8. Quality of Vegetables in Ghanaian Urban Farms and Markets

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This chapter shows results obtained from analyzing samples of vegetables taken at the farm gate and from selling points in Accra, Kumasi and Tamale. Microbiological data are based on a total of about 1,500 vegetable samples taken from different sampling points along the vegetable distribution chain – farm gates – and from different categories of sellers in Accra, Tamale and Kumasi. Fecal coliforms and helminth eggs were mainly used as the fecal contamination indicator organisms. For chemical contaminants, heavy metals and pesticides in irrigation water and vegetables were analyzed, while estrogens were used as an example for emerging contaminants.

8.1 Bacterial Contamination

While chapter 6 presented findings from studies on the quality of the water used for irrigation by vegetable farmers in and around Accra, Kumasi and Tamale, the following sections present how far the contamination was traced along the food chain.

Table 8.1 shows the fecal coliform contamination levels of lettuce at different entry points starting from farm to the final retail outlet. Irrespective of the irrigation water source, mean fecal coliform levels exceeded the recommended standard. There were no significant differences in the average lettuce contamination levels at different entry points (farm, wholesale market and retail outlet). Also the analysis of individual samples followed from farm to retail on the various sampling dates confirmed that the contamination of lettuce with pathogenic microorganisms does not significantly increase through postharvest handling and marketing (Amoah et al. 2007b). This is however not an ‘all clear’ for the postharvest sector as high on-farm contamination might simply overshadow any additional occurrence as for example any unacceptable log-4 value will hardly be noticed if there is already a log-6 contamination. In fact, the hygienic conditions, including washing habits, clean display and handling of food as well as availability of sanitation infrastructure on market sites is not very supportive. In 1998, a survey showed that only 31% of the markets in Accra have a drainage system, 26% have toilet facilities and 34% are connected to pipe-borne water (Nyanteng 1998); more recent data could not be found. While it thus appears as if the initial contamination on farm is so high that it hides any possible postharvest contamination, the latter however was also reality as seen in those cases where lettuce was irrigated with piped water, thus making this lettuce generally 1-2 logs safer at final retail, below the ‘unacceptable’ 10^5 100 gram $(g)^{-1}$ (wet weight) but above the ‘undesirable’ 10^3 100 g^{-1} (wet weight) ICSMF (1974) levels. Importantly, crop contamination also takes place on farm under irrigation with piped water. Likely sources of contamination in these cases included the already contaminated soil (FC levels of 1 x 10^4 10 g^{-1} in the upper 5 cm) and the frequent application of improperly composted (poultry) manure (Amoah et al. 2005).

TABLE 8.1. Mean fecal coliform contamination levels of lettuce from the same farm plots at different entry points along the production and consumption pathway of lettuce.

City	Irrigation water source	Statistics	Log fecal coliform levels (MPN* 100g $^{-1}$)		
			Farm	**Wholesale market**	**Retail**
Kumasi	Well (n=216)	Range	3.00 - 8.30	3.10 - 8.50	3.20 - 7.00
		Geometric mean	4.54	4.44	4.30
	Stream (n=216)	Range	3.40 - 7.10	3.60 - 7.20	3.50 -7.20
		Geometric mean	4.46	4.61	4.46
	Piped water (n=216)	Range	2.30 - 4.80	2.60 - 5.30	2.40 - 5.10
		Geometric mean	3.50	3.69	3.65
Accra	Drain (n=216)	Range	3.40 -6.00	3.00 - 6.80	3.00 - 6.50
		Geometric mean	4.25	4.24	4.48
	Stream (n=216)	Range	3.20 - 5.70	3.10 - 5.90	3.20 - 5.50
		Geometric mean	4.22	4.29	4.37
	Piped water (n=216)	Range	2.90 - 4.70	2.90 - 4.80	2.80 - 4.50
		Geometric mean	3.44	3.46	3.32

* MPN, Most Probable Number (adapted from Amoah et al. 2005, 2007b)

Accra: In Accra, lettuce, cabbage and spring onion samples were taken from Makola, Agbogbloshie, Dome and Kaneshie markets and from some individual sellers. In all markets and selling points, lettuce had the highest levels of fecal coliform population (Figure 8.1). Agbogbloshie is the main depot for vegetables from within and outside Accra, where vegetables are not washed as they are mainly sold to other vendors who are expected to wash them before selling (Figure 8.2).

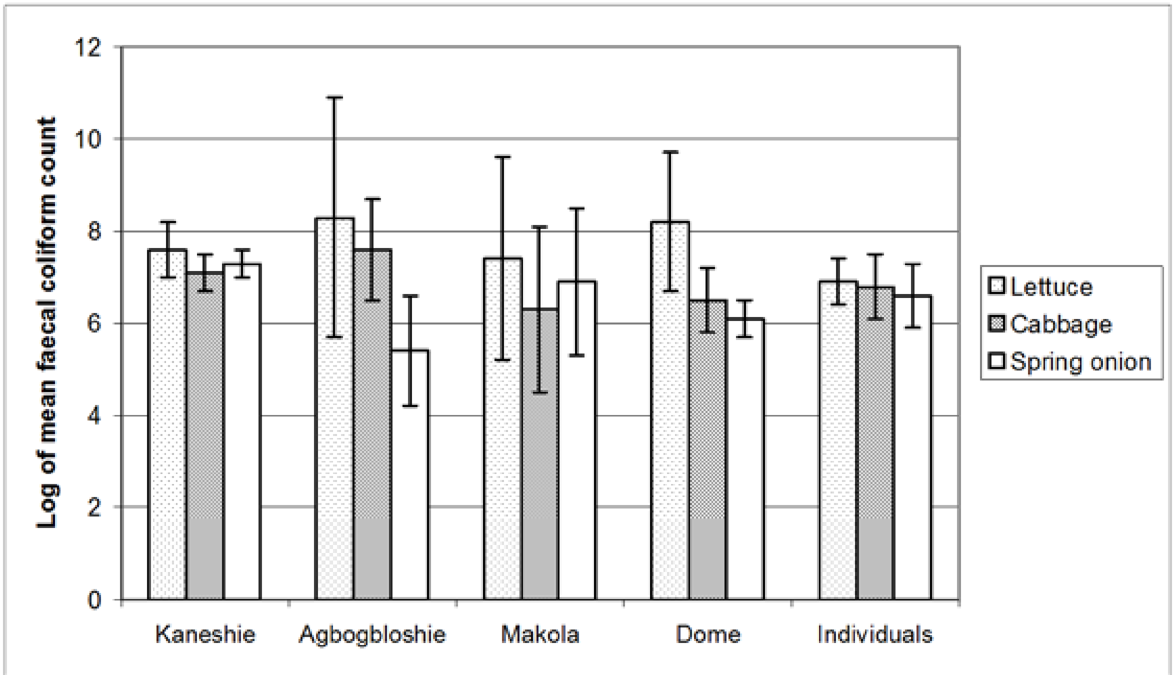

FIGURE 8.1. Fecal coliform populations on selected vegetables from some markets in Accra. (adapted from Amoah et al. 2007b).

FIGURE 8.2. A section of Agbogbloshie market showing vegetables displayed on the ground (photo: IWMI).

For both cabbage and lettuce, there were no significant differences in either fecal or total coliform levels when comparing these vegetables across markets. The same applies to spring onions, except for higher levels in Kaneshie compared to Agbogbloshie.

Kumasi: In Kumasi, vegetable samples were collected from three markets (‘White’ market [opposite the post office], Asafo and Central markets) and from some individual sellers. Samples collected from individual sellers had less contamination compared to the formal markets (Figure 8.3). However, these fecal coliform levels are still higher than the International Commission on Microbiological Specification for Food- (ICMSF 1974) recommended levels of 1 x 10^3 100 g^{-1} fresh weight.[1] Mensah et al. (2001) observed that on the smaller ‘White’ market where (expatriate) consumers asked frequently about produce quality, the sellers changed the water to wash their produce more often than in other markets and indeed reduced the pathogen level.

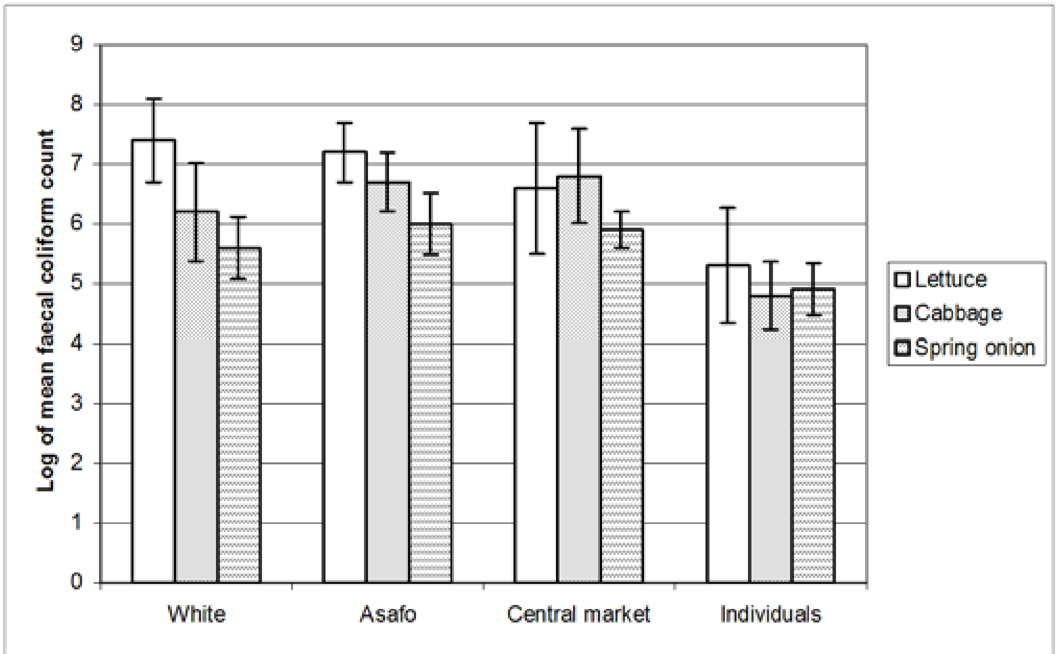

FIGURE 8.3. Fecal coliform populations on selected vegetables from markets in Kumasi (adapted from Amoah et al. 2007b).

[1] Ready-to-eat foods are considered to be still of ‘acceptable’ quality in England if they contain <100 *E. coli* per gram wet weight (i.e., <10^4 per 100 g) (Gilbert et al. 2000). This guideline value is used in many other countries, including Australia, Canada and New Zealand. As lettuce is a common component of many ready-to-eat foods, it makes little sense for the wastewater used to irrigate lettuce to be treated to a higher quality than is required for the lettuce itself (WHO 2006).

Tamale: Tamale has few vegetable markets and selling points, as it has a smaller population compared with Accra and Kumasi. Sampling was done in two markets (Aboabo and the main market), while some samples were also taken from individual sellers. Fecal coliforms ranged from 4.0 x 10^5 to 7.5 x 10^8 while total coliforms were between 1.5 x 10^7.and 1.6 x 10^{10} (see Figure 8.4) There was no significant difference in both total and fecal coliform counts for the three vegetables across markets.

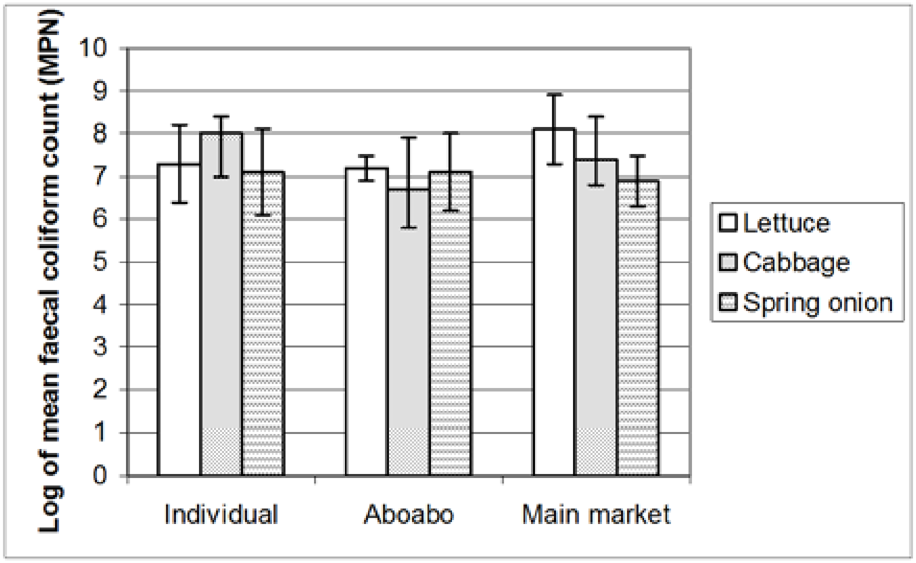

FIGURE 8.4. Fecal coliform populations on selected vegetables from some markets in Tamale (adapted from Amoah et al. 2007b).

Research by Donkor et al. (2010) pointed at the possibility of pathogen internalization in leaves of vegetables, i.e. that microbial contamination of vegetables in Ghana is not limited to the external surface, but internal vegetable parts could harbor microbes which pose risk to consumers.

Inter-city comparison of bacterial contamination: Lower levels of both total and fecal coliform populations were recorded for vegetable samples from Kumasi compared to those from Accra and Tamale (Figures 8.5 and 8.6). The reason for this could be both on-farm and postharvest handling of crops. Previous studies done in Kumasi (Cornish et al. 1999; Keraita et al. 2002) show that many farmers use shallow wells along the streams with better water quality for irrigation compared with Accra and Tamale where water from urban drains is mostly used. There is no scarcity of water in Kumasi and vegetables are washed on the farms (though with the same irrigation water), before they are taken to the market.

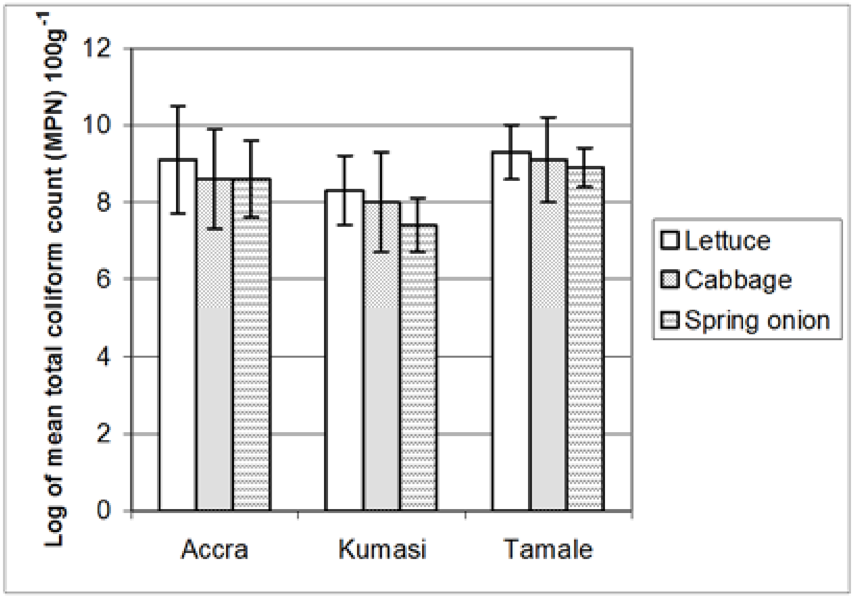

FIGURE 8.5. Total coliform levels in vegetables from Accra, Kumasi and Tamale (adapted from Amoah et al. 2007b).

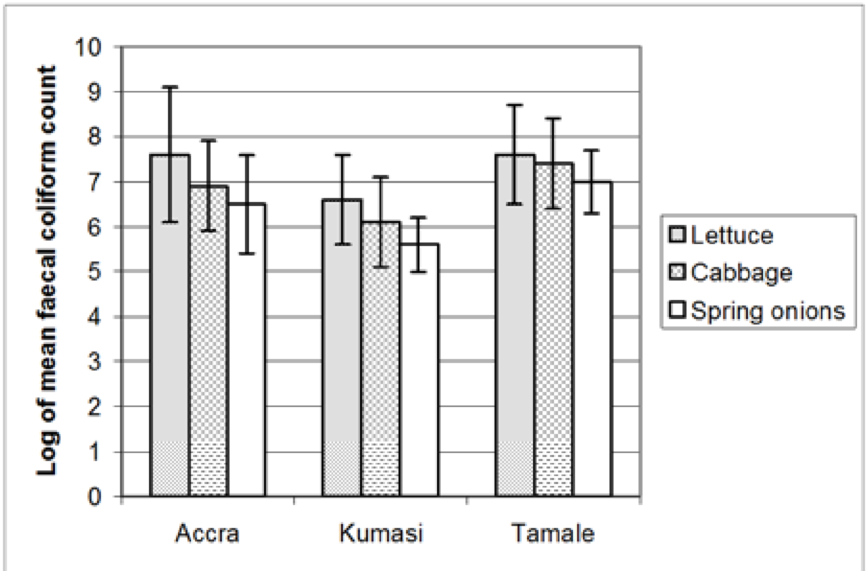

FIGURE 8.6. Fecal coliform levels in vegetables from Accra, Kumasi and Tamale (adapted from Amoah et al. 2007b).

Inter-vegetable comparison of bacterial contamination: Among the three vegetables, lettuce showed the highest levels of fecal and total coliform contamination (Figure 8.7) ranging between 10^6 and 10^{11} for total coliforms and between 10^3 and 10^9 for fecal coliforms. These contamination levels are in line with other studies on food contamination conducted in Accra (Akpedonu 1997; Abdul-Raouf et al. 1993; Ameko et al. 2012; Fung et al. 2011; Feglo and Sakyi 2012).

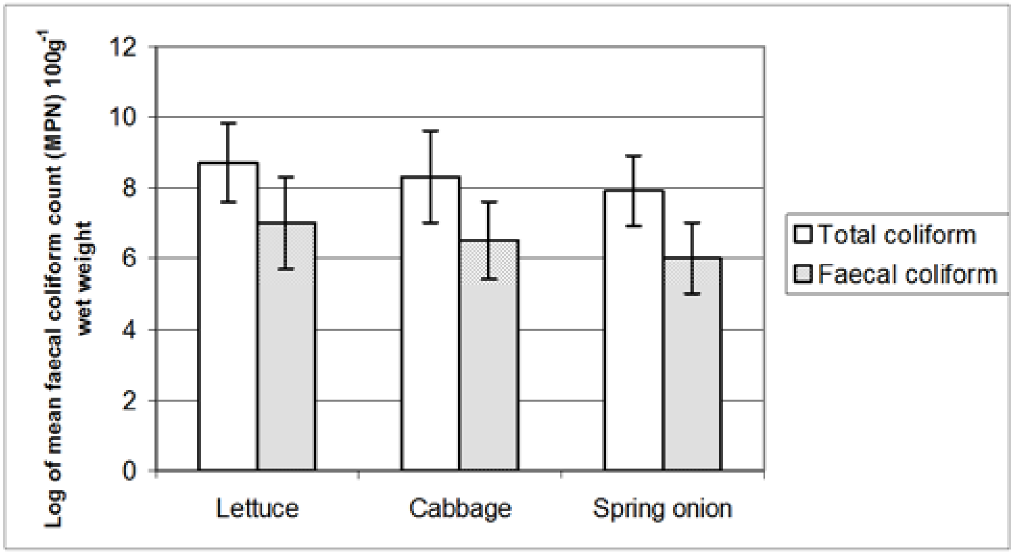

FIGURE 8.7. Fecal and total coliform populations on selected vegetables (adapted from Amoah et al. 2007b).

The differences were significant for fecal coliform counts, which could be attributed to the larger leave surface of lettuce offering a larger contamination surface. This foliage also protects microorganisms against exposure to environmental factors and prolongs microorganism survival (Shuval et al. 1986; Armon et al. 1994).

Seasonal Variations of Bacterial Contamination: Figure 8.8 illustrates fecal coliform populations on lettuce samples collected in Kumasi at the 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 2008). High levels of fecal coliform counts (usually above the common acceptable standard of 1×10^3 $100g^{-1}$ wet weight) were recorded on all irrigated lettuce including that irrigated with piped water.

Apart from stream water-irrigated lettuce from Accra, higher fecal 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 fecal coliform counts of samples analyzed from the farm gate, the market and final retail points.

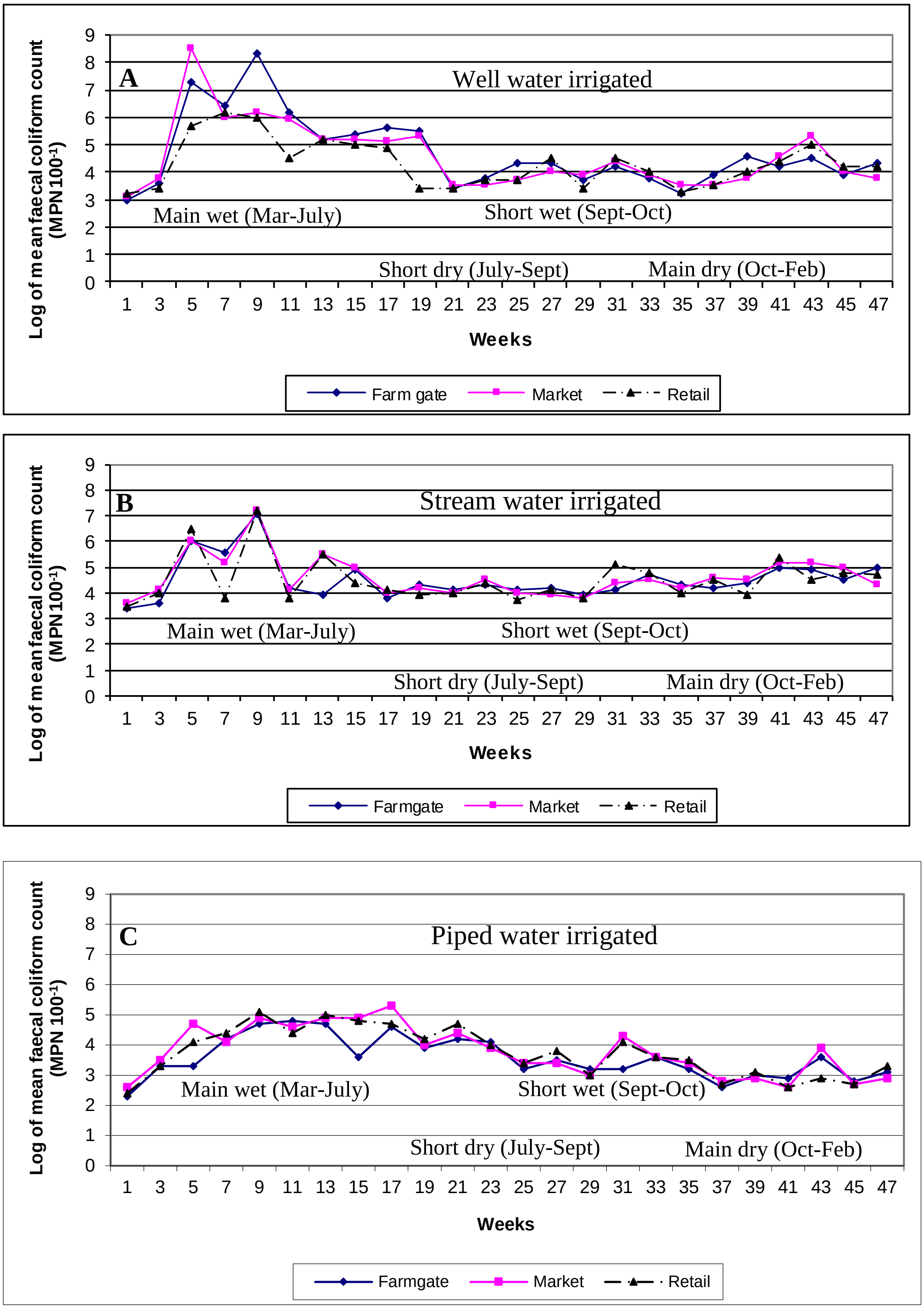

FIGURE 8.8. Fecal coliform levels at different entry points on production and consumption pathways of lettuce irrigated with water from well (A), stream (B) and piped water (C) in Kumasi (adapted from Amoah et al. 2007b, 2008).

8.2 Helminth Eggs

Helminths are worm-like parasitic organisms living in and feeding on living hosts, while disrupting their hosts' nutrient absorption, causing weakness and disease. Those that live inside the digestive tract are called intestinal parasites. Helminth eggs are commonly found in fecal matter-contaminated water and food. In Ghana, eggs of *Ascaris lumbricoides*, *Hymenolepis diminuta*, *Trichuris trichiura*, *Fasciola hepatica* and *Strongyloides larvae* are commonly detected on lettuce samples. Typical helminth egg populations analyzed on lettuce by Amoah (2007ab) ranged from 1 to 6 egg(s) 100 g^{-1} wet weight with between 50 to 75% of the eggs being viable (Table 8.2).

TABLE 8.2. Arithmetic mean of helminth egg contamination levels at different entry points along the production consumption pathway[1]

City	Irrigation water source (n=15 each)	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
[2] Numbers in the same column with the same letters showed no significant difference between water sources per city ($p>0.05$).
Figures in parentheses represent the standard deviation. Adapted from Amoah et al. (2007b).

In most cases, significantly ($p<0.05$) higher levels were detected in lettuce irrigated with polluted water than that from piped water-irrigated sources[2]. 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 (Table 8.2).

8.3 Heavy Metals

Heavy metal contamination on soils and vegetables could come from irrigation water (especially when wastewater is used), manures, chemical fertilizers and pesticides. Heavy

[2] As mentioned above, crops irrigated with clean piped water can still be affected by pathogens due to splash from soil, contamination through the application of fresh manure, or post-harvest contamination.

metal contamination of agricultural soils and crops is particularly likely in emerging economies where regulations and treatment facilities do not keep pace with industrialization, such as China and India (Sharma et al. 2006). While large-scale industrialization is not common in Ghana, smaller industries and businesses like vehicle repair shops are very common and the risk of wastewater contamination with heavy metals cannot be excluded (Akuffo 1998). Moreover, many urban farming sites are located in close proximity to roads with heavy vehicular movements, which can be additional sources of heavy metals.

Lente et al. (2012) analyzed heavy metal contamination of five different types of commonly grown vegetables that were sampled from four irrigated vegetable farming sites in and around Accra. The vegetable samples were analyzed for copper (Cu), zinc (Zn), lead (Pb), nickel (Ni), chromium (Cr), cadmium (Cd) and cobalt (Co). Table 8.3 shows the concentrations of heavy metals that were found on the vegetables. While many samples reported for chromium and cadmium data below detection limits of 0.002 and 0.006 mg/kg, respectively, all other Cr and Cd values remained below their respective maximum residue limit [MRL]. Levels exceeding the MRLs were reported for cadmium in studies conducted in Varanasi, Harare and Addis Ababa (Sharma et al. 2007; Mapanda et al. 2007; Weldegebriel et al. 2012). Muchuweti et al. (2006) in a study done in Harare reported that local *Tsunga* vegetable leaves irrigated with wastewater contained 3.68 mg Cd kg^{-1}, over 18 times that of the European standard. In Kumasi, a study done on vegetables grown on waste dumping sites showed high cadmium contamination of 0.68-1.78 mg kg^{-1} (Odai et al. 2008). Cadmium is becoming an increasing health concern in wastewater irrigated agriculture, especially due to its association with damage to kidneys and bones and its potential carcinogenic nature (Suruchi and Khanna 2011). However, Cd levels in wastewater irrigated vegetables sampled by Anim Gyampo et al. (2012) in Tamale and Lente et al. (2012) in Accra do not point at any health risks if compared with appropriate reference values.

Note of caution: *Official MRLs, like that of Cd, are based on intake of fresh vegetables, i.e. fresh weight. To compare the analyzed dry weight Cd values with a matching MRL the crop water content (>90% for many leafy vegetables) has to be considered. The adjusted MRL based on dry weight (see table 8.3) is higher than the official fresh weight value, and the actual risk correspondingly lower than stated in papers which miss the adjustment.*

In the Lente et al. (2012) study, zinc and copper concentrations on vegetables were below permissible limits. Mean concentrations were below 10 mg kg^{-1}, corresponding to <5% of Cu and <2% of Zn MRLs. No reliable reference levels were obtained for Co. However, levels analyzed were < 2 mg kg^{-1}, which seems tolerable. Similarly, though present in all vegetables, levels obtained for Ni were much lower than the MRLs. In any case Ni concentrations should not be of much concern as higher threshold levels have been reported in other studies e.g. 68 mg kg^{-1} by Weigert (1991) based on the argument that more than 90% of Ni consumption remains organically bound and will be safely excreted.

TABLE 8.3. Concentration of heavy metals in vegetable crops (n = 240 samples)

Crop	Levels of heavy metals in vegetables (mg kg^{-1} dry weight)						
	Cu	**Zn**	**Pb**	**Ni**	**Cr**	**Cd**	**Co**
Wastewater irrigated							
Cabbage	3.3±1.4	9.5±1.4	10.5±3.0	1.8±1.0	BDL	BDL	0.4±0.0
Lettuce	6.3±1.4	10.6±3.5	10.2±2.5	2.8±0.5	1.1±0.0	0.01±0.01	1.1±0.8
Green Pepper	7.8±2.1	6.9±2.0	9.4±1.5	1.8±0.8	BDL	BDL	0.2±0.0
Hot Pepper	5.3±2.8	5.1±1.5	7.6±1.8	1.7±0.9	BDL	BDL	0.4±0.0
Ayoyo	8.1±1.9	8.0±1.3	9.1±2.4	1.4±0.5	BDL	0.28±0.01	BDL
Groundwater irrigated control							
Cabbage	2.6±0.4	9.5±1.5	6.7±4.2	1.4±0.1	BDL	BDL	1.0±0.0
Lettuce	3.3±2.7	9.8±1.0	8.0±5.2	2.8±3.2	BDL	0.50±0.01	1.5±0.0
Green Pepper	6.2±0.4	6.1±2.1	5.6±3.5	2.1±0.2	BDL	BDL	0.8±0.0
Hot Pepper	7.4±2.5	9.3±2.2	6.7±0.7	4.1±0.0	BDL	BDL	BDL
Ayoyo	5.9±7.0	5.4±5.0	8.3±1.2	1.3±0.1	BDL	BDL	1.5±0.1
MRL(mg kg^{-1} dry weight)	200[b]	500[b]	3[a]	680[b]	23[c]	2[a]	-

MRL = maximum recommended limit; conversion of original wet weight values to dry weight done at mean 90% moisture content for all crops. Sources: [a] EC (2006), [b] Mapanda et al., (2007) based on UK and FAO/WHO standards, [c] Weigert (1991). BDL= below detection limit of 0.006 (Cr) and 0.005 (Cd, Co)

Source: Lente et al. (2012)

The concentrations of lead (Pb) on vegetables found by Lente et al. (2012) were high in all samples, also on the control sites. Mean Pb levels ranged between 5.6-10.5 mg kg^{-1}, with highest levels reported in cabbage and lettuce. These concentrations are higher than the dry weight MRL assuming a 90 to 95% water content. Similar Pb ranges were obtained by studies done in Kumasi (2.42-13.50 mg kg^{-1}) and in Harare, where mean Pb concentrations of 6.77

mg kg^{-1} were measured (Odai et al. 2008; Muchuweti et al. 2006). High Pb levels in Ghana could probably be more attributable to vehicular exhaust fumes (Affum et al. 2008) than to irrigation water or contaminated soils. This appears to be supported by the low Pb concentrations analyzed in (raw) wastewater, soils and crops in Tamale with its significantly lower traffic intensity than in Kumasi or Accra (Anim-Gyampo et al. 2012). Kylander et al. (2003) analyzed in Accra a Pb distribution following traffic density with levels reflecting a situation in Europe and the United States before the introduction of catalytic converters.

8.4 Pesticide Residues

Amoah et al. (2006) assessed the level of pesticide contamination on vegetables sold in nine major markets in Kumasi, Accra and Tamale. Table 8.4 shows pesticide prevalence on lettuce leaves and the respective maximum MRLs for consumption. In most cases, the pesticide residue levels observed exceeded the MRL. More than 60% of the lettuce samples had ≥2 pesticide residues. The data showed that 78% of the samples had chlorpyrifos residue. Only 14% had pesticide residue levels below detectable limits. There were no significant differences between pesticide residues levels observed on samples from the three cities except chlorpyrifos, for which significantly higher levels were recorded in Kumasi than in Accra.

TABLE 8.4. Pesticide prevalence: residue levels on lettuce (n = 60).

Pesticide	% of lettuce with pesticide residues	Range of pesticide residue on lettuce (mg kg^{-1})	Average value of pesticide residue on lettuce (mg kg^{-1})	MRL[1] (mg kg^{-1})
Lindane	31	0.03-0.9	0.3	0.01
Endosulfan	36	0.04-1.3	0.4	0.05
Lambda cyhalothrin	11	0.01-1.4	0.5	1.0
Chlorpyrifos	78	0.4-6.0	1.6	0.05
DDT	33	0.02-0.9	0.4	0.05

[1] Maximum residue limit (Pesticide Safety Directorate 2005).
Source: Amoah et al. (2006).

Dinham (2003) estimated that 87% of farmers use pesticides on vegetables. Insecticides are the most widely used among the different classes of pesticides with 41% pyrethroids, 37% organophosphates and the rest being organochlorines and carbamates (Ntow 2001; Okorley and Kwarteng 2002). Danso et al. (2002b) described how farmers mix cocktails of various pesticides to increase their potency in pesticide control. It is thus not surprising to read about evidence of chlorpyrifos contamination, for example 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 pests on coffee, whereas DDT is banned in Ghana. However, the data show clearly that these more potent agrochemicals are still being used irrespective of whether they are approved for vegetable production or not. Comparing the consumption risks, Amoah et al. (2006) concluded that the potentially negative impact of vegetable contamination through fecal matter is higher than through pesticides.

8.5 Estrogen Concentrations

The concentrations of estrogens, natural estrone (E1) and 17 β-estradiol (E2) and synthetic 17α-ethynylestradiol (EE2) were monitored in spring onion, green bell pepper and lettuce during a six-week period from farms at Dzorwulu and Korle-Bu in Accra (see chapter 6). Vegetables sampled from the selected site at Dzorwulu were irrigated with potable water conveyed in municipal pipelines into dugouts on site while plants at Korle-Bu were irrigated with water from a central open drain carrying wastewater from the Korle-Bu Teaching Hospital and a combination of household and septage from surrounding houses as well as urban runoff. Vegetable samples for each site were collected in triplicate and extracted estrogens were quantified by liquid chromatography tandem mass spectrometry (LC/MS/MS). The limit of quantification for E1, E2 and EE2 in the plants was 0.1 ng l^{-1}.

On most occasions, no detectable E1, E2 and EE2 levels were seen in onion or green pepper samples from both sites. Lettuce samples collected from Korle-Bu on the other hand, showed estrogen concentrations with levels reaching up to 1430 ng g^{-1} and 35.5 ng g^{-1} (dry weight) of E1 and EE2, respectively. The higher frequency of detection as well as higher concentrations of estrogens seen in lettuce compared to spring onion and green bell pepper suggested that either the lettuce roots were better capable of directly taking up the estrogens and translocating them into leaves or estrogens were being directly deposited on foliage during irrigation or as dust. Other studies have found that nonagricultural organic compounds associated with waste are more likely to be found as deposits on plant foliage left by waste application rather than through translocation from shoots (Overcash et al. 2005). No accumulation of estrogens in plant tissue was observed during the sampling period. Assuming the worst case scenario (highest estrogens detected in lettuce supplied by wastewater-irrigated farms during the study and thrice daily salad consumption), the daily EE2 equivalent dose of a person with vegetable ingestion per meal of 12 g (Amoah et al. 2007a) was estimated at 18 µg day^{-1}. This worst (and only theoretical) scenario dosage is comparable to therapeutic doses in human female birth control pills (10-50 µg EE2 day^{-1}).[3]

However, organic chemicals within the soil and taken up by plants usually undergo one or more phases of transformations including conversion through oxidation, reduction or hydrolysis, conjugation with glutathione, sugars or amino acids and or compartmentalization into plant tissues as bound residues non-extractable by chemical procedures (Ohkawa as cited in Dietz and Schnoor 2001). The actual and potential human health risks of the end products thus require further study.

8.6 Conclusions and Recommendations

Both fecal and helminth contamination of vegetables (lettuce, cabbage and spring onion) produced and marketed at various selling points in Accra, Kumasi and Tamale exceeded the ICMSF recommended food safety levels. Fecal contamination was higher than the ICMSF-recommended level of 10^3 fecal coliform 100 g^{-1} fresh weight. Helminth contaminations were also high (0.42-2.74 eggs g^{-1}). Results showed that except for piped water, all other sources of water used by urban farmers for irrigation showed fecal coliform levels exceeding common guidelines for unrestricted irrigation. The study identified the farm as the main point of microbiological lettuce contamination. Despite poor sanitary conditions in markets, postharvest handling and marketing did not affect the already high farm-gate contamination levels. Although lettuce irrigated with piped water had the lowest fecal coliform counts, contamination levels can still exceed common standards suggesting contamination through manure and the already contaminated farm soils, with postharvest contamination being again the comparatively lower risk factor in the case of Ghana while the situation can be different where irrigation water is much safer.

Comparing vegetables, it was observed that lettuce had the highest levels of fecal contamination, which is to be expected because of its open leaf structure. However helminth eggs were surprisingly higher on the green spring onion leaves in spite of lower surface area to volume ratio. Cross-market comparisons within cities showed in general no significant differences in contamination from fecal coliforms for lettuce and cabbage. Thus there is no particular market which could be recommended for the purchase of safe produce. This also

[3] Source: http://contraception.about.com/od/contraceptionglossaryef/g/Ethinyl-Estradiol-Synthetic-Estrogen.htm. Accessed 08 October 2014.

concerns supermarkets which sell salad greens from the same sources. However, there was a tendency to safer produce where – based on consumers' demand – sellers changed the water they used to refresh their crops more often than in other markets. Comparisons among cities showed that in general, the quality of vegetables in Kumasi was better than that in Accra or Tamale. This may be indicative of the water source (often shallow wells near streams) or better postharvest handling (washing of vegetables) practices.

Comparing different pathogens through quantitative ex-ante risk modeling (see chapter 9 for details), rotavirus dominated the disease burden, followed by norovirus, while Ascaris posed the smallest risk. The main question of the authorities is where intervention should be placed to reduce health risks for consumers. The results suggest that due to high water pollution, any possible postharvest contamination was overshadowed by heavy contamination on farm. As most sellers wash (or refresh) different vegetables before selling them with the same water again and again, it is likely that there is postharvest contamination. This water can easily spread pathogens from one to another crop. To reduce the health risk associated with the consumption of contaminated lettuce, it is evident from the study that the problem should first be tackled through better water treatment and safer agricultural practices on farm, while precautions should not ignore the postharvest sector. A related multibarrier approach will be presented in chapter 14.

In view of heavy metals, chemical contamination on vegetables is generally within permissible limits and so far less significant than that from pathogen contamination. Nevertheless, continuous monitoring is needed in view of poor practices in pesticide application (Ntow et al. 2006), the immense traffic in Ghana's main cities (and possible lead contamination) and the prospective growth in the industrial sector in Ghana. Importantly, estrogens were present in the analyzed vegetables at the Korle-Bu hospital site, although concentrations and occurrence varied among plant types. It appears from the limited data in the literature that most hydrophobic emerging contaminants are adsorbed by soil organic matter and are therefore not expected to translocate into and accumulate in harvested plants. However, the number of studies across Africa and the world are very limited (see Asem-Hiablie et al. 2013) and more are needed for any sound conclusions on uptake mechanisms (including foliar deposition) and associated human health risks. With increasing trends in dietary estrogen intake among women coupled with little improvement in wastewater treatment technologies, the overall estrogen load in wastewater is expected to increase.