CPWF Project Report

Safeguarding Public Health Concerns, Livelihoods and Productivity in Wastewater Irrigated Urban and Peri-urban Vegetable Farming

Project Number 38

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Program Preface:

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase the resilience of social and ecological systems through better water management for food production. Through its broad partnerships, it conducts research that leads to impact on the poor and to policy change.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface:

Safeguarding Public Health Concerns, Livelihoods and Productivity in Wastewater Irrigated Urban and Peri-urban Vegetable Farming

The goal of the project was to develop integrated and user-oriented strategies to safeguard public health concerns without compromising livelihoods and land and water productivity in wastewater irrigated urban and peri-urban vegetable farming. In this project, assessment of land and water productivity in wastewater irrigated farming was done, levels of contamination on irrigation water and vegetables quantified at different levels along the food chain (farms, markets and consumer level) and appropriate low-cost risk reduction strategies identified and participatory testing done with stakeholders at farm and consumer levels. A large number of students were involved in the project, significantly building human capacity.

CPWF Project Report series:

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

RESEARCH HIGHLIGHTS

There is an increasing demand for food in many cities in developing countries due to rising urban populations. While foods like cereals can be transported from rural areas, perishable crops like vegetables lose their market value during transportation as refrigeration is scarce. Most vegetables are therefore grown in and around cities to maintain their freshness and nutrition value. For instance in Accra, Ghana, about 1000 farmers are involved in market-oriented urban vegetable farming and the vegetables produced are eaten by 200, 000 Accra residents daily. However, the quality of irrigation water used is poor due to contamination from untreated wastewater resulting from poor urban sanitation. This practice though beneficial in its contributions to urban food security and livelihoods, it raises also public health concerns due to the risks posed from untreated wastewater to farmers and vegetable consumers.

In response, a number of research institutions in 2005 led by Kwame Nkrumah University of Science and Technology (KNUST) started a project entitled, "Safeguarding Public Health Concerns, Livelihoods and Productivity in Wastewater Irrigated Urban and Peri-urban Vegetable Farming". The project was funded by the CGIAR – CPWF (PN 38). The main goal was to develop integrated and user-oriented strategies to safeguard public health concerns without compromising livelihoods and land and water productivity in wastewater irrigated urban and peri-urban vegetable farming. It was completed by a Danida funded CPWF Project (PN 51). Here follows some highlights of the project's findings;

- Land availability and tenure is the main constraint to urban vegetable farming in Ghana. While productivity is high, land and labor are over-utilized in the production process.
- Initial assessments before the project intervention showed that irrigation water used in irrigated urban vegetable farming in Ghana has high levels of feacal contamination. Likewise, vegetables in markets were equally highly polluted with faecal matter and pesticides
- Though contamination of vegetables takes place in markets, most of it occurred in the farms
- Key stakeholders (farmers and vegetable traders) preferred simple and low-cost risk reduction interventions which they could easily adapt
- A wide range of risk reduction interventions were identified and assessed using participatory approaches. These include farm-based measures such as low-cost water treatment methods (ponds and filtration), use of drip kits, improved use of watering cans and cessation of irrigation before harvesting and post-harvest measures such as effective washing methods using running water and right concentrations of vinegar. These low-cost measures showed potential for risk reduction, but can achieve more when used in combination.
- Various kinds of training and awareness materials have been developed including videos, flip charts and policy briefs. The projects have received full support of policy makers who plan to integrate the best practices identified into their routine extension materials. More than 500 key stakeholders have participated in field assessments and trainings. In addition, more than 35 different kinds of scientific publications including 14 in peer-refereed journals were realized.
- Within the 3 year project period, the projects have trained 2 PhD students, more than 10 Masters Students and build capacity in many other local and international students and technicians.

EXECUTIVE SUMMARY

Project Objectives

This report is an output from CPWF Project, PN 38, "Safeguarding Public Health Concerns, Livelihoods and Productivity in Wastewater Irrigated Urban and Peri-urban Vegetable Farming". The main goal was to develop integrated and user-oriented strategies to safeguard public health concerns without compromising livelihoods and land and water productivity in wastewater irrigated urban and peri-urban vegetable farming. To achieve this, research was done based on five specific objectives;

(i) studying and evaluating current land and water use practices in urban and peri-urban vegetable farming
(ii) quantifying water pollution and comparing vegetable (de)contamination along the contamination pathway (farms to markets to households)
(iii) identifying innovative approaches for health risk reduction on-farm and post-harvest and quantifying their impacts on contamination levels, land and water productivity, and livelihoods and
(iv) developing related guidelines and awareness materials for stakeholders i.e. farmers, sellers, consumers, local authorities, and the WHO, and
(v) developing local human capacities in integrated research on irrigation, livelihoods and health through joint NARES-CGIAR student training.

Project Methods

The report is based in research carried out in West Africa, with a specific focus in Ghana. Due to the multidisciplinary nature of the project, a wide range of methods from different study fields including health sciences, agriculture, economics, engineering, environmental sciences, food sciences and social sciences were used. The project adapted a participatory approach to address its key objectives. The five main methods used included;

(1) *Literature review:* A wide range of literature was reviewed, which formed the basis of a number of activities in the project. For example, two project reports based on reviews, one on low-cost farm based measures and another on vegetable washing methods formed the basis of developing risk reduction interventions which are described under Objective 3.

(2) *Surveys and focus group discussions (FGDs) and interviews:* Surveys and interviews were extensively used in the project. For instance, a survey was conducted at the start of the project in all the three cities in Ghana to characterize the farming system which formed a basis for objective sampling while using other methods during in-depth studies. Surveys were also used while assessing land and water productivity (i.e. objective 1) and finding out what vegetable washing methods caterers were using (Objective 3). Interviews and FGDs were used extensively while conductive in-depth qualitative studies in Objectives 1 and 3. For instance for farm-based interventions, FGDs were used to identify risk reduction measures while interviews were used to obtain farmers' perceptions on risk reduction interventions during field testing.

(3) *Laboratory analysis:* This was the project's most used method. Thousands of vegetable, water and soil samples were analyzed in laboratories for mainly helminth eggs and faecal coliform bacteria. This was because microbial analysis data was used for health risk assessments. In addition, some samples were analyzed for other relevant physicochemical parameters, such as turbidity, nutrients and even pesticides. Laboratory analysis was the main method used for Objectives 2 and 3.

(4) *Field trials and laboratory based assessments:* This method was mainly used in Objective 3. For farm-based risk reduction interventions, assessment was carried out with farmers in their own fields (on-farm trials). For post-harvest interventions, especially washing methods, were conducted under controlled conditions i.e. laboratory.

(5) *Workshops:* This method was used throughout the project, but more so in Objectives 4 and 5. For instance in developing guidelines and awareness materials, workshops were held where relevant stakeholders participated in the development process and thereafter assessing the suitability of such materials.

Project Research findings

Land and water productivity in urban and peri-urban farming systems

The productivity of land, labour and water were estimated to be USD 9,153 per hectare, USD 7.21 per man-day and USD 65.48 per cubic meter respectively (Rate used: 1 USD = 1 GHC). Crop water use efficiency as well as field water use efficiency was also estimated to be 1061.71 kg/m^3 and 203.08 kg/m^3 respectively. Results from the stochastic frontier analysis showed that 78.5% of the variation in vegetable production output is attributable to technical efficiency differences among producers. About 21.5% of the variation in output among producers is due to random shocks such as unfavorable weather, water scarcity, pest and disease attacks and other factors outside the control of producers including errors in data collection and aggregation. The mean technical efficiency of the pooled sample is 66.67%. On the other hand, the allocative efficiency ratios for land and labour obtained from the study are 0.4556 and 0.4651, respectively an indication that both factors of production are overutilised in the production process. The main socio-economic factors which were assumed to have an influence on the productive efficiency of farmers included the age of the farmer, availability of off-farm income, access to credit, access to extension services, educational level of farmer and years of experience in the vegetable production industry. Age of farmer; contact with extension agents; access to off-farm income and access to credit all had negative coefficients. Farming experience and level of education had positive effects on technical efficiency.

Contamination in irrigation water and vegetables

The results also showed that polluted water is mostly used for urban vegetable production in the study sites. The faecal coliform levels observed in irrigation water in all the three cities were between 9.0×10^3 and 4.6×10^9 100 ml^{-1}). In Accra, faecal coliform levels ranged from 5.0×10^4 to 2.3×10^6 100 ml^{-1}.Throughout the 12-month sampling period faecal coliform levels in irrigation water from wells and streams significantly exceeded the WHO (2006) recommended level (1×10^3 100 ml^{-1}) for unrestricted irrigation of crops likely to be eaten raw. A number of different types of helminth eggs were isolated from all irrigation water sources except piped water. These included eggs of *Ascaris lumbricoides, Hymenolepis diminuta*, *Trichuris trichura*, *Facsiola hepatica,* and *Strogyloides* larvae but *Ascaris lumbricoides* was the most predominant species recorded; population density ranged between 2 to 4 eggs l^{-1} exceeding the recommended level of <1 egg l^{-1} for unrestricted irrigation (WHO, 2006).

Typical microbiologic and pesticide contamination levels of vegetables in Ghanaian markets were also high posing a threat to human health. The highest level of faecal coliform contamination was recorded on lettuce (geometric mean count of 1.1×10^7 per gram wet weight) likely due to the larger surface area exposed. Cabbage and spring onion showed geometric mean counts of 3.3×10^6 and 1.1×10^6 g^{-1} wet weight, respectively. No sample had less than 4000 faecal coliform g^{-1} (wet weight). The mean faecal coliform levels of all the three crops exceeded the International Commission on Microbiological Specifications for Food recommended level of 10^3 faecal coliform g^{-1} fresh weight. Only 14% of samples had no detectable pesticide residues. More than 60% of the lettuce samples had two or more pesticide residues, with 78% of samples showing chlorpyrifos, an organophosphate of moderate acute hazard.

Finally, the study has shown that the much of the microbial contamination of vegetables produced from urban sources occurs on the farm. The post harvest sector is likely a relatively minor contributor to lettuce contamination. The results confirm that even at the farm level, wastewater is only one of several sources of crop contamination, although it can be the major one. Besides irrigation water, other contamination sources identified in the farm are immature manure as well as the already contaminated soil.

Innovative risk reduction interventions

Stakeholders in Ghana such as farmers and caterers preferred simple and low-cost interventions, which they could easily adopt. Several risk reduction interventions were identified and some of them tested from where a number of best practices were identified. The best practices identified include:

Farm-based risk reduction best practices

The studies on alternative water sources, in this case groundwater, shows that the potential of using shallow groundwater as an alternative source of irrigation water for farmers using wastewater contaminated irrigation water is very low in the three cities. This is mainly because of the geology of the three cities and in Accra. There is an additional limitation from salinity as the city lies along the coastline.

Measures based on improving irrigation quality (ponds and filters), reduced helminth eggs to acceptable levels, however this was not achieved for thermotolerant coliforms which were too high on untreated irrigation water. Removal levels obtained for helminth eggs were 3-5 eggs per litre. For bacteria, die-off from prolonged exposure to unfavorable conditions is the main removal mechanism and filters. In ponds, there was significantly higher removal of thermotolerant coliforms when it was warmer (dry season) as this enhanced die-off, while with sand filters, removal increased with the formation of the biofilm that increased biological activity. The removal levels obtained in this study in ponds of 0.4-1.4 log units per litre, though within range, are lower than the reported removal levels of 1-6 log units for bacteria in pond systems in a review by WHO (2006). This is due to our short retention time (3 days) compared to the usual retention time of more than 15 days in a typical pond. Removal levels from slow sand filters (2.4 log units per litre) were comparable to the given range of 0-3 log units per litre.

On vegetables, the two interventions tested (irrigation methods and cessation of irrigation before harvest) use different removal mechanisms i.e. reducing contact of contaminated irrigation water with edible parts of vegetables (irrigation methods) and allowing for pathogen die-off (cessation). Performance of the two interventions was significantly better during the dry season than the wet season. This is because in warmer conditions (high temperature, low rainfall), there is more pathogen die-off on crop surfaces and soils. There is also less deposition of pathogens from soil splashes due to reduced rainfall occurrences (Bastos and Mara, 1995). On irrigation methods, drip kits had the highest bacteria removal levels (2-6 log units per 100 g). However, simple modifications in the use of watering cans which are predominantly used by farmers in the study area had surprisingly high bacteria removal levels (2-3 log units per 100 g), showing how simple adjustments can lead to significant contamination reduction.

Post-harvest risk reduction best practices

Nearly all households and restaurants interviewed in the pilot surveys in 11 cities in West Africa showed that there is a high awareness of the need to wash vegetables to be eaten raw. The surveys showed that various methods are used with different concentrations and contact times and very limited information on appropriate procedures. Noteworthy is the difference between Anglophone Ghana where salt solutions, water and vinegar are the dominant methods used for washing vegetables, while in all its Francophone neighbor countries chlorine bleach (commonly known as 'Eau de Javel') and potassium permanganate are well established disinfectants. Washing lettuce irrespective of the methods used reduces bacterial contamination especially when at least 2 minutes of contact time are granted. However, in many cases considerably high pathogen levels still remain on the vegetables. Generally, the efficacy of all methods (with relatively low sanitizer concentrations) tested in this study increased with increasing temperature. For example, the efficacy of salt and vinegar solutions increased significantly between about 1 to 2 log reductions from 25ºC to 40ºC. However, the higher temperature can have a deteriorating effect on the appearance of e.g. lettuce leaves. Also higher salt concentrations of 23 mg l^{-1} and 35 mg l^{-1} had a considerable deteriorating effect on the lettuce leaves and therefore may not be desirable. Washing vegetables in running water and also in increasing concentrations of vinegar were found to be the most effective washing methods (could remove more than 2 log units of faecal coliforms). However, the contact time need to be longer (more than 2 minutes).

Materials developed for raising awareness and training

After assessments (Objectives 1 and 2) and interventions (Objective 3) the next key project activity was knowledge sharing. This activity was done jointly with CPWF PN 51. So best practices developed from CPWF PN 51 have been integrated with those from this project to produce comprehensive materials. The project has developed training and awareness videos for farmers and food vendors/caterers as well as flip chart for agricultural extension agents. These materials have been developed hand in hand with policy makers and all key stakeholders (farmers, market women, extension material experts etc). Some of them have editions in English, French and/or local languages. For policy makers, the two projects wrote policy briefs, which are a synthesis of scientific data collected of relevance to policy making. For the scientific community, a number of different kinds of publications such as journal papers, magazines, posters etc. The project also has received extensive media coverage.

Capacity building

This was another joint activity with PN 51. Remarkably, two students completed their studies under these two projects. In addition, more than 10 postgraduate students (Masters level) also completed their thesis. Many more people were involved as technicians and interns (both from local and international universities).

Project Outcomes

The project has witnessed direct involvement in field trials and trainings of more than 200 urban vegetable farmers, 60 key vegetable sellers and more than 300 street food vendors. In addition, about 4 extension officers from each of the municipal directorates have been involved. There has been significant increase in awareness and knowledge levels regarding health risks and risk reduction interventions. A number of best practices identified in the project are increasingly been adopted by different stakeholders. For example, an increasing number of farmers in Kumasi are now using better constructing on-farm ponds and water fetching behavior has changes. Caterers are also making changes in their washing after trainings on what methods are effective.

International Public Goods (IPGs)

Urban vegetable farming using polluted water is a common phenomenon in many cities in low-income countries. Before starting this initiative in Ghana, we had visited a number of such cities and the practice had a lot of similarities. Traditionally, wastewater treatment has been seen as the ultimate solution, but with the costs being out of reach for many local authorities, it has turned out to be impractical. This is one of the first initiatives on testing low-cost treatment and non-treatment measures for irrigation water at field level. We have drawn largely from suggestions made in the WHO Guidelines on

Safe Use of Wastewater in Irrigated Agriculture which also encourages field testing of these "non-treatment options". So, what the contribution from this project as IPGs is the risk reduction interventions developed. In addition, approaches and methods used in project implementation could equally be helpful elsewhere. The project also produced many research publications in form of journal papers, student thesis, etc.

Project Recommendations

The project findings showed the potential of simple and low-cost risk reduction interventions in reducing health risks in wastewater irrigated urban farming systems. We recommended for a combination of measures based on the multiple-barrier approach for the risk reduction interventions developed in this project to make significant impact in health risk reduction. This will involve combining farm-based with pre and post harvest interventions. While the objectives of the project were well realized, further studies are recommended. These include;

1) *Further assessments on low-cost interventions:* Findings in this study should give a good basis for further assessments of low-cost intervention measures in other cities. Best practices identified could be up-scaled, though with care, considering differences in physical, socio-economic and cultural contexts.

2) *Pre-farm interventions:* Based on the principles of a multiple-barrier risk reduction framework, other barriers could be put up before wastewater ends up in the farms Even though conventional treatment of wastewater does not look feasible in the meantime, local authorities and communities should still be encouraged to invest in other innovative wastewater treatment systems.

3) *Assessing the effectiveness of combinations of risk reduction interventions***:** We have recommended for a combination of measures based on the multiple-barrier approach, this needs to be tested in actual field conditions to assess its effectiveness. A future challenge is the development of a comprehensive framework with best combinations of tested risk reduction strategies for wide application by national stakeholders and their potential transposition into legally enforceable national standards that can be monitored and verified.

4) *Detailed health assessments:* There is a large information gap on the actual risks for vegetable consumers and farmers from wastewater irrigation in Ghana. Detailed health assessments, in specific epidemiological studies complemented with Qualitative Microbial Risk Assessment (QMRA) studies, are recommended. Studies on occupational health risks including skin diseases are encouraged. The relative risk from wastewater in relation to other sources of similar risks for the same population such as poor drinking water quality, personal hygiene and bad sanitation needs to be clearly quantified. This is necessary so that investments can be directed to interventions that can have more impact on health protection.

5) *Indigenous adaptations to health risks***:** It is unclear to what extent the local population adapts to health risks. Studies on the contribution of indigenous observable risk-reduction measures to contamination reduction like removing soil from vegetables could also be assessed.

I. INTRODUCTION

About 800 million people are engaged in urban and peri-urban agriculture (UPA) worldwide and contribute about 30% to the world's food supply (UNDP 1996). This is increasingly becoming a common expression of most urban areas in developing countries and is seen as an important means of attaining balanced diets and urban food security. In several African cities, between 50 and 90% of the vegetable consumed are produced within or close to the city (Cofie *et al.* 2003). The proximity of UPA to consumers ensures freshness of the vegetables and likeliness to have higher nutrient contents than those stored and transported for long periods. This is especially important in Sub-Saharan Africa where refrigerated transport and cool storage are scarce. UPA also offers jobs for the poor, often especially women, and is an effective way to overcome poverty (Cofie *et al.* 2003). In many African countries, 65% of the people involved as UPA farmers or traders are women.

In Ghana, UPA is mainly characterized by backyards and commercial small-scale irrigated vegetable farming and is mainly carried out by men while marketing of the produce is predominantly a women domain. It also has significant contributions to livelihoods and food security; for example, around Kumasi, Ghana, more than 12,000 farmers are involved in vegetable farming during the dry seasons (Cornish *et al.* 2001) and urban farmers grow 90% of the main vegetables eaten in the city. This is done on virtually every open space more close to water sources of almost all major cities and urban centers in the West African subregion.

About 64% of Ghana's surface falls on the Volta Basin and many urban centers in Ghana draw their water from the basin. In Ghana, domestic and industrial urban water supplies entirely rely on surface water and water u se per capita is projected to increase by 15 liters to 91 l/cap/day by 2020. This will increase demands for higher quality water and more wastewater will be generated. Due to inappropriate and inadequate urban sanitation infrastructure, the wastewater ends up in nearby water bodies, which are often used as sources for irrigation water. In many areas of the basin wastewater constitutes the only available surface water for irrigation in the dry season, reducing the pressure on groundwater sources of the basin and sustaining many livelihoods. Use of the wastewater in UPA not only lessens the pressure on water resources but also increases water productivity through reuse of water and nutrients, which may be otherwise a nuisance to the environment.

However, this practice is known to have adverse public health and environmental effects, especially because untreated wastewater or polluted water has high levels of pathogenic organisms. There have been some outbreaks of diseases like typhoid in Santiago, Chile and helminth infections in Egypt and Jerusalem that have been associated with crop contamination from wastewater irrigation (Blumenthal *et al*. 2000). The use of wastewater can also affect the farm workers since significant ascaris and hookworm infections have been reported in sewage farmers in India (Blumenthal *et al*. 2000). This is one of the main reasons that make UPA in Ghana, like in many other West African countries, not to receive the appropriate public and institutional support despite its significant contributions to urban food supply, poverty alleviation, women empowerment and improved human nutrition through the provision of balanced diets.

Effective wastewater treatment can reduce pathogen levels but in most developing countries it is not an option for the municipal authorities due to the high costs involved (Keraita *et al*. 2002). In Ghana, most urban centres have no means of treating wastewater and the sewerage network serves only 4.5% of the total population (Ghana Statistical Services, 2002). Some attempts to develop new sanitation facilities have been faced with socio-economic challenges since they disrupt other existing infrastructure hence most new sewerage treatment plants in Ghana are operating below the design capacity. The related cost factor is tremendous. Calculations by Gijzen and Ikramullah

(1999) in Bos et al., 2004 showed that new investments in wastewater treatment would require payback periods exceeding by far the infrastructure's economic lifetime. As wastewater treatment does appear a realistic option, banning the use of polluted water by UPA has also been tried like in Accra and other cities within the Volta basin but has failed since such bans threaten many livelihoods, urban vegetable supply and are contrary to poverty alleviation strategies. In any case, related institutional and policy frameworks are weak and hardly practicable or enforced in the country. Urban farmers in this harsh situation expressed significant concerns as their livelihoods are at permanent risk. Any solution to reduce health risks without forcing them to change their (market-driven) cropping patterns or water access would be appreciated.

The result is a complex situation compounded by biophysical, technical, socio-economic and institutional elements that need a multidisciplinary and integrated approach. The Ghanaian municipalities recognized the challenge, and sought assistance from the research community. This was also supported by Ghana's Tourism Board, which started a campaign for "safer vegetables for healthier cities" as vegetables in urban areas were causing erratic gastrointestinal disorders especially to tourists. This project was therefore designed to find an appropriate balance between livelihood concerns and safeguarding health. It also aimed at supporting further revisions of the WHO wastewater irrigation guidelines in order to address the common situation of UPA in those developing countries where wastewater treatment up to the WHO (1989) norms is not possible. In addition, it was to address risk-reducing elements not covered yet in the WHO guidelines through the consideration of post-harvest contamination and decontamination of wastewater-irrigated crops.

For the Challenge Program for Water and Food, the project contributed directly to different Volta Basin goals and expected research outputs of Theme 4. The project was complemented by CPWF PN 51, which filled research gaps identified in the project. Appendix A shows the link in objectives and outputs of the two projects.

II. PROJECT OBJECTIVES

1. Objective 1: Studying and evaluating current land and water use practices in urban and peri-urban vegetable farming in Kumasi, Ghana.

1.1 Methods

1.1.1 Theory of production and productive efficiency

The economic theory of production provides the analytical framework for most empirical research on productivity and efficiency. Productive efficiency means the attainment of a production goal without a waste. The fundamental idea underlying all efficiency measures, however, is that of the quantity of goods and services per unit of input. There are two basic methods of measuring efficiency the classical approach and the frontier approach. Due to the dissatisfaction with the shortcomings of the classical approach which is based on the ratio of output to a particular input, the study used the frontier approach which suggests that efficient firms are those operating on the production frontier. The approach further suggests that the amount by which a firm lies below its production frontier is regarded as the measure of inefficiency.

1.1.2 Analytical models

For empirical analysis, Cobb-Douglas (1928) stochastic frontier production function was estimated. It is vital to note that the Cobb-Douglas frontier is the restricted form of the translog frontier, in which the second order terms in the translog function are restricted to be zero. A Cobb-Douglas production frontier was used to represent the production technology used by vegetable farmers.

1.1.3 Empirical estimation of technical efficiency

For the empirical analysis, the Cobb-Douglas frontier production function specifies the technology of the production process. The variables associated with production are categorized into output (Y) of lettuce and cabbage in kilograms, Labour (Lab) in man-days, Quantity of manure / fertilizer (M/F) used in kilograms, Quantity of pesticides applied in litres, Capital (Cap) used in Ghana cedis (GHC) , and Material (Mat) including seeds and pesticides are measured as the value of other inputs in GHC.

Environmental and social effects were not considered as having impact on input use in this study since the main concern was to find out the inefficiency in utilizing the labour and other inputs considered in the production process. Therefore, output, input and cost variables associated with wastewater irrigated vegetable production have been identified as detailed below. Other variables such as age, education and those relating to policy influences were also gathered. Inputs considered were as follows: *Land*, area devoted to Cabbage and Lettuce production (hectares) per season; *Labour*, sum of family and hired labour measured in man -days, one man-day is equivalent to 8 hours in this study; *Manure / fertilizer*, the quantity of manure /fertilizer in kilograms applied per hectare in a season; *Insecticides*, the volume of insecticides (in liters) used per hectare in a season; *Materia*l, refers to all cash expenses (variable cost) incurred in producing one kilogram of cabbage in a season; for example, the cost of seeds, fertilizer / manure, insecticides, and other service charges and Capital refers to the value of equipments at current cost used in production. Access to extension services was not included as this was found to be common to all farmers within the study area.

Determinants of efficiency were represented as:
R1 = Age of farmer
R2 = Level of education of farmer / decision maker
R3 = years of farming experience (vegetables only)
R4 = Access to credit during the cropping season
R5 = access to off-farm income

1.1.4 Socio-economic model

Average level of technical efficiency measured by mode of truncated normal distribution (i.e.μit) has been assumed (Dawson, Lingard and Woodford, 1991; Kumbhakar and Heshmatic, 1995 and Yao and Liu, 1998) to be a function of socio-economic factors such as age of farmer, level of education, farming experience, access to credit and access to off –farm income respectively. These variables are assumed to influence technical efficiency of the farmers.

1.1.5 Empirical estimation of allocative efficiency of vegetable production.

Allocative efficiency reflects the ability of a firm to use inputs in optimal proportions, given their respective prices. A production process is said to be allocatively efficient if it equates the marginal rate of substitution between each pair of inputs with the input price ratio. The requirement for the fulfillment of allocative efficiency is for the marginal physical product (MPP) of all productive resources to be known (Ellis, 1988). The aim of this study is to estimate the allocative efficiencies of labour and capital since it is these factors that are substituted for in the production process.

1.1.7 Estimates of the production frontier function

The estimation of the relative efficiency of production units is conducted by assuming the appropriateness of the log-linear Cobb-Douglas case. The specification of the translog function was also tested. The results of the translog function is not reported in this study because it did not have the right signs for the coefficients and almost all the variables included in the translog model were found not to be significant. Thus, the specification using the translog function to represent the production technology was not appropriate. Results of the Cobb-Douglas gave the best estimates and hence the choice for it. All the estimations were done using maximum likelihood methods from the statistical programme LINDEP Version 7.0.

1.2 Results and Discussion

1.2.1 Production and productive efficiency

The goodness of fit of the estimated regression equations evaluated by R2 for the ordinary least squares (OLS) looked low. The poor R^2 value may be accounted for by the fact that outliers existed. Apart from these outliers, the R^2 value implies that the inputs to the model did statistically explain the model output. In addition, the F-Statistic of 11.33 showed that the relationship between the variables were significant at 1% level. Tables 1.1 and 1.2 show the results of the OLS and maximum likelihood estimates with the computed log likelihood functions for the Cobb-Douglas frontier model.

Estimated OLS results obtained from the study revealed that most of the coefficients are statistically significant at either 1% or 5% level of significance. The poor R2 obtained from the results is not relevant for this study because that is not the focus and hence could be ignored. Dawson (1987) and Hallam and Machado (1996) noted that the estimates of the production frontier parameters are not the primary interest when the aim is the measurement of efficiency; in this case the overall predictive power of the estimated function is of great importance.

From the Cobb-Douglas frontier production function output presented in Table 1.2, the estimate of the variance ratio (γ) is significant. The value is as high as 0.7851.This implies that about 78.5% of the variation in vegetable output is attributable to technical efficiency differences among production units. By implication about 21.5% of the variation in output among producers is due to random factors such as unfavorable weather, errors in data collection and aggregation and the like. The γ parameter is very important because it shows the relative magnitude of the inefficiency variance associated with the frontier model which assumes that there is no room for inefficiency in the model.

Table 1.1: OLS estimates of vegetable production using Cobb-Douglas frontier production function.

Variables	Parameters	Coefficients	Standard error	t-value
Constant	B1	4.1947	0.4472	9.379**
Ln (land)	B2	0.1373	0.6373	2.155*
Ln (labour)	B3	0.3615	0.3400	0.915
Ln (Capital)	B4	0.3395	0.2787	4.998
Ln (materials)	B4	0.1923	0.4537	4.239**
Ln (Pesticides)	B6	0.1109	0.3348	3.316**
Ln (Manure/Fert)	B7	0.1916	0.3374	0.568
F-Statistic		11.33**		
R-squared		0.2586		

**,* mean significant at 1% and 5% levels, respectively

Table 1.2: Maximum Likelihood estimates of pooled sample using the Cobb-Douglas Production frontier function

Variables	Parameters	Coefficients	Standard error	t-value
Constant	B1	4.6540	0.3374	13.793**
Ln (land)	B2	0.1068	0.4740	2.254*
Ln (labour)	B3	0.1678	0.3205	0.052
Ln (Capital)	B4	0.3452	0.2992	1.154
Ln (materials)	B5	0.1586	0.3875	4.092**
Ln(Pesticides)	B6	0.1119	0.3687	3.035**
Ln (Manure/Fert)	B7	0.3578	0.3254	1.099
Variance-ratio	γ	0.7851		
Total variance	$\sigma2$	0.1218		
Sigma-squared	$\sigma2$ u	0.0956		
Log likelihood Fn		-0.4204		

**,* mean significant at 1% and 5%, respectively

1.2.2 Technical efficiency

The results indicate a great difference in efficiency levels among production units. It is appropriate to question why some producers can achieve relatively high efficiency whilst others are technically less efficient. Variation in the technical efficiency of producers is probably due to differences in managerial decisions and farm characteristics that may affect the ability of the producer to adequately use the existing technology.

Table 1.3 shows the distribution efficiency estimates of vegetable producers in the study area using Jondrow et al. (1982) conditional expectation predictor.

Table 1.3: Frequency distribution of Technical Efficiency estimates

Technical Efficiency (%)	No. in Sample	Percentage	Cumulative %
Less than 30	7	5.18	5.18
30 – 40	8	5.92	11.11
41 – 50	7	5.18	16.29
51 – 60	12	8.88	25.18
61 – 70	15	11.11	36.29
71 – 80	67	49.62	85.92
81 – 90	17	12.59	98.51
91 – 100	2	1.48	100
Total	135	100	

The study shows that technical efficiency ranges between 21.9% - 95.02%.The lowest level of efficiency is 21.9% which is far below the efficient frontier by 78.1%. Such production units are technically inefficient. The highest level of efficiency is 95.02% and such production units can be classified as being technically efficient since in reality production units hardly operate at 100% level of efficiency. The mean technical efficiency of the pooled sample is 66.67%.This compares favorably with other efficiency studies conducted in other areas of agriculture. For instance, previous studies in rice had 65% (Kalirajan and Shand, 1986); 75% (Kumbhakar, 1994); 50% (Kalirajan and Flinn, 1983); 59% (Bravo-ureta and Evenson, 1993) and 66% (Pierani and Rizzi, 2002).

The 66.67% mean technical efficiency implies that on the average, 33.33% more output would have been produced with the same level of inputs if producers were to produce on the most efficient frontier following best practices. A greater proportion of the production units (49.6%) are concentrated in the efficiency class of 71 – 80%.The next highest concentration of producers' the efficiency class 81 – 90% which contains 12.59% of the pooled sample.

Analysis of technical efficiency differences among production units in the enterprise using analysis of variance (ANOVA) test shows that there is no significant difference in the technical efficiency estimates between production units at 5% level of significance. The test results show that the first null hypothesis of technical efficiency for the production units is rejected. Thus inefficiency exists among the production units considered in this study. The ANOVA results show that there are no significant differences in the technical efficiency estimates among the production units at 5% level of significance.

Table 1.4: Test of significance differences in efficiency between production units.

Source	df	SS	MS	F	F-critical
Regression	1	0.4533	0.4533	0.9429	3.6800
Error	134	64.4165	0.4807		
Total	135	64.4440			

From the results in table 1.4 above, F calculated is less than the F critical, so we fail to reject the null hypothesis. This means that there are no wide variations in technical efficiency of the sampled production units. The absence of wide variation in the level of efficiency is an indication that little opportunity exists for these production units to raise their level of efficiency.

The OLS results presented in Table 1.1 was used alongside with the mean values of the variables included in the model to estimate the allocative efficiencies. From the OLS results, the following mean values were obtained for the variables (Table 1.5).

Table 1.5. Mean values were obtained for the variables.

Variable	Mean
Output	6.9077
Land	4.8891
Labour	5.4801
Capital	5.2849
Materials	5.4655
Pesticides	7.7493
Fert/manure	6.7935

The factor elasticities and marginal value products were then computed from the OLS results. The resulting allocative efficiencies are presented in Table 1.6. If the allocative efficiency index is less than unity, it implies the resource is overutilised. If it is greater than unity, it implies the resource is underutilized and if it is equal to unity, it implies the resource is efficiently utilized.

Table 1.6: Allocative efficiency estimates

Variable	MVP	MFC	R= MVP/MFC
Land	30,378	63,725	0.4767
Labour	3,645	8,000	0.4556

Since the most limiting factors in peri-urban vegetable production are land and labour, these two are singled out for emphasis. From Table 1.6 above, both land and labour are overutilised in the production process. This implies an inefficient utilization of the two factors of production. Labour and land is paid less than their MVP in the production process. This is because the allocative efficiency ratios for both factors are less than unity. This may be due to the fact that almost all the operations on the farm are carried out manually on a fixed piece of land usually smaller in size. Also due to urbanization and scarcity of water resources, farmers are restricted to a particular piece of land, which in most cases do not attract any rent. Thus, shifting cultivation can no longer be practiced resulting in over utilization of the land.

1.2.3 Determinants of efficiency

The determinants of efficiency were modeled using socio economic factors that affects farm operations and also has policy implications. The main socio-economic factors which were assumed to have an influence on the productive efficiency of farmers and hence included in the modal include the age of the farmer, availability of off-farm income, access to credit, access to extension services, educational level of farmer and years of experience in the vegetable production industry. These variables were regressed on the inefficiency due to production scores. The results are presented in Table 1.7 below.

Table 1.7: Determinants of efficiency.

Variable	Parameter	Coefficient	SE	t-Value
Constant	α1	2.3893	0.7988	2.991
Ext. Contact	α2	-0.2990	0.1558	-0.192
Age	α3	-0.5870	0.2344	-2.504**
Off INC	α4	-0.5870	0.1196	-0.217
Education	α5	0.3722	0.1228	0.303
Experience	α6	0.7911	0.1143	0.692
Credit	α7	-0.2241	0.2686	-0.835

**, means significant at 1% level.

Access to credit and contact with extension agents during the production season were represented as dummy variables in the model; 1 being having access to credit or extension and 0 otherwise. From the OLS results presented in Table 1.7 above, Age of farmer; contact with extension agents; access to off-farm income and access to credit all had negative coefficients. The negative coefficients imply negative influence on technical inefficiency. Therefore increasing age would significantly lead to increasing technical inefficiency. The results obtained here follow the *apriori* expectation. Ageing farmers would be less energetic to work on farms. Hence, they are expected to have low technical efficiency. The negative coefficient of credit means that the use of credit tends to result in declining technical inefficiency. If the production credit obtained by farmers is invested in the farm, it is expected that it would lead to higher levels of technical efficiency since the farmers would be able to purchase high yielding production inputs. Therefore the results obtained follow *apriori* expectation.

The positive coefficients obtained for level of education, and years of farming experience also follows *apriori* expectation, given that educational is an important factor in technology adoption. Educated farmers are expected to be receptive to improved farming techniques and therefore should have a higher level of technical efficiency than farmers with less education. The positive coefficient of education is in line with the findings of previous studies by Obwona (2000), Sidhu and Baanate (1981), Jamison and Lau (1982), and Pudasaini (1983) that education has a positive effect on profits, a result that shows the existence of management related inefficiency (Ali and Byerlee, 1991).

Farming experience having positive coefficient indicates that farming experience would lead to an increase in technical efficiency. This result has also confirmed *apriori* expectation. More experienced farmers are expected to have higher level of technical efficiency than farmers with low farming experience, given that farming business involves annual routine activity. Even though from theory access to credit, availability of off-farm income, contact with extension agents and number of years of farming experience are expected to impact positively on the productive efficiency of farmers, the overall results obtained from this study is at variance with it. This is explained by the fact that only a small proportion of the respondents had access to these services. Majority of the respondents (59%) did not achieve basic education required to enhance their efficiency. Only 4.44% of the respondents had tertiary education and 36.3% had secondary education (JSS & SSS). Also, only 7.4% of the respondents had access to credit; 15.5% had access to extension services; and 29.6% had access to off-farm income.

The age of the farmer was found to be highly significantly related to productive efficiency at the 1% level of significance. This is explained by the fact that majority of the respondents covered by the study were between the ages of 18 –39 required to boast agricultural production. They are described as being energetic, smart to adopt new technologies and market oriented in production. This therefore enhances their chances of being efficient in the production process. The study revealed that 76.3% of the respondents were between the ages of 18-39 years; 20% were between 40 – 49 years and only 3.7% was fifty years and above old. This therefore suggests a greater potential to make the vegetable industry more efficient. Due to the youthful nature of the age structure of the respondents, the number of years that farmers had been in production was very less. Since majority of the respondents were youthful with few years of experience in the vegetable production industry, the study found age not to be significantly related to productive efficiency.

1.2.4 Productivity of land and labour

Partial productivity measures for individual inputs were estimated. The productivity of land is the ratio of gross revenue obtained from production to the land area put under cultivation. The productivity of land was determined for all the nine sites covered by the study. Productivity of land varies from ¢72,386,587/ha to ¢140,325,417/ha (1USD=1GHC or 10,000 old cedis at the time of the study). The highest productivity of land was found at Georgia. This could be explained by the fact that the site is strategically located closer to the central market site and just behind a popular hotel (Georgia). Because of high demand for lettuce and cabbage at the site, the price of output per unit area is higher than all the other sites. Also the high productivity of land could be attributed to the clean water they use for irrigation. The study revealed that over 80% of the producers were using piped water for irrigation. The average productivity of land is estimated to be ¢91,525,684 per hectare. This means that if an area of one hectare is put under cultivation for lettuce and cabbage, all things being equal, a revenue of ¢91,525,684 could be realized per season.

The productivity of labour is the ratio of output obtained to the amount of labour input in man days spent on the field. From Table 1.8, the productivity of labour obtained from the study varies from ¢52,596.00 to ¢111,776.00 per manday. Labour was found to be more productive at the engineering site than all the other locations. This probably is due to high managerial ability of farmers resulting in better employment of labour in the production process. A greater proportion of farmers at this site were directly responsible for carrying out their farm operations as compared to the other locations where the use of ‘farm boys’ was prominent. The average productivity of labour is estimated to be ¢72,119 per manday. This implies that if an adult person is made to work on the farm for a production season, all things being equal the potential to generate ¢72,119 exists. The productivity estimates for the various factors are presented in Table 1.8 below.

Water productivity is very essential in any production process most especially in agriculture. Because water is life, it must be used judiciously. The productivity of water is the ratio of the value of output obtained to the volume of water applied during the production process. Water productivity values as revealed by the study ranges from a minimum of ¢891,616 per cubic meter of water used per season. The lowest water productivity figures were recorded at Kotei. This could be explained by the fact that most of their fields were on high grounds and easily dry up. The highest frequency of watering was also seen at the site resulting in a greater water usage in the production process. The average water productivity is found to be ¢654,754 per cubic meter per season.

Table 1.8: Productivity estimates

Location	Land productivity (¢/ha)	Labour productivity (¢/man-days)	Water productivity (¢/m3)	Crop water use efficiency (kg/m3)	Field water use efficiency (kg/m3)
Genyase	83,472,733	72318.84	639,129	3649.68	182.47
Kotes	97,401,268	52596.68	740,856	3393.38	169.66
Bus.School	75,755,494	70705.12	778,405	5025.95	251.29
Engineering	72,386,587	111776.64	776,993	4498.00	224.90
Kentikrono	86,095,433	55197.36	567,198	4041.73	202.08
Kotei	96,891,049	65417.95	489,482	3485.08	174.25
Eduasi N.S.	107,673,973	74801.32	891,616	6397.95	319.89
Kakari	86,633,663	83665.33	508,499	2598.69	129.92
Georgia	140,325,417	82614.88	683,517	4519.93	225.94
Total	91,525,684	72119.87	654,754	4061.71	203.08

In order to evaluate as to whether the water applied by farmers is being utilized by the crop efficiently or not, crop water use by plants were estimated. Crop water use efficiency is the ratio of the physical output obtained from the field to the amount of water depleted by the crop in the process of evapotranspiration. The rate of evapotranspiration was assumed to be 5% for this study. The average crop water use efficiency is estimated to be 4061.71 kg/m^3.

Finally, the field water use efficiency was determined as the ratio of crop yield to the total amount of water applied per hectare. The study revealed that crops grown at the

Eduasi New Site were using water more efficiently than crops grown in all other locations covered in the study. This could be attributed to soil conditions and the managerial ability of farmers at a site. The average field water use efficiency for the study area is estimated at 203.08 kg/m^3.The implication is that, for every one cubic meter of water used in production, a physical output of 203.08 kg could be achieved.

1.2.5 Resources in Vegetable production

1.2.5.1 Land

Land is a major factor of production and without it no production can take place. The type of ownership of land can affect the efficiency of production. Farmers were asked to indicate how they acquire the ownership of the land used in production. The various forms of ownership of land is summed and presented in Figure 1.1.

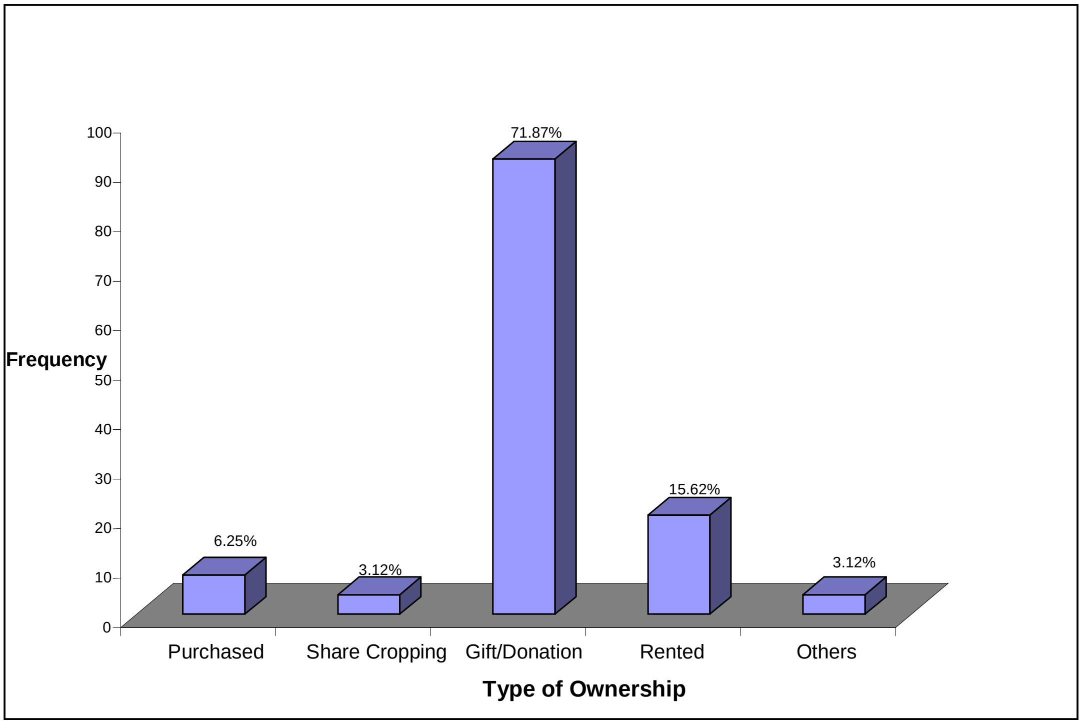

Fig. 1.1: Land Tenure /Ownership

From Fig. 1.1, twenty respondents representing 81.87% acquired their lands through either gift of donations. It was found that majority of the farmers covered by the study were farming on the University of Science and Technology land and are less secured as they could be asked to stop production at any time. Some were also producing on plots either given to them by Chiefs or were caretakers for people studying outside the region or abroad. The implication is that, the development of permanent structures such as wells to ensure all year round production and enhance efficiency in production cannot be achieved. About 3.12% of the respondents were practicing share cropping system. Under this arrangement, land owners are allocated a specified number of beds in every production season. This system is mostly practiced at Kentikrono area. Almost all the farmers who had their lands through this arrangement were migrants from Northern Ghana specifically Upper East Region. One quarter of the number of beds produced per season goes to the land owner while three-quarters goes to the farmer.

About 6.25% of the respondents had their lands through purchase. The average amount paid for an area of 10,000m2 varies from ¢3,000,000 to ¢12,000,000 cedis. Only

3.12% of the respondents hand their lands through inheritance. In general, over 80% of vegetable producers covered by the study do not owe land permanently to undertake any meaningful production. The implication is that, investments made in developing the land is minimal or non-existent, permanent farm structures cannot be erected and the future of the vegetable industry is uncertain though it proves profitable to most farmers.

1.2.5.2 Irrigation water

The use of untreated water in agriculture is growing due to water scarcity, population growth and urbanization which all lead to the generation of yet more wastewater in urban areas. Farmers in the Kumasi metropolis use a variety of water sources for irrigation. Out of the total number of respondents covered by the study, 9.62% were using the same water source for both drinking and irrigation of vegetables. Majority of the respondents (90.37%) were found not to be using the same water used for irrigation for drinking (Table 1.9).

Table 1.9. Sources of water used in irrigation

Number	Source	Frequency	Percentage (%)
1	Steam	33	23.9
2	Well	3	2.1
3	Pipe	6	4.3
4	Dugout	96	69.5
Total		138	100

1.2.6 Marketing of vegetables

The study revealed that all the farmers covered by the study sell their produce at the farm gate level through market women. Farmers in the study area are therefore restricted to a single channel through which they sell their produce. One hundred percent of the farmers covered were found to be selling their produce through market women. When asked why they could not go to the central market and sell directly to individuals and other organizations, varied responses were given. The main reasons offered by farmers include the intensive nature of their farm operations which may not allow them time to wait and make sales at the market; creating jobs for others (market women); and difficulty in selling the produce at the desired price because of collusive behavior of market women.

Table 1.10 presents the main problems encountered by vegetable farmers in the production process. In most developing countries production is not much of a problem but rather marketing. Farmers were asked to state at least two most pressing problems in order of priority facing them relating to marketing of their produce. The main problems raised is summarized and presented below.

Table 1.10. Problems of Marketing Vegetables.

Number	Problems	Frequency	Percentage (%)
1	Low/ Unstable prices of produce	62	32.46
2	Non-reliability of customers	84	43.97
3	Limited sale outlets	3	1.57
4	Low/No demand for the produce	34	17.80
5	Lack of storage facilities	4	2.09
6	Lack of financial support	2	1.05
7	Others (Effects of importation; effect of bird flu on prices etc.)	2	1.05
Total		191	100

From Table 1.10, 43.9% of the respondents said the non- reliable nature of their customers is their greatest worry in marketing their produce. Almost all the farmers covered by the study were selling their produce through market women. The non-reliability of customers could be seen in drastic reduction in price levels offered by the market women even when price so low as alleged by the women, delay in payment of produce after making a credit purchase levels were not and untimely visits of market women leading to the deterioration of the produce on the field in bad condition. This, many of the farmers described as an disincentive to production and does not motivate them to produce more even when the capacity to do so exists. The study revealed that low and unstable prices of produce are a major worry to producers since it is a factor outside their domain. Out of a total of one hundred and ninety one (191) problems raised, 32.46% of the responses were centered on price instability due partly to seasonal fluctuations. Most farmers were of the view that government could play a major role in stabilizing prices.

Only 1% of the responses gathered gave attention to lack of storage facilities and lack of financial support. Only 2% cited limited sale outlets as a major problem. This implies that though they were problems in the vegetable production industry, they constitute the least problems facing farmers. To most farmers, the industry was lucrative during the months of March, April, and May when the number of producers was fewer due to drying up of most dugouts resulting in higher prices.

1.3 Conclusions

- The results obtained by the one-stage ML estimation of the Cobb-Douglas frontier model shows that output is irresponsive to changes in labour input. This most likely implies that labour in the agricultural sector is oversupplied and it is not used efficiently. It also has an implication for average earnings rate for farmers. In such circumstances farmers will be paid to work at a very low rate of earnings.

- Results from the stochastic frontier analysis shows that 78.5% of the variation in vegetable production output is attributable to technical efficiency differences among producers. About 21.5% of the variation in output among producers is due to random shocks such as unfavorable weather, water scarcity, pest and disease attacks and other factors outside the control of producers including errors in data collection and aggregation. The mean technical efficiency of the pooled sample is 66.67%. This high level of efficiency confirms the 'poor but efficient' hypothesis.

- The allocative efficiency ratios for land and labour obtained from the study are 0.4556 and 0.4651, respectively an indication that both factors of production are overutilised in the production process.

- The main socio-economic factors which were assumed to have an influence on the productive efficiency of farmers and hence included in the model include the age of the farmer, availability of off-farm income, access to credit, access to extension services, educational level of farmer and years of experience in the vegetable production industry. Age of farmer; contact with extension agents; access to off-farm income and access to credit all had negative coefficients. Farming experience and level of education had positive effects on technical efficiency.

- The productivity of land, labour and water were estimated to be ¢91,525,684 per hectare, ¢72,119 per man days and ¢654,754 per cubic meter respectively. Crop water use efficiency as well as field water use efficiency was also estimated to be 1061.71 kg/m^3 and 203.08 kg/m^3, respectively.

- The study revealed that majority (81.87%) of vegetable farmers in the Kumasi metropolis are producing on government lands. The implication is that, the development of permanent structures such as wells to ensure all year round production and enhance efficiency in production cannot be achieved.

- Generally, farmers are aware of the health implications associated with the use of contaminated water for irrigating salad vegetables. About 91.5% of farmers hold the view that the quality of water being used for irrigation is good and do not pose any threat to the lives of consumers. Water quality is of little priority concern to farmers. What matters most to them is regular supply of water all year round since most of them do not pay for it.

2. Objective 2: Quantifying water pollution and comparing vegetable (de)contamination along the contamination pathway (farms to markets to households).

2.1 Methods

2.1.1 Study sites

The study was divided into three phases. The first phase (market sampling) was conducted in the three Ghanaian cities of Accra, Kumasi and Tamale. This was a preliminary study undertaken to obtain the background information on the hygienic quality of irrigated vegetables produced and sold in three major cities of Ghana and an understanding of the public health implications. The second phase (water to field to market sampling) took place in Accra and Kumasi. Phase II was carried out to assess the contamination pathways of pathogens (bacteria and helminths) on wastewater irrigated crops to determine where interventions should be placed and to suggest appropriate health risk reduction strategies at food preparation points. The third phase (field trials) was only conducted in Accra to determine sources of pathogen contamination other than irrigation water.

Accra is the capital city of Ghana with a population of about 1.7 million (GSS, 2002). It is located in the Gulf of Guinea in the coastal savannah belt. The total average rainfall for the wet and dry seasons in Accra are as follows: main wet 620 54 mm, short dry 65 mm, short wet 145 mm and main dry 92 mm (Figure 1)

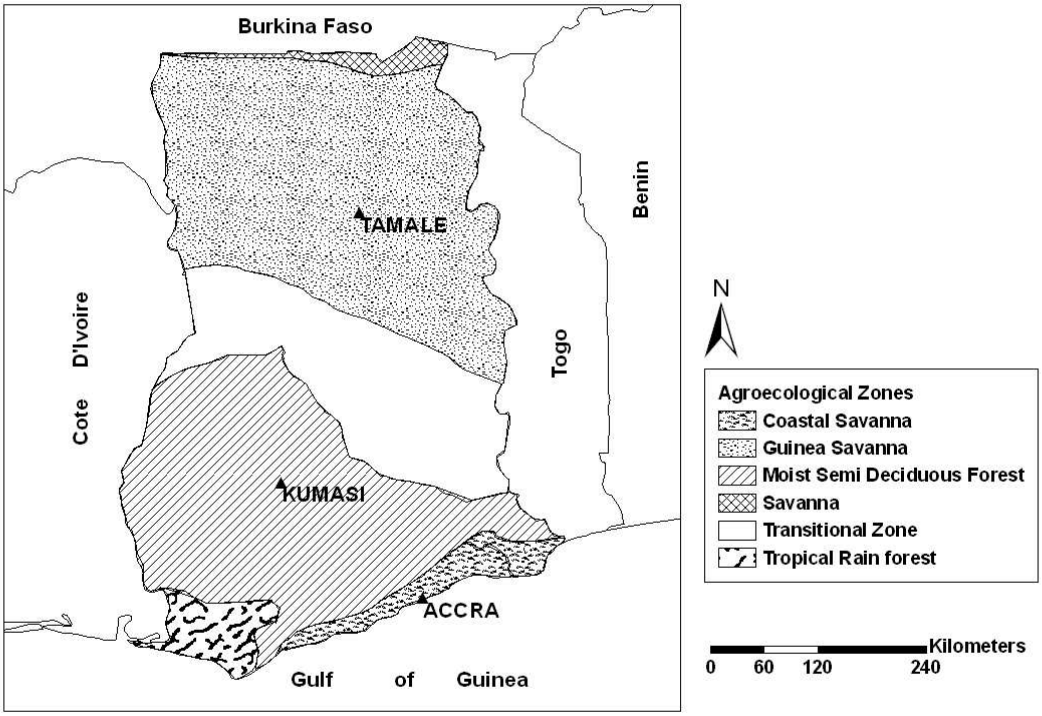

Figure 1.2 Map of Ghana showing location of the study areas

Kumasi is the capital town of the Ashanti Region and the second largest city in Ghana with a population of about one million (GSS, 2002). Kumasi is located in the forest belt of Ghana and the total average rainfalls for the wet and dry seasons in Kumasi are as follows: Main wet 680 mm, short dry 220 mm, short wet 350 mm and main dry 160 mm. Tamale is the administrative and regional capital of the Northern Region. It is located in Ghana’s savannah zone and has a population of about 300,000 (GSS, 2002). In contrast to Accra and Kumasi, the Tamale Municipality is poorly endowed with water bodies. There are only a few seasonal streams. The second phase of the study was carried out at selected sites in Kumasi and Accra (Figures 2 and 3).

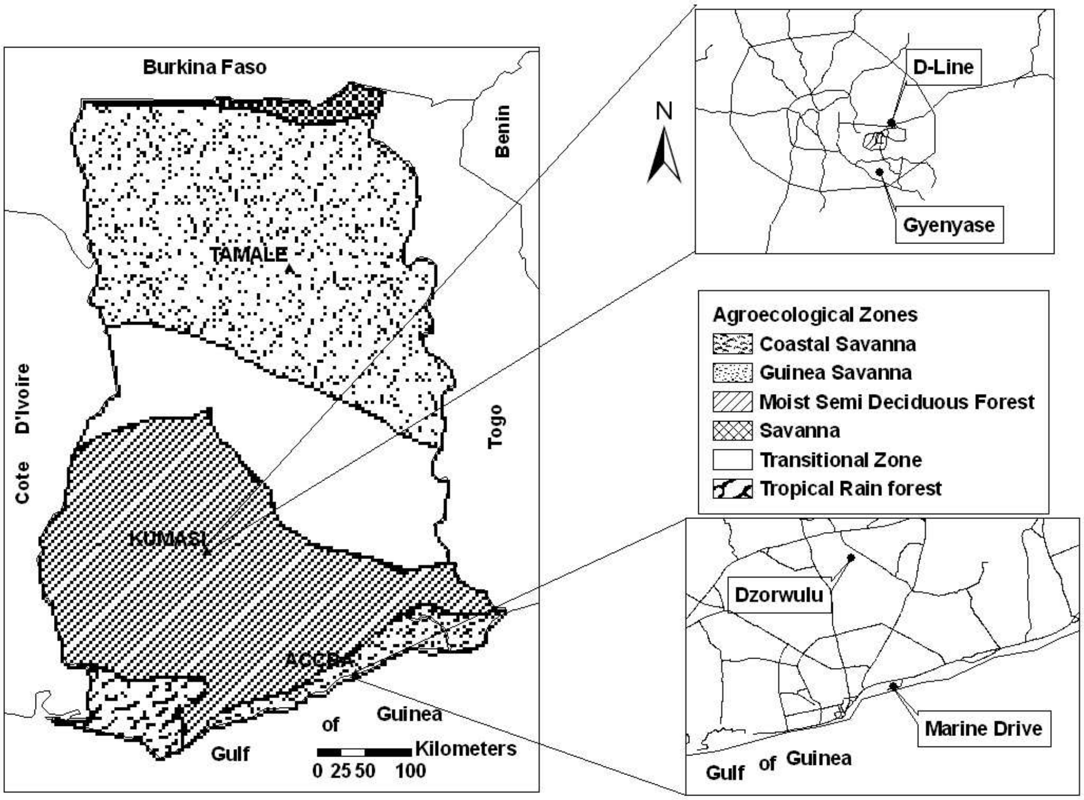

Figure 1.3 Map showing the study sites in Accra and Kumasi.

In Accra, between 47 and 162 ha are cultivated with vegetables, with the higher figure in the dry season. In Kumasi, about 40 ha are cultivated throughout the year. The production takes place on some 5-8 major open spaces per city, usually along urban streams or drains or in inland valleys. In both cities, there are also 3 - 5 larger markets and a significant number of community or neighborhood markets, which often specialize on vegetables and fruits. In this study, two major irrigated vegetable production sites were selected per city for sampling. Selection criteria were irrigation water sources and the type of vegetables grown (i.e. lettuce). The sites in Accra used water from drains and streams while those in Kumasi used water from streams or shallow wells close to streams of inland valleys. At least one of the two sites in each city had a group of farmers using piped water as irrigation water source over a period of at least three years. All the sites had similar land use history in terms of continuous vegetable cultivation and the use of poultry manure as preferred fertilizer sources for at least five years.

Site description

Dzorwulu and Marine Drive in Accra

Dzorwulu is one of Accra's suburbs with a major vegetable production site within the metropolis with a total land area of about 12 ha cultivated by over 300 farmers. Most of the farmers use water from the Onyansa stream which receives wastewater from the surrounding communities and few others use piped water. Marine Drive is a smaller vegetable production site in Accra near the Independence Square and the Presidential office. The area is about 4 ha and has more than 100 vegetable growers. Water for irrigation is from a local wastewater drain. Crops grown at Dzorwulu and Marine Drive sites are mainly lettuce, cabbage, and spring onions.

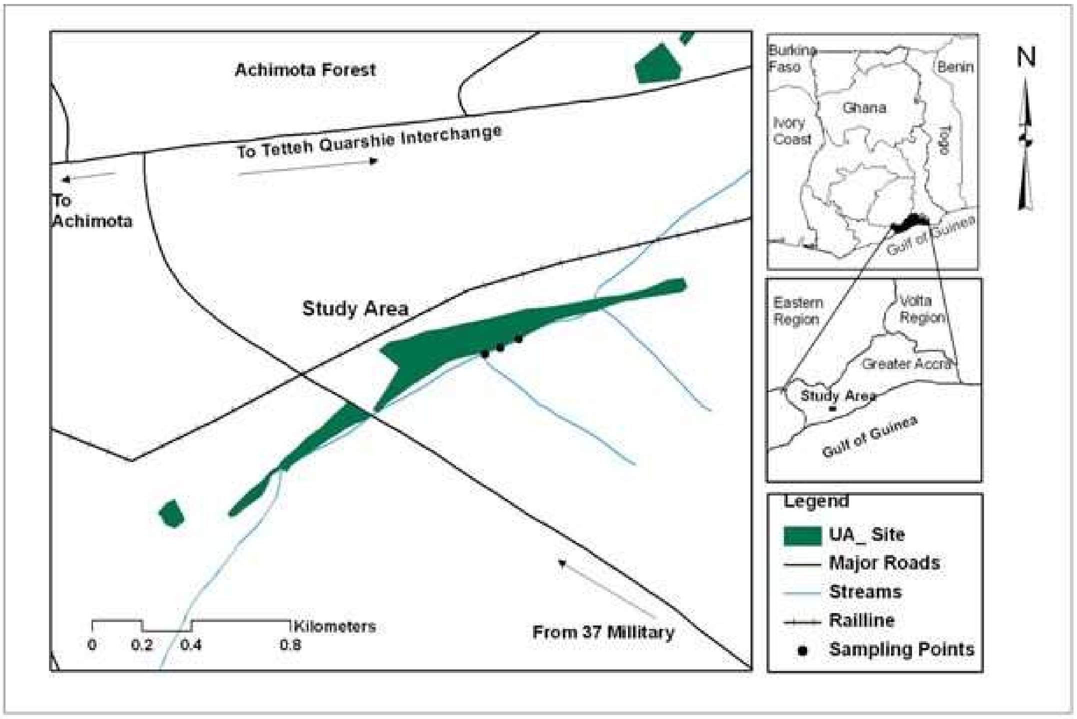

Figure 1.4 Water and lettuce sampling sites at Dworwulu

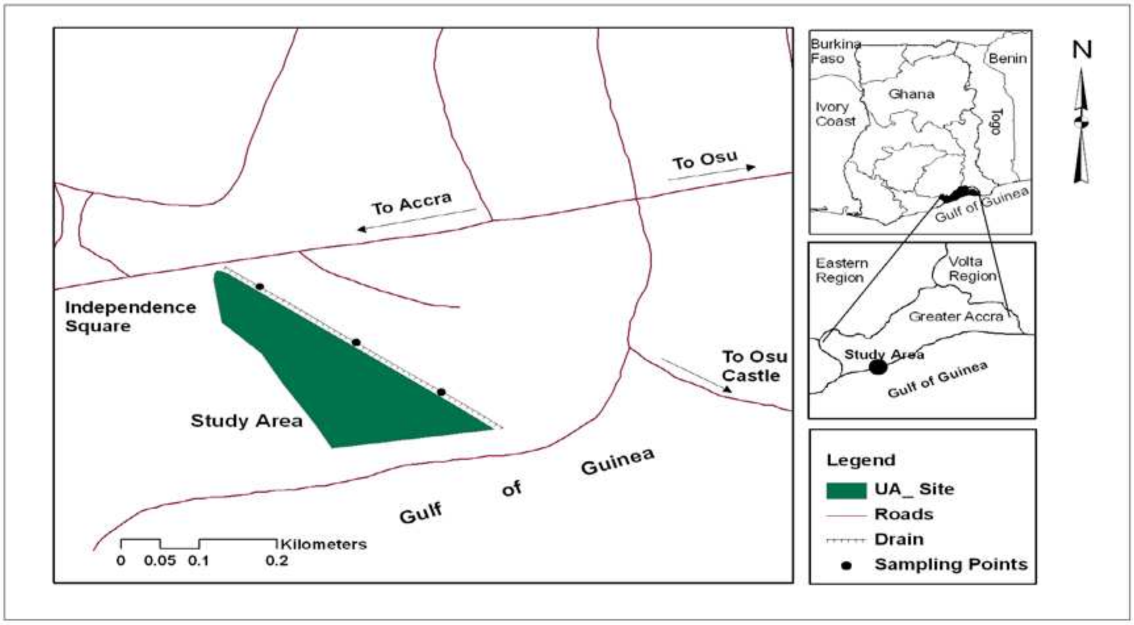

Figure 1.5. Water and lettuce sampling sites at Marine Drive

Two sites were also chosen in Kumasi. The Gyenyase site (Figure 5) is the largest urban vegetable growing site in Kumasi with a total land area of about 6 ha with shallow dug out wells serving as irrigation water source. It is located next to the Kwame Nkrumah University of Science and Technology (KNUST) at latitude 06˚39’44”N 57and longitude 01˚34’38”W. There are about 60 vegetable farmers at this site. The second site, D line, (figure 6) is a suburb of KNUST. There are close to 40 farmers and a total cultivation area of about 3 ha. This site is located at 06˚41’14”N and longitude 01˚33’58”W. Types of crops grown at these two sites are the same as those described for Accra.

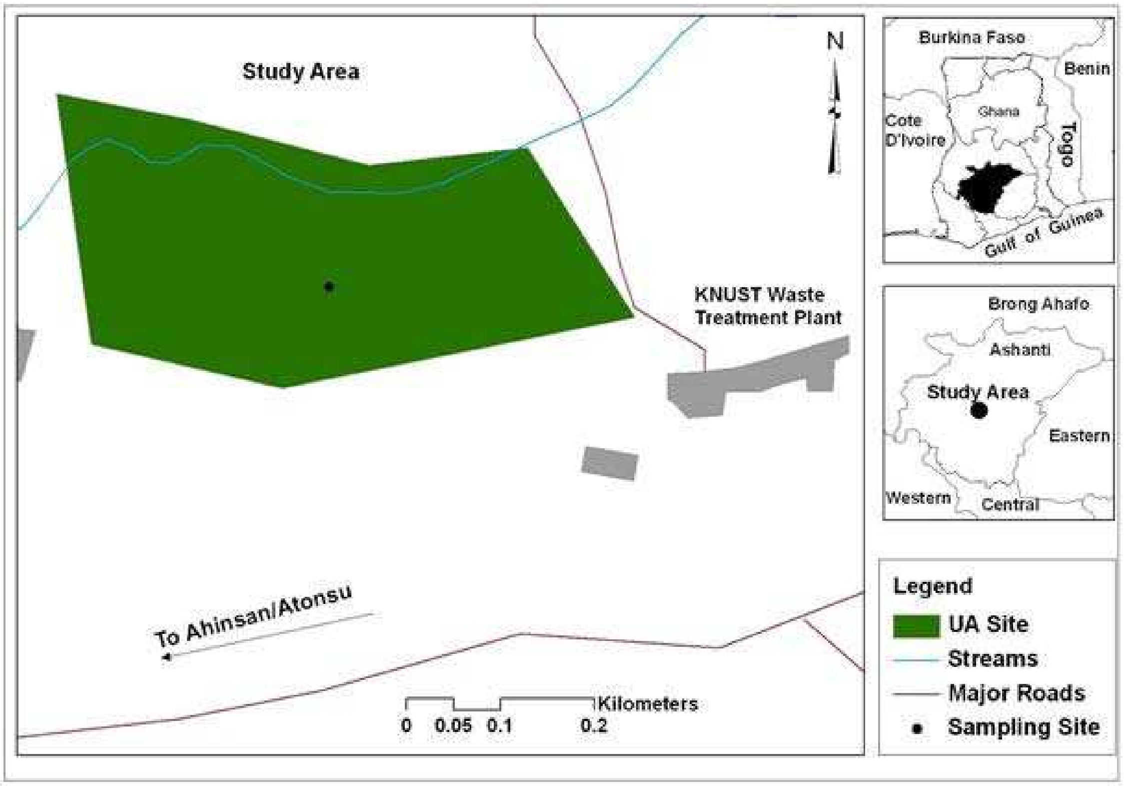

Figure 1.6 A figure showing the study area and water sampling site at Gyenyase

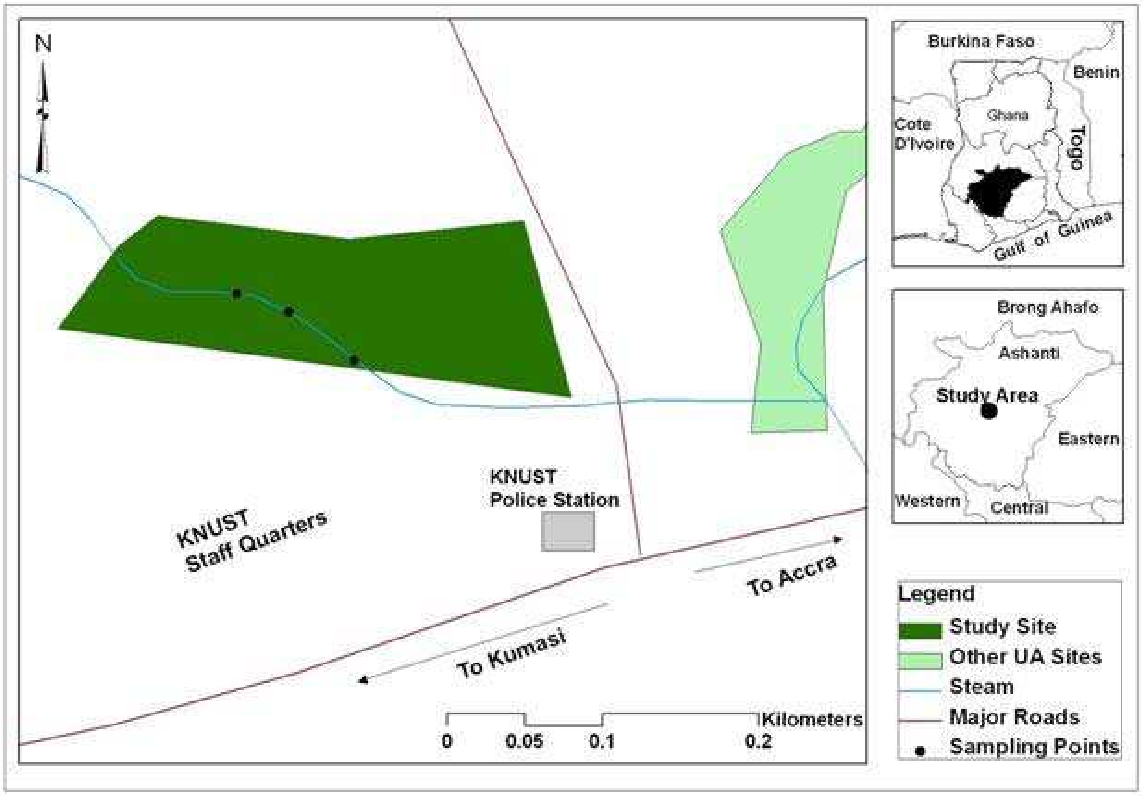

Figure 1.7 A figure showing the study area and water sampling sites at D'Line

2.1.2 Phase I: Sampling of vegetables at the markets

The purpose of this phase was to determine pathogens and pesticide contamination of vegetables produced at urban agricultural sites. From October to December, 2002, a total of 180 vegetable samples (lettuce, cabbage and spring onion) were collected from nine major markets and 12 specialized, individual vegetable and fruit sellers (i.e., sellers with permanent stalls outside of designated markets) in Accra, Kumasi, and Tamale. At each market, samples were collected under normal purchase conditions from three randomly selected sellers. A minimum of three composite samples — each containing two whole lettuce heads, three bunches of spring onions (each containing two bulbs), and three cabbages — were collected from the upper, middle and lower shelves of each seller, put in sterile polythene bags, and transported on ice to the laboratory where they were analysed immediately or stored at 4°C until analysis could occur within 24 hours.

These and all other samples collected were analysed for coliform and helminth egg populations using the most probable number (MPN) method (APHA–AWWA-WEF 2001) and the floatation and sedimentation method following a modified US-EPA method (Schwartzbrod, 1998), respectively. Gas Chromatography (Flame Ionization Detector; A Hewlett Packard 5890 series II) was used for pesticide residues on lettuce following the method adopted by Ntow et al (2001) (also see details in Amoah et al, 2006). Sample peaks were identified by their retention times compared with those of the corresponding pesticide standard obtained from the International Atomic Energy Agency. The ability of the laboratory to identify these substances has been verified by cross-tests of river sediments in Ghana.

2.1.3 Phase II: Contamination pathway study

This study was undertaken to determine the microbiological contamination levels at various entry points along the production-marketing chain. In Accra and Kumasi, two major irrigated vegetable production sites were selected based upon the source of irrigation water and the type of vegetables grown, with emphasis on exotic vegetables such as lettuce that were probably going to be consumed raw. Both sites in Accra used water from drains and streams, while shallow wells and streams provided the sources in Kumasi. Farmers in at least one of the two sites in each city used irrigated, piped water as their source over a period of at least three years. All sites had a similar history of land use. For instance, all were under vegetable cultivation for periods of not less than five years, and all farmers used poultry manure as a source of fertilizer.

2.1.3.1 Irrigation water

This study monitored the physico-chemical and microbiological quality of irrigation water from different urban sources. One composite sample per week was collected from each source for 52 weeks from May 2003 to April 2004. In all, six were irrigation water sources were involved — stream, shallow well and piped irrigation water sources in Kumasi and drain, stream and piped water in Accra. Sampling at all sites was carried out between eight and ten in the morning in keeping with farmer's irrigation practices (APHA-AWWA-WEF, 2001). At each site, 200 ml glass bottles were used to take water from three different points in the wells, or in 20 m intervals along the drain or stream. Piped water was collected directly from the water hose used by the farmers for irrigation. Samples from a particular site were later combined into one composite sample per source and transported to the laboratory on ice. A total of 312 composite water samples were analysed for total and faecal coliform populations. Sampling for helminth egg quantification in irrigation water was done twice every month for five months from November 2003 to March 2004 at all the selected sites. Two-liter samples were taken after deliberately disturbing the bed of the irrigation water source to stimulate agitation that might occur when farmers are filling their watering cans. This was intended to bring out the eggs, as they usually settle under their own weight (Cornish et al, 1999).

2.1.3.2 Lettuce

Over a period of 12 months, from May 2003 to April 2004, a total of 1296 lettuce samples were collected at different entry points[1] from farm to the final retail outlet. The original set of lettuce was either irrigated with stream, drain, well or piped water (microbiological quality of these water sources were monitored as described in section above). Twice a month, a minimum of three composite samples (each containing two whole lettuces) from each of the selected farm sites were randomly collected using sterile disposable gloves just before harvesting for sale at the market. These were put into separate sterile polythene bags and labeled as farm samples. The seller was followed to the wholesale market where another sample from the same original stock was collected before being finally sold to a retailer. At the final retail point, three composite samples were again sampled after vegetables were displayed on the shelves for at least two to three hours, which is a typical turn-over period at the retail point. Producers and sellers were paid for their produce. Sampled vegetables were transported on ice to the laboratory where they were analysed for total coliform (TC), fecal coliform (FC) and helminth counts. To eliminate potential biases during analysis, staff working in the laboratories were not aware of the sources of the samples.

2.1.4 Phase III: Field trials of lettuce

Field trials were conducted to identify the different possible sources (wastewater, poultry manure, and soil) of contamination. The experiments were conducted at two vegetable growing sites in Accra in the major rainy season (May to July, 2004) (see detailed description of methodology in Amoah et al, 2006).

2.1.5 Data analysis

The results were analysed using SPSS for Windows 10 (SPSS Inc., Chicago. IL, USA) and GENSTAT version 13. All data were double-keyed and cross tabulated to ensure the accuracy of the entries made. Total and faecal coliform populations (MPN) were normalised by log transformation before analysis of variance (ANOVA). The t-test (both one sample and two independent samples) was used to test significance of difference between mean faecal coliform levels on different vegetables and in irrigation water from different urban sources and the recommended standards. ANOVA was used to compare faecal coliform levels on different crops. Pearson's correlation and linear regressional analysis were also used to establish the relationship between selected variables. Exponential smoothening was used to filter out "noise" from the faecal coliform sequence plots. Residual plots were analysed to ensure that residuals were randomly distributed and that fitted values were adequate. Unless otherwise stated, results of analysis are quoted at $p < 0.05$ level of significance.

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[1] There are three main stages from harvesting to the main retail outlet where consumers are ready to buy: (1) farm, where samples are collected just before harvesting, (2) market, an area where wholesalers converge before finally selling and (3) retailer, where samples were taken 2–3 hours after vegetables have been displayed and in part refreshed.

2.2 Results

2.2.1 Phase I – Contamination levels of vegetables in markets

2.2.1.1 Bacterial contamination

Most of the vegetable samples showed high faecal coliform contamination levels (Table 2.1). The highest level of faecal coliform contamination was recorded in lettuce (geometric mean count of 1.1×10^7 per gram wet weight) likely due to the larger surface area exposed. Cabbage and spring onion showed geometric mean counts of 3.3×10^6 and 1.1×10^6 g^{-1} wet weight, respectively. No sample had less than 4000 faecal coliform g^{-1} (wet weight). The mean faecal coliform levels of all the three crops exceed the International Commission on Microbiological Specifications for Food (ICSMF, 1974) recommended level of 10^3 faecal coliform g^{-1} fresh weight.

Table 2.1 Ranges of total and faecal coliform population on selected vegetables.

Vegetable	MPN* g^{-1} wet weight	
	Total coliform	Faecal coliform
Lettuce	9.3×10^5 to 1.5×10^{11}	4.0×10^3 to 9.3×10^8
Cabbage	2.6×10^5 to 1.5×10^{11}	1.4×10^4 to 2.8×10^7
Spring onion	9.3×10^5 to 1.9×10^{10}	1.5×10^4 to 4.6×10^8

*MPN = most probable number

2.2.1.2 Helminth egg contamination

About 30% of vegetables had no eggs. Lettuce, cabbage and spring onion carried mean helminth egg populations of 1.1, 0.4 and 2.7 g^{-1} wet weight, respectively. No significant difference was observed in the mean helminth egg populations recorded in lettuce and cabbage; however, the difference between spring onion and both lettuce and cabbage was significant ($p < 0.05$).The eggs identified included those of *Ascaris lumbricoides, Ancylostoma duodenale, Schistosoma heamatobium* and *Trichuris trichiura* with *A. lumbricoides* eggs being predominant (60%, 55% and 65% of lettuce, cabbage and spring onions, respectively, were contaminated with *A. lumbricoides* eggs).

2.2.1.3 Pesticide contamination

Table 2.2 shows pesticide detection prevalence and residues recorded on lettuce leaves, with maximum residue limits (MRL) in UK as comparators. Only 14% of samples had no detectable pesticide residues. More than 60% of the lettuce samples had two or more pesticide residues, with 78% of samples showing chlorpyrifos, an organophosphate of moderate acute hazard. Chlorpyrifos was the only pesticide with higher levels in one city, Kumasi. In most cases, pesticide residue levels observed exceeded the MRL.

Table 2.2 Pesticide residue detection and concentrations on lettuce (N=60).

Pesticide	% of lettuce with detected pesticide residues	Range of concentrations (mg/kg) on lettuce with residues	Mean value (mg/kg) lettuce	MRL[1] (mg/kg) lettuce
Lindane	31	0.03–0.9	0.3	0.01
Endosulfan	36	0.04–1.3	0.4	0.05/0.5
Lambda cyhalothrin	11	0.01–1.4	0.5	1.0/0.1
Chlopyrifos	78	0.4–6.0	1.6	0.05/0.5
DDT	33	0.02–0.9	0.4	0.05

[1] MRL: maximum residue limit (UK Pesticide Safety Directorate, 2004)

2.2.2 Phase II- The contamination pathway study

2.2.2.1 Microbial quality of irrigation water

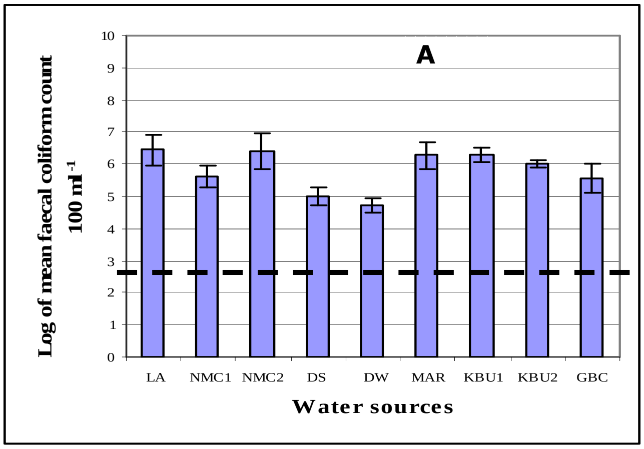
In Accra, faecal coliform levels ranged from 5.0 x 10^4 to 2.3 x 10^6 100 ml^{-1}. The lower values were recorded in Dworwulu where farmers used pipe water stored in shallow wells while farming sites in Korle-Bu, La and Marine Drive where farmers used water from urban drains for irrigation recorded higher values (Fig. 2.1a). The faecal coliform levels in water samples from Kumasi ranged between 9.0 x 10^3 and 9.2 x 10^7 100 ml^{-l} with the highest concentration recorded at Gyenyase 1 (stream) (Fig. 2.1b) while the wells showed low faecal coliform population density. In Tamale, the highest level of faecal coliform levels (4.6 x 10^9 100 ml^{-1}) was recorded at Kamina (Fig. 2.1c). All samples from the three cities exceeded (WHO, 1989) recommended level of 1000 faecal coliform per 100 ml.

Irrigation water sources in Kumasi and Accra showed considerable variation in total and faecal coliform concentrations (Table 2.3). The maximum faecal coliform contamination densities for shallow well and stream samples in Kumasi were 4 x 10^6 and 4 x 10^8 100 ml^{-1}, respectively, while drain and stream samples in Accra showed densities of 9 x 10^6 and 2 x 10^7 100 ml^{-1}, respectively.

Table 2.3 Range of total and faecal coliform bacteria in irrigation water at the four vegetable production sites in two cities

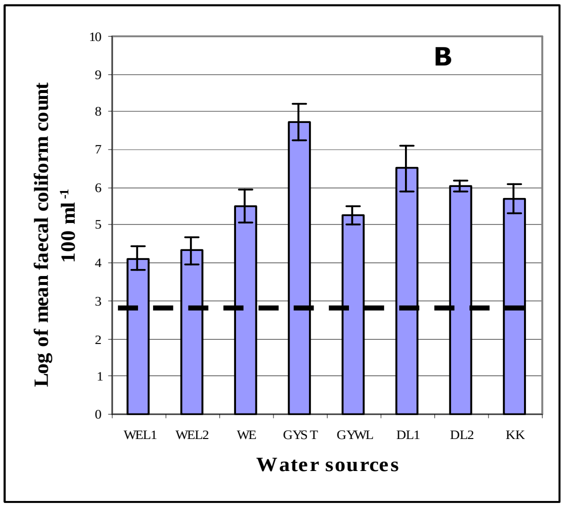
	Irrigation water	Irrigation water (MPN 100ml^{-1})	
City	source*	Total coliform	Faecal coliform
Kumasi	Shallow well	4 x 10^4 - 2 x 10^8	2 x 10^3 – 4 x 10^6
	Stream	4 x 10^5 2 x 10^{10}	4 x 10^3 – 4 x 10^8
	Piped water	0 – 6	0
Accra	Drain	2 x 10^4 - 2 x 10^9	4 x 10^2-9 x 10^6
	Stream	4 x 10^4-2 x 10^8	9 x 10^2-2 x 10^7
	Piped water	0 – 3	0

* N=52 for each irrigation water source



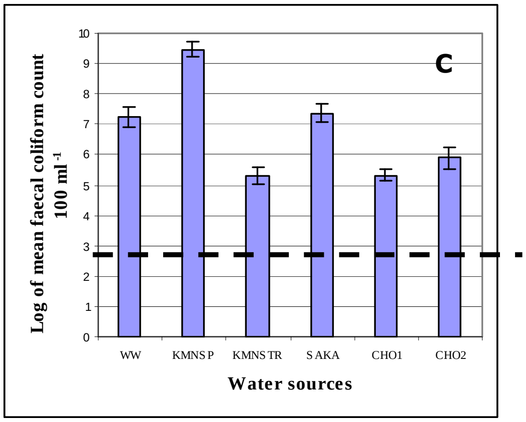
Legend

LA	Waste stabilization pond La
NMC1	Nima creek (stream, Opeibea)
NMC2	Nima creek (stream, CSIR)
DS	Dworwulu stream
DW	Dwowulu shallow well
MAR	Marine drive, drain
KBU1	Korle-Bu, drain 1
KBU2	Korlebu, drain 1
GBC	Ghana Broadcasting cooperation,



Legend

WEL1	Shallow well 1, Weweso
WEL2	Shallow well 2, Weweso
GYST	Gyenyase, stream
GYWL	Gyenyase, shallow well
DL1	D'line, stream 1
DL2	D'line, stream 2
KK	Karikari farms, drain



Legend

WW	Water works, drain
KMNSP	Kamina, stabilization pond
KMNSTR	Kamina, stream
SAKA	Sakasaka, drain
CHO1	Chogu, shallow well 1
CHO2	Chogu, shallow well 2

— — — WHO recommended level

Error bars represent standard deviation of the mean

Fig 2.1. Faecal coliform levels of irrigation water sources in a) Accra, b) Kumasi and c) Tamale

Significantly higher faecal coliform level (*P* = 0.001; CI = -1.3827 to – 0.6943) was observed in well water than in stream water from Kumasi. However, the difference in faecal coliform populations in drain and stream water from Accra was not significant (*P* =

0.994; CI = -0.5084 to 0.3672) (Table 2.4). Mean faecal coliform level in stream water from Kumasi was significantly (*P* = 0.001) higher than all other irrigation water sources in both Kumasi and Accra.

Table 2.4 Faecal coliform contamination levels of irrigation water used in lettuce production in two cities

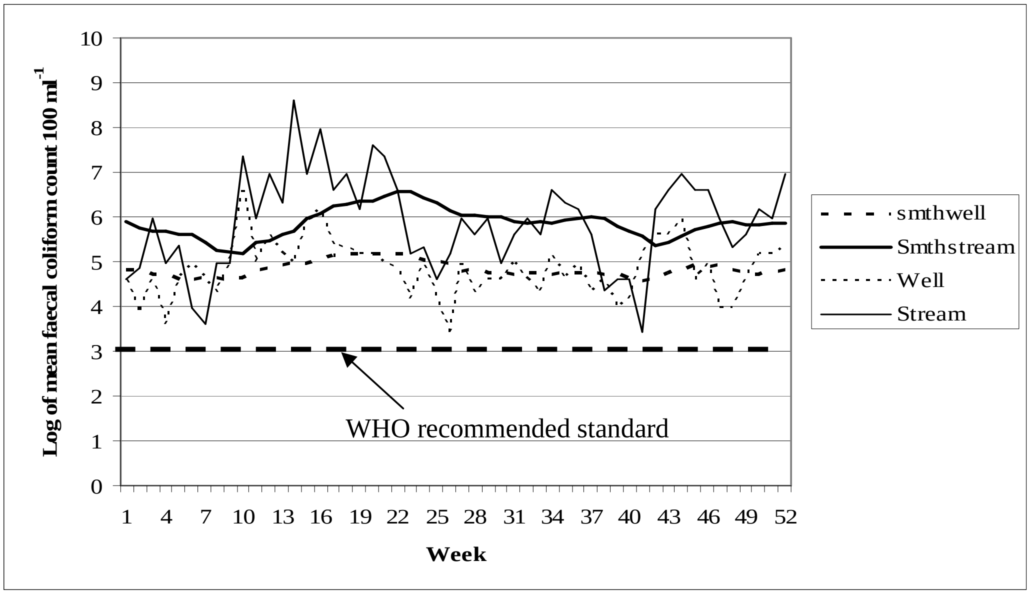
City	Irrigation water source[1]	Log of geometric mean of faecal coliform counts (MPN[2]100 ml^{-1})				
		Range	Geometric mean	Standard error	p-value	95% Confidence interval
Kumasi	Well (n=52)	3.36 – 6.62	4.81 (0.64)[3]	0.1735	0.001	-1.3827 to -0.6943
	Stream (n=52)	3.44 – 5.75	5.75 (1.13)			
Accra	Drain (n=52)	2.60 – 6.62	4.89 (1.13)	0.2207	0.994	-0.5084 to 0.3672
	Stream (n=52)	2.95 – 7.18	4.99 (1.12)			

[1] Piped water was excluded in the statistical analysis because no faecal coliforms were detected during the study period

[2] Most Probable Number

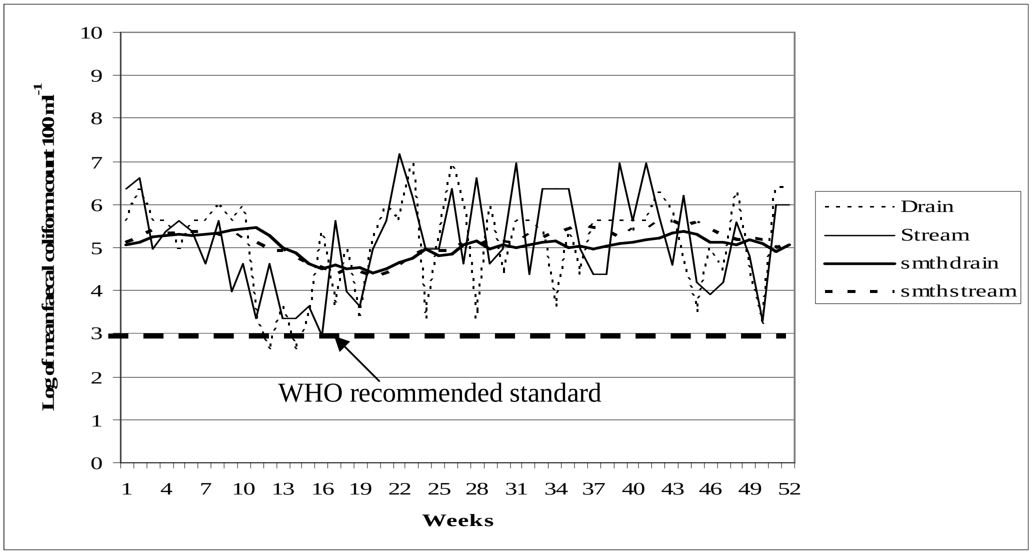
[3] Figures in parenthesis are the standard deviation

Throughout the 12-month sampling period faecal coliform levels in irrigation water from wells and streams in Kumasi significantly exceeded the WHO (2006) recommended level (1 x 10^3 100 ml^{-1}) for unrestricted irrigation of crops likely to be eaten raw. Faecal coliform counts were generally higher in water samples from streams than from shallow wells in Kumasi (Fig. 2.2). There was no such clearly defined pattern between faecal coliform levels in drain and stream water sources in Accra where the WHO recommended coliform levels were equally exceeded in the majority of cases (Fig. 2.3).



*piped water was excluded because faecal coliform level was zero throughout the study period).
** Smthwell and smthstream are curves for well and stream after exponential smoothening.

Fig 2.2 Faecal coliform levels in irrigation water from shallow well and stream in Kumasi



*piped water was excluded because faecal coliform level was zero throughout the study period
**Smthdrain and smthstream are curves for well and stream after exponential smoothening.

Fig. 2.3 Faecal coliform levels in irrigation water from stream, drain and piped water in Accra

2.2.2.1.1 Helminth egg population in irrigation water

A number of different types of helminth eggs were isolated from all irrigation water sources except piped water. These included eggs of *Ascaris lumbricoides, Hymenolepis diminuta*, *Trichuris trichura*, *Facsiola hepatica,* and *Strogyloides* larvae (Table 2.5). The results from Kumasi showed a higher helminth egg population in stream water than in shallow wells. From all the irrigation water sources in both Kumasi and Accra, *Ascaris lumbricoides* was the most predominant species recorded; population density ranged between 2 to 4 eggs l^{-1} (Table 2.5) exceeding the recommended level of <1 egg l^{-1} for unrestricted irrigation (WHO 2006).

Table 2.5 Arithmetic mean numbers of helminth eggs in irrigation water[1] from different vegetable growing sites in two cities (N = 10 for each irrigation water source)

	Arithmetic mean[2] of eggs per litre			
	Kumasi		Accra	
Helminth	Shallow well	Stream	Drain	Stream
Ascaris lumbrecoides	2 (3)[3]	3 (2)	3 (2)	4 (4)
Hymenolepis diminuta	0	4 (1)	0	6 (2)
Facsiola hepatica	0	2 (2)	5 (3)	0
Schistosoma sp	0	3 (4)	0	0
Strongyloides[4]	0	15 (12)	0	5 (2)

[1] Piped water, as irrigation water source was not included because no helminth eggs were found during the study period
[2] Mean rounded to the nearest whole number
[3] Figures in parentheses are standard deviation; values were rounded to the nearest whole number
[4] These were larvae and not eggs

2.2.2.1.2 Physicochemical quality of irrigation water

Water samples from Accra were neutral to slightly alkaline while those from Kumasi were slightly acidic to slightly alkaline. None of these sites showed pH outside the expected normal range (6.5 to 8.4) for irrigation water. In Kumasi no significant difference (P = 0.835) in mean pH was recorded between water samples from well and stream. However, significantly higher (P = 0.001) mean electrical conductivity levels were recorded in drain water than in stream water from Accra. The mean pH and temperature values of the irrigation water from stream and drain in Accra were not significantly (*P* = 0.755 for pH and *P* = 0.137 for temperature) different.

In Kumasi, significant positive linear correlations (*P* = 0.001; r = 0.651 for well and *P* = 0.001; r = 0.785 for stream) between faecal coliform population and electrical conductivity were observed for well and stream water sources. Similar results were observed in Accra (*P* = 0.001; r = 0.555 for drain and *P* = 0.001; r = 0.635 for stream) for drain and stream water sources, respectively. In both Kumasi and Accra, between 31 and 62% (R square) or 39 and 61% (adjusted R square) of variations in faecal coliform populations in the irrigation water sources can be explained through different electrical conductivity values. The standard error for these values was between 0.49 and 0.95. The results of the heavy metal concentration levels showed mean concentrations mostly below the recommended maximum for crop production cited by Pescod (1992). Only manganese exceeded the FAO threshold for crops at all sites in both Accra and Kumasi.

2.2.2.2 Microbiological quality of lettuce

Table 2.6 shows the faecal coliform contamination levels of lettuce at different entry points starting from farm to the final retail outlet. Irrespective of the irrigation water source, mean faecal coliform levels exceeded the recommended standard (10^3 per 100 ml). For all treatments in both cities, there were no significant differences in the average lettuce contamination levels at different entry points (farm, wholesale market, and retail outlet).

Table 2.6 Mean faecal coliform contamination levels at different entry points along the production - consumption pathway of lettuce

City	Irrigation water source	Statistic	Log faecal coliform levels (MPN*100g^{-1})		
			Farmgate	Wholesale market	Retail
Kumasi	Well	Range (N=216)	3.00 – 8.30	3.10 - 8.50	3.20 - 7.00
		Geometric mean	4.54 (± 1.32)**	4.44 (± 1.23)	4.30 (± 1.04)
		Standard error	0.27	0.25	0.18
	Stream	Range (N=216)	3.40 – 7.10	3.60 – 7.20	3.50 – 7.20
		Geometric mean	4.46 (± 0.81)	4.61 (± 0.84)	4.46 (± 0.91)
		Standard error	0.17	0.17	0.19
	Piped water	Range (N=216)	2.30 – 4.80	2.60 – 5.30	2.40 – 5.10
		Geometric mean	3.50 (± 0.70)	3.69 (± 0.84)	3.65 (± 0.82)
		Standard error	0.14	0.17	0.17
Accra	Drain	Range (N=216)	3.40 – 6.00	3.00 - 6.80	3.00 - 6.50
		Geometric mean	4.25 (± 0.74)	4.24 (± 0.86)	4.48 (± 0.78)
		Standard error	0.15	0.18	0.16
	Stream	Range (N=216)	3.20 - 5.70	3.10 - 5.90	3.20 - 5.50
		Geometric mean	4.22 (± 0.66)	4.29 (± 0.62)	4.37 (± 0.59)
		Standard error	0.13	0.13	0.12
	Piped water	Range (N=216)	2.90 - 4.70	2.90 - 4.80	2.80 - 4.50
		Geometric mean	3.44 (± 0.40)	3.46 (± 0.43)	3.32 (± 0.37)
		Standard error	0.08	0.09	0.08

*MPN, Most Probable Number
**Figures in parentheses are standard deviations

Figure 2.4 illustrates faecal coliform populations on lettuce samples collected in Kumasi at farm gate, wholesale market, and retail outlets over a 12 month period and for three irrigation water sources. Similar levels were recorded on samples from Accra (See Amoah et al 2007a). High levels of faecal coliform counts (usually above common acceptable standard of 1×10^3 $100g^{-1}$ wet weight) were recorded on all irrigated lettuce including those irrigated with piped water.

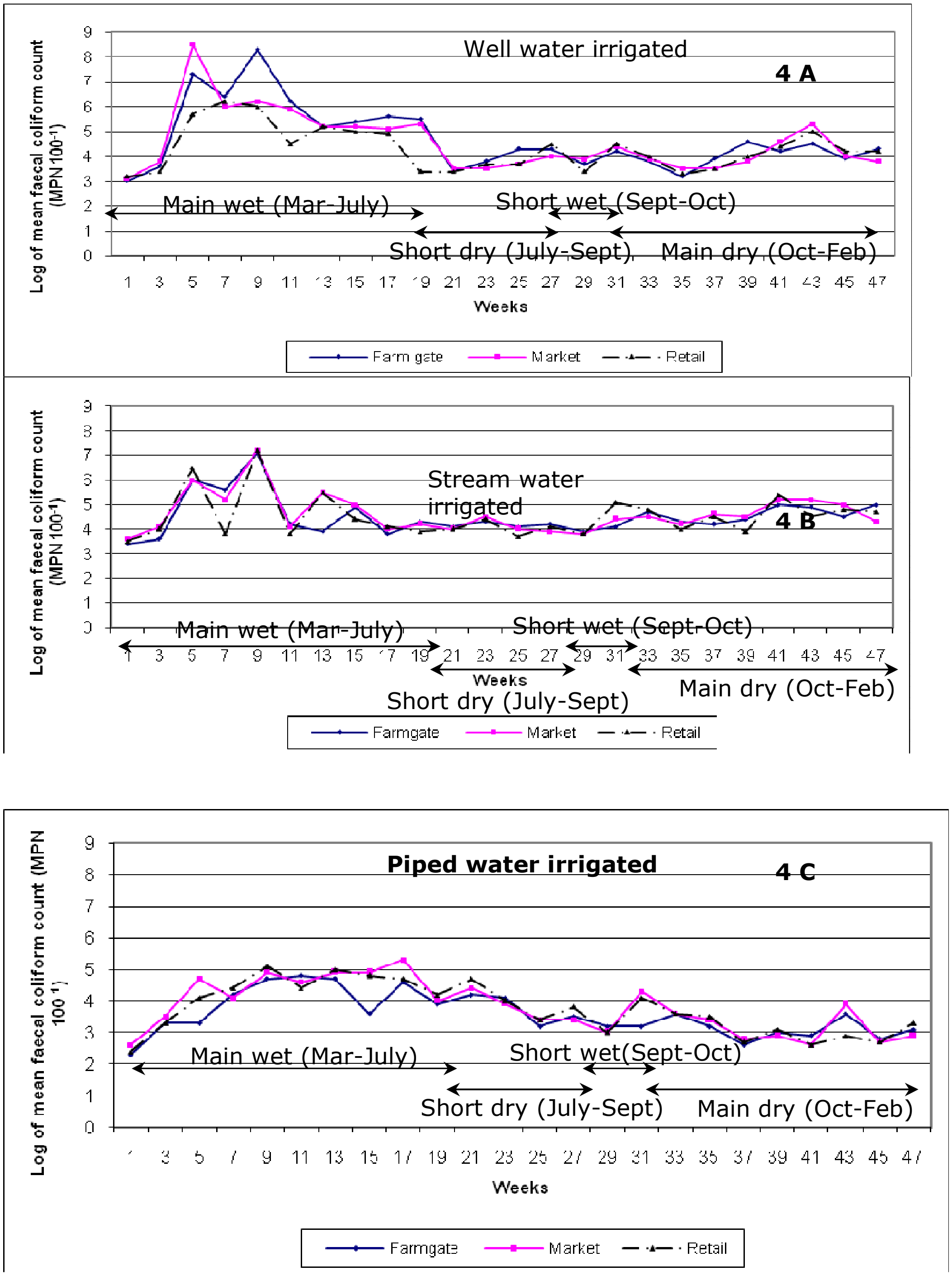


Fig 2.4. Feacal coliform levels at different entry points on production- consumption pathway of lettuce irrigated with water from well (A) stream (B) and piped water (C) in Kumasi. (see figures from Accra in Amoah et al., 2007a)

Apart from stream water irrigated lettuce from Accra, higher faecal coliform levels were recorded on lettuce from all the other irrigation water sources in the rainy season than in the dry season. However, the differences were significant ($p<0.05$) only in the cases of well and stream water irrigated lettuce from Kumasi. The results further showed that in 80 to 90% of the weeks sampled in Accra and Kumasi, there was no significant difference in the faecal coliform counts of samples analyzed from the farm gate, the markets, and final retail points.

Helminth eggs including that of *Ascaris lumbricoides*, *Hymenolepis diminuta*, *Trichuris trichiura*, *Fasciola hepatica* and *Strongyloides larvae* were detected on lettuce samples at the different entry points. The helminth egg population ranged from 1 to 6 egg(s) 100 g^{-1} wet weight and between 50 to 75% of the eggs was viable. In the majority of cases, significantly ($p<0.05$) higher levels were detected in lettuce irrigated with polluted water than those from piped water irrigated sources. However, mean helminth egg populations on lettuce from the same original stock and irrigation water source did not show any significant difference from field to market (See Table 2.7).

Table 2.7 Arithmetic mean of helminth egg contamination levels at different entry points along the production consumption pathway[1]

City	Irrigation water source	Helminth egg 100 g^{-1} wet weight		
		Farm	Wholesale Market	Retail
Kumasi	Well	4.1 ± (1.6) a[2]	4.9 ± (1.3) a	4.2 ± (1.3) a
	Stream	5.9 ± (1.4) b	4.9 ± (0.9) a	4.7 ± (0.6) a
	Piped water	1.9 ± (1.5) c	1.9 ± (1.2) b	1.2 ± (0.9) b
Accra	Drain	5.7 ± (1.1) a	5.9 ± (1.2) a	5.2 ± (1.5) a
	Stream	3.8 ± (0.9) b	3.1 ± (0.9) b	3.9 ± (1.2) ab
	Piped water	3.2 ± (0.7) b	2.1 ± (1.2) b	3.3 ± (1.0) b

[1] Mean numbers represent the mean of all the different types of eggs as well as *Strongyloides* larvae. (N=15 for each irrigation water source)
Figures in parentheses represent the standard deviation.
[2] Numbers in the same column with the same letters showed no significant difference between water sources per city ($p>0.05$).

Significantly higher levels of faecal coliforms in well and stream water irrigated lettuce were recorded in Kumasi during the rainy season than in the dry season (Figures 5 and 6). A similar trend was observed in Accra. However, the differences were not significant ($P > 0.05$).

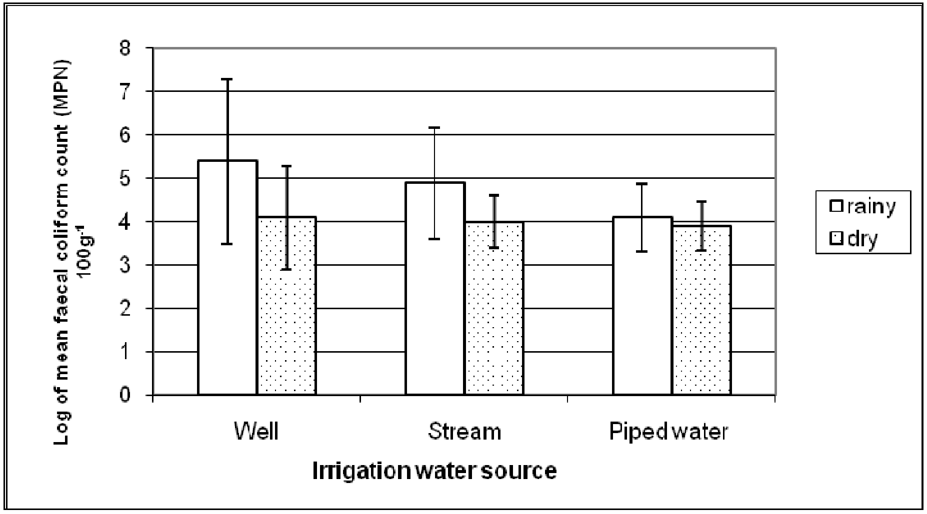


Fig. 2.5. Seasonal variation in faecal coliform contamination levels of farm gate lettuce produced with piped, well and stream water in Kumasi (N = 72 composite lettuce samples for each irrigation water source); Error bars represent the standard deviation

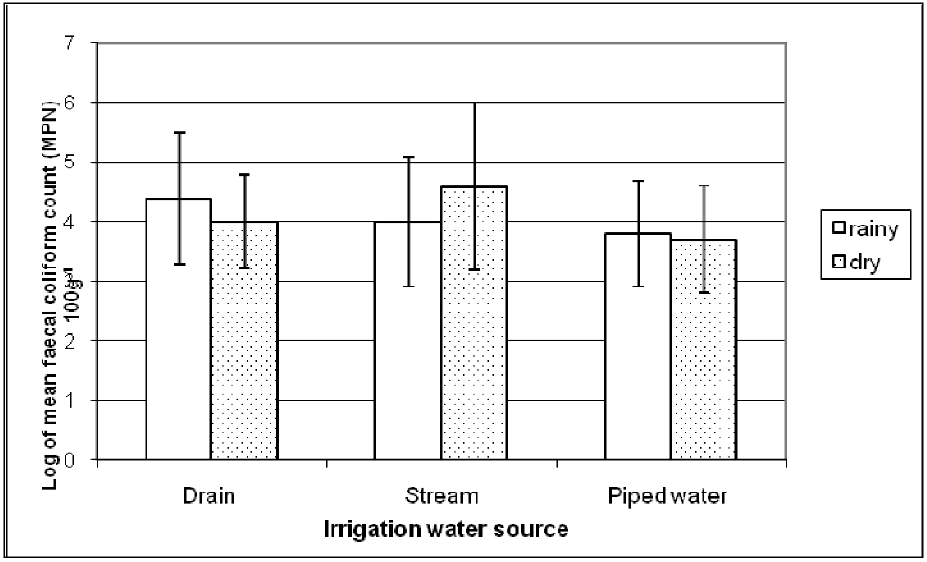


Fig. 2.6. Seasonal variation in faecal coliform contamination levels of farm gate lettuce produced with piped, drain and stream water in Accra (N = 72 composite lettuce samples for each irrigation water source). Error bars represent standard deviation.

2.2.3 Phase III - Field trials

2.2.3.1 Faecal coliform levels in irrigation water

Mean faecal coliform levels in irrigation water from drains used during the study period were 1.1 x 10^6 for the first, 2.3 x 10^6 for the second, and 1.0 x 10^7 cells per 100 ml for the third trials.

2.2.3.2 Microbiological quality of soil at planting

Considerably high faecal coliform contamination levels ranging between 3.9 x 10^3 and 4.1 x 10^5 100 g^{-1} were recorded in the soil samples taken from the lettuce fields Samples from control plots (*nearby plots with no farming activity*) showed significantly lower faecal coliform levels (ranging between 0 and 2.1 x 10^2 100 g^{-1}). Prior to the start of the experiment all plots had more or less similar contamination levels. Although the range of helminth numbers was very wide the differences were not significant (see details in Amoah et al., 2005)

2.2.3.3 Microbiological quality of lettuce at harvesting

Most (85%) wastewater-irrigated vegetables in all the three trials recorded a comparatively higher faecal coliform contamination levels than the piped water irrigated ones. The difference was however significant only in 33% of the cases (Table 2.8).

Table 2.8 Faecal coliform contamination levels[1] on irrigated lettuce produced with poultry manure and inorganic fertilizer (N = 96 composite samples)

Irrigation water source	Planned Treatment[2]	MPN 100 g^{-1} (fresh weight)		
		Trial 1	Trial 2	Trial 3
Wastewater	PM1	6.1 x 10^4	3.6 x 10^5	3.0 x 10^5
	PM2	6.7 x 10^4	9.1 x 10^4	3.6 x 10^5
	PM3	8.3 x 10^4	4.7 x 10^5	8.0 x 10^5
	F	5.5 x 10^4	9.8 x 10^4	9.2 x 10^5
Piped water	PM1	6.8 x 10^4	3.5 x 10^5	1.8 x 10^3
	PM2	6.4 x 10^4	3.0 x 10^5	1.9 x 10^4
	PM3	4.1 x 10^4	5.9 x 10^3	2.9 x 10^3
	F	1.9 x 10^4	2.0 x 10^3	2.0 x 10^3

[1] Geometric mean counts

[2] PM1, PM2, PM3: poultry manure samples with faecal coliform contamination levels 4.3 x 10^7, 2.4 x 10^5 and 3.3 x 10^3, respectively. F: Inorganic fertilizer, 15, 15, 15 NPK

In the wastewater-irrigated plots, there was no relationship between the faecal coliform levels on lettuces and the faecal coliform concentration in poultry manure applied plots. This may be due to the dominant effect of contaminants from the irrigation water. Under piped water irrigation, the effect of the different poultry manure (PM) contamination levels, among each other and in comparison with inorganic fertilizer (F) became more apparent. Generally, higher faecal coliform levels were recorded on plots receiving poultry manure and piped water as compared to those receiving just piped water. However, the differences were only significant in 22% of the cases. Helminth egg contamination in lettuce was significantly higher in 30% of the wastewater irrigated plots than the piped water irrigated ones. Significantly higher levels of helminth egg contamination were observed in only 8% of the piped water irrigated plots than those irrigated with wastewater (Table 2.9).

Table 2.9 Helminth egg contamination levels of waste/piped water irrigated lettuce produced with poultry manure and inorganic fertilizer (N=96 composite samples i.e. 12 composite samples per planned treatment)

Irrigation water source	Planned Treatment[1]	MPN 100 g-1 (fresh weight)		
		Trial 1	Trial 2	Trial 3
Wastewater	PM1	3 (2)[2]	5 (2)	6 (2)
	PM2	4 (1)	3 (2)	2 (2)
	PM3	3 (3)	2 (2)	3 (2)
	F	2 (3)	2 (2)	3 (3)
	Total	12	12	14
Piped water	PM1	3 (3)	2 (1)	1 (2)
	PM2	1 (1)	3 (2)	1 (1)
	PM3	2 (2)	3 (4)	5 (1)
	F	3 (1)	2 (1)	1 (1)
	Total	3	10	8

[1] PM1, PM2, PM3: poultry manure samples with faecal coliform contamination levels 4.3 x 10^7, 2.4 x 10^5 and 3.3 x 10^3, respectively. F: Inorganic fertilizer, 15, 15, 15 NPK

[2] Figures in parentheses are standard deviation; values were rounded to the nearest whole number

2.3 Discussion

2.3.1 Quality of market vegetables

Several factors may account for the high levels of faecal coliform recorded in most of the analysed vegetables. Among these is the use of polluted irrigation water and fresh poultry manure, both of which are applied on top of the crops. Significantly high faecal coliform contamination levels (between 4.8×10^3 and 2.8×10^6 100 ml^{-1}) which usually exceed common standards have been recorded in irrigation water (Mensah et al, 2001; Cornish et al, 1999; Keraita et al, 2002; Drechsel et al, 2000). High faecal coliform populations (between 3.6×10^4 and 1.1×10^7) were also reported in poultry manure in the same study areas. Another potential source of contamination is market-related handling, especially where provision for better sanitary standards (e.g. clean water for crop washing and refreshing) is lacking. A relatively high total and faecal coliform population recorded on some vegetables was also reported by Johnson (2002) and Armar-Klemesu et al, (1998) analysing street food and market crops in Accra, respectively.

Biologically, the highest health risk is helminth infections as compared to other pathogens. Because helminths persist for longer periods in the environment, host immunity is usually low to non-existent and the infective dose is small (Gaspard et al, 1997). Such microbial and parasitic contamination likely contributes to the high number of food-borne and water-related diseases in Accra, such as diarrhea (sometimes caused by typhoid or cholera) as well as intestinal worm infections. However, these also have to be seen in the context of generally sub-optimal sanitary conditions in parts of the metropolis (Arde-Acquah, 2002).

The results on pesticide residue indicated that several pesticides (particularly chloropyrifos) are widely used by vegetable producers in Ghana, in keeping with other studies (Okorley and Kwarteng 2002). As also described by Danso et al, (2002), farmers mix cocktails of various pesticides to increase their potency. Vegetables are often eaten raw so it is not surprising to read about evidence of chloropyrifos contamination such as can be found in waakye, a popular Ghanaian dish (Johnson 2002). Lindane and endosulfan are restricted for the control of capsids on cocoa, stem borers in maize and for pests on coffee, while DDT is banned in Ghana. However, the data show clearly that these potent agrochemicals are used irrespective of whether approved for vegetable production or not. In several African countries, the legislation on importation and regulation of pesticides is sketchy, nonexistent or imbedded in bodies of legislation indirectly related to pesticides. Because of the lack of proper regulations, organochloride pesticides banned in industrialized countries for their retention in the environment or their high toxicity are still commonly used.

The widespread pesticide contamination, often exceeding the MRL, indicates potential health risks to consumers. Washing vegetables before consumption is highly recommended, but the majority of pesticides cannot just be washed away and may still pose health risk (www.annamariavolpi.com/pollutants.html). A rough calculation helps understand this potential: The Acceptable Daily Intake (ADI)[2] of chlorpyrifos, for example, is 0.01 mg kg^{-1} body weight (WHO 1997). To exceed the ADI, a child weighing 30 kg would have to consume at least 0.3 mg of chlorpyrifos per day. With a residue level of 1.6 mg kg^{-1} lettuce, the child would have to eat close to 200 g of lettuce per day. The amount of lettuce (usually served with other staples e.g. rice) is usually below 30g daily. However, if a child was malnourished they might be more susceptible; moreover, fetal (via maternal) or chronic neurodevelopmental effects might occur, since they are not always included in MRL analysis.

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[3] The Acceptable Daily Intake (ADI) is a measure of the quantity of a particular chemical in food, which, it is believed, can be consumed on a daily basis over a lifetime without harm.

2.3.2 Irrigation water quality

The results of the microbiological quality of irrigation water confirm earlier reports that low quality water is being used for urban vegetable production in most Ghanaian cities (Cornish *et al.,* 1999; Mensah *et al*., 2001). Other studies carried out in Accra (Armar-Klemesu *et al*., 1998; Zakariah *et al*., 1998; Sonou, 2001) also showed that there are hardly any unpolluted water sources available for irrigation. Vegetable growing sites in Korle-Bu, La, and Marine Drive where farmers used water from urban drains for irrigation recorded the higher values compared to Dworwulu where some farmers used piped water stored in shallow wells. The lack of differences between the mean faecal coliform levels in stream water at Dworwulu and drain water at Marine Drive was not surprising because streams and rivers in most Ghanaian cities are more or less drains and receive untreated wastewater from the surrounding communities. In Tamale, the highest level of faecal coliform levels was recorded at Kamina, where farmers used a broken down sewage pond for irrigation purposes. However, farmers here grow mostly indigenous vegetables, which are eaten cooked and therefore may pose less or no risks to consumers.

The significant differences recorded in faecal coliform levels between the two sources in Kumasi (well and stream) may suggest that shallow well water may pose relatively less risk to farmers and consumers, although the coliform levels exceeded 1000 counts per 100 ml. Similar results have been reported from Kenya (Hide *et al*., 2001) but Cornish *et al*. (1999) recorded in Kumasi temporarily higher faecal coliform population in shallow wells than in nearby streams. This may be due to the fact that probably the wells used in their study were shallower and got more easily contaminated through surface runoff on the field (Drechsel *et al*., 2000).

Shallow wells or “dugouts” might be expected to meet the WHO recommended standard due to the natural filtering of aquifer materials and long underground retention times (Cornish *et al*., 1999) but those used in this study were often not protected against surface inflow and could have easily received pollutants from the surrounding farm environment through runoff. In spite of that, shallow wells in Kumasi had, in general, better quality water than the streams. These were associated with water entering the wells and the extensive use of (fresh) poultry manure in vegetable farming (Cornish *et al*., 1999). There is therefore the need to improve on well systems to avoid run-off entering the wells.

As expected the quality of piped water from Accra and Kumasi had no faecal coliforms during the study period and would pose no health risks to farmers. However, this is rarely an official or reliable option for farming due to its price and/or common supply shortages. For example, only 40% of residents of Accra have access to clean piped water. On the other hand the availability of marginal quality water affords farmers year-round production with a strong competitive advantage in the dry season. In Dakar, the use of polluted water allows 8-12 harvests of lettuce per year compared with 5-6 harvests by farmers who had no access to wastewater. The significantly high positive correlation between electrical conductivity and coliform levels in polluted irrigation water sources accords with results reported by Cornish *et al.* (1999). This may be related to the degree of pollution from household kitchens and bathrooms where salts from soaps and detergents together with coliform bacterial contaminants are released into the system untreated.

The pH values observed in drain, stream, and well water sources used for irrigated vegetable production in Accra and Kumasi corresponded with the optimum pH of 6.5 to 8.5 required by most faecal coliform for growth. The analysis of heavy metal concentrations in irrigation water used for irrigation in Kumasi and Accra did not show values of public health concern as reported by Mensah *et al*. (2001). In most cases, the heavy metal levels in streams in and around Kumasi do not exceed common standards

(Cornish *et al.* 1999; Mensah *et al*. 2001; McGregor *et al*. 2002). The results confirm the notion that pathogen is the dominant source of pollution, with little evidence of significant water pollution from heavy metals in the study area.

2.3.3 Quality of lettuce at different entry points

This study revealed that the contamination of lettuce with pathogenic microorganisms does not significantly increase through post-harvest handling and marketing. This was not expected in view of the alarming low hygienic conditions, including washing habits, poor display and handling of food as well as limited availability of sanitation infrastructure on market sites. For example, Nyanteng (1998) reported that only 31% of the markets in Accra have a drainage system, only 26% have toilet facilities, and only 34% are connected to pipe-borne water.

Considering lettuce irrigated with water from polluted sources, it seems the initial contamination on the farm was so high to mask the effect of the applied concentrations. However, lettuce irrigated with piped water showed lower on farm contamination which indicates that there is no post-harvest contamination hidden behind huge farm-gate levels. The results on microbiological contamination of lettuce (from field to market) are contrary to results of Armar-Klemesu *et al*. (1998), who attributed the significantly higher faecal coliform levels found on market than the farm vegetables (*including lettuce*) to handling. Their study did not however establish the produce from the markets had come from the specific farm sources examined in their study.

This study also revealed that even at the farm level, wastewater is only one of several sources of crop contamination, although it can be the major one. Besides irrigation water, other identified contamination sources in the farm are immature manure as well as the previously contaminated soil. Both sources of contamination might be difficult to control (e.g. mulch to reduce splash), which stresses the need for post harvest measures, such as efficient washing practices in markets and at the household level should reduce the contamination considerably. Beuchat (1999) reported that vegetables can become contaminated with microorganisms capable of causing human diseases while still on farm, or during harvesting, transport, processing, distribution and marketing, or in the home. The results of this study however suggest that post harvest contamination is not a major contamination source as compared to contamination on the farm.

To reduce health risk associated with the consumption of contaminated lettuce, it is important therefore to tackle the problem first at the farm level through good agricultural practices, including changes in irrigation methods. However, common guidelines for wastewater use in agriculture are rarely adopted for a variety of reasons. For example, economic constraints limit the level of wastewater treatment that can be provided in developing countries. Also small size and insecure land tenure are significantly constraining farmer’s ability to invest in farm infrastructure such as drip irrigation or on-farm sedimentation ponds (Drechsel *et al.,* 2002). Although earlier trials by Keraita *et al*. (2007) show that the contamination levels can be reduced on the farm through minor changes in practices, it is unlikely that contamination can be minimized below the threshold of safe consumption as the data from the use of piped water show.

It will therefore be necessary to wash the crops in addition to on farm techniques designed to reduce health risks. The last stage in the production-consumption chain, where food for home consumption or fast food for street sales is prepared, appears to be a good entry point. Awareness for food safety is generally high in Ghana as more than 90% of the food vendors and consumers wash their salad before serving. However, individual methods vary largely and there is no information on effectiveness of these variations of the methods. Consumers often associate good quality food with neat appearance of vendors and visually clean food (Olsen, 2006), which is a first step but not sufficient to avoid contaminated food (Mensah *et al*., 2002).

2.3.4 Deductions from field trials

The results of the field trial (Amoah et al, 2005) confirmed that even at the farm level, wastewater is only one of several sources of crop contamination. The soil and poultry manure were identified as other sources of microbiological contamination, although wastewater can be the major one. The need to reduce the potential health risks resulting from faecal coliform and helminth contamination of urban and peri-urban vegetables thus requires a more holistic approach rather that concentrating solely on wastewater.

2.4 Conclusions

The results of this study showed that typical microbiologic and pesticide contamination levels of vegetables in Ghanaian markets pose a threat to human health. The potential harmful effects could be minimized through enforcement of legislation on harmful pesticides. However, this is not easy as long as human and financial resources are scarce. Also, the legislation against wastewater use could be improved, but more powerful entry points for risk decrease that maintain the value of urban and periurban agriculture are education and awareness campaigns in markets and households.

Washing or cooking food before eating is common in Ghanaian households. This could decrease or eliminate much of the microbiologic and pesticide residues if done more consciously. The comparison of both risks factors shows that efforts for health interventions should focus more on microbiologic crop contamination, especially on helminthes, while the pesticide problem, despite its dimension, is in comparison less critical for consumers’ health in the given context.

The results also confirmed that polluted water is mostly used for urban vegetable production in the study sites. This poses high health risks to farmers especially when farmers fetch water without protection from possible contamination. The application of irrigation water (with watering cans) on the leaves of vegetables could also increase pathogen contamination and pose health risk to consumers. The pH, electrical conductivity, and heavy metal levels were generally within the acceptable limits.

Finally, the study has shown that the much of the microbial contamination of lettuce produced from urban sources in Accra and Kumasi occurs on the farm. The post harvest sector is likely a relatively minor contributor to lettuce contamination. The results confirm that even at the farm level, wastewater is only one of several sources of crop contamination, although it can be the major one. Besides irrigation water, other contamination sources identified in the farm are immature manure as well as the already contaminated soil. Both might be difficult to control (e.g. mulch to reduce splash), and stresses the need for post-harvest measures, such as efficient washing practices at markets and at the household level. From the results, it may be concluded that a focus only on wastewater treatment is insufficient to safeguard consumers’ health. This is more so the case where wastewater treatment is inadequate. The reduction of potential health risks resulting from faecal coliform and helminth contamination of urban and peri-urban vegetables thus requires a more holistic approach taking care of various contamination sources.

3. Objective 3: Identifying innovative approaches for health risk reduction on-farm and post-harvest and quantifying their impacts on contamination levels, land and water productivity, and livelihoods.

3.1 Methods

3.1.1 Alternative irrigation water – Shallow groundwater

3.1.1.1 Study Areas

This study was carried out in 8 urban vegetable farming sites in Ghana's three major cities of Accra, Kumasi and Tamale. Table 3.1 has some information on these sites.

Table 3.1 Description of study vegetable farming sites

City	Farming site	No. of farmers	Total Irrigated Area (ha)	Main water sources
Accra	Marine Drive	98 (1)*	4	Polluted stream and drains
	Dzorwulu	60 (2)	15	Polluted stream, pipe and drains
Kumasi	Engineering	25 (1)	9	Shallow dugout wells and streams
	Karikari	18 (0)	3	Shallow dugout wells and streams
	Gyenyase	16 (0)	13	Shallow dugout wells and runoff
Tamale	Gbumbihini	60 (20)	7	Polluted drains, dam spillage
	Kamina barracks	145 (116)	7	Raw sewage
	Sangani	25 (0)	1	Pond

** Numbers in parenthesis show number of female farmers*

3.1.1.2 Geophysical survey

Geophysical studies were carried out on the 8 vegetable farms in three cities in September 2005. Two main methods were used i.e. electromagnetic profiling (EM) and electrical resistivity sounding. EM measurements were carried out along carefully selected traverse lines in all the farms using Geonics EM34-3 ground conductivity meter. Measurements were taken at every 10 m intervals in both the horizontal and vertical dipole modes. The 10 m-intercoil separation cable was used for the survey, since the proposed tube-wells to be provided would not be deeper than 15 m. After this, vertical electrical sounding (VES) was carried out at selected locations on the EM profiles where conductance has been detected. The ABEM SAS 1000C terrameter using Schlumberger electrode configuration was adopted for this survey. The maximum depth of investigation was 40 m below ground surface at each of the EM points. Selection of points for test drilling was based on regolith thickness and resistivity. Sounding points were ranked in order of preference as test drilling points or hand-dug-well construction points, and identified with wooden pegs with their location numbers written on them in the field.

3.1.1.3 Test drilling

Test drilling was done manually using hand augers due to financial limitations. In this method, the cutting lips of a rotating auger cut material loose from the bottom of the well. Holes are lined with PVC pipe to prevent the hole from collapsing. The end of the completed well has at least 4 meters of PVC casing below the water table. The lowest 3 meters of the PVC casing have narrow slots covered with polyester filter cloth to allow water to enter the well at the same time preventing fine sand from entering the well. Safe yield for the wells were determined using a recuperation test.

3.1.1.4 Performance assessment for new well and treadle pump system

Both microbiological water quality analysis and qualitative methods were used. In water quality analysis, fecal contamination levels in water from both the new hand dug well and old shallow well (15 m away) were monitored over a period of 6 consecutive weeks in April and May 2006. Fecal coliform bacteria and helminth counts were used as indicators for fecal contamination. Sampling and laboratory analysis followed standard methods as detailed in APHW–AWWA–WEF (1998) and Schwartzbrod (2001). Qualitative methods were used to assess the system's suitability for use in irrigation. Participant observations were made on the use of the well and pumps, maintenance practices, crops irrigated with water from the well and other uses of the well water for six months. This was followed by an in-depth interview with the farmer who was mainly used the pump for irrigation. Finally, an in-depth discussion was conducted with the key farmers from the site on the entire system. These observations, interviews and discussions centered on the key issues for socio-economic and adoption assessment of innovations as outlined by FAO (1992) and Phansalkar (2002).

3.1.2 Farm-based risk reduction interventions while using wastewater

3.1.2.1 Farmers perceptions and identification of farm-based risk reduction interventions (RRIs)

3.1.2.1.1 Study population: First, a survey was conducted in the two study cities, where farmers' general perceptions on wastewater irrigation and urban vegetable farming were gathered. A total of 238 farmers were interviewed which included 138 farmers in Accra and 100 in Kumasi. This was followed by a more focused and detailed study involving only those farmers using wastewater for growing vegetables eaten raw where a total of 60 farmers i.e. 28 in Accra and 32 in Kumasi participated. Participants for the detailed study were nominated by the respective farmers' associations from each major farming site in the study cities. Each farming site was represented by at least four members. Participating farmers had a wide range of farming experience, educational qualifications and age and originated from different parts of the country.

*3.1.2.1.2 Farmers' perceptions**:*** Perceptions of farmers towards sources of pollution of irrigation water, contamination of vegetables, perceived health risks and impacts were gathered in focus groups. Sub-grouping was made based on the how long farmers had been involved in the practice. Therefore we had "established farmers" who had farmed for more than two years and "new farmers" who were mainly youths, with less that two years urban farming experience, mainly doing farming while hoping for better jobs in the city. During the focus groups, individual rating was done for the perceived health risks on a risk range scale of 0-5 (0=no risk, 1=lowest risk, 5=highest risk).

The focus groups were followed by conducting a cause and effect analysis, where the problem tree technique was applied using visual index cards. Starting with the problem (in this case contamination of irrigation water and vegetables), participants were required to identify the effects on two levels i.e. immediate effects and long-term impacts. The same was done on the causes with identification of immediate causes and root causes. This helped to explain relationships between e.g. the microbiological contamination of water and vegetables, its causes and associated effects in a simple and systematic way. It was done in such a way that farmers could visualize and easily understand the discussions since some were illiterate.

*3.1.2.1.3 Identification of farm-based RRIs**:*** The Visualization in Participatory Programs (VIPP) approach was then used to collect measures that farmers perceived could minimize health risks. The approach combines techniques of visualization with methods for interactive learning (Rifkin and Pridmore, 2001). Adopting the cards technique, farmers wrote feasible measures for risk reduction on large multi-colored 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 in their midst but care was taken by facilitators to minimize influence. After displaying the cards, discussions started among farmers for clarifications which led to the identification of additional measures. These primary measures were entirely suggested and identified by farmers. The research team was not involved in the discussions. Afterwards, the research team gave inputs to farmers' discussions, which generated additional risk reduction measures, referred to as secondary measures. Finally, perceptions were collected on risk reduction measures already presented in WHO guidelines (WHO, 2006). Individual suitability rating was done for the suggested WHO measures on a suitability range scale of 0-5 (0=not suitable, 1=least suitable, 5=most suitable). Visual aids were used to demonstrate some unknown measures like drip irrigation.

3.1.2.1.4 Pilot testing: Perceptions were gathered from farmers who tested identified risk reduction measures in their fields. Perceptions were collected mainly from individual in-depth discussions. This was done only in Kumasi and involved eight farmers from three farming sites. These farmers were part of those who attended the first phase meeting and were willing to participate in on-farm trials. These trials were conducted on farmers' fields during farmers' daily routines and took about six months.

3.1.2.2 Field testing of the identified farm-based RRIs

3.1.2.2.1 Assessment parameters and general sampling procedures: Sampling was done between 0600 and 0900 hrs. Two water samples were taken from each source used to irrigate all the four blocks during each repeated trial at the time of harvesting. Sterilized two-liter bottles were used for water sampling at depths of 0.2 m (UNEP-WHO 1996). A total of 36 samples were taken. Two lettuce samples were taken from each plot by randomly cutting off lettuce leaves in sterilized polythene bags and each sample weighed more than 200 g to suffice the amounts needed for both fecal coliform and helminth eggs analysis. Typically, sampling of lettuce is done by uprooting whole lettuce heads but this method of cutting off leaves was adapted due to the cultivar of lettuce planted i.e. loose leaf type and not iceberg lettuce and also to fit the experimental design. Samples were then transported in ice-cold containers reaching in the lab within 1 hr after sampling. Fresh weights of lettuce were taken by weighing 20% of the number of lettuce plants per treatment on site, just after sampling. Perceptions on cessation of irrigation before harvesting were obtained through systematic and continuous participant observations, discussions with farmers involved in the trials and focused group discussions involving other farmers in the farming site (n = 15) at the end of trials for each planting season.

3.1.2.2.2 Qualitative data collection: Participating farmers were given record sheets in which they maintained daily records of their common practices including amounts of water used, rainfall days, and other farm practices carried out, such as fertilization. Key observations on each plot were also recorded by farmers. A similar observation record sheet was filled by a field technician. Data on farmers' perceptions on the methods were collected through in-depth interviews with farmers involved in the trials after every replication. This was followed by focus group discussions with all the 30 farmers in the same farming site.

3.1.2.2.3: Specific field designs and treatments

(i) Sedimentation ponds

- *Pond measurements:* Measurements were taken on 31 ponds at study sites (Karikari and Gyenyase)

- *Psycho-chemical parameters:* Water samples were taken from twenty randomly selected ponds from both sites for physicochemical analysis. Parameters analyzed were Electrical Conductivity, Turbidity, pH, Nitrates (NO_3-N), Ammonia (NH_3-N), Phosphorus (P) and Potassium (K). Sampling and laboratory analysis followed standard procedures as described in APHA-AWWA-WEF (1998).

- *Microbial parameters:* To assess the effect of sedimentation on removal of microbial organism, water samples were taken when ponds were a) settled, b) disturbed or unsettled and c) sediments**.** Settled water samples were taken early in the morning before farmers used the ponds, unsettled water samples were taken during irrigation and at least 2 hrs after taking settled samples and sediments were taken after irrigation and from the lowest parts of the ponds i.e. near the bed of the ponds. To establish sedimentation rates, trials were restricted to Karikari for better control and monitoring. Four new ponds with similar characteristics as other on-farm sedimentation ponds were constructed for controlled monitoring. Each pond was 1 m wide and 0.6 m deep. Initial filling for all ponds was done from the same water source for uniformity. The ponds were not used for irrigation and minimal disturbance was ensured when taking the samples for laboratory analysis. Sampling followed standard procedures (APHA-AWWA-WEF, 1998).

(ii) Filtration techniques

Sand filters were made from cylindrical PVC pipes with a 0.17 m diameter and 1.4 m long, sealed at the lower end. Outflow points were positioned about 0.1 m from the lower end and raised with a hose pipe so as 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 filtration media after being manually washed and thoroughly mixed. 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 0.2 m gravel layer was underlain on each filter for drainage. Each filter had a 40-litre plastic bucket reservoir with an outlet tap to regulate flow into the filters. The reservoirs were raised to allow influent to flow by gravity. The detailed setup of the filters is shown in Figure 3.1. The sand filters were set up in a one hectare vegetable farm in urban Kumasi and water used for irrigation (household wastewater, mainly greywater) was used as influent.

Simple fabric filters were made from a cotton cloth, nylon clothand 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 in Kumasi (Gynyase and Karikari). For each site, one source of water was used as influent for all the three filters.

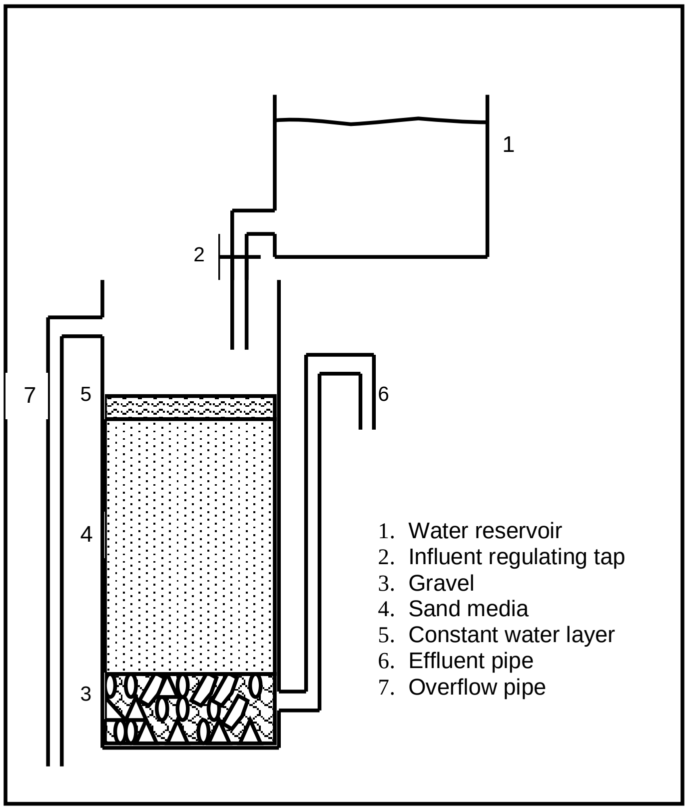


Fig 3.1. Schematic diagram of sand filter setup

(iii) Irrigation methods

- *Watering can method (WC*): This is the common irrigation method used by farmers in the area. An average watering can has a capacity of 15 liters. The average cropping density is 15 lettuce plants m^{-2}, which was also used in this experiment. Each WC plot was about 20 m^{2}.

- *Bucket drip irrigation kits (DIK):* Home garden micro irrigation kits fitted with micro-tube emitters (Bhinge Brothers, Maharashtra, India) provided by International Development Enterprises (IDE) were used. Each kit was 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 40-litre plastic bucket and was filtered by a cotton cloth supplied with the kits. The bucket was raised one meter high and supported by a simple wooden structure.

- *Furrow irrigation (FI):* Each plot had four parallel corrugated furrows spaced about 0.5 m apart; following 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 3m wide by 8m long. The average cropping density obtained was 10 lettuce plants m^{2}.

Plots for irrigation methods were randomized in three blocks, each block 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 season. 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. Soil samples were taken at the start of each replication from six random points, on each plot at depths of 0.1-0.2 m. A composite sample was made from the six sub-samples collected from each plot. A total of 72 composite soil samples were taken. In addition, three poultry manure samples were taken from each of the five trial farms at the time farmers were applying it on lettuce.

(iv) Cessation of irrigation before harvesting
Treatments were designed with two day intervals for up to 6 days of irrigation stoppage prior to harvesting i.e. irrigating till harvesting day, stopping 2 days before, 4 days before, and 6 days before. Treatments were randomized in four blocks, with each block having 4 treatment plots. Each treatment plot was about 10 m^2. Three farmers, Owusu (OW), Badu (BA) and Takyi (TA), were involved in the trials. During the dry season, each farmer conducted four repeated sequential trials and two repeated sequential trials during the wet season. Farmers were restricted to use the same water source for all the four blocks during each repeated sequential trial. A total of 576 samples were collected. For 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 last irrigation was done. In addition, a total of 90 inner and outer lettuce samples were also taken to quantify differences in levels of contamination.

3.1.3 Post-harvest RRIs – Washing methods

3.1.3.1 Exploratory surveys

A first exploratory survey was carried out with assistance of CREPA by different local teams in the cities of Cotonou, Porto-Novo, and Sèmè-podji (all Benin), Ouagadougou (Burkina Faso), Niamey (Niger), Lomé (Togo), Bamako (Mali) and Dakar (Senegal). The survey targeted a cross section of 145 restaurants of different standards and 440 randomly selected households (Klutse et al., 2005). This was complemented by a more detailed survey in Ghana where a total of about 452 respondents in Accra, Kumasi and Tamale (consisting of consumers, street food vendors and restaurants operators) were interviewed. Interviews were conducted in the different communities in the cities to cover a broad spectrum of the population. The purpose of the interviews was to find out the general risk awareness and washing methods used for pathogen decontamination of vegetables before consumption.

3.1.3.2 Efficacy trials for common washing methods

These trials were based on the results of the stakeholder interviews on common washing methods used for washing vegetables. Laboratory analyses were conducted to determine the efficacy of these common practices on faecal coliform decontamination. The efficacies of these methods were measured in terms of log reductions. The impact on helminth egg populations was less explored as their removal requires more physical changes than chemical. The effect of selected factors (e.g. temperature, pH, sanitizer concentration and contact time) on the efficacy of the methods was determined.

3.1.3.3 Sampling lettuce for decontamination trials

Lettuce samples from wastewater-irrigated farms in Accra (Ghana) were randomly collected into sterile polythene bags and transported on ice to the laboratory for analysis. These samples were pooled and homogenized. Vegetable samples used for each of the microbial decontamination trials were derived from the same pool of lettuce.

3.1.3.4 Tested common decontamination methods

Washing under running tap water; washing in a bowl of water, bowls with different salt (NaCl) solutions (7 ppm, 23 ppm and 35 ppm); in vinegar (Vin) solution of up to 6818 ppm, and a salt/vinegar solution at 7 ppm/6818 ppm. A washing detergent (OMO©) was used at a concentration of 200 ppm before washing and rinsing in clean water. Household bleach products were used at the concentration of 1 ml on 1 liter (a tea spoon on 5 liters). Different chlorine bleach brands with unspecified compositions (Eau de Javel, Thick Bleach©, Power Zone©, etc.) from local shops in Lomé and Accra were tested. All concentrations were calculated following descriptions by users. Only a few products had instructions for use: Chlorine tablets containing sodium dichloroisocyanurate (NaDCC) as now sold in Ghana for salad decontamination (Foodsaf - Hydrachem Ltd. Sussex England) were used at a concentration of 100 ppm. Potassium permanganate (KM) from PHARMAQUIC S. A., Cotonou, Benin, USP 24, was used following common practices (about 100 ppm) and manufacturer's instructions (200 ppm). Fifty grams of lettuce was held in each solution for different fixed time washed and briefly rinsed with sterile tap water before analyzing for faecal coliform population estimates.

3.1.4 Laboratory analysis of fecal coliforms and helminth eggs:

Water and lettuce samples were analyzed for fecal coliform and helminth eggs. The Most Probable Number (MPN) method was used to determine fecal coliform numbers in all samples. Ten grams of lettuce samples were aseptically cut into stomacher bag and washed in a pulsifier (Microgen Biproducts Ltd, Surrey, UK). This is followed by ten fold serial dilutions and a set of triplicate tubes of MacConkey broth supplied by MERCK (Darmstadt, Germany) was inoculated with sub samples 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 lettuce from the MPN table. Helminth eggs were enumerated using the US-EPA 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 100 g of the lettuce samples are washed in 2 liters of tap water using the pulsifier.

3.1.5 Data analysis

Two-way ANOVA in randomized blocks was done by GENSTAT-32 for Windows (Rothamsted Experimental Station). Thermotolerant coliform and helminth eggs 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). Other data analysis, graphs and tables has been done by Microsoft Excel.

3.2 Results

3.2.1 Alternative irrigation water sources – Shallow groundwater

3.2.1.1 Potential points for shallow groundwater extraction from geophysical study

An overview of sites selected for test drilling is shown as in Table 3.2. In Accra, high electromagnetic conductivity (EMC) values of between 40 to 300 Ω-m were recorded within the depth of investigation i.e. 15 m at the two study sites (marine Drive and Dzorwulu). Six representative points were selected in each of the two farming sites for further investigation using VES. VES studies showed that the two farming sites are underlain by three sub-surface geological layers of very low resistivities ranging between 0.6 and 62.0 Ω-m. These resistivities decreased with depth indicating thick weathering or presence of saline groundwater.

Table 3.2 Rank list of selected test drilling sites in the three cities

City	Farming site	Rank list of selected drilling points
Accra	Marine Drive	C70, B210, A240, A3110, B300, A40
	Dzorwulu	A100, B50, A30, D50, E20, C50
Kumasi	Engineering	C10,B80, D20, A30, B30
	Karikari Farms	B50, C30, A20
	Gyenyase	A80, B90, A360, A240, B170, B290.
Tamale	Gbumbihini	A70, C260, C40, B100, E40, A170, D40
	Kamina Barracks	A190, C0, B30, A30 and C70
	Sangani	B20, A30 and A80

In Kumasi, EM responses were low (10-13. Ω-m) at Karikari indicating a shallow overburden thickness while at Gyenyase higher values (10-26 Ω-m) were recorded indicating relatively higher weathering profile of shale and clay. Engineering had two traverses in the range of Karikari and the other two in the range of Gynyase. VES studies showed that the three sites are underlain by three to four sub-surface geological layers. Engineering had an aquifer between the second and third layers (4-11 m) which were fractured and could yield some quantity of groundwater to wells. At Karikari and Gynyase, resistivities were much higher. In the two sites, the third layers (between 10 – 30 m deep) were slightly fractured. At Karikari, groundwater could be obtained at a mean depth of 15 m and beyond 26 m depth at Gynyase. At all the three farming sites in Tamale, had very high conductivity values ranging from 42 to 288 Ω-m indicating a very thick clay content of the overburden. Resistivity values from VES studies were low (less than 73 Ω-m) at all the three sites probably due to shale and clay deposits. However, resistivities decreased with depth i.e. lower resistivities were recorded in deeper layers (more than 15 m deep) indicating that groundwater could be available at greater depths. From these values, appreciable amounts of water can be expected beyond the 30 m depth.

3.2.1.2 Actual groundwater availability from test drilling

Test drilling was done on 10 of the 40 points identified during the geophysical studies. This was done on one farming site in Accra (Marine Drive) and all the three farming sites in Kumasi. Test drilling was not done in Tamale as proposed depths for water yields were much deeper (more than 25 m), than the maximum 15 m taken for this study. Unfortunately, none of the 10 points for test drills yielded enough water for irrigation. Therefore, small diameter shallow wells have no potential of being used in the urban vegetable farming sites surveyed in the three cities. Table 3.3 shows the summary of the test drill outcomes.

Table 3.3 Outcomes of test drills in the selected farming sites

Farming study site	Depth achieved (m)	Time taken (hrs)	Reason for failure
Marine Drive, Accra (C70)	8.0	5.0	Dry hard clay materials which was difficult to auger
Engineering, Kumasi			
C10	7.0	5.0	Profile had some course sand between 3-5 m depth which could yield water, but afterwards turned to clay. Pumping test was done but recharge rate was low
B80	2.0	3.0	Dry heavy textured clay profile, too difficult to auger
D20	3.5	3.0	Dry heavy textured clay profile, too difficult to auger
Karikari, Kumasi			
A20	3.5	3.0	Heavy textured clay profile, too difficult to auger
C70	5.0	2.5	Heavy to fine clay that was hard to auger, but with terraces of water
B50	7.0	3.0	Moist clay for most of the depth but yield was very low
Gynyase, Kumasi			
A360	3.5	2.0	Dry clay with silica materials
B90 and A 80	3.5	2.0	Heavy clay becoming drier with depth

Low-cost manual well drilling using hand augers is best suited to sites where coarse sand aquifers are found below unconsolidated stone free strata. For irrigation when using a treadle pump or other suction pumps, the water table should be less than 7 meters deep from the surface. Hand-dug wells and deeper tube wells using mechanical drills are recommended in Kumasi and Tamale, though they are much more expensive to install. the need for the use of expensive pumps increases the costs of installation and operation further. In Accra, not much can be done as groundwater is saline.

3.2.1.3 Performance evaluation of the installed well-treadle pump system

3.2.1.3.1 System description and its uses: For this study, one hand-dug well was installed at Karikari, where two treadle pumps were used for water lifting. The system was installed at Karikari farming site in September 2005. The system has a lined well of about 5 m deep and 1 m diameter, with a raised concrete protective casing. One treadle pump was fitted on each side of the well. Each treadle pump has a hosepipe of about 20 m long, which is used for watering vegetables. One farmer used the system to irrigate 10 lettuce beds while the other used it for 15 beds (one lettuce bed is averagely 20 m^2). The yields of lettuce were as good as when watering cans are used, i.e. averaging 2.5 kg/m^2 of fresh weight for lettuce. The system could also be used for other crops with ease. The well also serves as a domestic water source, (and sometimes for drinking), for farmers and the nearby community of about 100 households. The water level hardly drops, making the well a very reliable source of water during the dry season and when piped drinking water is scarce.

3.2.1.3.2: Microbiological quality of irrigation water: Farmers in Karikari use shallow unprotected dugout wells or ponds not more than 1 m deep. The farming site is in a marshy place and other than groundwater recharge, the dugouts and ponds also collect surfaced runoffs from farms and households hence the high fecal contamination levels. High fecal coliform levels of 5-6 log units were recorded during the monitoring period. The new hand dug well recorded less than 3 log units in fecal coliform levels, which were in acceptable ranges for irrigation of vegetables eaten raw (WHO, 2006). The trend was almost similar with helminth egg counts. The old well had between 1.0 and 2.5 helminth eggs per litre of water, while the new well recorded no counts in four of the six weeks, with the highest recorded level being 0.5 eggs/litre. Most helminths were ascaris. Helminth eggs and fecal coliform counts in old and the new wells were significantly different.

3.2.1.3.3: Opportunities and challenges of using the new installed system: Farmers using this system observed that it had lower labor requirements than for example if a 'rope and bucket' system was used to draw water then watering can used for irrigation. They estimated that one could irrigate 2-3 times the area than when using watering cans to irrigate. When using watering cans, farmers use them for collecting water from the source, carrying it to the vegetable beds and for irrigation. However, the treadle pump system requires one person to pump water from the well, and another person at the other end irrigates the crops. The limitation therefore is getting the two people to work at the same time, as farmers usually don't work in pairs because every farmer has his own schedule of activities. Farmers suggested the use of a reservoir, although this has cost implications.


Figure 3.2 Treadle pump system

Farmers engaged in urban vegetable farming have very small sizes of plots averaging 0.1 ha which they also don't own (Obuobie et al., 2003). The small sizes of land limits installation of irrigation systems like this one. In Karikari for instance, the well and treadle pumps are in one farmers plot but the system can serve many other farmers. So even if farmers now have the ability to irrigate 2-3 times more than the area they could with watering cans, due to limited farmland availability. Land owners also don't want farmers to install more permanent structures like treadle pumps since it becomes difficult to expel farmers when the need arises. In some cases, the installation of more permanent structures like the treadle pump leads to landowners making extra demands from the farmers. Therefore, while farmers' clearly appreciate the benefits of using the system, they are reluctant to develop it further as it may lead a loss of the farmland, hence their livelihood. Land zoning by authorities for urban vegetable production can go a long way to address this challenges.

3.2.2 Farm-based risk reduction interventions while using wastewater

3.2.2.1. Farmers' perceptions on health risks and identified interventions

Farmers in the study sites perceived that occupational health risks from wastewater irrigation such as skin infections, muscular pains and sore feet to be of greater risk than consumption-related risks (Table 3.4). Skin diseases are increasingly being highlighted as one of the "ignored health risks" for wastewater farmers which need more attention especially where farmers have long contact durations in irrigation water (Trang, 2007).

Table 3.4 Health risks that farmers associated with wastewater irrigation in Accra and Kumasi, Ghana

Perceived Health risk	Accra		Kumasi	
	New farmers (N=16	*Established farmers(N=12)*	*New farmers (N=18)*	*Established farmers (N=14)*
Occupational				
Skin infections	3.13[b] ±0.7[c]	1.91 ±0.8	2.06 ±0.9	1.43 ±1.1
Sore feet	2.06 ±1.1	1.25 ±0.8	3.17 ±0.7	2.02 ±1.0
Bad odor	4.25 ±0.7	1.08 ±0.9	1.22 ±0.9	1.14 ±0.9
Bilharzias	1.19 ±1.0	0.33 ±0.5	1.08 ±0.8	1.01 ±1.0
Muscular pains	3.38 ±0.8	3.17 ±1.0	2.89 ±1.1	3.43 ±0.9
Headaches	2.06 ±0.9	2.33 ±0.9	1.28 ±1.0	0.93 ±0.7
Consumption				
Diarrhea[d]	2.04 ±0.9	1.25 ±1.1	1.06 ±0.9	1.21 ±0.4
Abdominal pains	1.31 ±0.7	2.33 ±0.9	1.22 ±0.9	0.29 ±0.5
Cholera	0.88 ±0.8	0.83 ±0.7	0.22 ±0.4	0.43 ±0.5
Typhoid	1.19 ±0.8	1.00 ±0.6	0.44 ±0.7	0.43 ±0.6
Other risks				
Pesticides-Impotency	4.31 ±0.7	3.17 ±1.3	4.78 ±0.4	4.21 ±0.7
-Skin burns	3.25 ±0.9	2.33 ±1.0	3.33 ±0.9	2.36 ±1.0
Fertilizers - Skin burns	3.38 ±0.9	2.08 ±0.8	1.17 ±0.9	0.36 ±0.5
Manure - Bad odor	1.94 ±0.9	0.92 ±0.8	3.39 ±1.2	1.93 ±0.9

[a] New farmers – had been farming for less than 2 yrs and established farmers for more than 2 yrs
[b] Risk range: Lowest risk = 1, Highest risk = 5, and (0) means risk was not mentioned
[c] Standard Deviation
[d] As mentioned by farmers, although they are symptoms of diseases mentioned like cholera and typhoid

Possible health risks to consumers were rated very low and many farmers said that they were sensitized through the media and projects that eating vegetables produced in irrigated urban farming could pose health risks. Farmers also did not associate intestinal nematode infections to wastewater irrigation and even bacterial diseases were perceived to have minimal risks. This does not correspond to overwhelming scientific evidence from epidemiological studies (WHO, 2006). However, a follow up study that compared perceptions on disease infections between farmers using wastewater and those using pipe water, which was done in one farming site in Accra (Dzorwulu) found no significant differences between the two groups (Gbewonyo, 2007). Similar findings were reported in a study done in Ouagadougou, Burkina Faso that involved 750 households under two groups; one engaged in irrigated urban agriculture and the other in non-agricultural control activities (Gerstl, 2001).

It is hard to conclude that there is no additional risks based only on these perception studies and also since no detailed epidemiological studies have been conducted in the study areas. Other factors that could influence these farmers' perceptions in the study farming sites to give such responses include that fact that farmers;

(i) have no education on invisible risk factors like pathogens and how they can affect human health
(ii) usually do not eat the vegetables they produce and, therefore, have no experience of the impact
(iii) live in poor suburbs which lack good sanitation and improved water supply, which could be more associated with these risks than vegetable farming
(iv) could have adopted defensive strategies to show that their farming is safe as a response to pressure from the public and media

Farmers perceived some of the risk reduction measures suggested in the international guidelines (WHO, 2006), such as wastewater treatment and crop restrictions as not suitable in their farming conditions (Table 3.5).

Table 3.5 Perceptions of farmers on risk management measures proposed in international guidelines (WHO, 2006)

Health risk	Accra (N = 28)	Kumasi (N = 32)
Human exposure control		
Protective clothing – gloves, boots	2.07[a] ±0.9[b]	2.88 ±1.0
Safe sanitation and drinking water	2.43 ±1.0	1.78 ±0.9
De-worming	0.96 ±0.7	1.16 ±1.0
Immunization	1.04 ±0.8	1.00 ±0.8
Health promotion programs for farmers e.g. creating awareness, hygiene education	4.54 ±0.9	4.88 ±0.5
Crop restriction measures		
Planting non-food crops	0.38 ±0.8	0.06 ±0.2
Planting foods cooked before eating	0.93 ±0.8	1.13 ±0.9
Water application techniques		
Safer irrigation methods	3.11 ±1.1	2.84 ±0.9
Cessation of irrigation prior to harvesting	2.21 ±1.0	2.03 ±1.2
Wastewater treatment	0.29±0.7	0.03 ±0.2
Conventional	2.93 ±0.3	1.94 ±0.6
Low-cost		

[a] Suitability range: Least suitable = 1, Most suitable = 5, and (0) means not suitable
[b] Standard Deviation

They instead identified simple and low-cost measures, which they could easily adopt (Table 3.6). These included alternative water sources such as shallow groundwater, low-cost water treatment methods for irrigation water such as ponds and filters, and better irrigation practices. Most measures identified require little capital investment, few changes in farming practices and behavior, but need higher labor input. Measures identified are very location-specific and should not be used universal solutions. This is because it is hard to compare farmers' preferred choices in different locations as they take into consideration many factors before making choices (Slovic, 1987). Nonetheless, there is hardly any documented study on this, so it gives no room for further discussion. However, factors that influenced choice of innovations (risk reduction measures) like capital investments and changes in practice are quite similar to those reported in other studies done in resource-poor communities (Marenya and Barrett, 2007; Avila and Jabbar, 1992).

Table 3.6 Measures identified by farmers to reduce health risks

Contamination source	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 - Using boots when stepping in water sources	- Leaving water in irrigation sources to settle and not stepping inside - Applying water to roots not on leaves - Using right amounts of water - Stopping irrigation days before harvesting
Soil	- Treat soils	- Reducing splashing of soils on vegetables - Better timing of manure application and using right amounts. - Using well-composted manures - Using gloves when applying manure

[a] Measures identified by from farmers only
[b] Measures identified following discussions with researchers

3.2.2.2. Effectiveness of farm-based measures assessed in reducing microbial contamination

The focus of the first two measures (Ponds and Filters) was on improving irrigation water quality while the latter two measures (irrigation methods and cessation) were specifically for reducing contamination on vegetables. Measures based on improving irrigation quality (ponds and filters), reduced helminth eggs to acceptable levels, however this was not achieved for thermotolerant coliforms which were too high on untreated irrigation water (Table 3.7 and Table 3.8). Since parasites are larger in size and denser than bacteria, helminths sedimented faster in ponds and were strained more in slow sand filters than bacteria (Dahi, 1990). Removal levels obtained in this study for helminth eggs (3-5 eggs per litre) are slightly higher compared to the 1-3 eggs per liter for helminth eggs removed by slow sand filters and ponds based on a review of more than 20 studies (WHO, 2006). The reason could be because of the size of the ponds as ponds used in this study were smaller and had less effect from disturbance by wind and recirculation of water, hence enhancing sedimentation.

Table 3.7. Indicator organisms in ponds under different pond status (n=36 per pond status per location)

Location	Pond status	No. of samples	Thermotolerant coliforms *(log of MPN 100 ml^{-1})*	Helminths *(No. of eggs $litre^{-1}$)*
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
Gynyase	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

Table 3.8: 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)	Thermotolerant 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	-
[a]Filter 1	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	100.00	0.1±0.2	98.26
	60[b]	0.09	2.09±0.19	100.00	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]Filter 1 had 0.5 m sand depth, Filter 2 had 0.75 m sand depth and Filter 3 had 1 m sand depth
[b] Clogged filters [c] Standard Deviation

For bacteria, die-off from prolonged exposure to unfavorable conditions is the main removal mechanism and filters (Mara, 2004; Stevik *et al.,* 2004). In ponds, there was significantly higher removal of thermotolerant coliforms when it was warmer (dry season) as this enhanced die-off, while with sand filters, removal increased with the formation of the biofilm that increased biological activity. The removal levels obtained in this study in ponds of 0.4-1.4 log units per litre, though within range, are lower than the reported removal levels of 1-6 log units for bacteria in pond systems in the same WHO review (WHO, 2006). This is due to our short retention time (3 days) compared to the usual retention time of more than 15 days in a typical pond. Removal levels from slow sand filters (2.4 log units per litre) were comparable to the given range of 0-3 log units per litre.

On vegetables, the two interventions tested (irrigation methods and cessation of irrigation before harvest) use different removal mechanisms i.e. reducing contact of contaminated irrigation water with edible parts of vegetables (irrigation methods) and allowing for pathogen die-off (cessation). Performance of the two interventions was significantly better during the dry season than the wet season. This is because in warmer conditions (high temperature, low rainfall), there is more pathogen die-off on crop surfaces and soils. There is also less deposition of pathogens from soil splashes due to reduced rainfall occurrences (Bastos and Mara, 1995)

On irrigation methods (Table 3.9), drip kits had the highest bacteria removal levels (2-6 log units per 100 g). However, simple modifications in the use of watering cans which are predominantly used by farmers in the study area had surprisingly high bacteria removal levels (2-3 log units per 100 g), showing how simple adjustments can lead to significant contamination reduction (Table 3.10).

Table 3.9 Counts of thermotolerant coliforms and helminth eggs on lettuce irrigated by different irrigation methods (n=36 samples per irrigation method per season)

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

[a] WC - Watering cans, FI – Furrow irrigation and DIK– Drip irrigation kits

Table 3.10 Levels of thermotolerant coliform counts and helminth eggs on lettuce irrigated using watering cans from different heights (n=30 samples per irrigation height per season)

		Thermolerant coliforms *(log of MPN 100 g^{-1})*				Helminths *(No. of eggs 100 g^{-1})*			
		Capped [a]		Uncapped [b]		Capped		Uncapped	
	Irrigation height (m)	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 caps at the outlet

[b] Uncapped – watering cans used had no caps at the outlet

No study has been documented on using drip kits and improved use of watering cans on contamination reduction for comparing these findings. However, the new WHO guidelines mention drip kits as a low-cost localized irrigation method with potential to reduce contamination (WHO, 2006). A typical range of 2-4 log units of pathogen removal has been given for localized irrigation, which usually uses pressurized systems like bubbler, drip and trickle irrigation systems (NRMC and EPHCA, 2005). In this study, removal was generally much higher for thermotolerant coliforms than helminth eggs. This is because helminth eggs usually survive much longer on crops (> 30 days) than bacteria which usually take <15 days (Strauss, 1985). In any case, the transfer of helminths from irrigation water and contaminated soils to leafy vegetables is known to be very limited (Ayres *et al.,* 1992). Though cessation of irrigation before harvesting reduced bacterial contamination over days (Table 3.11), the challenge with this measure was particularly on high yield losses (Table 3.12).

Table 3.11 Mean levels of thermotolerant coliforms and helminth eggs on lettuce (n=72samples per cessation interval per season)

		Thermotolerant coliforms (log of MPN 100 ml^{-1})			Helminth eggs (No. of eggs l^{-1})		
	Cessation time (days)	OW	BA	TA	OW	BA	TA
Dry season	0	6.32 (0.40)[b]	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)

[a] OW, BA and TA are farmers
[b] Figures in parenthesis are standard deviations

Table 3.12 Fresh weights of lettuce (n =36 samples per cessation interval per season)

		Mean fresh weights (kg m^{-2})					
	Cessation time (days)	OW		BA		TA	
		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

[a] OW, BA and TA are farmers

3.2.3 Post-harvest risk reduction interventions – Washing methods

3.2.3.1 Treatment of vegetables by food vendors and consumers before consumption

The most unexpected result from the survey was the general high level (>90%) of awareness of potential health risks from consuming raw vegetables and the corresponding unanimous application of risk mitigation measures in all the cities. However, due to the exploratory nature of the survey, this result needs to be verified in different section of the urban population. On the other hand, the applied measures varied largely in each city and differed significantly also between the Francophone country group and Ghana. Also the quantities of disinfectant used per quantity of product or water varied strongly.

The most common methods used in Francophone West Africa are the use of "Eau de Javel" (bleach) and potassium permanganate, both practically unknown as food disinfectant in Ghana. In Ghana, various salt and vinegar solutions are dominantly used besides cleaning in water only or a mixture of all three (Table 3.13). There was a clear tendency in the Francophone countries that in lower classes more often only water or water with salt, soap and e.g. lemon juice was used, while in middle and upper class households and restaurants, the use of bleach or permanganate appeared to be systematic. The permanganate sold at the market is a pulverised product while the permanganate sold in pharmacies is formulated in the form of tablets (the dosage can be one tablet for one or five litre of water). Except for permanganate tablets and Foodsaf chlorine tables (locally promoted in Ghana), there are no guidelines available on how to use any of the other disinfectants. Respondents were unaware of international recommendations and used their own judgement on dosages and contact times.

Table 3.13 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

3.2.3.2 Efficacy of common methods used in Ghana

Washing vegetables irrespective of the methods and concentrations commonly used reduced faecal coliform levels in lettuce. For locally common methods tested, faecal coliform population reductions under a contact time of two minutes ranged from 1.0 to 2.2 log units, while reductions of 0.2 to 1.1 log units were observed when vegetables were just dipped into the solution (Table 3.14).

Table 3.14 Efficacy of common methods at different exposure times (N= 10 for each treatment)

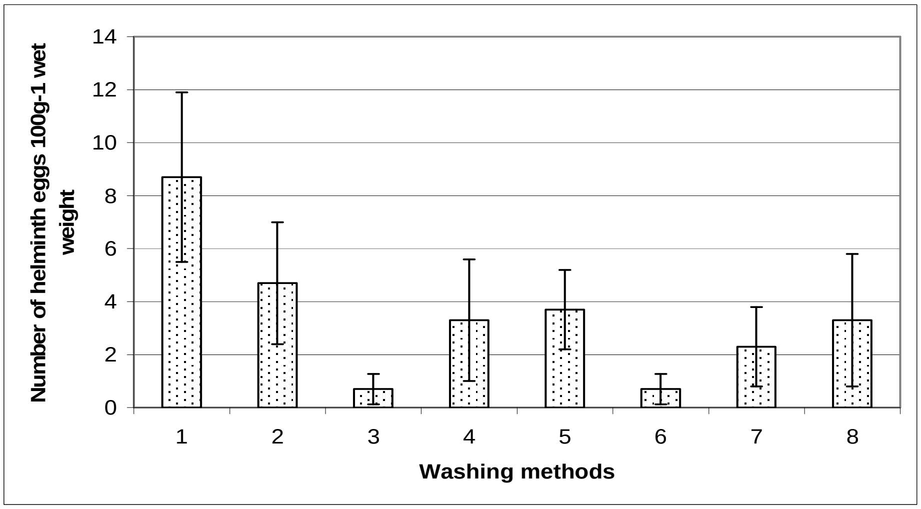
Contact time	Treatment *	FC population (log MPN)	Log reduction
Dipping (3-4 sec)	Unwashed	5.5 ± 1.1	-
	Cold water	4.5 ± 1.4	1.0
	NaCl_{7}	5.0 ± 1.2	0.5
	NaCl_{23}	4.7 ± 0.8	0.8
	NaCl_{35}	4.4 ± 0.9	1.1
	Running tap	5.2 ± 1.1	0.3
	Vin_{6818}	5.3 ± 1.2	0.2
	NaCl_{7} + Vin_{6818}	5.2 ± 1.4	0.3
	KM_{100}	4.8 ± 1.2	0.7
Two minutes contact	Unwashed	6.1 ± 1.0	-
	Cold water	4.7 ± 1.0	1.4
	NaCl_{7}	4.7 ± 0.8	1.4
	NaCl_{23}	4.6 ± 1.5	1.5
	NaCl_{35}	4.0 ± 1.2	2.1
	Running tap	3.9 ± 0.8	2.2
	Vin_{6818}	5.1 ± 1.5	1.0
	NaCl_{7} + Vin_{6818}	4.7 ± 1.0	1.4
	KM_{100}	4.9 ± 1.1	1.2

*Subscripts represent concentration in ppm; Vin = Vinegar, KM = potassium permanganate

Significant coliform reductions ($p<0.05$) were recorded for all methods at a contact time of two minutes, and for dipping in a 35 ppm NaCl solution. Increasing salt concentration from 7 ppm to 35 ppm improved its efficacy from 1.4 to 2.1 log units (two minutes contact). However, at high concentration (35 ppm), the quality of the lettuce leaves was greatly reduced. The combination of vinegar and salt at low concentration did not perform better than salt alone. Washing lettuce two minutes under running tap water achieved the highest log reduction of 2.2 units.

3.2.3.3 Efficacy of common washing method on helminth egg contamination level

The removal of helminth eggs requires first of all a physical process. Independently of the method/disinfectant, washing in a bowl reduced the helminth egg population by half or more (Figure 3.3). Washing under running tap (without any sanitizer) appeared even more effective, reducing helminth egg contamination levels from about 9 to 1 egg 100 g^{-1} wet weight.



1) Unwashed; 2) Light washing in a bowl, 3) Washing in salt solution (7 ppm); 4) Washing in salt solution (23 ppm); 5) Washing in salt solution (35 ppm); 6) Washing under running water; 7) Vinegar solution 6818 ppm; 8) Salt/vinegar solution (7 ppm/6818 ppm).

Figure 3.3 Efficacy of common washing method on helminth egg contamination level

3.3 Discussion

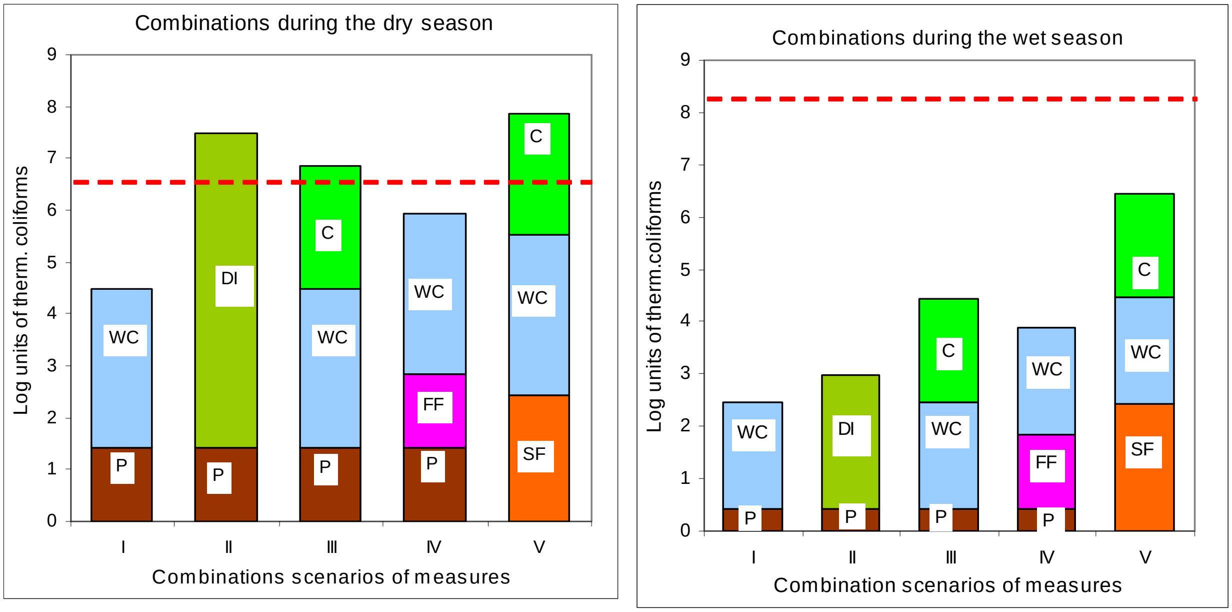
3.3.1 Farm-based RRIs

The studies on alternative water sources, in this case groundwater, shows that there the potential of using shallow groundwater as an alternative source of irrigation water for farmers using wastewater contaminated irrigation water is very low in the three cities. This is mainly because of the geology of the three cities and in Accra, there is an additional limitation from salinity as the city lies along the coast. Large scale extraction of groundwater for irrigation in Accra will worsen the salinity problems as there will be intrusion of saline water from the coast. Tamale's water table is too low and even extraction of water for domestic use has been difficult. The case study of Kumasi where large diameter well was installed for irrigation use has exposed further challenges of using such systems, though it showed very reduced fecal contamination levels to acceptable standards.

However, studies from RRIs where wastewater is used showed some potential. Careful combination of the measures tested in this study could achieve a higher aggregate reduction in vegetable contamination. This is because for water to end up on vegetables, an irrigation method has to be used. In this study, the two measures used for improving water quality (ponds and filters) were very effective in removing helminth eggs while the other two measures (cessation before irrigation and irrigation methods) were more effective in reducing bacteria. This outcome is significant because careful combination of these four measures tested can reduce both helminth eggs and bacteria, which are primary concerns in irrigated urban vegetable farming in Ghana. A wide range of combinations are possible ranging from combining only two measures (e.g. drip kits + cessation) to all the four measures (e.g. ponds+sand filters + improved use of cans + cessation).

Nevertheless, not all of these combinations may be feasible and in some cases they may be unnecessary. For instance, if sedimentation ponds can reduce helminth eggs to less than one egg per litre, then there is less sense of combining it with slow sand filters, which could do almost a similar task. Important also is to consider which options fit for a particular farming location and what farmers in that site are most comfortable to adopt. For instance, if a farming site is already using some form of ponds, then it may be more appropriate to improve the ponds than install a sand filtration system.

Based on the removal levels achieved, field conditions and adoption feasibility, the project developed five scenarios of possible combinations of the interventions for optimum reduction in contamination of vegetables for the study farming sites. Figure 3.4 shows how measures tested can be practically combined to achieve acceptable levels of thermotolerant coliforms in the wet and dry seasons. Ideally, the improved use of ponds and/or filtration systems should reduce helminth eggs adequately. 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 very significant aggregate reduction 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 improvements or more suitable interventions would be needed for the wet season. However, the use of filtration systems as shown in scenarios IV and V (wet season) could be helpful. Though the analysis on combinations done is location specific, comparison with other studies was to be more helpful. However, there are hardly any practical experiences on this.



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

Figure 3.4 Feasible combinations of interventions and achievable reduction of thermotolerant coliforms for the study area.

3.3.2 Post-harvest RRIs – Washing methods

Nearly all households and restaurants interviewed in the pilot surveys in 11 cities of the subregion showed that there is a high awareness of the need to wash vegetables to be eaten raw. Although this result will need further verification especially from low-income households and street restaurants, it is highlighting one important avenue for campaigns supporting a multiple barrier approach for health risk reduction where a comprehensive wastewater treatment is unlikely. The surveys showed that various methods are used with different concentrations and contact times and very limited information on appropriate procedures. Noteworthy is the difference between Anglophone Ghana where salt solutions, water and vinegar are the dominant methods used for washing vegetables, while in all its Francophone neighbor countries chlorine bleach (commonly known as 'Eau de Javel') and potassium permanganate are well established disinfectants. To understand the usefulness of the observed 'indigenous' washing methods, they were repeated in the laboratory. In further steps, factors possibly influencing their efficacy were modified to see how with maybe minor changes with respect to financial, time and labour constraints of the users, the methods could be optimized. Table 3.15 is summarizing the results of the washing tests so far conducted.

Table 3.15 Summary of methods used and effects on faecal coliform levels

Method	Log reductions	Comments
Only water (bowl)	1- 1.4	• Increased contact time improves the efficacy of cold water considerably. • Not very efficient compared to washing with other sanitizers. • Not very effective for helminth eggs if washing has to be done in a bowl of portable water • Increasing the temperature does not significantly increase its efficacy
Salt solution	1.4- 2.1	• Salt solution is a better sanitizers compared to potable water at an appropriate concentration and 2 min contact time • Efficacy improves with increasing temperature and increasing concentration, however, high concentration have a deteriorating effect on the appearance of some crops like lettuce
Vinegar	1- >4.0	• Very effective at higher concentration but this could have possible negative sensory effects on the washed vegetables • To achieve a high efficacy at lower vinegar concentration, the contact time should be increased • Efficacy is improved even at low concentration if carried out at a higher temperature
Running tap water	1- 2.2	• Comparatively effective compared to washing in a bowl, also for helminth egg removal • Increased impact with increased contact time • Limited application potential due to absence of running taps in poor households
Potassium permanganate	1.2- 2.5	• More effective at higher concentrations (200 ppm) and also with increasing temperature (3 log units) and contact time • Higher concentration colours washed vegetables purple which requires more water for rinsing or may raise questions on a negative health impact
Washing detergent (OMO)	1.6- 2.3	• Significant reductions could be achieved. As OMO contains surfactants which could affect health, thorough rinsing is required • Perfumes might affect consumer's perception • Peoples perception that soap is not to be eaten could affect its use
Removal of outer leaves	0.4- 0.8	• Effective additional method for risk reduction. Its effectiveness depends on the type of crop being washed o Less effective for lettuce because the leaves are open o More effective for cabbage where outer leaves protect the crop
"Eau de Javel" (chlorine bleach)	2.1- 3.1	• Effective but content and concentrations vary without proper labeling. Potential health risk if overdosed; but widely used in most Francophone West African countries • Effect of higher dosages on efficacy not tested in this study
Chlorine tablets	2.3- 2.7	• Effective but not commonly used in West African countries • Effect of higher concentrations on efficacy not tested in this study

3.4 Conclusions

Farm-based and post-harvest risk reduction interventions provide more direct solutions to the health challenges in wastewater-irrigated urban and peri-urban agriculture. Though the effectiveness of individual measures in risk reduction may not be sufficient, they can be used in combination to complement each other so to achieve the acceptable risk levels. Combination can be done within and between operation levels, i.e., farms, markets and households. While measures discussed in this paper are best practices identified for risk reduction from wastewater irrigation in major cities of Ghana, they could still be improved and adapted to be used in different locations. At present, one challenge remains the wide application of tested risk reduction measures by national stakeholders and their potential transposition into legally enforceable national standards that can be monitored and verified. We are also encouraging the use of participatory approaches to enhance adoption of these measures from all sectors. Farmers need also to be encouraged to continue with farm innovations by equipping them with knowledge, incentives, and providing them institutional support and access to higher quality waters and inputs.

4. Objective 4[3]: Developing related guidelines and awareness materials for stakeholders i.e. farmers, sellers, consumers, local authorities, and the WHO.

4.1 Methods

This CPWF project (PN38) and a related project (PN51) addressed public health concerns related to the use of wastewater in vegetable production through a number of activities including tracing the contamination pathway and testing a number of interventions from farm-to-fork. To enhance food safety and the institutionalization potential of such interventions, the activities were carried out in collaboration with farmers in a participatory manner. Farmers were involved in:

- the identification of feasible risk reduction measures
- evaluating the suitability of suggested measures like those documented in WHO guidelines
- assessment of field testing criteria

Farmers and scientists agreed on some measures to be tested and field testing and assessment done jointly on-farm. Additionally, laboratory analysis on feasible but safer post-harvest handling strategies (for vegetable refreshing in markets, vegetable washing in kitchens and households/restaurants using different media, peeling etc.) were carried out and tested qualitatively and quantitatively for their impact. From the database generated (*see related publications attached*) on feasible health risk reduction strategies both on and off farm, practical (easy to do), clear and simple messages on risk reduction methods for farmers, sellers and food vendors were developed.

A series of Knowledge Sharing (KS) workshops were carried out with the individual target groups in three cities in Ghana (Tamale, Kumasi, Accra) to discuss and feedback on the applicability of suggested interventions. The main aim of this approach was to create a café-like atmosphere where people could relax and feel comfortable to openly discuss the topic provided in smaller groups. The participants were invited to sit at the tables, with their tea or coffee, to discuss the topics given (*see Fig 4.1*)

Figure 4.1: A World Café approach used to openly discuss research messages and their potential for uptake

After this, suggestions from the participants of the meeting were assessed and modifications made to the messages. Final layout and messages were checked and the type of extension material was determined by Ministry of Food and Agriculture (MoFA) staff. To facilitate regional outreach, most of the materials were translated into French and other local languages (Twi and Dagbani)

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[3] *This objective was jointly carried out with CPWF PN 51*

4.2 Results

Based on the feedback from the meetings held, guidelines, awareness materials and training modules were developed for various stakeholders (farmers, sellers, consumers, authorities, WHO) on risk reducing options and technologies.

4.2.1 Awareness materials

The following are examples of awareness materials produced:

(1) Training and awareness videos for farmers and food vendors/caterers

Videos on good farming practices and rules of food hygiene

(2) Flip chart for agric extension agents

The flipchart is designed to stimulate interaction with the farmers. With very simple illustrations, it encourages the farmers to ask questions and make comments during the interactions

(3) Scientific publications
Several scientific articles: research reports, books and book chapters, journal articles (see the list of published articles attached.

(4) Accra starter Kit CD
This is a CD compilation of data and publications related to urban water management and this includes several if not all the outputs of the two projects (CP 38 and 51)

(5) Policy Briefs
These policy briefs translate peer-reviewed research findings into useful information for policymakers and planners. These are also on line.

(6) Posters
With permission from the WHO, modifications were made to portions of the WHO "Five keys to safer food" poster with some results on better ways of washing vegetables. The poster was also translated into both international (French) and local (Twi and Dagbani) languages for easy understanding and usage.

(7) A leaflet as an addendum to "Five keys to safer food manual".

The leaflet with instructions on good ways of washing vegetables has been inserted into the manual to serve as teachers guide in catering schools etc.

4.2.2 Update on outreach programs where our materials were used.

- Training of over 300 food caterers on risks of consumption of contaminated vegetables and safer/efficient vegetable washing methods in Nestlé organized workshop. August 2008. Aviation Social Centre, Accra-Ghana
- Training of Agric Extension Agents (AEAs) of the Ministry of Food and Agriculture, Accra Metropolitan Assembly, on simple on-farm methods for health risk reduction in wastewater irrigation (April, 2008)
- Ghana's Food and Drug Board, used our videos on food hygiene and safer agricultural practices during all workshops organized during their annual food safety week

- The Ghana Trade Hub, a commercial organization supporting marketing efforts of farmers and organizing training for catering schools requested for our caterer and farmer training videos (20 each), 5-key posters (40) and related revised manual (20) for distribution in the catering schools and farmer associations. These were provided.

4.2.3 Impact assessment using simple pre-post survey of CP 38 and 51

In early 2005, project participants and key stakeholders were interviewed during the CP38 and CP51 inaugural workshop (n=36) on their knowledge on options for health risk reduction where wastewater is used for irrigation and on their attitudes towards irrigation urban agriculture. The same questionnaire survey was carried out during the final workshop in 2008 (n=29).The analysis (KASA analysis) does not replace more complex monitoring and impact assessments, but gives a first feedback on intangible changes. It was originally applied to evaluate extension programs (Bennett, 1977, FAO 1990) but also used to assess semi-quantitatively changes in knowledge, attitudes, skills and aspirations through applied research projects (Asante-Mensah et al., 1998). A key result of the two closely related CPWF projects was a shift in knowledge on health risk reduction options from 'modest' to 'good' and 'very good'. The percentage of participants indicating very good knowledge nearly tripled from 14% in 2005 to 38% in 2008, while the number with 'modest' knowledge dropped from 28 to 10% (Fig 4.2).

Fig. 4.2**:** Changes in Knowledge on options for risk reductions in street restaurants

Asked about ways to reduce health risk on farm, only 22% of all mentioned options pointed in 2005 at safer practices of water fetching and application. This figure increased to 64% in 2008.This change in knowledge about options for risk reduction positively influenced the attitude of the stakeholders towards irrigated urban agriculture.

While in 2005 still 35% had a negative or more negative than positive attitude, this changed throughout to positive or positive with hesitation (Fig. 4.3). Indeed, 83% of the 2008 participants indicated that they see today a brighter future for irrigated urban farming than before the project (14% neutral, 3% others).

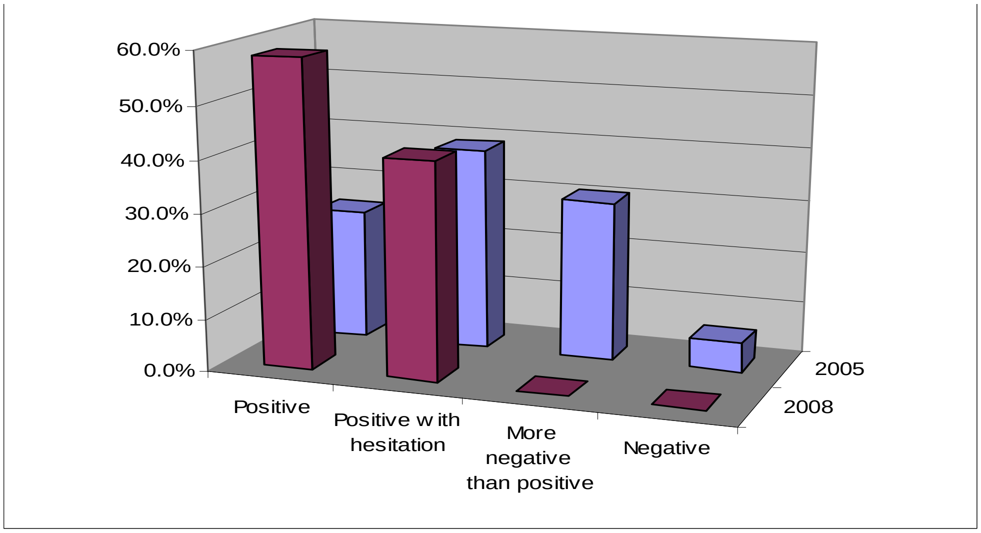

Fig. 4.3: Attitude concerning wastewater irrigated urban agriculture

Asked about possible options to support farmers' behavior change towards safer practices, about half of all participants indicated in 2005 the traditional approach of training and education. This changed in 2008 to a much more diverse response highlighting options from market incentives to land security (Fig 4.4). The result was similar for food vendors.

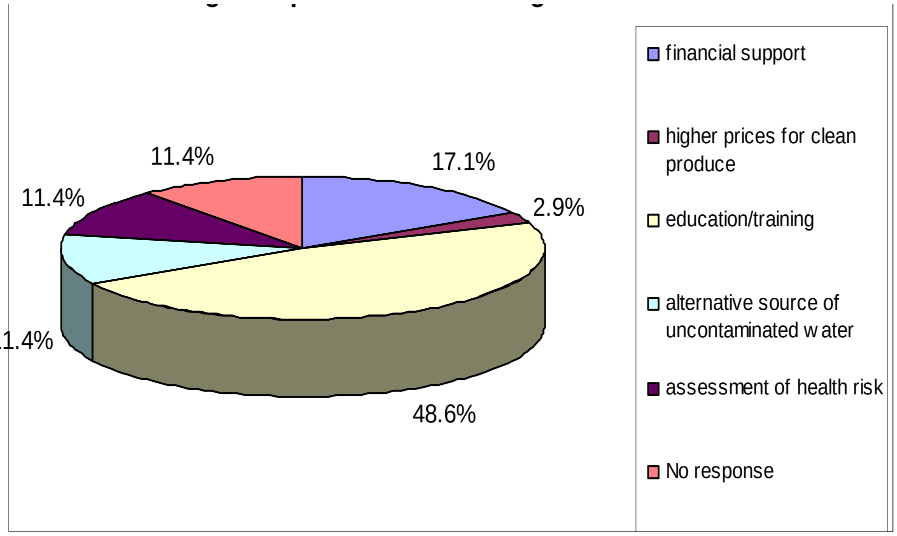

Fig. 4.4a: Options for motivating farmers 2005

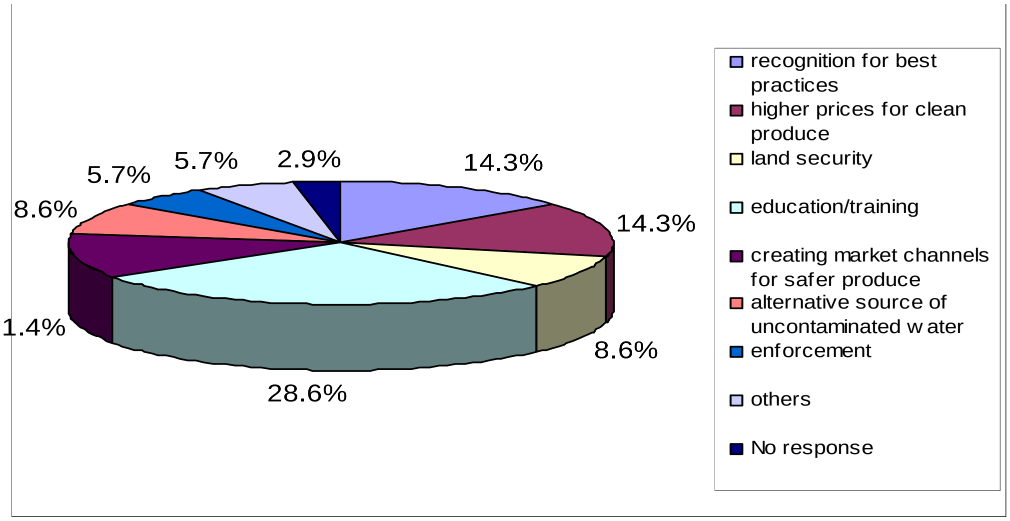

Figure 4.4b: Options for motivating farmers 2008

In general, 69% of the respondents saw their aspirations towards the projects very much fulfilled while 24% were somehow satisfied. Three of four respondents were confident that behavior change is possible if the related campaign is well done, and nearly all pledged their full support. Equally, over 90% suggested combining such a campaign with other aspects of food safety and hygiene.

4.2.4 Presentation and distribution of materials

- At an Expert Meeting organized by FAO and WHO for CODEX ALIMENTARUS; 5th – 9th May, 2008, Bangkok, Thailand on risks associated with leafy greens and herbs, all 40 international experts received copies of our video on safer vegetable production.

- Our videos were also shown as part of a presentation on "Microbial contamination of fresh fruits and vegetables in Africa: production practices, issues and challenges to be addressed" presentation at expect meeting organized by FAO and WHO for CODEX ALIMENTARUS, 19th -22nd September, 2007, Rome, Italy.

4.2.5 Media coverage

Promotion of our reports on wastewater use in urban agriculture received significant media coverage at World Water Week 2008 in Stockholm, including stories by over 20 global and regional news agencies, most notably Agence France-Presse, ANSA (Italy), Asian News International (India), Associated Press, Australian Associated Press, Reuters, Inter Press Service, Press Trust of India, and Xinhua (China). Print stories appeared in *Le Figaro* (France), *Gazeta Mercantil* (Brazil), *The Guardian* (UK), *Miami Herald* (USA), *Le Monde* (France), *New Scientist*, and *Süddeutsche Zeitung* (Germany), among others.

In addition, BBC News, *Economist*.com, *National Geographic* Online, *Newsweek* Online, and SciDev.net ran original stories on their websites. An op-ed on the food crisis by Colin Chartres was published on the BBC's *Green Room*, which hosts opinion articles on environmental topics on the BBC News website. Radio interviews with Colin Chartres, David Molden, Liqa Rashchid-Sally, and Pay Dreschel of IWMI appeared on evening broadcasts of BBC World Service, Deutsche Welle Spectrum, Radio France International and SABC's Channel Africa, thus broadening the reach of the story to millions of radio listeners around the world. (*see details in the table 4.1 below*)

Table 4.1: Interviews conducted

Interview Requests for David Molden	
Deutsche Welle Radio	Rajiv Sharma
TIME Magazine	I-Ching Ng
Interview Requests for Colin Chartres	
BBC World Today	Robert Brown
Deutsche Welle Radio	Rajiv Sharma
Reuters	Stockholm correspondent

Qz Interview Requests for Liqa Raschid-Sally	
BBC Mundo	Julian Miglierini
BBC Radio Science	Andrew Luck-Baker
Deutsche Welle Radio	Rajiv Sharma
Le Figaro (France)	Yves Miserey
Le Monde (France)	Laetitia Clavreul
Radio France Internationale	Frédéric Garat
Interview Requests for Pay Dreschel	
Deutsche Welle Radio	Rajiv Sharma
National Geographic Online	Tasha Eichenseher
Newsweek	Mac Margolis
South African Broadcasting Corporation	Bibi-Ayesha Wadvalla
WrenMedia	Mike Davison

In total, news stories appeared in more than 11 languages (Chinese, Dutch, English, French, German, Greek, Malay, Polish, Portuguese, Spanish, and Vietnamese) in almost every region of the world. The key messages (*mostly from these two projects*) were highlighted in most of the news coverage, perhaps most notably by *The Economist*, which managed to touch on the report’s more nuanced messages and findings.

5. Objective 5[4]: Developing local human capacities in integrated research on irrigation, livelihoods and health through joint NARES-CGIAR student training.

A number of students and technical personnel were involved in this project. The list is presented in Table 5.1

Table 5.1 Details of students and technicians involved in the project

1. Research Students				
Name	Institution	Research Topic	Level	Year
1. Tuabu, Obed Kofi:	UDS – Tamale	Crop water requirement calculation for Ayoyo and cabbage crop at Gumbehene and Zagyuri in Tamale.	BSc	2006
2. Akumanue Diana:	UDS – Tamale	Calculation of crop water requirement for lettuce in Sangani, Tamale	BSc	2006
3. Adambil-laar Solomon:	UDS – Tamale	Waste water utilization for small scale vegetable production in Zagyuri, Gumbehene and Sangani, Tamale	BSc	2006
4 Adams Abdulai	KNUST – Kumasi	Resource use efficiency in vegetable production: the case of smallholder farmers in the Kumasi metropolis.	MSc	2006
6. Philip Amoah	KNUST – Kumasi	Wastewater Irrigated Vegetable Production: Contamination pathway and health risk reduction in Accra, Kumasi and Tamale – Ghana	PhD	2008
7. Bernard Keraita	University of Copenhagen	Low-cost measures for reducing health risks in wastewater-irrigated urban vegetable farming in Ghana.	PhD	2008
2. Technical staff and interns				
Name	Institution	Role	Level	Yr
8. Maxwell Akple	IWMI	Project Assistant – Objective 3	BSc	2005-2007
9. Osei Boateng	IWMI	Project Assistant – Objective 3	BSc	2005-2007
10. Osei Tutu	KNUST	Lab assistant – Objective 2	Techn.	2005-2007
11. Ben Nobila	CSIR - WRI	Field assessments – Objective 1	MSc	2005-2006

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[4] *This objective was jointly carried out with CPWF PN 51. But students and outputs of PN 51 are listed elsewhere.*

III. OUTCOMES AND IMPACTS

6. Outcomes and impacts profoma

This portion of the study focuses on the outcome and impacts made by the project. A summary description is given in Table 6.1.

Table 6.1 Summary Description of the Project's Main Impact Pathways

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
Farmers	- Farmers are increasingly implementing safer irrigation practices especially sedimentation ponds and change of water application techniques	- Understanding how water and vegetables get contaminated with wastewater - Understanding of health risks, and how they affect consumers and farmers - Understanding on how they can reduce risks using simple innovative - Ability to monitor the quality of irrigation water and vegetables	- Use of participatory in identifying risk reduction strategies and testing them with farmers in their own fields - Involving farms in assessing efficiency of risk reduction interventions - One output was development of awareness materials and training module for farmers. This enhanced their understanding hence change to safer practices	- Reached about 60% of the 1300 urban vegetable farmers in three major cities in Ghana with knowledge on health risks and health risk reduction interventions
Vegetable sellers	- Vegetable sellers implementing safer market handling practices	- Vegetable sellers know the practices that increase contamination at market level such as washing in irrigation water, refreshing using dirty water, displaying vegetables on bare ground etc	- Active training and awareness raising using video documentaries and flip charts produced in the project	- About 60 lead vegetable sellers trained
Street food	- Changing to	- These	- Active training	More than 300

vendors and caterers	safer vegetable washing methods	stakeholders have increased their understanding on what vegetable washing methods are effective and which ones are not.	and awareness raising using video documentaries and flip charts produced in the project	street food vendors and caterers involved
Agricultural extension officers	- Training farmers on best practices generated from the project	- Better understanding of reducing vegetable contamination	- Training using materials obtained from the project	- An average of 4 extension officers relevant in vegetable farming from the Metropolitan Directorates of Agriculture in the three cities involved.

Of the changes listed above, which have the greatest potential to be adopted and have impact? What might the potential be on the ultimate beneficiaries?

Farmers changing to simple safer practices and also improved vegetable handling at markets have the greatest potential for adoption. These changes only need slight behavioral changes with no much capital investments. Before, many stakeholders were actually not aware what of their practices increases vegetable contamination. But now as they know, whatever behavioral change they can make, many of them have already done that.

What still needs to be done to achieve this potential? Are measures in place (e.g., a new project, on-going commitments) to achieve this potential? Please describe what will happen when the project ends.

We already have a follow-up projects trying to upscale the best practices identified and also a knowledge sharing project embedded in PN 38 to argument one of the project's objectives i.e. object IV. Basically, the aim is to reach as many stakeholders as possible with the knowledge gathered from the project.

Each row of the table above is an impact pathway describing how the project contributed to outcomes in a particular actor or actors.
Which of these impact pathways were unexpected (compared to expectations at the beginning of the project?)

- We did anticipate the low knowledge and awareness levels about health risks and health risk reduction measures from stakeholders as we finally found out.

- Participation from policy makers were surprisingly encouraging

Why were they unexpected? How was the project able to take advantage of them?

- We thought that there were already enough awareness programs on food safety especially for marketers and caterers. But this seemed never translated to action. So a lot of time was spent to educate the stakeholders on risks even before embarking on developing risk reduction interventions
- Before the project, in some study areas, some local authorities like in Accra had banned the farming practice. So we anticipated reluctance from the local authorities and other policy makers to participate. However, it also turned out that they were looking for solutions for the challenge, which turned out to be a big boost for the project. Encouraging active participation from local authorities and other policy makers, especially from agriculture directorates in all stages of the project also contributed to the policy support that the project finally attained, even to the extent of the agriculture ministry planning to adapt the best practices as part of its extension materials

What would you do differently next time to better achieve outcomes (i.e. changes in stakeholder knowledge, attitudes, skills and practice)?

- Increased use of participatory approaches in all components of the project. They seem to slow down the progress at the start of projects, but on the long run, they are effective.

7. International Public Goods

Urban vegetable farming using polluted water is a common phenomenon in many cities in low-income countries. Before starting this initiative in Ghana, we had visited a number of such cities and the practice had a lot of similarities. Traditionally, wastewater treatment has been seen as the ultimate solution, but with the costs being out of reach for many local authorities, it has turned out to be impractical. This is one of the first initiatives on testing low-cost treatment and non-treatment measures for irrigation water at field level. We have drawn largely from suggestions made in the WHO Guidelines on Safe Use of Wastewater in Irrigated Agriculture which also encourages field testing of these “non-treatment options”. So, what the contribution from this project as IPGs is the risk reduction interventions developed (see Section 3).

It is however difficult to directly transfer these best practices to other locations with water pollution problems because local conditions even within the cities under study differed to some extent. However, the approach used and best practices developed can be adapted to suit local conditions. In Ghana, we are using farmer field schools where demonstrations are made for farmers within the study studies who were not involved in these trials and farmers from other cities. We are also using agricultural extension officers from other urban areas that come to the study cities, learn and hence train farmers in their localities. Outside Ghana, we are sharing knowledge generated with our collaborators, like Urban Harvest in Nairobi, IWMI in India and Ethiopia etc. Generally, making proper linkages with other information systems and databases that provide physical information on biophysical factors such as climate, soils, water and other socio-economic and cultural factors will enhance appropriate transferability. In addition, it is always advisable to start with what the farmers use in a particular locality and work towards in improving it. For example, in Nairobi, furrow irrigation is predominantly used unlike Ghana where watering cans are used. In this case, more effort is being laid on improving furrow irrigation to lessen contact. Other international partners like WHO and FAO who are interested in our work will certainly accelerate transferability of our initiative.

We decided to use a participatory action research approach, so as to involve key stakeholders especially farmers in the whole process from identifying feasible interventions to testing and assessing measures their farms to enhance adoption and compatibility with national frameworks. So, we strongly recommend the participatory approach and the process used in this project; especially in informal systems (see Methods in section 2 and 3).

We have also extensive publications available as IPG (see section 10).

8. Partnership Achievements

A number of institutions were involved in this project. Partnership between the institutions involved has been strengthened and further collaboration started in other related projects. Greater understanding on operations of NARES, NGOs, Government Institutions and CGIAR centers has been achieved. Other than institutions, we have witnessed increased partnerships between researchers involved in the project as evidenced joint publications and reports. The project has also established strong working relationship with NGOS, farmer organizations and other networks such as Urban Agriculture Network (URBANET), Maggi Food Sellers Association of Ghana (MAFFAG), Farm-well Organic Growers Association etc. For example, URBANET in Tamale has been actively been involved in mobilizing urban farmers, even those outside project study areas Common activities to participate in awareness programs and even doing radio broadcasts about the project. The project has also led to the formation of the Ghana Environmental Health Platform, which seeks to continue in research and training on the basis of the outcomes of the project.

9. Recommendations

Based on this study, the following areas are recommended:

i. **Further assessments on low-cost interventions:** The use of untreated wastewater for urban vegetable farming is common in cities in sub-Saharan African. In cities like Dakar, Senegal and Nairobi, Kenya, direct use of untreated wastewater is practiced (Scott *et al.,* 2004). Findings in this study should therefore give a good basis for further assessments of low-cost intervention measures in other cities. In low income countries. Best practices identified could be up-scaled, though with care, considering differences in physical, socio-economic and cultural contexts. Research in this area should also give more emphasis on identifying measures that are more suitable for the wet season as interventions tested in this study were better suited for the dry season.

ii. **Pre and post-harvest interventions:** Based on the principles of a multiple-barrier risk reduction framework used in this study, farms are just one of the levels where barriers (interventions) can be put up for risk reduction. Other barriers could be put up before wastewater ends up in the farms and for post-harvest handling of produce and foods. In Ghana, some studies on other post-harvest barriers like vegetable washing methods, food hygiene and handling practices have been conducted (Amoah *et al.,* 2007b; Rheinländer, 2006). Further studies on this are recommended but even more on interventions at market level, where not much has been done. Even though conventional treatment of wastewater does not look feasible in the meantime, local authorities and communities should still be encouraged to invest in treatment systems. A number of treatment systems exist, especially those based on ecological sanitation principles, which could be implemented at household and community levels and significantly reduce volumes of untreated wastewater ending up in irrigation water sources.

iii. **Assessing the effectiveness of combining risk reduction interventions:** We have recommended for a combination of measures based on the multiple-barrier approach for the risk reduction interventions developed in this project to make significant impact in health risk reduction. This will involve combining farm-based with pre and post harvest interventions. However, this needs to be tested in actual field conditions to assess its effectiveness. A future challenge is the development of a comprehensive framework with best combinations of tested risk reduction strategies for wide application by national stakeholders and their potential transposition into legally enforceable national standards that can be monitored and verified. This will require the coordinated interaction of the research community, beneficiaries and policy makers at all levels.

iv. **Detailed health assessments:** There is a large information gap on the actual risks for vegetable consumers and farmers from wastewater irrigation in Ghana. Detailed health assessments, in specific epidemiological studies complemented with Qualitative Microbial Risk Assessment (QMRA) studies, are recommended. Such kinds of studies have been conducted in wastewater irrigation schemes in Pakistan, India and Vietnam (Ensink, 2006; Trang, 2007). The methodologies of such studies as recommended by the WHO are detailed in Blumenthal *et al.* (2000). Studies on occupational health risks including skin diseases are encouraged. The relative risk from wastewater in relation to other sources of similar risks for the same population such as poor drinking water quality, personal hygiene and bad sanitation needs to be clearly quantified. This is necessary so that investments can be directed to interventions that can have more impact on health protection.

v. **Indigenous adaptations to health risks:** It is unclear to what extent the local population adapts to health risks as generally foreigners or new farmers are more prone to health risks than indigenes and established farmers. Assessment tools like QMRA hardly considers this. This study is needed to further target risk reduction interventions to where needed most. Studies on the contribution of indigenous observable risk reduction measures to contamination reduction like removing soil from vegetables could also be conducted. This is because farmers and vegetable sellers actually try to remove "dirt" from water and vegetables while many farmers wash their bodies before leaving farms but we could not quantify the impact of such practices

10. Publications

Peer reviewed journals

1. Drechsel, P. Raschid-Sally, L., and Abaidoo, R. (**2008**). Reducing risk from wastewater use in urban farming – A case study of Accra, Ghana. In 'Urban water security: managing risks' Edts Jimenez B., and Joan Rose. UNESCO publication (in press)

2. Seidu, R. Amoah, P., Heistad, A. Strenstrom, T. –A., and Drechsel, P. (**2008**). A Quantitative Microbial Risk Assessment of Reclaimed Water Irrigation in Accra: Exploring the Effects of Water Quality and Marketing Points on Health Risks. Journal of Water and Health (accepted)

3. Drechsel, P., Keraita, B., Amoah, P., Abaidoo, R. Raschid-Sally, L., Bahri, A. (**2008**). Reducing health risks from wastewater use in urban and peri-urban sub-Saharan Africa: Applying the 2006 WHO guidelines. Water Science & Technology 57 (9)

4. Keraita, B., Drechsel, P., and Konradsen, F. (**2008**). Using on-farm sedimentation ponds to improve microbial quality of irrigation water in urban vegetable farming in Ghana. Water Science & Technology 57 (4): 519–525

5. Keraita, B., Drechsel, P., Konradsen, F. and Vreugdenhil, R.C. (**2008**). Potential of simple filters to improve microbial quality of irrigation water used in urban vegetable farming in Ghana, Journal of Environmental Science and Health, Part A, 43:7, 749 – 755. Amoah

6. Amoah, P., Abaidoo, R., and Drechsel, P. (**2008**). Sources of pathogen contamination in urban vegetable farms in Ghana. In: F.-R. Mahieu (Ed.) Agricultures et Développement Urbain en Afrique de l'Ouest et du Centre. Editions de L'Harmattan, collection "éthique économique", p. 123-132.

7. Cofie, O.O. and P. Drechsel. (**2007**). Water for Food in the Cities: The Growing Paradigm of Irrigated (Peri)-Urban Agriculture and its Struggle in Sub-Saharan Africa. African Water Journal 1(1) 23-32
8. Keraita B., Kondrasen, F. Drechsel, P. Abaidoo R.C. (**2007**). Reducing microbial contamination on wastewater irrigated lettuce by cessation of irrigation before harvesting. Tropical Medicine and International Health 12(Suppl 2) :7-13

9. Keraita B., Kondrasen, F. Drechsel, P. Abaidoo, R.C. (**2007**). Effect of low-cost irrigation methods on microbial contamination of lettuce irrigated with untreated wastewater Tropical Medicine and International Health 12(Suppl 2):14-21.

10. Amoah, P., P Drechsel, P., Abaidoo, R. C, Klutse, A. (**2007**) Effectiveness of common and improved sanitary methods in West Africa for the reduction of coli bacteria on vegetables. Tropical Medicine and International Health 12(Dec, 12):39-49.

11. Amoah, P., P Drechsel, P**.**., Abaidoo, R. C., and Henseler, M.(**2007**) Irrigated urban vegetable production in Ghana: Microbiological contamination in farms and markets and associated consumer risk groups Journal for Water and Health, 5 (3): 455–466

12. Osei, K.B., Karaita, B., and Akple, M.S.K. (**2007**). Gyinase organic vegetable growers' association in Kumasi, Ghana. Urban Agric. Mag.) pp38-40

13. Amoah, P. P. Drechsel, P., Abaidoo, R.C., Ntow, J.W. **2006**. Pesticide and pathogen contamination of vegetables in Ghana's urban markets. Arch. Environ. Contam. Toxicol. 50:1–6.

14. Amoah , P. Drechsel, P., Abaidoo, R.C. (**2005**). Irrigated urban vegetable production in Ghana: sources of pathogen contamination and health risk elimination. Irrigation and Drainage 54 (S1**)**: S49-S61.

Peer-reviewed book chapters/monographs

15. Drechsel, P., Cofie, O.O. and Niang, S. (**2008)**. Sustainability and Resilience of the Urban Agricultural Phenomenon in Africa. In: D. Bossio and K. Geheeb (eds). Conserving Land, Protecting Water. Chapter 8; Comprehensive Assessment, p.120-128

16. Manzoor Qadir (Coordinating lead author); Dennis Wichelns, Liqa Raschid-Sally, Paramjit Singh Minhas, Pay Drechsel, Akiça Bahri, and Peter McCornick (Lead authors); Robert Abaidoo, Fatma Attia, Samia El-Guindy, Jeroen H.J. Ensink, Blanca Jimenez, Jacob W. Kijne, Sasha Koo-Oshima, J.D. Oster, Lekan Oyebande, Juan Antonio Sagardoy, and Wim van der Hoek (Contributing authors) (**2007)**. Agricultural use of marginal-quality water resources presents opportunities and challenges. In (M.Qadir ed.) Comprehensive Assessment of Water Management in Agriculture. 2007. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture.* London: Earthscan and Colombo: International Water Management Institute"

17. Drechsel, P., Keraita, B., Amoah, P. Abaidoo, R., Raschid Sally, L., Bahri, A. (**2007**). Reducing health risks from wastewater use in urban and peri-urban sub-Saharan Africa: Applying the 2006 WHO guidelines. Proceedings of the 6th IWA Specialist Conference on Wastewater reclamation and reuse for sustainability. Belgium, October 2007. (**Award-winning paper).**

18. Obuobie, E., Keraita, B., Danso, G., Amoah, P., Cofie, O.O., Raschid-Sally, L. and P. Drechsel. (**2006**). Irrigated urban vegetable production in Ghana: Characteristics, benefits and risks. IWMI-RUAF-IDRC-CPWF, Accra, Ghana: IWMI, 150 pp. www.cityfarmer.org/GhanaIrrigateVegis.html

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19. Seidu, A. R., Drechsel, P., Amoah, P., Löfman, O., Heistad, A., Fodge, M., Jenssen, P. and Stenström, T.-A. (**2008**). Quantitative Microbial Risk Assessment of Wastewater and Faecal Sludge Reuse in Ghana. Paper presented at the 33rd WEDC International Conference, Accra, Ghana, 2008. Preproceedings p. 90-97

20. Seidu, R., Drechsel, P., Schonning, C., Carlander, A., Stenstrom, T.A., Jenssen P.D. (**2008**). Household Ecological Sanitation Toilets as an Option for Health Risk barrier for Faecal Sludge Reuse in Northern Ghana. Poster presentation at the Sanitation Challenge Conference, May 19-21, 2008 in Wageningen.

21. Pay Drechsel: Keynote speech at "Deutscher Tropentag" (**2007**), 9-11. Oct. on Urbanization and wastewater irrigation in developing countries: Applied research on food safety in the rural-urban interface

22. Abaidoo, R.C., Drechsel, P., Amoah, P., Keraita, B. and Kranjac-Berisavljevic, G. **2007**. Minimizing health risks associated with wastewater and excreta use in urban and peri-urban vegetable farming in Ghana through improved consciousness in personal hygiene and food safety. World Water Week, 12-18 August 2007.

23. Kranjac-Berisavljevic, G., I.B. Yakubu, I.B., L. Dari, L. **2006.** Vegetable Production in Urban Environment: experiences in the Tamale, Metropolis GiHE

24. Drechsel, P. 2005. Potential and options for the use of partially or untreated urban wastewater in agriculture: An African perspective**,** World Water Week, Workshop 3, August 2005.

25. Abaidoo, R.C., Drechsel, P., Amoah, P., Keriata, B., Agyekum, W., and Titiati, A. **(2005**). Minimizing health risks and improving system productivity in irrigated urban and per-urban vegetable farming for enhanced livelihoods. (CGIAR CPWF International Workshop on enhancing human and ecological well-beings in Africa through sustainable increases in water productivity. November 28th – December 1st , 2005).

26. Abaidoo, R.C., Kondrasen, F., Samuelsen, H., and Henseler, M. (**2005**). The impact of waste water irrigation on human health and food safety among urban communities in the Volta Basin – opportunities and risks. (CGIAR CPWF International Workshop on enhancing human and ecological well-beings in Africa through sustainable increases in water productivity. November 28th – December 1st , 2005).

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33. Drechsel, P. and S. Varma 2007. Recognizing informal irrigation in urban and peri-urban West Africa. Water Policy Briefing 26. IWMI Colombo, Sri Lanka, www.iwmi.cgiar.org/waterpolicybriefing/files/wpb26.pdf

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VI. APPENDIX

Appendix A. Link with PN 51

Outputs CP38		Outputs CP51
1. Information base on land and water use practices in irrigated urban and peri-urban vegetable farming established.		1. A health risk reduction strategy with guidelines for health promotion, based on actual and perceived health risks of urban waste water irrigation, jointly with CP38;
2. Database on water pollution and changes in vegetable contamination from farms to markets and households set up.		2. A policy brief presenting the contribution of waste water irrigated vegetable production to the nutritional status of children and livelihoods;
3. Appropriate health risk reduction strategies identified and tested, and their impact on livelihoods and land and water productivity assessed.		3. Appropriate strategy for the protection of consumer safety through the reduction of infective microorganisms; in particular, protozoan parasites in waste water irrigated vegetables sold at *markets*;
4. Guidelines, awareness materials and training modules developed for stakeholders (farmers, sellers, consumers, authorities, WHO) on risk reducing options and technologies.		4. Human capacity built through training of students from Ghana or other West African countries at M.Sc. level;
5. Human capacity built through collaborative training of local students (PhD, MSc, and undergraduate and laboratory assistants), thesis reports, and joint journal articles and research reports.		5. Increased knowledge among international research community through the publication of journal articles, theses and research protocols.

Appendix B. Abstracts

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Effectiveness of common and improved sanitary washing methods in selected cities of West Africa for the reduction of coliform bacteria and helminth eggs on vegetables

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Summary

OBJECTIVE To analyse and improve the effectiveness of common indigenous washing methods for the reduction of faecal coliform (FC) populations on the surface of wastewater-irrigated vegetables and to determine simple factors affecting their efficacy.

METHODS Questionnaire interviews were used to gather information on common methods used for washing vegetables in seven West African countries. The efficacy of the most common decontamination methods was measured in terms of log reductions in FC populations on homogenised contaminated lettuce, cabbage and spring onion samples.

RESULTS The large majority of urban households and restaurants in the subregion are aware of vegetable-related health risks and wash vegetables before consumption. Methods used vary widely within and between Ghana and neighbouring francophone West African countries. However, several of the most common methods do not reduce the contamination to any desirable level. Significantly, different log reductions are achieved depending on the washing method, contact time and water temperature. Tests to improve the apparent ineffective methods were especially promising in view of the relatively expensive vinegar. However, up to 3 log units reduction is also possible at a much lower price with 'Eau de Javel' (household bleach), which is commonly used in francophone West Africa.

CONCLUSION Washing vegetables before consumption is an important component of a multiple barrier approach for health risk reduction. The high risk perception among consumers demands that more information be made available on the appropriate use of these washing methods. Any washing method will need complementary efforts to reduce contamination before the vegetables enter the kitchen, such as safer irrigation practices.

keywords faecal coliforms, pathogen removal, wastewater, washing, vegetables, Africa

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Effect of low-cost irrigation methods on microbial contamination of lettuce irrigated with untreated wastewater

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Summary

OBJECTIVE To assess the effectiveness of simple irrigation methods such as drip irrigation kits, furrow irrigation and use of watering cans in reducing contamination of lettuce irrigated with polluted water in urban farming in Ghana.

METHODS Trials on drip kits, furrow irrigation and watering cans were conducted with urban vegetable farmers. Trials were arranged in a completely randomised block design with each plot having all three irrigation methods tested. This was conducted in both dry and wet seasons. Three hundred and ninety-six lettuce, 72 soil, 15 poultry manure and 32 water samples were analysed for thermotolerant coliforms and helminth eggs.

RESULTS Lettuce irrigated with drip kits had the lowest levels of contamination, with, on average, 4 log units per 100 g, fewer thermotolerant coliforms than that irrigated with watering cans. However, drip kits often got clogged, required lower crop densities and restricted other routine farm activities. Watering cans were the most popular method. Using watering cans with caps on outlets from a height <0.5 m reduced thermotolerant coliforms by 2.5 log units and helminthes by 2.3 eggs per 100 g of lettuce compared with using watering cans without caps from a height >1 m.

CONCLUSION Simple, cheap and easily adoptable irrigation methods have great potential to reduce crop contamination in low-income areas. When used in combination with other on-farm and post-harvest risk reduction measures, these will help to comprehensively reduce public health risks from using polluted water in vegetable farming.

keywords Low-cost irrigation methods, wastewater, lettuce, microbial, contamination, urban agriculture

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Potential of simple filters to improve microbial quality of irrigation water used in urban vegetable farming in Ghana

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Irrigation water used for growing vegetables in urban areas in many low-income countries is contaminated with untreated wastewat
Many wastewater treatment methods are economically prohibitive and continued use of such irrigation water pose health risks
vegetable consumers and farmers. As part of a larger study on possible interventions for health risk reduction, the potential of sim
interventions was explored. Column slow sand filters with three levels of sand depths (0.5 m, 0.75 m and 1 m) and fabric filters made
nylon, cotton and netting were assessed. More than 600 water samples were analyzed for helminth eggs and thermotolerant colifor
Flow rates were also measured. From slow sand filters, 71–96% of helminths and 2 log units (from 7 to 5 log units) of thermotoler
coliforms were removed. Sand depths had no significant influence in the removal. Lower removal rates were achieved by fabric filte
with an average removal of 12–62% for helminth eggs and 1 log unit for thermotolerant coliforms. Nylon filters had higher remo
rates especially for helminth eggs (58%). Average flow rates for sand filters were 3 m per day and fabric filters had steady flows
about 1.5 liters per second, but flow reduced with time in cotton filters. The simple filters tested improved the microbial quality
irrigation water and could easily be used in combination with other interventions to further reduce health risks. The unit cost of
filters tested also appear acceptable to farmers and some incentives like better prices will motivate many farmers to invest in su
simple interventions.

Keywords: Slow sand filters, fabric filters, low-cost wastewater treatment, urban agriculture, microbial contamination.

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Using on-farm sedimentation ponds to improve microbial quality of irrigation water in urban vegetable farming in Ghana

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ABSTRACT

This paper presents an assessment of the potential of using on-farm ponds to reduce levels of microbial contamination in wastewater -contaminated irrigation water. The study involved observations on the use of ponds in urban agriculture in Kumasi, Ghana, and more than 300 irrigation water samples were taken for physico-chemical and microbial laboratory analysis. The study shows that while on-farm ponds are commonly used, their potential to remove pathogens through sedimentation has not been fully optimized. Two-thirds of helminth eggs were in the sediments and careful collection of irrigation water without disturbing sediments reduced helminth eggs in irrigation water by about 70%. Helminth eggs reduced from about 5 to less than 1 egg per litre in three days in both dry and wet seasons while thermotolerant coliforms took six days in the dry season to reduce from about 8 to 4 log units per 100 ml, to meet the WHO guidelines. For optimal pathogen removal, better pond designs, farmers' training on collection of water with minimal disturbance and any other means to enhance sedimentation and pathogen die-off can be essential components of a multiple-barrier approach complementing farm-based measures like simple filtration techniques, better irrigation methods and post-harvest contamination.

Key words | microbial water quality, on-farm sedimentation ponds, urban farming, wastewater

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Pesticide and Pathogen Contamination of Vegetables in Ghana's Urban Markets

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Abstract. The objective of the study was to determine and compare the current level of exposure of the Ghanaian urban population to hazardous pesticide and fecal coliform contamination through the consumption of fresh vegetables produced in intensive urban and periurban smallholder agriculture with informal wastewater irrigation. A total of 180 vegetable samples (lettuce, cabbage, and spring onion) were randomly collected under normal purchase conditions from 9 major markets and 12 specialized selling points in 3 major Ghanaian cities: Accra, Kumasi and Tamale. The samples were analyzed for pesticide residue on lettuce leaves, total and fecal coliforms, and helminth egg counts on all three vegetables. Chlopyrifos (Dursban) was detected on 78% of the lettuce, lindane (Gamalin 20) on 31%, endosulfan (Thiodan) on 36%, lambda-cyhalothrin (Karate) on 11%, and dichloro-diphenyl-trichloroethane on 33%. Most of the residues recorded exceeded the maximum residue limit for consumption. Vegetables from all 3 cities were fecally contaminated and carried fecal coliform populations with geometric mean values ranging from 4.0×10^3 to 9.3×10^8 g^{-1} wet weight and exceeded recommended standards. Lettuce, cabbage, and spring onion also carried an average of 1.1, 0.4, and 2.7 helminth eggs g^{-1}, respectively. The eggs were identified as those of *Ascaris lumbricoides*, *Ancylostoma duodenale*, *Schistosoma heamatobium*, and *Trichuris trichiura*. Because many vegetables are consumed fresh or only slightly cooked, the study shows that intensive vegetable production, common in Ghana and its neighboring countries, threatens public health from the microbiologic and pesticide dimensions. Standard recommendations to address this situation (better legislations, law enforcement, or integrated pest management) often do not match the capabilities of farmers and authorities. The most appropriate entry point for risk decrease that also addresses postharvest contamination is washing vegetables before food preparation at the household or "chop" bar (street restaurant).

Sub-Saharan Africa is one of the regions most affected by urbanization. It has an annual growth rate of 2.8% in the total population and 5.8% in the urban population (World Bank 2000). In Ghana, the urban population is growing at an estimated annual rate of 4.2% compared with the overall population growth of 2.7% (Ghana Statistical Service 2002). The increase in urban population and food demand has catalyzed the use of urban open spaces for food production ("urban agriculture"). A typical expression of urban agriculture is the production of perishable high-value crops such as most exotic and some traditional vegetables. Because the demand for these vegetables is not seasonal, farmers attempt year-round production wherever irrigation water is available. This takes place closest to the urban markets on unused spaces in the urban environment. The production is input and output intensive with several harvests per year and depending heavily on irrigation, manure, and pesticide application.

The use of potable water for vegetable production is constrained because > 40% of city dwellers in Ghana are still without good drinking water. Therefore, the irrigation water used by these farmers is derived from different urban sources including drains, which are often highly polluted because no or little option exists for water treatment (Keraita *et al.* 2002). Another potential health risk derives from the use of pesticides, although this is beneficial in decreasing crop loss both before and after harvest (Clarke *et al*. 1997). Despite the recognition of urban agriculture as a source of urban food security, concern has been growing among city authorities. Efforts have been made toward safer cultivation of vegetables in Ghana (Sonou 2001) although few data exist on the actual gravity of the problem for guidance of appropriate interventions or policy formulation.

Therefore, to assess the public health implications, this investigation went beyond water analysis and aimed to assess the hygienic quality of irrigated vegetables produced and sold in major cities of Ghana. The objective was to determine the current level of exposure of the Ghanaian local population to fecal microorganisms and hazardous pesticides. The study is part of a larger investigation cofunded by the International Water Management Institute (IWMI) and International Development Research Centre (IDRC-AGROPOLIS), both of which target contamination at farm gates and markets as well as develop strategies to decrease health risks at different entry points (*e.g.*, water source, farm, markets, households).

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IRRIGATED URBAN VEGETABLE PRODUCTION IN GHANA: SOURCES OF PATHOGEN CONTAMINATION AND HEALTH RISK ELIMINATION†

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ABSTRACT

Microbiological water and crop contamination was monitored on urban vegetable farms in Ghana. Faecal coliform and helminth egg contamination levels of irrigation water from drains, streams and shallow wells significantly exceeded WHO recommendations for unrestricted irrigation. High faecal coliform levels exceeding common guidelines for food quality were also recorded on lettuce irrespective of the irrigation water source, with significantly lower coliform concentrations on lettuce irrigated with piped water than with shallow well or stream water. Higher crop contamination levels were observed in the rainy season in spite of lower irrigation frequencies, compared to the dry season. The main species of helminth eggs isolated in water and on lettuce were *Ascaris lumbrecoides, Hymenolepis diminuta, Fasciola hepatica* and *Strogyloides* larvae. Results from field trials showed that apart from wastewater, already contaminated soil as well as poultry manure also contribute to crop contamination, but contributions from these sources could be only partially quantified. The need to reduce the potential health risks resulting from faecal coliform and helminth contamination of urban and peri-urban vegetables thus needs a more holistic approach than a simple focus on irrigation water quality.

KEY WORDS: wastewater; lettuce; coliforms; helminthes; urban agriculture; Ghana

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Reducing microbial contamination on wastewater-irrigated lettuce by cessation of irrigation before harvesting

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Summary

OBJECTIVE To assess the effectiveness of cessation of irrigation before harvesting in reducing microbial contamination of lettuce irrigated with wastewater in urban vegetable farming in Ghana.

METHODS Assessment was done under actual field conditions with urban vegetable farmers in Ghana. Trials were arranged in completely randomized block design and done both in the dry and wet seasons. Seven hundred and twenty-six lettuce samples and 36 water samples were analysed for thermotolerant coliforms and helminth eggs.

RESULTS On average, 0.65 log units for indicator thermotolerant coliforms and 0.4 helminth eggs per 100 g of lettuce were removed on each non-irrigated day from lettuce in the dry season. This corresponded to a daily loss of 1.4 tonnes / ha of fresh weight of lettuce. As an input for exposure analysis to make risk estimates, the decay coefficient, k, for thermotolerant coliforms was 0.66 / day for the wet season and 1.49 / day for the dry season.

CONCLUSION In combination with other measures for improving water quality, the measure can significantly reduce faecal contamination of lettuce during the dry season. However, it is not suitable for the wet season due to unfavourable conditions for pathogen die-off and re-contamination by splashes from contaminated soils. The results provide a good basis for risk assessments and for devising more appropriate measures for risk reduction, especially in sub-Saharan Africa.

Keywords wastewater, lettuce, cessation of irrigation, microbial contamination, urban agriculture