliform reductions of up to 3 log units were also achieved for cabbage and spring onion using a similar concentration, i.e., about one part of vinegar in five parts of water for 10 minutes (Abaidoo et al. 2010).

TABLE 12. Efficacy of various washing methods to reduce fecal coliform levels on lettuce.

Method[a]	Use	Contact time[b]	Mean log_{10} FC levels before and after treatment per 100g						Log reduction
			Mean before	95% CI lower	95% CI upper	Mean after	95% CI lower	95% CI upper	
Cold water	C	3-4 sec.	5.5	4.9	6.1	4.5	3.8	5.1	1.0
	C	2 min.	6.1	5.2	6.9	4.7	4.0	5.4	1.4
Running tap	C	3-4 sec.	5.5	4.9	6.1	5.2	4.7	5.9	0.3
	C	2 min.	6.1	5.2	6.9	3.9	3.3	4.5	2.2
$NaCl_{7}$	C	3-4 sec.	5.5	4.9	6.1	5.0	4.4	5.7	0.5
$NaCl_{23}$	C		5.5	4.9	6.1	4.7	4.2	5.3	0.8
$NaCl_{35}$	C		5.5	4.9	6.1	4.4	3.8	4.8	1.1
		2 min.							
$NaCl_{7}$	C	2 min.	6.1	5.2	6.9	4.7	4.1	5.2	1.4
$NaCl_{23}$	C	2 min.	6.1	5.2	6.9	4.6	3.5	5.6	1.5
$NaCl_{35}$	C		6.1	5.2	6.9	4.0	3.2	4.9	2.1
$NaCl_{7}$+$Vinegar_{6818}$	C	3-4 sec.	5.5	4.9	6.1	5.2	4.3	6.0	0.3
$NaCl_{7}$+$Vinegar_{6818}$	C	2 min.	6.1	5.2	6.9	4.7	3.9	5.4	1.4
$Vinegar_{6818}$		3-4 sec.	5.5	4.9	6.1	5.3	4.2	5.7	0.2
		2 min.	6.1	5.2	6.9	5.1	3.5	5.6	1.0
$Vinegar_{12500}$	T	5 min.	3.7	3.4	3.8	1.9	0.3	1.3	1.8
		10 min.	3.7	3.4	3.8	0.0	0.0	0.0	3.6
$Vinegar_{21400}$	T	5 min.	4.7	3.8	5.6	0.0	0.0	0.0	4.7
		10 min.	4.7	3.8	5.6	0.0	0.0	0.0	4.7
Removal of outer leaves (Vinegar $_{12500}$)	T	5 min.	4.3	3.8	4.9	3.8	3.4	4.2	0.5
	T	10 min.	4.3	3.8	4.9	3.4	3.0	3.8	0.9
Laundry Omo™ (Detergent)	T	5 min.	4.3	3.8	4.9	1.7	0.9	2.4	2.6
	T	10 min.	4.3	3.8	4.9	1.9	1.1	2.7	2.4
Eau de Javel™ (Bleach:165 µS/cm)	C	5 min.	6.4	6.3	6.5	4.0	3.7	4.3	2.4
	T	10 min.	6.4	6.3	6.5	3.5	3.3	3.8	2.9
Thick bleach™ (Bleach: 248 µS/cm)	T	5 min.	6.3	5.7	6.9	3.8	3.1	4.4	2.5
	T	10 min.	6.3	5.7	6.9	3.8	2.7	4.9	2.5
Power zone™ (Bleach:223 µS/cm)	T	5 min.	6.3	5.7	6.9	4.1	3.8	4.6	2.2
	T	10 min.	6.3	5.7	6.9	3.3	3.1	3.4	3.0
KM_{100}	C	3-4 sec.	5.5	4.9	6.1	4.8	4.3	5.2	0.7
	T	2 min.	6.1	5.2	6.9	4.9	4.2	5.4	1.2
KM_{200}	T	5 min.	6.4	6.3	6.5	4.4	4.2	4.5	2.0
	T	10 min.	6.4	6.3	6.5	3.9	3.8	4.0	2.5
Chlorine $tabs_{100}$	T	5 min.	6.4	6.3	6.5	4.1	3.8	4.3	2.3
	T	10 min.	6.4	6.3	6.5	3.7	3.3	4.1	2.7

Source: Modified from Amoah et al. 2007b.

[a] Subscripts in values represent sanitizer concentration in ppm.

[b] Contact time of dipping vegetables in the washing solution; C: commonly used; T: tested variation; KM: potassium permanganate; NaCl: table salt; tabs = tablets; sec.: seconds; min.: minutes.

Fecal coliform reductions of about 2.5 log units were obtained when lettuce leaves were kept for 5 and 10 minutes, respectively, in a laundry detergent solution, and then rinsed with tap water (Table 12). These reductions were both significant (p=0.001) with no additional effect of the longer contact time.

Significant (p=0.001) log reductions of 2.5 to 3 units were also observed where lettuce was washed for ideally 10 minutes with either bleach, potassium permanganate or chlorine tablets (Table 12).

Efficacy of selected washing methods on helminth egg populations. All the treatments employed reduced helminth egg population on lettuce at least by half (Figure 5). Washing under running tap water without any sanitizer appeared most effective and reduced helminth egg counts from about 9 to 1 egg 100 g^{-1} wet weight. Similar results were obtained for spring onion and cabbage.

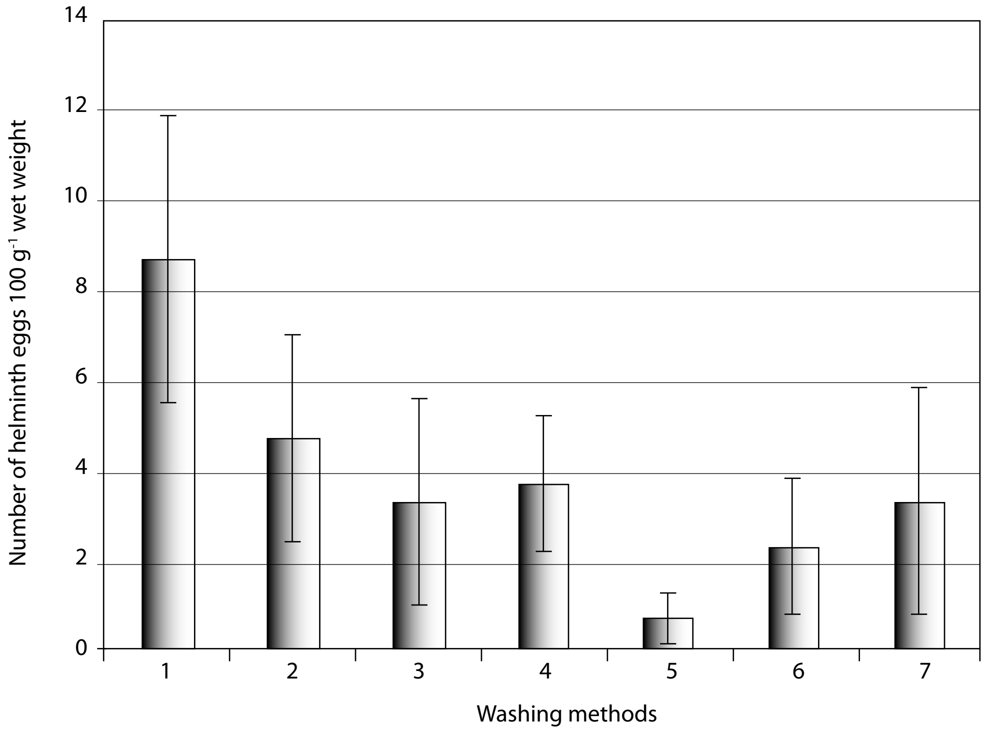

FIGURE 5. Efficacy of common washing methods on helminth egg contamination level.

Notes: 1) Unwashed; 2) light washing in a bowl; 3) washing in salt solution (23 ppm); 4) washing in salt solution (35 ppm); 5) washing under running water; 6) vinegar solution 6,818 ppm; and 7) salt/vinegar solution (7 ppm/6,818 ppm).

Discussion

On-farm Trials

One of the suggested options for pathogenic risk reduction included the exploration of alternative water sources (groundwater) initiated by Ghana's Water Research Institute and the Ministry of Food and Agriculture. In most cases, the results were unsatisfactory due to various reasons (saline groundwater, deep aquifers and high drilling costs; land tenure problems). Another suggestion followed the WHO (2006) recommendation to grow vegetables which are *not* eaten raw. Given the market prices for raw salad greens, this option did not stand any chance of implementation. In fact, earlier attempts to ban the use of polluted water in urban farming, did not work out either given the large number of farmers or livelihoods concerned (Obuobie et al. 2006).

Apart from these options, farmers participated actively in exploring interventions for risk reduction. What was favorable was that most of the identified measures required little capital investment; however, farming practices and behavior required changes, partly with implications for labor inputs.

Sedimentation

No significant differences in fecal coliform counts were expected as the principal removal mechanism for fecal coliforms is die-off (Mara 2004). However, removal through sedimentation can occur from adsorption of bacteria to particles in irrigation water (Sharma et al. 1985).

Sedimentation should serve mostly the removal of helminth eggs. Indeed most of the eggs were found in the pond sediments. On average, ten eggs, five eggs and one egg per liter were found in sediments, and in unsettled and settled irrigation water, respectively, regardless of the season or total egg counts. This is in line with other studies which have shown that the highest concentration of helminth eggs is common in stream sediments (Karim et al. 2004). It is therefore important that sediments in ponds are not disturbed during water collection and even better, that sediments should be removed regularly for safe disposal. Practical ways for not disturbing the bottom of the ponds were explored with farmers. The usual practice is stepping into the pond for filling the watering can. Alternative options depend on local possibilities and included stepping on a wooden log and bending down to fill the watering can (Figure 6), using a rope attached to the can, using cans with extra-long spouts for holding the cans while fetching, etc. In all these cases, material costs were marginal, while some behavior change is required. A

FIGURE 6. Water fetching without stepping in the pond and whirling up sediment.

perceived advantage for the farmers was that these alternatives also reduce their own exposure to the water.

In Accra, interesting variations of pond systems were found on two larger farming sites. On one site, interconnected ponds were created to reduce the transport distance of the watering can (Box 2) while on the other site small streams were blocked with sand bags four to six times over approximately 1,000 m creating a cascade of man-made weirs. In front of the weirs farmers deepen the streambed to create inner-stream ponds which facilitate water accumulation and fetching (http://video.google.com/videoplay?docid=-7881268516571430438&hl=en). Although the motivation in both cases was to facilitate water access rather than to reduce health risk, the installed systems created opportunities for the sedimentation of helminth eggs, on which interventions could build.

Box 2. Improved on-farm pond networks for wastewater treatment in Accra, Ghana.

Location: A large vegetable farming site in Accra where water from polluted streams and drains is the common source of irrigation water for about 100 farmers. Individual ponds and networks of interconnected ponds are common (Figure 7). Networks of ponds are managed by two to over 20 farmers depending on their size. These systems enhance fecal coliform removal from 10^6 to 10^7 MPN/100 ml by at least 2 log units from the wastewater source to the last pond. Also, for individual ponds, a removal of 1-1.5 log units was observed over 2 days. Unfortunately, from the research point of view, helminth eggs were only occasionally found in the water source at this site (up to two eggs^{-1}) and dropped below one egg^{-1} in the first pond.

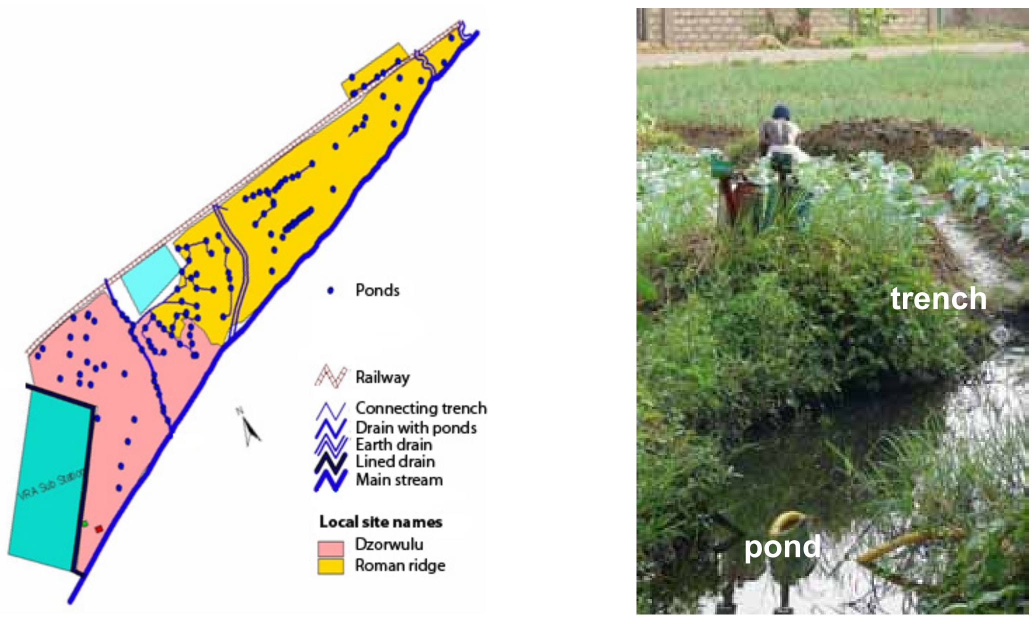

FIGURE 7. Distribution of individual and interconnected ponds and dugouts on a farming site in Accra, Ghana, drawing water via pumps from polluted streams and wastewater drains (Reymond et al. 2009).

(Continued)

Box 2. Improved on-farm pond networks for wastewater treatment in Accra, Ghana (Continued).

A pilot project was initiated to upgrade an existing five-pond network for enhanced risk control. The project was carried out in a participatory way with the farmers. Design modifications aimed at doubling the water volume and reducing "short-circuiting" (rapid flow), to increase the overall water retention time in the systems from 1 to 2 days.

FIGURE 8. Pond with hardwood baffle.

Technology description. Trenches were slightly widened and ponds were deepened and their shape regularized. Some stairs were built to facilitate fetching of water without risk of unsettling the sediment. Simple baffles were placed in transit ponds to increase the retention time of the water (Figure 8).

Required inputs. Mostly labor for construction (two man-days) and $50 per farmer for construction materials.

Removal of pathogens. It became important to install a floodgate (weir or pipe-elbow that can be turned) to stop the continuous inflow of pathogen-rich water from the main stream which undermined the support of natural die-off and sedimentation.

Potential for out-scaling the technology. While this case does not illustrate a designer solution for reduction of health risk, it shows opportunities that indigenous systems offer for further improvements through participatory research. Important site criteria for networks of ponds are space, sufficient tenure security to allow the setup of infrastructure, and an adequate slope to allow flow by gravity for interconnected systems. Given the load of carrying two 15 l watering cans, every reduction in transport distance will be an incentive for farmers to cooperate.

Although pathogen reduction can be achieved within the network of ponds, the reduction should ideally take place before the first pond used for fetching water. More details on farm-based pond systems are described by Cofie et al. (2010).

Filtration

The removal levels obtained by various methods of filtration were within the typical range reported with bacterial removal of 0-3 log units and 1-3 log units for helminth eggs (WHO 2006). Clogging, which is usually associated with the presence of clay or silt particles or the use of fine sand of effective size smaller than 0.15 mm, was observed after more than 40 days of filtration in the filter with a depth of 0.5 m. As clogging would be more likely in a longer filter, its reason might be less associated with filter depth than particle deposits. Equally important is the flow rate of the effluent. The average flow of 3 m/day (Table 4) will be enough to water a typical farm of 0.02 ha in urban Kumasi.

With the three sand filter depths used (0.5, 0.75 and 1.0 m) performance on both pathogen indicators was not significantly different. This shows that the depth of filtration media, at least for the range of 0.5 to 1.0 m, had no significant influence on the removal of indicator organisms. However, while the removal rate for fecal coliforms remained almost constant in the three filters, removal of helminth eggs increased steadily from an average of 83% in the 0.5 m sand filter to 89% in the 1 m sand filter. This could be attributed to the different removal mechanisms for helminth eggs and fecal coliforms in slow sand filters (Stevik et al. 2004). Due to their larger size, most helminth eggs are removed by straining, and movement is restricted to the lower end of the sand filter and then to the effluent (Logan et al. 2001). On the other hand, the removal of bacteria is mainly due to biological activities that occur in the top layers of the sand bed. Muhammad et al. (1996) showed that bacteriological purification occurs within the top 0.4 m of a sand bed, while Bellamy et al. (1985) observed that sand depth could be reduced to 0.48 m with no change in the removal of bacteria. This could explain why the three filters tested showed no significant differences in the removal of fecal coliform as all had deeper beds than 0.5 m. It was also observed that removal rates of fecal coliforms improved over time, unlike those of helminth eggs. This can be attributed to the gradual formation of a biofilm layer rich in microorganisms that are mainly responsible for the removal of bacteria (UNEP 1997).

A slow sand filter system can also be installed within the farm. For a typical urban vegetable farm in Kumasi of 0.1 ha, a column of sand filter with a surface area 0.4 m^2 with some simple reservoir storage tanks will be enough. Further studies are needed to test filter performance over a longer time interval than in this study and with different qualities of wastewater.

Removal rates for both indicator organisms (attached to organic particles) were much lower when low-cost fabric filters were used. Nylon filters (e.g., a sock) achieved a fecal coliform removal averaging about 93% and removal of helminth eggs of about 58%. Though removal levels of fabric filters were not so high, using these filters does not take much effort and costs less than using sand filters. They can be easily placed at the inlet of irrigation water storage reservoirs so that filtration can be done as water is collected or even attached to water application containers like watering cans which farmers throughout West Africa mostly use. In Togo or Senegal, farmers already use different forms of sieves, like mosquito nets on the intake hole of watering-cans to prevent particles like algae, waste and organic debris from entering the can. Filtration materials can also be attached to irrigation equipment such as pumps. In all cases, it is recommended to fine-tune the mesh size to find the best balance between easy water fetching and maximal filtration of debris. As farmers are already used to these types of coarse filter systems to eliminate visible obstacles, an opportunity exists for adaptive field studies with high adoption potential. Guidance might be needed on appropriate cleaning of the filters.

Generally, the filters tested showed some potential to improve the microbial quality of irrigation water. They are simple, low-cost and can be easily adapted for use in urban vegetable farming in many low-income countries where irrigation water is heavily contaminated with untreated urban wastewater.

Irrigation Methods

This component of the study showed notable differences in levels of indicator organisms on lettuce between the three irrigation methods. Data obtained in this study show a difference of up to 6.1 log units and 2.5 log units of fecal coliforms 100 g^{-1} of lettuce for the dry and wet seasons, respectively, reconfirming the advantage of drip irrigation for risk reduction, followed by furrow irrigation. Contamination levels on lettuce in drip irrigated plots were below the acceptable levels of 3 log units 100 g^{-1} of lettuce (ICMSF 1995). Although most research on drip kits is focusing on water savings, the advantages of drip kits, in view of risk reduction, have been shown in other studies (Oron et al. 1991, 1995). While furrows provide more protection than overhead irrigation, low-growing vegetables like lettuce can still come in partial contact with the irrigation water.

Drip irrigation can result in high yields especially where water is limiting (El Hamouri et al. 1996). Nevertheless, depending on the wastewater-quality, drip kits, often clogged during weeding, required adjustments to achieve high planting densities. Another challenge was that farmers without security of land tenure feared their kits and storage barrels might get removed. On the other hand, these systems can save water and labor, and also reduce the exposure of the farmer to the polluted water. A careful analysis of farmers' opportunities and constraints will help better evaluate and further develop these methods.

Caps at watering can outlets reduced the size of irrigation water particles and lower irrigation heights reduced the soil striking velocities. Based on empirical pathogen transportation models, detachment and transportation of pathogens on soils can be reduced this way (Tyrrel and Quinton 2003). Data obtained showed that using watering cans with caps reduced fecal coliforms on lettuce by an average of 1 log unit and 1 helminth egg 100 g^{-1} of lettuce. An average reduction of 2.5 log units of fecal coliforms and 2.3 helminth eggs 100 g^{-1} of lettuce contamination was from capped watering cans raised less than 0.5 m high as compared to using uncapped cans releasing water from a height of more than 1 m that is, in addition, more labor-intensive, but common where beds are high and broad. This shows that simple changes in the use of watering cans can reduce crop contamination. As these changes are easily adopted by farmers, research should focus first of all on improving common practices by improving designs and usage.

The observation that improved irrigation practices have a significantly higher impact during the dry than the wet season was explained through soil analysis. Next to irrigation water, topsoil particles showed high levels of indicator organisms, with rain continuously splashing soil on bottom leaves of plants. Thus, even with improved – low-splash or low-contact – irrigation methods, leaves still got contaminated in the rainy season reducing the anticipated impact. This challenge could be addressed through various soil and water management options, such as localized water application and a good soil cover to lessen soil wetting and splashing, or by rotating crop beds over time to support soil bacteria die-off periods, or through the conscious removal of lower outer leaves.

Cessation of Irrigation

Increasing the number of days between the last irrigation of vegetables and harvesting can be effective in reducing microbial contamination. In this study, average daily reductions of 0.65 log unit for indicator fecal coliforms and 0.4 helminth eggs 100 g^{-1} of lettuce were achieved under field conditions in the dry season. 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. Although in hot climates higher coliform reduction rates of up to 3 log units day^{-1} have been reported (Fattal et al. 2002), the values obtained in this study were within a range of several studies reviewed by WHO (2006), which recorded a reduction of 0.5-2.0 log units day^{-1} after final irrigation.

However, under intensive sunshine, cessation periods can also adversely affect productivity and freshness of vegetables. During the dry season, up to a third of the fresh weight was lost over the 6 days without irrigation. The lost benefit was not acceptable to the farmers and only shorter periods with a smaller impact also on bacterial die-off could be recommended (Table 13). Cessation of irrigation before harvesting did not appear effective in reducing contamination during the wet season. As described above, rainfall caused recontamination of vegetables through splashes from soils while wet conditions generally favored pathogen survival (Strauss 1985; Bastos and Mara 1995).

TABLE 13. Cost estimates of selected interventions at the farm level.[a]

Interventions	Fixed costs[b] ($)	Operation, maintenance and labor costs ($/yr)	Total cost estimate for year 1 ($)
Drip kits[a]			
Locally made	105[c]	36	141
Imported	175	36	211
Current practice without intervention	10[d]	15	25
Improved use of watering cans	10	20	30
Cessation before harvest[e]	Gone benefit (yield loss)		
For 2 days	40	14	54
For 4 days	70	13	83
Wooden log for fetching water from ponds	17	25	42
In-stream (sedimentation) pond creation with two rows of sand bags	24	43	67

[a]Based on a typical farm of ca. 0.03 ha (irrigated vegetable farming in urban areas in Ghana).

[b]Cost related to the preparation of the water sources (stream, dugout) not included.

[c]Based on the requirement of 1 kit per 0.004 ha, i.e., about 7 kits per farm, including water buckets.

[d]Cost of two watering cans.

[e]Losses are estimated as 5% of total harvest per day. Selling price of lettuce estimated as $1.00 m^{-2}.

Post-harvest Studies

Previous work in Ghana established that vegetable contamination there occurs mostly on the farm while contamination in markets through unhygienic handling is relatively low (Amoah et al. 2005). This can be the other way round where the irrigation water is less heavily polluted as in the Ghana case (e.g., Ensink et al. 2007). Here tested interventions showed that markets offer some options to support either active (e.g., through washing with clean water) or passive decontamination (e.g., supporting die-off through appropriate storage) as well as possibilities to prevent additional contamination (through improved display or hygienic handling). Most promising of these appeared to be a) the option to reduce the outer leaves of cabbage, and b) the observation that traders respond well to customer demands for cleaner crops.

Given the relatively higher-risk-awareness among kitchen staff of street restaurants compared to farmers and traders, washing vegetables before consumption appears a valuable entry point for risk reduction. Interventions could build on common practices, but will require improvements, especially in Ghana where the commonly used concentration of the otherwise highly effective vinegar was too low.

Although all methods were able to reduce bacteria and populations of helminth eggs, some sanitizers worked better than others, while the removal of eggs depended more on physical methods than on the use of chemicals. Washing under a running tap for 2 minutes appeared very effective (see also Beuchat 1998; Erlom 2002). While street food kitchens might not have a tap, many caterers prepare their food components at home. Also, washing vegetables in a bowl with potable water, then again washing or rinsing in potable water would aid in removing microorganisms. Additional tenfold to hundredfold reductions can be achieved by using disinfectants, e.g., those containing chlorides (Beuchat 1998).

According to Parish et al. (2003), the efficacy of the method used to reduce microbial populations usually depends on the type of treatment, type and physiology of the target microorganisms, characteristics of produce surfaces, exposure time and concentration of cleaner/sanitizer, pH, and temperature. Generally, the efficacy of all methods tested increased with increasing temperature confirming the sanitizing effect of high temperature. For example, the removal efficacy of salt and vinegar solutions increased significantly by about 1 to 2 log units when the temperature of the solution was increased from 25 to 40 ºC but negatively affected lettuce leaves as also indicated by Parish et al. (2003). Similarly, higher salt concentrations affected lettuce leaves negatively.

Another constraint can be the costs of the sanitizer. For example, while it was possible, with a vinegar concentration of 21,400 ppm (approximately 1 part of vinegar in 2 parts of water), to reduce fecal coliform counts below any risk threshold in less that a minute, only upper-class restaurants could afford this practice. Lower concentrations (approximately 1 part of vinegar in 5 parts of water) could be equally effective if combined with an increase in contact time (up to 10 minutes).

If this is still too expensive, then potassium permanganate, chlorine tablets, or bleach are recommended. For the same 5 l bowl (1:5 dilution), vinegar would cost in the above example from Ghana about $1.00 while the other sanitizers would cost between $0.03 and $0.06. Unfortunately, these three alternatives are so far rarely used in Ghana while especially potassium permanganate and bleach are among the most common disinfectants in its neighboring Francophone countries. It should thus not be too difficult to extend their promotion to Ghana. Care has to be taken with common bleach brands which can vary in their composition without appropriate labeling.

Combined Effects of Simple Interventions

For health protection under unrestricted irrigation, WHO (2006) has set a health protection level of 10^{-6} [6]DALY loss person^{-1} yr^{-1} as the maximum tolerable additional burden of disease. This could be achieved through a fecal coliform reduction of 6-7 log units achievable preferably through produce cooking. Cooking, however, is not possible for crops like lettuce which are served as salad.

In view of the tested interventions, none alone could reduce contamination of fecal coliform to the required level although some options, such as drip irrigation, running water, cabbage peeling or vinegar treatment achieved a remarkable reduction in pathogens. Limitations to an even higher impact resulted from the loss of freshness, look or taste of the produce under increased sanitizer concentrations (Parish et al. 2003). Therefore, based on the removal levels achieved, field conditions and adoption potential, different scenarios of possible *combinations* of interventions for the reduction of contamination of vegetables can be considered for the farming sites or the whole system from the farm to the fork. This is the multi-barrier approach supported by WHO (2006) which builds on the common HACCP concept of food safety. Although the coliform target is a risk reduction of 6-7 log units at the end of the food chain, WHO (2006) accepts that, in some situations or countries, current conditions do not allow full risk reduction. *Thus, any reduction as an interim step is supported as long as incremental increases are targeted*. This concept supports the principle that every contribution to risk reduction is better than none.

Figure 9 shows examples of how measures tested can be practically combined to achieve

[6]A less strict value of 10^{-4} DALY loss person^{-1} yr^{-1} is currently under discussion by WHO, which would require pathogen reductions of 2 log units lower than mentioned in the text.

higher or even acceptable levels of reduction of actual fecal coliform levels in the wet and dry seasons, considering only farm-based interventions. Scenario I is the most adoptable combination (most farmer-friendly) as it entails making modifications on already existing technologies. However, this option gives the least, but significant aggregate, reductions in contamination levels for both the dry (4.5 log units) and wet (2.5 log units) seasons. Generally, the combined intervention measures show very good performance during the dry season, but additional post-harvest interventions would be needed for the wet season (see Box 3 for a note of caution). In view of helminths, the improved use of ponds and/or filtration systems should reduce their eggs adequately.

As the analysis of possible combinations is location-specific, comparison with other studies would be helpful. However, there are hardly any practical experiences on this.

Box 3. Adding up log units of pathogen reduction.

An important note of caution refers to the addition of individually tested bacterial or helminth egg reductions. First, the removed organism might have been the same in different interventions. An example could be helminth eggs where those removed through a filter might also be those which settle first into the sediment. Second, as tests in Kumasi showed, different interventions might be more effective at high levels of contamination but less at lower levels which would happen if interventions are actually combined and follow each other. In other words a reduction of 2 log units at one place and 2 logs units at another might only sum up to 3 log units if one intervention follows the other.

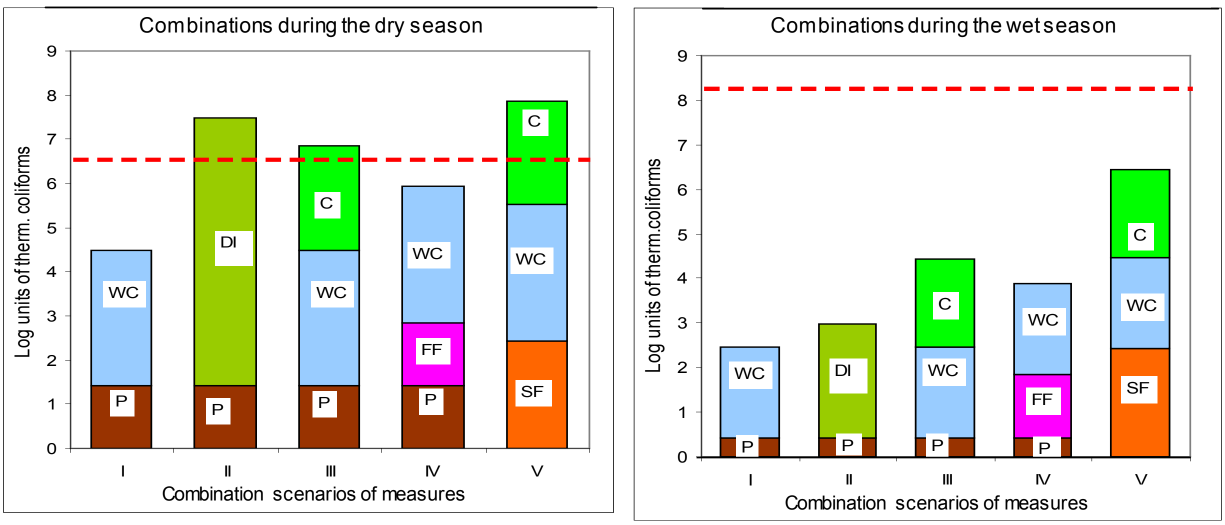

FIGURE 9. Effect of combined farm-based methods on the reduction of actual fecal coliform contamination levels.

Notes: therm.= thermotolerant; 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 view of the technical results and different risk awareness among the concerned stakeholders, a campaign to reduce the risk for consumers might ideally be based at least on two pillars:

a) Farm-based interventions to reduce crop contamination where it mostly occurs.

b) Kitchen-based interventions to reduce crop contamination where it might require the lowest efforts given the higher risk awareness in this sector and range of washing practices.

Seidu and Drechsel (2010) calculated a high cost-effectiveness of farm- and kitchen-based interventions as long as the adoption rate in one sector (pillar) reaches 75% while it can be in the other 25% or vice versa. If those farms could, in addition, benefit from partially treated wastewater the overall safety would be significantly increased.

Table 14 gives a summary of the options currently recommended by WHO to which this research contributed (Scheierling et al. 2010; Mara et al. 2010).

TABLE 14. Health-protection control measures and associated pathogen reductions in irrigation water or on crop.

Control measure	Pathogen reduction (log units)	Notes
A. Wastewater treatment	6−7	Reduction of pathogens depends on type and degree of treatment selected.
B. On-farm options		
Crop restriction (i.e., no food crops eaten uncooked)	6−7	Depends on (a) effectiveness of local enforcement of crop restriction, and (b) comparative profit margin of the alternative crop(s).
On-farm treatment:		
(a) Three-tank system	1−2	One pond is being filled by the farmer, one is settling and the settled water from the third is being used 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	Reduction of 2 log units for low-growing crops, and reduction of 4-log units for high-growing crops.
(c) Reduction of splashing	1−2	Farmers trained to reduce splashing when watering cans are used (splashing adds contaminated soil particles on 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. Post-harvest options at local markets		
Overnight storage in baskets	0.5−1	Selling produce after overnight storage in baskets (rather than overnight storage in sacks or selling fresh produce without overnight storage).
Production of preparation prior to sale	1−2	(a) Washing salad crops, vegetables and fruits with clean water.
	2−3	(b) Washing salad crops, vegetables and fruits with running tap water.
	1−3	(c) Removing the outer leaves of cabbages, lettuce, etc.
D. In-kitchen produce-preparation options		
Production of disinfection	2−3	Washing salad crops, vegetables and fruits with an appropriate disinfectant solution and rinsing with clean water.
Production of peeling	2	Fruits, root crops.
Production of cooking	5−6	Option depends on local diet and preference for cooked food.

Sources: EPHC-NRMMC-AHMC 2006; WHO 2006; and the results summarized in this report.

For comprehensive risk reduction, it is recommended to look also at other risk factors and not only at the irrigation practices. For example, many urban farmers use poultry manure which is a highly effective fertilizer especially for short-rotation crops, such as lettuce. The manure is often used fresh resulting in additional soil and crop contamination with pathogens (Amoah et al. 2005). Using well-composted manure and discarding outer lower leaves which are more in contact with contaminated soils can help in reducing this contamination source (IWMI 2008). Another example is the practice of many vegetable traders after buying their produce on-farm to clean it on the spot in the locally available contaminated water. This unsettling practice has to be addressed as it would undermine any risk reduction efforts from the farmers' end (Hope et al. 2008). A research area which might need further attention is the possibility of internalized microbes in vegetables (Donkor et al. 2010). Finally, any campaign targeting vegetables should consider the various risks of cross-contamination in poorly equipped markets and street restaurants. Any effort to support appropriate vegetable washing has thus to be seen in the overall context of improved hygiene and food safety (IWMI 2007).

Conclusions

The research work explored different low-cost options to reduce the health risk for farmers and consumers where wastewater collection and treatment cannot prevent large-scale water pollution, especially in urban and peri-urban areas. The resulting microbiological contamination levels of irrigated vegetables in Ghanaian markets were identified as a significant risk factor to human health in contrast to common levels of heavy metals. Neither full-scale water treatment nor banning the use of wastewater is a feasible option to address the situation; the former because of the cost and the latter because of the adverse impacts on livelihoods and food supply. Also, crop restrictions would not work as a) salad greens attract best profits while b) regulations are seldom enforced. There are, however, also in the context of a low-income country like Ghana a range of other options that can significantly reduce the risks to human health in line with the WHO wastewater use guidelines (WHO 2006).

Among the on-farm risk reduction options, sedimentation in ponds as well as sand filters were particularly effective in removing helminth eggs. The study also showed that simple changes in the handling of watering cans can reduce crop contamination. These changes received least hesitation for adoption from the farmers' side. The examples where farmers constructed cascades of ponds for economic reasons offer further opportunities for participatory research addressing the potential of these structures also for reducing health risks.

Although the use of drip kits was most effective from the point of risk reduction, followed by furrow irrigation it provided logistical challenges which have to be addressed. From a financial point of view, it would be required to develop local low-cost kits which help handle poor water quality without clogging. Other than irrigation water, soils and most of the analyzed poultry manure had high levels of indicator organisms. Therefore, appropriate farming practices should also address other inputs while irrigation methods should lessen soil wetting and splashing, especially in lettuce beds.

Cessation of irrigation of vegetables before harvesting can be effective in reducing microbial contamination during the dry but not the wet season. However, depending on the climate a few days without water can adversely affect productivity and freshness of vegetables. Compromises are required as any negative effect on crop yields would directly affect farmers' interest in the recommended practice.

Market-based interventions can help reduce contamination carried over from the farm (e.g., peeling cabbage), support microbial die-off (e.g., appropriate storage) or at least prevent recontamination (e.g., maintaining hygienic conditions). Washing of produce where running tap water is available, and also via well-concentrated sanitizers can be more effective. Although there is a certain level of risk awareness among kitchen staff, actual knowledge about waterborne or food-borne diseases is low. Common methods of vegetable washing vary widely and are often applied ineffectively because of lack of better information or cost reasons (vinegar is an example of an expensive washing detergent that, for cost reasons, is used in too low or ineffective concentrations). None of the common methods used in the Ghanaian kitchens could be relied on to remove any significant amount of fecal coliform populations on vegetables. However, the efficacy of these methods could be easily improved by using alternative low-cost sanitizers which are far more common outside Ghana, and/or the correct sanitizer concentrations and contact times.

For risk control, combined intervention measures are suggested which address a) the place where most contamination takes place, i.e., the farm, and b) the place where it might be easiest to reduce the pathogen load, i.e., the kitchen. While farm-based measures might already be sufficient in the dry season, off-farm measures have to be added in the wet season, but a combination of both year-round will be better.

Although most measures identified for risk reduction require limited capital or labor investment, they will require behavior change which should not be underestimated. As most recommended practices do not reduce production costs, and market demand for safer vegetables remains low due to low risk awareness, there are hardly any economic market incentives for urban farmers to adopt safer practices. Therefore, it requires well-planned efforts to support the adoption of safer practices, especially where regulations are hardly enforced. Increasing risk awareness (education) as well as nonmarket incentives (e.g., increased tenure security, credit access, rewards) should be part of any related strategy (Karg et al. 2010). Without investments in social marketing research to identify the best drivers and triggers for behavior change, it is unlikely that a high and cost-effective adoption rate can be achieved (Seidu and Drechsel 2010).

The study showed that there is a high potential in Ghana to safeguard public health through improved irrigation and handling of vegetables despite the fact that the used irrigation water is usually of low microbial quality. Campaigns on food safety should be based on awareness creation, social marketing and incentive studies, involving the public and private sectors, for example, to promote more effective sanitizers for vegetable washing. While the identified options and levels of risk reduction should be seen as location-specific most have a high potential for adaptation and application in similar farming systems as found across urban and peri-urban sub-Saharan Africa.

As the research reported here was based on Quantitative Microbial Risk Assessment and pathogenic indicators (only) it is recommended to verify the risk assumptions by analyzing actual pathogens, their transmission and human resistance, as also pointed out in the Accra Consensus (Annex 1).

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Annex 1. Accra Consensus

Agenda for Research, Capacity Building & Action on the Safe Use of Wastewater and Excreta in Agriculture

Rapidly expanding cities, escalating water scarcity, food supply and livelihood needs, particularly in low-income regions, are all driving the increasing demand for untreated and treated wastewater and excreta for agriculture. Although much progress has been made in our understanding of these issues since the 'Hyderabad Declaration' of 2002, significant challenges remain to make the use of wastewater and excreta in agriculture safe, economically productive, and sustainable.

We – an expert group from 30 international, regional, and national research institutes, multilateral and bilateral bodies, and universities based in 17 countries – emphasize the need to support policy makers around the world to make informed decisions that lead to cost-effective interventions that improve public health, promote sustainable sanitation, protect the environment, and support food security and economic development.

Achieving this goal requires consolidation of information on the science and practice of wastewater and excreta use, and well-targeted research to address gaps in the evidence base needed to support informed decision-making. Therefore, we propose the following multi-disciplinary agenda for action:

1. Integrate health and economic impact assessments to determine the actual contribution of wastewater and excreta use to the burden of disease, particularly in low-income settings, and to prioritize interventions to improve health and livelihood outcomes.
2. Facilitate the adoption of the 2006 World Health Organization guidelines for the safe use of wastewater, excreta and greywater in low-income settings through the development and application of appropriate local practices and standards that take into account local capacities and resources. Specifically:
   - Fill data gaps on levels, transmission, persistence, and reduction of key pathogens along the environmental pathways from fecal origin to human exposure, and measure disease incidence among those exposed.
   - Rigorously evaluate – in multiple geographical contexts – a range of wastewater and excreta treatment approaches and other risk mitigation strategies for their cost-effectiveness and impacts on health, livelihood, and the environment.
3. Increase human, institutional, and technical capacities in low-income settings to:
   - Detect important pathogens in human and environmental samples
   - Design and operate wastewater and excreta treatment systems that can be maintained in their ecological and economic context, and thereby support the safe and productive use of wastewater and excreta in agriculture
   - Develop and support effective participatory governance mechanisms for sustainable sanitation design and operation and safe and productive wastewater and excreta use.
4. Facilitate the exchange of information on best practices, including successful risk assessment and mitigation strategies, among partners around the globe through national and regional knowledge hubs and web-based data banks.

Accra, 9th October 2008

Web page: www.iwmi.org/Theme3/Accra_Consensus.aspx

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