6. Quality of Irrigation Water Used for Urban Vegetable Production

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This chapter presents findings from studies conducted in Accra, Kumasi and Tamale aimed at assessing the quality of irrigation water used by farmers in and around the cities. Samples for laboratory analysis were taken from sources of water used for irrigation. Microbiological, chemical and other emerging contaminants are presented.

6.1 Urban Sanitation and Water Quality Linkages

The quality of water used for irrigation has implications for agricultural productivity and human health. In Ghana, most irrigation water sources are contaminated with untreated domestic wastewater emanating from poor urban sanitation. The latest National Population and Housing Census conducted in Ghana in 2010 shows that most Ghanaians (34.6%) continue to use public toilets, while about 19% of the total population practice open defecation[1]. The percentage of houses served by sewers is less than 5% (GSS 2012a). The Joint Monitoring Programme, which does not consider shared public toilets as improved sanitation facilities, reports that only 19% of urban Ghanaians and 8% of rural Ghanaians have access to improved sanitation facilities (WHO/UNICEF 2013).

About 47% of households dispose of their liquid waste (mostly graywater) through street gutters (GSS 2012a). For black water most houses in low-density areas have on-plot pit latrines or septic tanks, but usually without drain fields. The overflow of septage from septic tanks into soils, stormwater drains and water courses is common and pollutes the urban environment. Subsequently, most street drains, which cover about 60% of Accra and were meant for stormwater (and graywater) conveyance, also show high coliform levels.

Wastewater and fecal sludge that is collected in Ghana is rarely treated before discharge into the environment. There is no official or definitive inventory of wastewater and fecal sludge treatment plants in Ghana. In 2001, Ghana's Environmental Protection Agency (EPA) recorded 44 treatment plants in an unpublished national survey (EPA 2001), while in 2008 IWMI

[1] Using in cities black plastic bags ('flying toilets'), which are then removed with solid waste or end up outside the compound, often in stormwater drains.

identified 63 wastewater treatment plants and eight fecal sludge treatment plants across the country (Murray and Drechsel 2011). Ghana's National Environmental Sanitation Strategic Action Plan (NESSAP) quoted this survey in its list of treatment facilities in Accra, Kumasi and Tema, many of which overlapped with the EPA's survey (MLGRD 2010). In 2013, IWMI conducted a second survey which excluded some decommissioned facilities and counted 66 wastewater treatment plants and 11 fecal sludge treatment plants; however three of these were still under construction at the time of the survey (Figure 6.1). Among the 66 identified wastewater treatment plants, only three could be considered centralized municipal wastewater treatment plants, while the majority served decentralized sewer systems. Informal fecal sludge disposal sites (mostly depressions without concrete infrastructure) were not included in the IWMI 2013 survey.

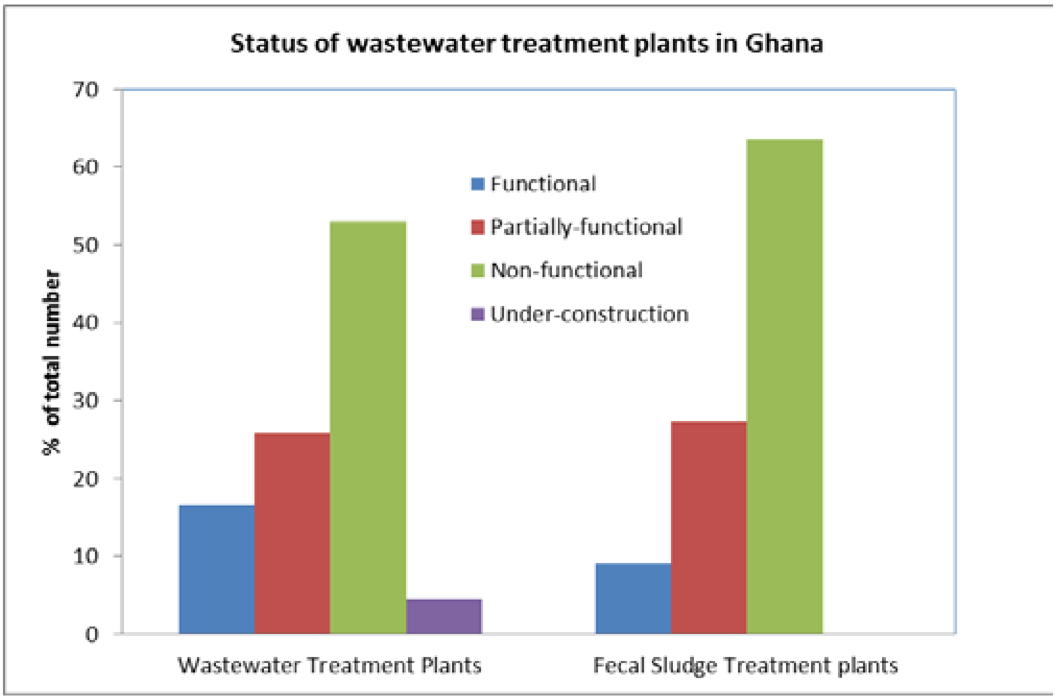

FIGURE 6.1. Status of wastewater and fecal sludge treatment facilities in Ghana in 2013.
Source: IWMI (unpublished, 2013).

Of the 74 wastewater and fecal sludge treatment facilities identified in the 2013 survey (not including the three under construction), only 12 (11 wastewater and one fecal sludge treatment plants), representing about 16% of all treatment plants, were found to be fully functional. About 27% had some some capacity to treat influent waste but were unable to treat it to a level that rendered it safe for environmental and public health prior to discharge. Most of these functional and semi-functional plants were small capacity plants owned by hotels and private companies as also shown by Murray and Drechsel (2011). Most facilities (56.7%) could not be considered functional, although the majority were not officially decommissioned and still received wastewater or sludge. Already in 1998, Akuffo (1998) stated that none of Accra's 18 sewer systems and treatment plants were working or maintained as designed, while Hodgson and Larmie (1999) found the treatment plants in Tamale to be in a deplorable state, the EPA (2001) deemed less than 10 of 44 treatment plants as functional, and MLGRD (2010) categorized only five of the 27 treatment plants in Accra, Tema and Kumasi as rehabilitated or functional.

This general overview illustrates that most of Ghana's wastewater ends up in the environment in its untreated form. Given that the situation is worse in urban areas due to high population density, there is a strong link between a lack of wastewater treatment and the use of polluted water in irrigated urban agriculture; farmers have, in many locations, no option but to collect water from waterways or reservoirs impacted by untreated wastewater, including fecal matter.

6.2 Bacteriological Quality of Irrigation Water

A number of fecal indicator microorganisms are used to assess levels of microbiological contamination. Fecal indicator organisms are not necessarily pathogenic but are used to signal the potential presence of waterborne pathogens. However, indicator organisms have varying degrees of specificity in detecting the source of contamination. For example, *E. coli* is a more exact indicator for fecal contamination than fecal coliforms or total coliforms, which could be of animal or environmental origin. However, given that analyzing water samples for specific pathogens can be expensive or difficult to perform, fecal coliforms (also referred to as thermotolerant coliforms) are commonly used as indicators of bacterial contamination.

Thermotolerant coliform concentrations measured in irrigation water sources in Accra, Kumasi and Tamale are presented in Figure 6.2 (Amoah et al. 2005, 2007a). In general, thermotolerant coliform concentrations ranged between 4-10 log units per 100 millilitres (ml), with mean concentrations of about 6 log units per 100 ml of irrigation water. These data indicate that irrigation water sources were highly polluted across all cities, with a few exceptions, such as the shallow well at Weweso farming site in Kumasi. Previous studies carried out in Accra (Armar-Klemesu et al. 1998; Sonou 2001; Zakariah *et al*. 1998) also found that few unpolluted water sources were available for irrigation. The worst case was the highly populated drainage basin of the Odaw River and Korle Lagoon, which covers more than 60% of Accra (Biney 1998). Donkor et al. (2010) found for example very high fecal coliform levels of 2.3×10^7 CFU $100ml^{-1}$ in well water and 1.6×10^9 CFU $100ml^{-1}$ in stream water used by urban farmers in Accra.

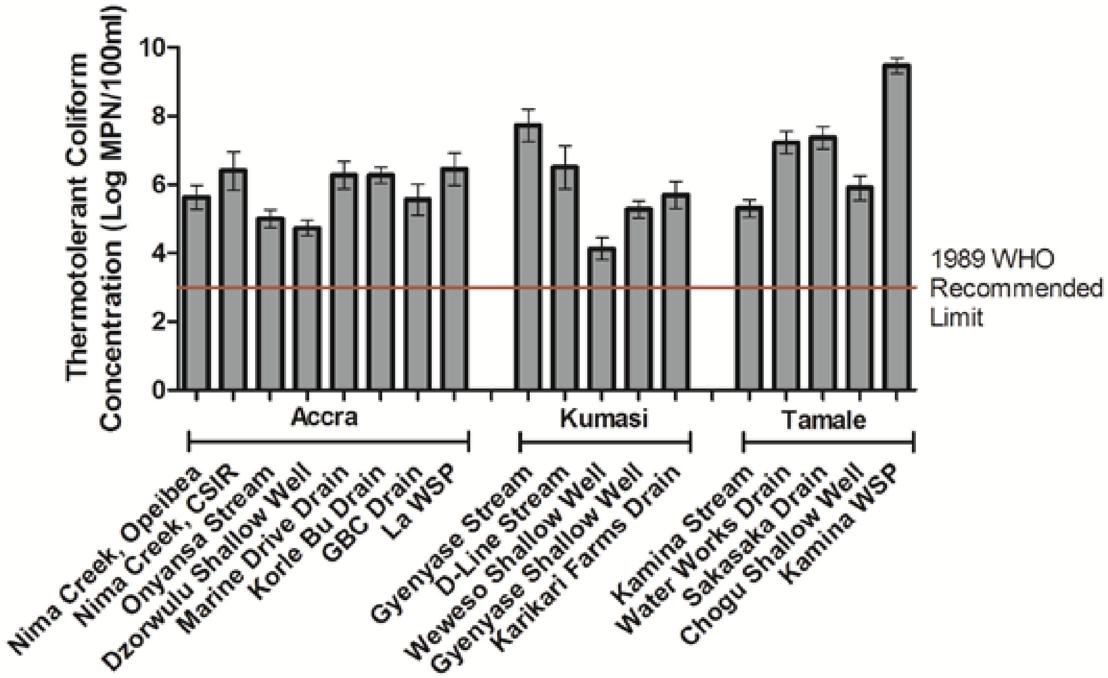

FIGURE 6.2. Average thermotolerant coliform concentrations measured in irrigation water sources in 2003 and 2004 (Amoah et al. 2005, 2007a).

Another recent study conducted in Accra in 2010 used a more specific fecal indicator bacteria, *E. coli*, to assess irrigation water quality (Silverman et al. 2013). The study also found widespread and increasing contamination of irrigation water sources (Figure 6.3).

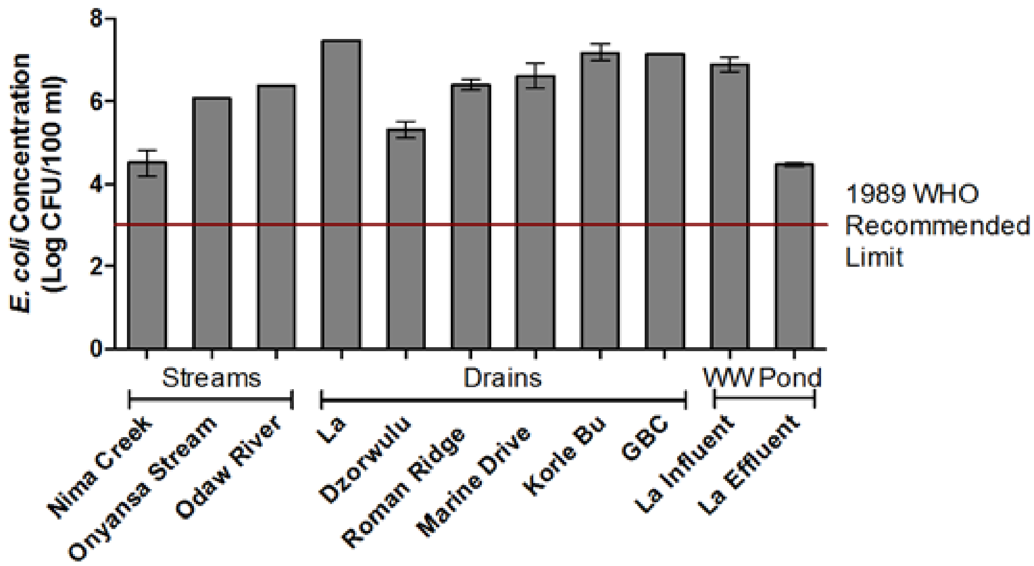

FIGURE 6.3. Average *E. coli* concentrations measured in irrigation water in Accra in July 2010 (Silverman et al. 2013). The denoted 1989 WHO recommended limit is for thermotolerant coliform, a classification of bacteria that includes *E. coli*.

E. coli concentrations in all irrigation waters sampled were greater than the maximum thermotolerant coliform concentration recommended by the previous 1989 WHO guidelines for wastewater use in irrigation (Figure 6.3). *E. coli* levels generally ranged between 4.5-7.5 log colony forming units (CFU) per 100 ml. The study also found high contamination regardless of farming site and irrigation water source, other than Nima creek and effluents from stabilization ponds at La, which had comparatively lower levels of *E. coli.*

To assess seasonal variability in irrigation water quality, Amoah *et al*. (2005) monitored thermotolerant coliform concentrations in Accra and Kumasi from May 2003 to April 2004 (Figure 6.4).

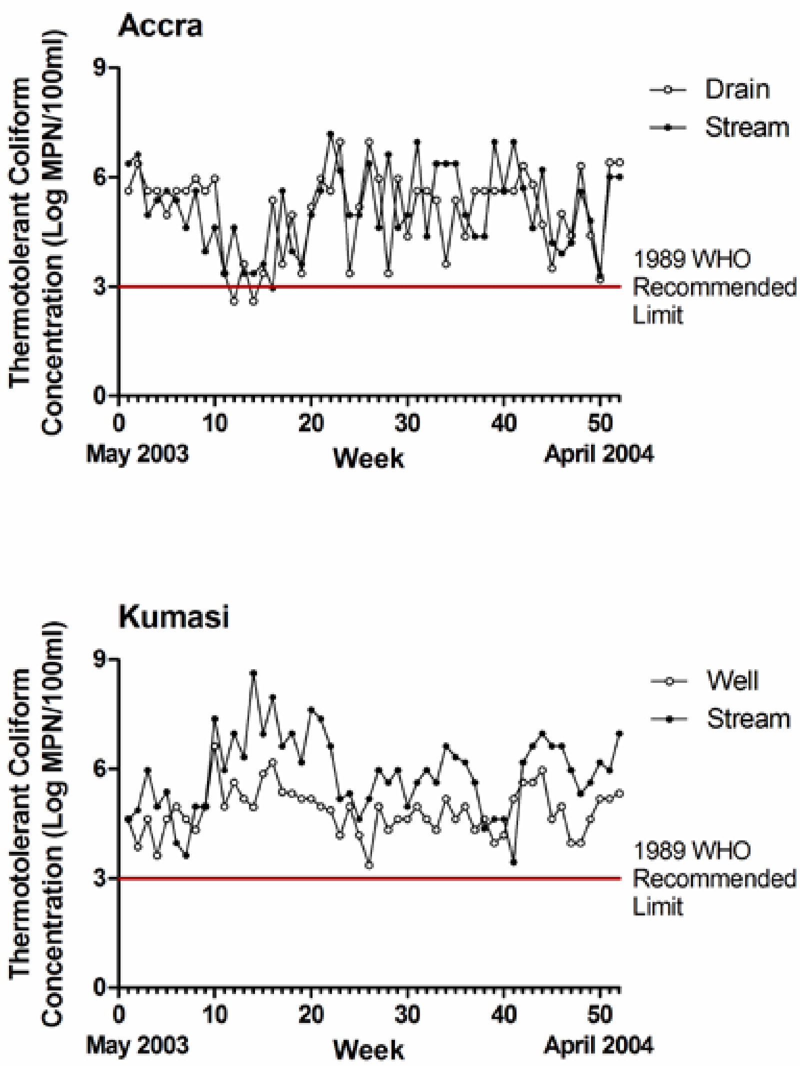

FIGURE 6.4. Temporal variation in thermotolerant coliform concentrations in stream, drain and shallow well water in Accra and Kumasi.

(Source: Amoah et al. 2005, 2007a).

Composite samples were collected each week from streams and wells in Kumasi and streams and drains in Accra. Throughout the 12-month sampling period, thermotolerant coliform concentrations in irrigation water in Accra and Kumasi exceeded the WHO (1989) recommended limit for unrestricted irrigation of crops likely to be eaten raw (Figure 6.4). In Kumasi, thermotolerant coliform counts were generally higher in water samples collected from streams than from shallow wells; there was no clearly defined pattern between thermotolerant coliform concentrations in drain and stream water sources in Accra.

Water samples collected in July 2014 in Tamale show a wide range of *E. coli* and fecal coliform contamination level in the irrigation water (Table 6.1) with most levels above the WHO 1989 threshold. The samples were taken from the watering cans after farmers fetched the water. It is important to note that even at Gumbihene Old dam where treated pipe borne water is used fecal coliforms were detected. One reason could be that the watering cans were also used for other water sources. Aside Gumbihene Old dam, other taps mentioned in Table 6.1 probably belonged to mechanized wells (with manual pumps), which could explain possible contamination.

TABLE 6.1. Common pathogen levels in irrigation water at different farming sites in Tamale.

Water Source (n=3 each)	**E. coli CFU 100ml^{-1}**		**Fecal coliforms CFU/100m^{-1}l**		**Helminth eggs l^{-1}**
	Range	**Mean**	**Range**	**Mean**	**Mean**
Sangani (dugout)	0 to 4.0×10^3	1.8×10^3	6.7×10^4 to 2.2×10^5	1.3×10^5	2
Choggu Dam (tap)	0	0	0 to 9.0×10^3	4.0×10^3	0
Choggu Dam (reservoir)	0 to 1.0×10^3	2.0×10^0	5.1×10^4 to 2.8×10^5	1.4×10^5	3
Gumbihene Old Dam (treated tap water)	0	0	0 to 3.0×10^3	1.2×10^3	0
Gumbihene New Dam (tap)	0 to 1.0×10^4	1.8×10^3	1.2-6.7×10^5	3.1×10^5	0
Gumbihene Water-works (canal/drain)	0 to 8.0×10^4	3.7×10^4	2.5×10^5 to 9.0×10^6	2.2×10^6	4
Jekeryili (stream)	1.2-6.4×10^5	3.9×10^5	1.8- 3.6×10^6	2.7×10^6	3
Builpela (reservoir)	0	0	8.0×10^4 to 2.0×10^5	1.5×10^5	2
Kamina (stabilization pond)	0	0	6.8×10^4 to 1.6×10^5	9.2×10^4	5
Nyanshegu (tap)	0 to 1.0×10^3	7.0×10^0	2.9×10^4 to 1.4×10^5	7.1×10^4	0
Dabogpa (Ghanasco reservoir)	0 to 1.0×10^3	3.0×10^0	3.8×10^4 to 1.8×10^5	8.8×10^4	2
Tunayili (tap)	0 to 1.0×10^3	5.0×10^0	1.1-2.2×10^5	1.6×10^5	0
Tunayili (stream)	0 to 1.0×10^4	4.7×10^3	1.0×10^4 to 2.2×10^5	1.1×10^5	2

Sources: IWMI and Lea Bartels, University of Freiburg (unpublished data; UrbanFoodPlus).

6.3 Helminth Eggs

A number of different types of helminth eggs were isolated from irrigation water sources sampled in Accra and Kumasi; these included eggs of *Ascaris lumbricoides*, *Hymenolepis diminuta*, *Trichuris trichiura*, *Fasciola hepatica* and *Strongyloides* larvae (Table 6.2). *Ascaris lumbricoides* eggs were the most predominant species observed, with egg concentrations ranging between 2 to 4 helminth eggs per liter. No helminth eggs were found in piped water sources. The use of pond systems on many farm sites contributed to helminth egg removal through sedimentation, leading to low egg concentrations. Helminth egg concentrations, however, increased in the dry season when farmers must collect water closer to pond sediments due to dropping water levels.

TABLE 6.2. Mean helminth egg concentrations measured in irrigation water in Kumasi and Accra (Amoah et al. 2005, 2007a).

Helminth	**Mean helminth egg concentration (egg l^{-1})**			
	Kumasi		**Accra**	
	Shallow well /ponds	Stream	Drain	Stream
Ascaris lumbricoides	2	3	3	4
Hymenolepis diminuta	0	4	0	6
Facsiola hepatica	0	2	5	0
Schistosoma sp.	0	3	0	0
Strongyloides sp. larvae	0	15	0	5

A detailed study on helminth eggs in irrigation water derived from the broken down sewer of the Kamina barracks in the Zagyuri community of Tamale showed 13 different types of helminths. The typical fertile *Ascaris lumbricoides* and *Strongyloides stercoralis* as well as *Schistosoma mansoni* were observed to be the most predominant types of helminths. *Ascaris lumbricoides* was the most predominant species recorded with arithmetic mean population of 12 and 17 for wet and dry season, respectively (Abagale et al., 2013). Limited water supply in Tamale as a result of irregularity of flow of domestic pipe water, especially during the dry season, was said to influence greatly the concentration of the helminth eggs in the water samples.

6.4 Viruses

To determine whether human viruses were present in irrigation water in Accra, Silverman et al. (2013) analysed irrigation water samples for virus concentrations using quantitative polymerase chain reaction (qPCR) and reverse transcription qPCR (RT-qPCR) (Jothikumar et al. 2005; Da Silva et al. 2007); the results for two human viruses, adenovirus and norovirus genogroup II (GII), are presented. Depending on the serotype, adenovirus can cause respiratory disease or gastroenteritis. Human adenovirus was detected in 11 out of 20 irrigation water samples (55%, Figure 6.5), and found at concentrations above the limit of quantification (LOQ) in seven samples. Of the samples with quantifiable concentrations of adenovirus, concentrations ranged between $(2.80 \pm 0.92) \times 10^2$ and $(6.50 \pm 0.60) \times 10^4$ gene copies per 100 ml (LOQ range: 27-240 gene copies per 100 ml). Norovirus is a leading cause of gastroenteritis worldwide, with norovirus GII the most prevalent of five norovirus genogroups in human infection (Atmar and Estes 2006; Da Silva et al. 2007). Norovirus GII was detected in 16 out of 20 irrigation water samples (80%, Figure 6.4) and found at concentrations above the LOQ in 11 samples. Of the samples with quantifiable concentrations of norovirus GII, concentrations ranged between $(4.75 \pm 2.20) \times 10^2$ and $(1.58 \pm 0.28) \times 10^4$ gene copies per 100 ml (LOQ range: 330-2,200 gene copies per 100 ml).

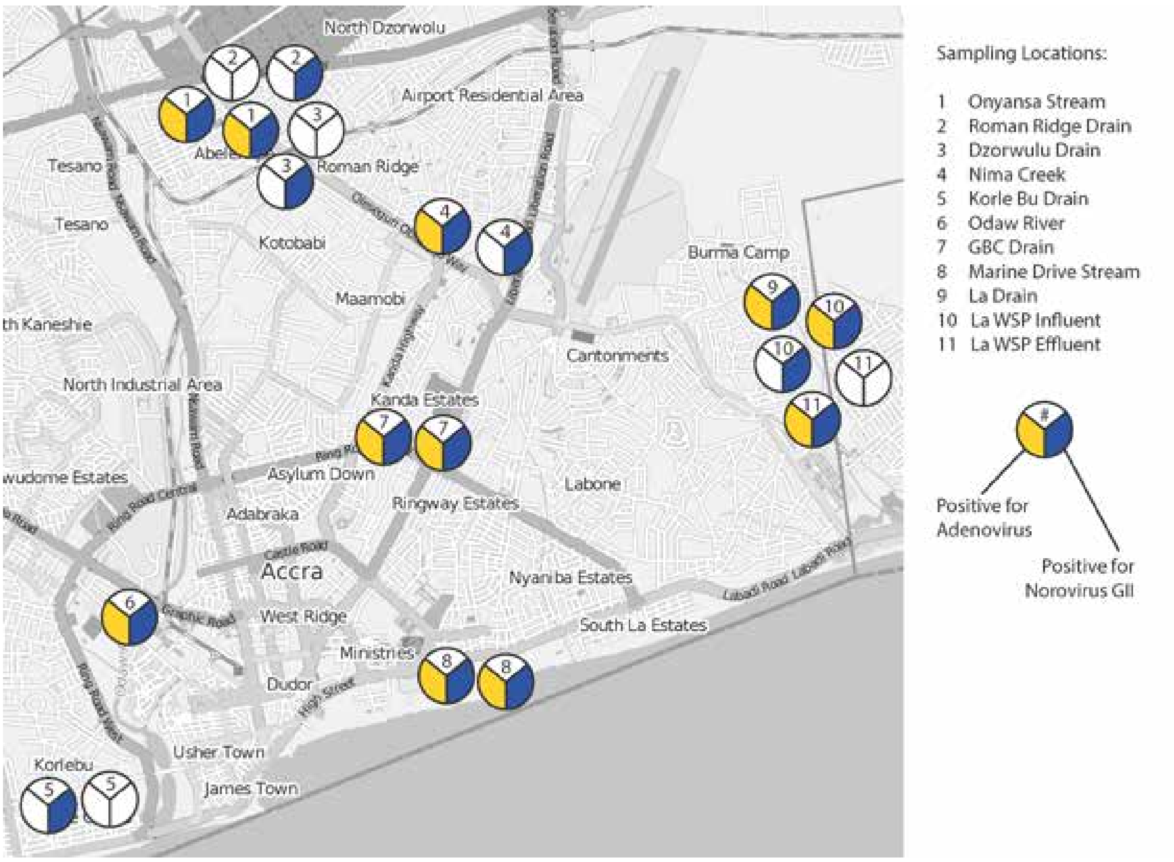

FIGURE 6.5. Occurrence of adenovirus and norovirus GII in irrigation water samples collected in Accra (Silverman et al. 2013). WSP: Wastewater Stabilization Pond

6.5 Emerging Contaminants

In addition to pathogens, the domestic sector is a key source of a large number of so called 'emerging' contaminants (ECs), which are receiving increasing global attention. Many of these organic contaminants are endocrine disruptors (meaning that they can interfere with the production, release, transport and metabolism of natural hormones in the body) and derive from pharmaceutical and personal care products. Examples of endocrine disruptors include steroid hormones such as estrogens. While ECs and their treatment standards are the subject of lively debate in developed countries, most Sub-Saharan countries lack information on the actual state and risks of ECs due to low analytical capacity to detect and quantify these organic chemicals in the environment and food chain. Given the huge waste problems faced by many parts of Africa, as well as indiscriminative use of pharmaceuticals and biocide, low risk perception, and seldom enforced environmental standards, there is a significant risk of long-term negative impacts to human and environmental health. Although direct evidence of adverse health effects in humans is lacking, reproductive abnormalities, altered immune function and population disruption potentially linked to exposure to these substances have been observed in amphibians, birds, fish, invertebrates, reptiles and mammals (IPCS 2002).

In a study carried out by S. Asem-Hiablie in Accra, estrogen (E1, E2 and EE2[2]) levels in irrigation water on two farming sites (Korle-Bu and Dzorwulu) were quantified during a six-week study. All three estrogens were present in irrigation water samples (Table 6.3). Estrone was detected in irrigation water samples at Korle-Bu on all sampling days (<LOQ – 11.1 ng/L) however, E2 was recorded once only at a concentration of 1.2 ng/L which was close to the LOQ. As E1 is the primary degradation product of E2, it is likely that microbial breakdown of E2 occurring in the open drains explains the absence of E2 and the dominance of E1 in water samples from the Korle-Bu. The EE2 concentrations were as high as 59.8 ng/L, and being the least biodegradable of the three estrogens, its presence water at Korle-Bu is an indication of its common use among the population. At the Dzorwulu site, where at one end irrigation water was piped from municipal potable water sources and stored in earthen impoundments, estrogens were detected less frequently and E1 and E2 concentrations ranged from below the detection limit to 8.1 and 3.0 ng/L, respectively throughout the sampling period. There was a one-time detection of 3.0 ng/L EE2 in duplicate samples during the 4th week of sampling. Natural estrogen was only detected once in irrigation water derived from the inlet to the farming site at

[2] Natural estrone (E1), 17 β-estradiol (E2), synthetic 17α-ethynylestradiol (EE2)

Dzorwulu. However, the concentration detected in the faucet water was very low (1.4 ng/L) and close to the method's limit of detection (1.0 ng/L). Sources of the natural estrogens (E1 and E2) may be attributed to the influx of contaminants carried by runoff from manure-applied farm plots and manure stockpiles.

TABLE 6.3. Concentrations of estrogens 17 β-estradiol (E2), estrone (E1), and 17 α-ethynylestradiol (EE2) observed in irrigation water samples from the study sites Dzorwulu and Korle-Bu in the Accra metropolis (Source: S. Asem-Hiablie, unpublished).

		Korle-Bu			**Dzorwulu**		
	Sample Number	**E1 (ng/L)**	**E2 (ng/L)**	**EE2 (ng/L)**	**E1 (ng/L)**	**E2 (ng/L)**	**EE2 (ng/L)**
Week 1	1	1.4	< LOQ	< LOQ	7.2	1.6	< LOQ
	2	5.5	< LOQ	< LOQ	8.1	2.6	< LOQ
	3	< LOQ	< LOQ	15.9	6.8	2.2	< LOQ
	4	< LOQ	< LOQ	13.7	-	-	-
Week 2	1	5.0	< LOQ	< LOQ	6.6	2.0	< LOQ
	2	4.1	< LOQ	< LOQ	6.7	2.5	< LOQ
	3	4.0	< LOQ	< LOQ	7.4	3.0	< LOQ
	4	3.5	< LOQ	< LOQ	4.9	1.5	< LOQ
Week 3	1	5.8	< LOQ	16.1	< LOQ	< LOQ	< LOQ
	2	9.9	< LOQ	28.2	< LOQ	< LOQ	< LOQ
	3	6.8	< LOQ	12.3	< LOQ	< LOQ	< LOQ
	4	-	-	-	< LOQ	< LOQ	< LOQ
Week 4	1	11.1	1.2	31.9	4.9	< LOQ	3.0
	2	9.1	< LOQ	48.5	5.4	< LOQ	3.0
	3	6.3	< LOQ	46.1	< LOQ	< LOQ	< LOQ
	4	9.9	< LOQ	18.9	< LOQ	< LOQ	< LOQ
Week 5	1	7.7	< LOQ	22.1	< LOQ	< LOQ	< LOQ
	2	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ
	3	2.3	< LOQ	2.2	< LOQ	< LOQ	< LOQ
	4	-	-	-	< LOQ	< LOQ	< LOQ
Week 6	1	11.1	< LOQ	59.8	< LOQ	< LOQ	< LOQ
	2	< LOQ	< LOQ	40.1	< LOQ	< LOQ	< LOQ
	3	6.5	< LOQ	45.7	-	-	-

LOQ: Limit of quantification; < LOQ: Below detection limit

Studies of streams receiving sewage effluent in several parts of the world have shown E1, E2 and EE2 concentrations in part per trillion (ng l^{-1}) levels (Jobling et al. 2005; Spengler et al. 2001; Peck et al. 2004). The irrigation waters sampled in Korle-Bu represent typical E1 concentrations observed in sewage effluent; EE2 concentrations measured in this study, however, were higher.

6.6 Heavy Metals

Industrial wastewater contamination of surface waters in cities in Ghana is not significant when compared to domestic wastewater volumes and pathogenic contamination. Heavy metal contamination appears mostly to be localized. The metal concentrations analysed in streams in and around Kumasi and Accra did not exceed suggested standards (McGregor et al. 2002; Simon et al. 2001; Cornish et al. 1999; Mensah et al. 2001). Heavy metal concentrations measured in streams and drains in Accra and Kumasi are presented in Table 6.4 (Amoah 2008).

TABLE 6.4. Concentration of selected heavy metals in irrigation water sources sampled in Accra and Kumasi (Source: Amoah 2008; thresholds for plant toxicity from Pescod 1992).

City	Irrigation water source	Heavy metal	Mean concentration (mg l^{-1})	Standard deviation (mg l^{-1})	Range (mg l^{-1})	Recommended maximum concentration
Accra	Drain	Fe	1.34	0.92	0.26-3.02	5.0
		Pb	0.03	0.02	0.01-0.06	5.0
		Mn	0.34	0.17	0.09-0.67	0.2
		Cd	0.006	0.005	0-0.01	0.01
		As	0.02	0.03	0.01-0.07	0.1
	Stream	Fe	1.15	0.51	0.51-2.13	5.0
		Pb	0.03	0.02	0.01-0.06	5.0
		Mn	0.64	0.002	0.06-1.21	0.2
		Cd	0.003	0.002	0-0.01	0.01
		As	0.01	0.02	0.01-0.05	0.1
Kumasi	Well	Fe	1.23	0.49	0.59-1.99	5.0
		Pb	0.03	0.02	0-0.06	5.0
		Mn	0.29	0.21	0-0.68	0.2
		Cd	0.02	0.03	0-0.10	0.01
		As	0.002	0.003	0-0.01	0.1
	Stream	Fe	1.15	0.44	0.51-1.90	5.0
		Pb	0.02	0.02	0-0.06	5.0
		Mn	0.43	0.33	0.09-1.0	0.2
		Cd	0.007	0.01	0-0.3	0.01
		As	0.009	0.009	0.01-0.03	0.1

The data show mean metal concentrations mostly below the maximum concentrations recommended by the United Nations' Food and Agriculture Organization (FAO) for crop production (Pescod 1992). Only manganese exceeded FAO's threshold for crops at all sites in both Accra and Kumasi. A recent study (Lente et al. 2012) conducted at major urban vegetable farming sites in Accra did not find significant differences in heavy metal concentrations from those reported in Table 6.4. Chromium, cadmium and cobalt concentrations were below detectable limits at all farming sites, while Fe, Mn, Cu, Zn, Pb and Ni were below the recommended maximum limits for healthy plant growth (Lente et al. 2012). Data reported by Anim Gyampo et al. (2012) from Tamale showed slightly elevated Mn and Cd levels in the (raw) wastewater used for irrigation at Kamina barracks. The situation might be worse in Ghana's rural gold mining areas or if manufacturing and industrial production in Ghana's cities increases without regulation of treatment and disposal of industrial effluent.

6.7 Conclusions

With the exception of piped water and selected small reservoirs, most irrigation water sources sampled at farm sites in Accra, Kumasi and Tamale showed high levels of fecal contamination. High concentrations of fecal indicator bacteria signal the presence of bacterial, viral and protozoan infectious agents, which can present health risks to farmers and vegetable consumers. Of 20 irrigation water samples collected in Accra, 80% contained human adenovirus, norovirus GII or both. After recognizing that available irrigation water sources were contaminated, more recent studies have moved from risk assessments towards developing measures for safe reuse of wastewater (Amoah et al. 2011). Cheaper pathogen detection methods, such as for viruses, are recommended, so that routine monitoring of pathogens can be performed. Overall, chemical contamination (e.g. in the form of heavy metals) is so far relatively limited. That being said, the situation can change if there is an expansion of industry given the common gaps in monitoring and regulation of industrial effluent collection and treatment.

Inadequate sanitation infrastructure and waste management are the main cause of contamination of urban waterbodies that farmers use for irrigation. Inequitable population growth and sanitation infrastructure development will lead to an increase in pollution of water resources. This will not only affect urban agricultural farming sites but many peri-urban farming sites and communities downstream of cities like Kumasi. Stream and rivers passing through Accra flow directly into the ocean, while Tamale does not have any permanent natural waterway (Obiri-Danso et al. 2005; Keraita et al. 2003). In addition to inadequate sanitation infrastructure and waste management, an increase in water scarcity will contribute to the risks from pollution, as limited rainfall will make pollutants increasingly concentrated.