9. Human Health Risks from Wastewater-irrigated Vegetable Farming

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Contamination levels of water and crops which exceed common standards are only a first indication of human health risks. This chapter shows estimates of human health risks from consumption of wastewater-irrigated vegetables based for example on dose-response modeling. The chapter focuses on human health risks and risk perceptions of microbiological and chemical contaminants such as heavy metals and pesticides.

9.1. Risk from Wastewater Irrigation

The impact of poor sanitation services on the urban population in Ghana is felt through various channels and contact points. Disease transmissions via the fecal-oral route discussed in the context of this book are those where (waste)water-borne pathogens affect farmers in contact with the water, and those where the pathogens enter the food chain, thus affecting consumers (Figure 9.1). As explained in previous chapters, there is limited overlap between farmers and consumers in the case of exotic vegetables.

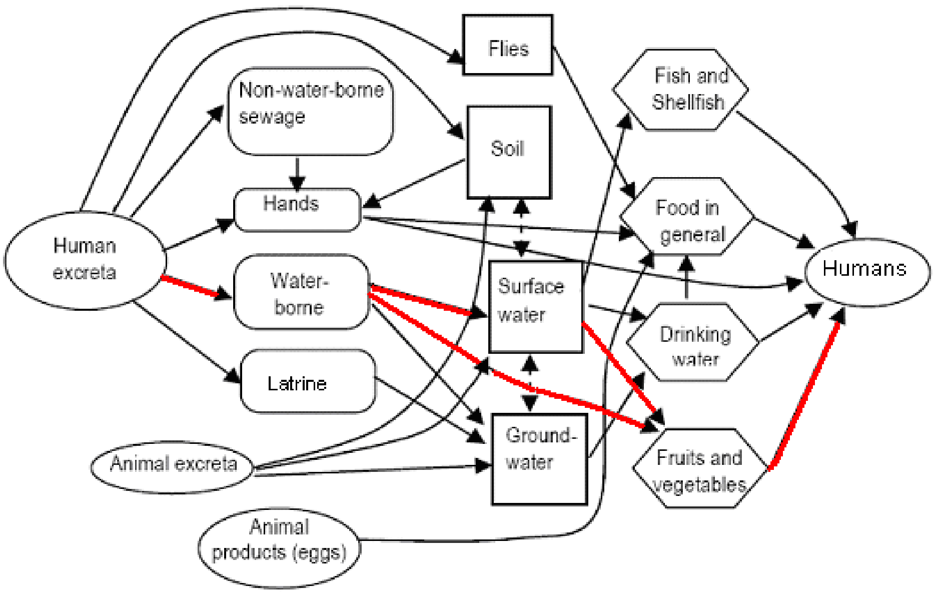

FIGURE 9.1. Common fecal-oral pathways affecting consumers (Fewtrell et al. 2007). Red lines indicate critical pathways related to irrigation with polluted water sources.

Wastewater contains a variety of pathogens and pollutants. Extensive studies on human health risks through wastewater irrigation, especially from pathogen contamination, were facilitated by the World Health Organization (WHO 2006). Table 9.1 is a simplified presentation of the main microbiological- or pathogen-related health risks, affected groups and exposure pathways. However, there are also other pollutants which can affect soils, crops and/or human health, such as salts, metals, metalloids, residual drugs, organic compounds, endocrine disruptor compounds and other residues from, for example, personal care products (Tchobanoglous et al. 1995). Discussions often focus on different types of pollutants depending on regional risk relevance. For instance, in low-income countries, risks from microbiological contaminants receive the most attention. This is because people in these countries are most affected by diseases caused by poor sanitation such as diarrhoeal diseases and helminth infections (Prüss-Ustün and Corvalan 2006). The situation changes significantly in transitional economies and is different in high-income countries, where microbiological risks are largely under control through comprehensive wastewater collection and treatment. In this context, chemical pollution (heavy metals, pesticides) and emerging pollutants (such as pharmaceutical residues) remain of concern.

In the Ghanaian context, urban dwellers in low-income and high density areas, such as Nima in Accra, are exposed to wastewater-related health risks due to the lack of toilets and/or wastewater collection and conveyance systems. With stormwater gutters taking over the function of gray water sewers especially children playing in the street have a high exposure probability (Labite, 2008; see below). Exposure related to urban vegetable irrigation can take place through (i) consuming irrigated produce (consumption-related risks); (ii) coming into contact with wastewater when working on farms (occupational risks); and (iii) by exposure to wastewater and wastewater-irrigated soils when walking in fields or children playing in fields (environmental risks). There are of course many other locations where children and others can be exposed more frequently to wastewater; thus a good risk assessment should consider the larger context of the potentially affected population, allowing authorities to use their usually limited budget for risk mitigation most effectively.

Constituents of most concern in wastewater are excreta-related pathogens and skin irritants (Blumenthal et al. 2000; van der Hoek et al. 2005). For consumption-related health risks, the primary concern is uncooked vegetables dishes such as salad (Harris et al. 2003). Several diarrhoeal outbreaks have been associated with wastewater-irrigated vegetables (Shuval et al. 1986; WHO 2006).

There is also strong epidemiological evidence for *Ascaris lumbricoides* infections for both adults and children who consume uncooked vegetables irrigated with wastewater, although not from Ghana (Peasey 2000). Helminth infections, especially *A. lumbricoides* and hookworm, have higher importance in relation to occupation-related risks compared to bacterial, viral and protozoan infections (Blumenthal et al. 2000). The most affected group is farm workers, owing to the long duration of their contact with wastewater and contaminated soils (Blumenthal and Peasey 2002; WHO 2006). Recent studies from Vietnam, Cambodia, India and Ghana have associated skin diseases such as dermatitis (eczema) to contact with untreated wastewater (Keraita et al. 2008a).

TABLE 9.1. Simplified presentation of the main human health risks from wastewater irrigation (modified from Abaidoo et al. 2010).

Kind of risk	Health risk	Who is at risk	Exposure pathway
Occupational risks (contact)	- Parasitic worms such as *A. lumbricoides* and hookworm infections - Bacterial and viral infections - Skin irritations caused by infectious and noninfectious agents – itching and blisters on the hands and feet - Nail problems such as koilonychias (spoon-formed nails)	Farmers/ field workers	- Contact with irrigation water and contaminated soils - Contact with irrigation water and contaminated soils
		Marketeers of wastewater-grown produce.	- Contact with contaminated soils during harvesting - Exposure through washing vegetables in wastewater
Consumption-related risks (eating)	- Mainly bacterial and viral infections such as cholera, typhoid, ETEC, hepatitis A, viral enteritis, which mainly cause diarrhoea - Parasitic worms such as *Ascaris*	Vegetable consumers	- Eating contaminated vegetables, especially those eaten raw
Environmental risks	- Similar risks as those exposed to occupational and consumption risks, but decreasing with distance from farm	Children playing in wastewater-irrigated fields People walking on or nearby fields	- Soil particle intake - Aerosols

9.2 Risks from Microbiological Contaminants

While the previous chapters showed that we can find pathogens in irrigation water and also on crops, this information is only a first indication of a possible health risk. To quantify the risk, it is important to assess human exposure.

For consumption-related risks, this includes, for example, the amount and frequency of vegetable intake, information about the person, like age, and needs to consider the dose-response function of individual pathogens. A common modelling tool is Quantitative Microbial Risk Assessment (QMRA) with 10,000 (so-called) Monte Carlo simulations. In Ghana, QMRA was applied extensively by Seidu (2010) and also other research teams; see for example Barker et al. (2014) for methodology and further references.

Seidu et al. (2008) evaluated the annual risks of rotavirus and *Ascaris* infections for consumers of lettuce irrigated with the different water qualities after postharvest handling and of farmers using different irrigation water qualities. A tolerable risk (TR) of infection of 7.7×10^{-4} and 1×10^{-2} per person per year (ppy) were used for rotavirus and *Ascaris*, respectively, as acceptable limit. The assessment revealed a high risk of *Ascaris* and rotavirus infections above the TR levels for farmers using different irrigation water quality and also the much larger number of consumers of irrigated lettuce. The risk of *Ascaris* infection was within a magnitude of 10^{-2} ppy for farmers accidentally ingesting drain or stream irrigation water; approximately 100 ppy for farmers accidentally ingesting farm soil and 100 ppy for farmers ingesting any of the irrigation waters and contaminated soil. The median annual risks of rotavirus infection for consumers of drain- and stream-irrigated lettuce were of the same magnitude and above the WHO-TR: the annual risks of *Ascaris* and rotavirus infections were 100 ppy and 10^{-3} for drain- and stream-irrigated lettuce respectively, with slight increases for rotavirus infections along the postharvest handling chain.

The risks of *Ascaris* and rotavirus infections recorded for consumers of irrigated lettuce were attributed mainly to the contamination of the lettuce on farm and to a lesser extent on postharvest handling. Such contamination was attributed to common irrigation practices involving watering cans and the application of fresh poultry manure (Amoah et al. 2005). As current on-farm arrangements do not allow any time lapse for pathogen die-off between the last irrigation/manure application and harvesting (Obuobie et al. 2006) attention should also be given to soil contamination. In fact, trials with tap water showed that soil contamination levels may pose a significant health risk above TR levels even when the irrigation water quality or the related crop exposure is temporarily improved to meet international standards.

Two notes of caution are required in view of contamination during harvest and postharvest activities:

a) Traders normally buy their crops on farm following their agreements with farmers at the start of the growing cycle. At least in Kumasi, it is a common practice to wash the vegetables while on farm to remove soil particles in the same water used for irrigation with obvious contamination consequences. This was not observed where the water source is a drain.
b) Due to very high contamination on farm, any likely postharvest contamination at wholesale or retail outlets and in street food restaurants is ‘hidden’. Studies in locations where the irrigation water had lower fecal coliform counts showed clearly that significant contamination can take place during vegetable transport and marketing (Ensink et al. 2007).

The QMRA assessment estimated a loss of about 12,000 disability-adjusted life years (DALYs) annually in Ghana’s major cities through the consumption of salad prepared from wastewater-irrigated lettuce (Drechsel and Seidu 2011). This figure represents nearly 10% of the WHO-reported DALYs occurring in urban Ghana due to various types of water- and sanitation-related diarrhoea (Prüss-Üstün et al. 2008; GSS 2004). Barker et al. (2014) re-assessed the risk for consumers in the case of Kumasi using more conservative data when running QMRA but also concluded that rotavirus dominates the disease burden, while *Ascaris posesa* smaller risk. Rotavirus exposure doses were sufficiently high in most scenarios that annual probability of illness was ~1 resulting in a maximum annual disease burden of ~10^{-3} DALYs ppy. Important to note is that even if the risks from both rotavirus and *Ascaris* were eliminated, the risks from norovirus can remain significant. The Barker study concluded that risk assessments (only) based on water analysis are not recommended.

Under the umbrella of the EU funded SWITCH project, another QMRA was undertaken in Accra to assess different water- and sanitation-related exposure pathways leading to diarrhoeal diseases. The study compared the disease burden associated with contaminated drinking water, flooding, playing at open drains, swimming at urban beaches and occupational contact with fecal matter (Labite 2008; Lunani 2007) and consumption of wastewater-irrigated vegetables.

If we compare the calculated loss of healthy life years (DALY) with the QMRA data reported above for the same population size in Accra, the consumption of wastewater-irrigated vegetables is probably the second largest challenge next to the risk of children exposed to open drains which is possible everywhere in Accra (Figure 9.2).

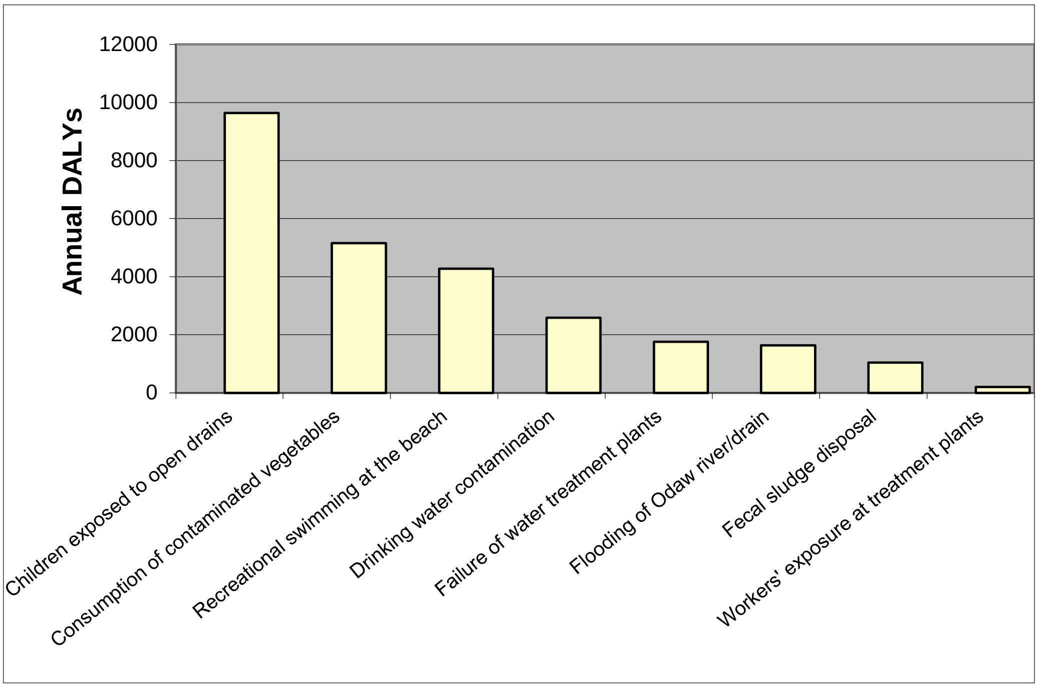

FIGURE 9.2. DALYs per exposure scenario (estimates for Accra; IWMI, unpublished).

In view of risk reduction, and based on the numbers of affected urban dwellers along the food chain (see chapter 5), the studies in Ghana focused on the large group of consumers. Compared with about 800-1000 farmers using wastewater in Accra, every day probably more than 200,000 urban dwellers eat fast food with contaminated raw vegetables (lettuce, cabbage) in street restaurants (Amoah et al. 2007b). The number is higher if canteens and other restaurants are also considered (Table 9.2).

TABLE 9.2. Target groups for risk mitigation (estimated number of affected farmers, consumers per day, and street food kitchens) based on city survey data (IWMI estimates, 2008; adjusted 2014, unpublished).

City	Consumers eating dishes with raw salad component	Street food kitchens serving raw salad (usually as side dish)	Urban farmers producing exotic vegetables
Accra/Tema	160,000-300,000	1,050-1,750	800-1000
Kumasi	140,000-240,000	1,100-1,400	>330
Cape Coast	15,000-35,000	110-170	ca. 30
Tamale	20,000-40,000	190-300	>400
Takoradi	15,000-35,000	120-200	80
Other cities	150,000	1,000-2,500	100-200
Total	500,000-800,000	3,570-5,320	1740-2040

Although the risk reduction studies focused on consumers, many of the recommended practices (see chapter 14) to reduce crop contamination, like drip irrigation, will also reduce farmers' occupational exposure.

To reduce the risk for consumers, an analysis of the marketing and contamination pathways from irrigation water source to farm as well as wholesale market, retail and consumer outlets showed key entry points for risk-reducing interventions. These are (a) the farm, where by far the most contamination takes place and (b) the kitchen, where most salads are eventually prepared for sale/consumption:

a) Emphasis was given to interventions on the farm, as this is the place where probably 90% of vegetable *contamination* takes place, much of it being avoidable. The key contamination source is the polluted irrigation water. Another source is the farm soil which is contaminated by the irrigation water, thus soil particles rain-splashed on the crop contribute to its contamination. Another contamination source, but with less significance as it is only temporarily used, is fresh poultry manure, broadcast over fields and crops.
b) Interventions in the (street food) kitchens, popularly called 'check-check' bars, were also given priority as these locations can combine easy ways to *eliminate pathogens* while vegetable washing with the incentive that the kitchens serve the actual consumer who might be affected (while a farmer might never see the consumer). Moreover, nearly all kitchens already wash salad greens before serving them, but – as verified – certainly not effectively enough to kill pathogens (Amoah et al. 2007a, 2011).

There was an additional suggestion to consider wholesale markets as an entry point for risk reduction, as these markets offer a convenient single geographical transfer station for most of the traded salad greens in the city, involving only a few wholesalers, compared to the many farm sites and even more retail markets and plethora of street restaurants. However, as the crops pass through the wholesale markets in large packed bundles, opening them for washing purposes was eventually considered risky in terms of additional exposure and risk of contamination. Thus, instead of direct interventions in markets, Amoah et al. (2007ab) advocated 'good handling practices' in markets to avoid *additional* contamination. The effectiveness of tested inventions to reduce *already existing* contamination was generally limited to one log unit (Amoah et al. 2011, see chapter 14).

9.3 Risks from Heavy Metals

Heavy metal intake by consumers normally occurs through metal absorption from contaminated soils via crop roots or by deposition on crop surfaces (Sawidis et al. 2001; Jassir et al. 2005). Uptake through roots depends on many factors such as the soluble content of heavy metals in soil, soil pH, humidity, plant growth stages as well as type of crops, fertilizers and soil (Sharma et al. 2006; Ismail et al. 2005). Deposition of heavy metals from industrial and vehicular emissions on crop foliar surfaces may occur during production, transportation and marketing (Sawidis et al. 2001; Jassir et al. 2005). In vegetables, these heavy metals accumulate in edible parts (leaves and roots). Heavy metals most often found in vegetables include As, Cd, Cu, Co, Mo, Zn, Mn and Pb. When in trace quantities, some of these heavy metals are micronutrients. However, in elevated concentrations or after prolonged dietary intake, they can pose a significant health risk to humans, leading to various chronic diseases (Gupta and Gupta 1998; Sharma and Prasad 2009). Other than safety concerns, excessive heavy metals also contaminate soils and affect crop growth and quality (Fergusson 1990). In fact, for some metals, like Cu, Mn., Ni and Zn, crops function as a safety barrier in the food chain as they would stop growing or die before harvesting if content was excessive (Table 9.3). Routine monitoring of heavy metal concentrations in soils and crops remains essential to know the levels and devise strategies to minimize contamination, hence reducing risks to human health. This is particularly applicable to Cd (Table 9.3).

TABLE 9.3. Heavy metal bioavailability grouping (Source: Hamilton et al. 2005).

Group	Metal	Soil adsorption	Phytotoxicity	Food chain risk
1	Ag, Cr, Sn, Ti, Y, and Zr	Low solubility and strong retention in soil	Low	Little risk because they are not taken up to any extent by plants
2	As, Hg, and Pb	Strongly sorbed by soil colloids	Plant roots may adsorb them but not translocate to shoots; generally not phytotoxic except at very high concentrations	Pose minimal risks to the human food chain
3	B, Cu, Mn, Mo, Ni, and Zn	Less strongly sorbed by soil than Groups 1&2	Readily taken up by plants and phytotoxic at concentrations that pose little risk to human health	Conceptually the ‘soil-plant barrier’ protects the food chain from these elements
4	Cd, Co, Mo, and Se	Least of all metals	Pose human and/or animal health risks at plant tissue concentrations that are not generally phytotoxic	High probability of human bioaccumulation through the soil-plant-animal food chain

Estimation of Daily Intake of Heavy Metals

The degree of toxicity of heavy metals to human beings depends upon daily intake and the concentration of heavy metals. Amoah et al. (2007b) estimated daily intakes of vegetables (fresh weight) as follows:

- Lettuce: Mostly eaten as raw salad. Estimated 30 g per person eaten on average three times in a week with, for example, fried rice and chicken (*check check*) = 12.86 g per person per day (pppd);
- Cabbage: Consumed as raw salad and stew. Frequently eaten in Ghana but not necessarily in addition to lettuce. Estimated 50 g per person eaten five days in a week = 35.71 g pppd;
- Hot pepper: Usually eaten with local diets like *kenkey* and *banku*. Can be added to stews also for flavor. Eaten about five days in a week and about 5 g each time = 3.57 g pppd;
- Green pepper: Green pepper is sometimes also eaten as salad and to make stews. Estimated 10 g per person eaten five times in a week = 7.14 g pppd;
- *Ayoyo:* Typical in local diets to make stew. Not frequently eaten, about twice a week but amounts consumed are high, on average so about 200 g = 57.14 g pppd.

Based on these estimates, Lente et al. (2012) calculated the daily intakes of heavy metals via irrigated vegetable consumption assuming a ‘worst case’ scenario that all vegetables are consumed and not one or the other (Table 9.4). The calculated values were compared with the Minimal Risk Levels (MRLs) as provided by the US Agency for Toxic Substances and Disease Registry (ATSDR). It could however be more appropriate to use safe limits from more universal institutions like WHO or FAO and their Expert Committees on Food Additives, but coverage of heavy metals (referred to as contaminants) is not comprehensive. So while there could be varying MRLs or Potential Tolerable Daily Intake (PTDIs) values in different publications, ATSDR values were used as they cover most heavy metals and are relatively recent (current version at print, July 2013).

The levels obtained by Lente et al. (2012) in Accra were all below the MRLs and PTDIs obtained in the literature. Pb, though not elevated, showed the highest ratio with its MRL. For example, the highest concentration of Pb was in wastewater-irrigated cabbage (35% of the MRL). All others were less than 10% of the MRL values.

In a related study done on wastewater-irrigated vegetables in Harare, Zimbabwe where similar heavy metal elements were analyzed, Mapanda et al. (2007) showed that all heavy metal elements were below the MRLs, except Cd which was in all cases above the MRL of 12 µg Cd day^{-1} (which is slightly stricter than the one suggested today by ATSDR), and might indicate a specific Cd source in the study area. However, also compare with this MRL, all samples in Accra are far below the threshold. Another study conducted in Varanasi, India, showed that contributions of irrigated vegetables to daily intake of Cu, Zn, Cd and Pb could be as high as 13, 1, 47 and 9% of the PTDI, respectively (Sharma and Prasad 2009).

TABLE 9.4. Estimated daily intake of heavy metals from consumption of irrigated vegetables in Accra (Source: Lente et al. 2012).

Water Source	Crop	Estimated daily intake (µg day^{-1})						
		Cu	**Zn**	**Pb**	**Ni**	**Cr**	**Cd**	**Co**
Wastewater Irrigated	Cabbage	23.78	68.21	75.06	12.64	0.01	0.01	3.14
	Lettuce	8.05	13.64	13.10	3.58	0.00	0.01	1.38
	Green Pepper	11.14	9.91	13.48	2.50	0.00	0.00	0.34
	Hot Pepper	5.62	5.42	8.15	1.80	0.10	0.00	0.43
	Ayoyo	46.40	45.48	51.71	8.17	0.01	1.60	0.01
Groundwater irrigated	Cabbage	18.93	68.21	47.71	10.28	0.01	0.01	7.14
	Lettuce	4.27	12.05	10.28	3.59	1.44	0.06	1.87
	Green Pepper	8.78	8.65	7.98	2.93	0.00	0.00	1.13
	Hot Pepper	7.90	9.95	7.15	4.34	0.00	0.00	0.00
	Ayoyo	33.66	30.91	47.60	7.43	0.01	0.01	8.63
MRL		600	18000	214	720	300	30	600

MRL: Minimal Risk Levels stated as µg/day for a 60 kg person

MRL sources: ATSDR, 2013, FAO/WHO, 2010 (Pb) and WHO, 2005 (Ni)

Hazard Index Values

All heavy metals analyzed had a hazard quotient of less than one (HQ < 1) with lead reaching the highest value of 0.35 in wastewater irrigated cabbage. On average, chromium had the lowest HQ, and lead the highest (Cr < Cd < Co < Zn <Ni < Cu < Pb). The HQs on these urban farming sites are probably typical for West Africa with low industrial development but differ from HQs obtained from emerging economies like China and India, where several studies have shown HQs of more than 1 (e.g. Singh et al. 2010; Cui et al. 2004). Wastewater irrigated cabbage had with 42 % the relatively highest risk followed by wastewater irrigated *ayoyo* (38 %). Only the consumption of all analyzed vegetables would result in a cumulative Total HI of about 1 under wastewater irrigation, compared to 0.7 under groundwater irrigation (Figure 9.3).

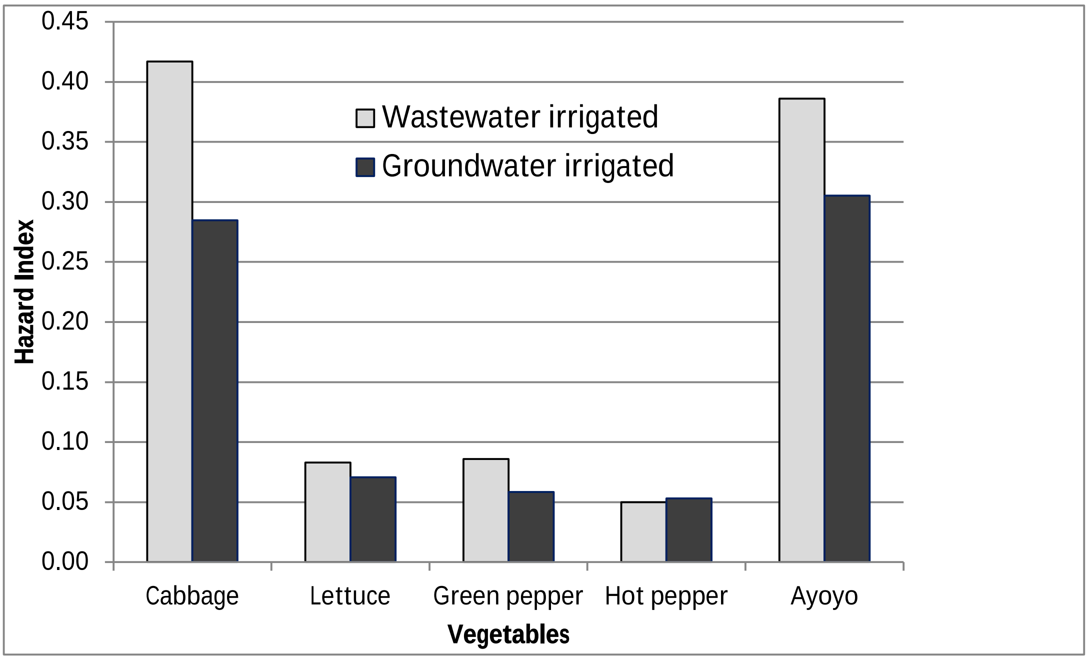

FIGURE 9.3. Hazard Index values for different types of vegetables (Lente et al. 2012).

9.4 Risks from Pesticides and Emerging Contaminants

Although irrigation water might contain pesticides, the main exposure to crops is direct pesticide application. The findings by Amoah et al. (2006) which showed that some residue pesticide levels exceeded their acceptable thresholds are strongly indicative of potential health risk to consumers. For example, all 47 (78%) lettuce samples with detectable chlorpyrifos contamination exceeded the recommended residue level of 0.05 mg kg^{-1} indicating a high probability of exposure to this chemical. Although an assessment of actual pesticide intake will be needed to ascertain the actual risk, a rough calculation can show the risk potential. For example, the acceptable daily intake (ADI, i.e. the measurement of the quantity of a particular chemical or food that, it is believed, can be consumed on a daily basis during a lifetime without harm) of chlorpyrifos is 0.01 mg g^{-1} body weight (WHO 1997). To exceed the ADI, a child weighing 30 kg would have to consume at least 0.3 mg day^{-1}. With a residue level of 1.6 mg kg^{-1} lettuce, the child would have to eat close to 200 g of lettuce/day. The amount of lettuce (usually served with other staples such as rice) is usually less than 30 g, indicating that even persons of low body weight are not presently at risk. Amoah et al. (2006) concluded that urban dwellers face in fact a much higher pathogen than pesticide risk from vegetable consumption.

Of the group of the, so-called, emerging contaminants, only selected estrogens have been analyzed so far in Ghana. These preliminary studies targeted irrigation water and irrigated vegetables as reported in the previous chapters, and also in catfish grown in wastewater treatment ponds (Asem-Hiablie et al. 2013). Given the paucity of data, it is still very difficult to establish any reference values or dose-response function for humans to estimate the possibility of risk, especially in the long term. Compared to the data available on pesticide contamination, it appears as if the analyzed estrogen levels are of limited concern for now.

9.5 Conclusions

Human health risk assessments are so far based on the comparison of analytical values found in the environment (water, produce) with thresholds established in the literature. Some assessments use modelling to better predict the potential risk. However, to date no detailed epidemiological study has been carried out to (re)confirm the risk and compare it with other risk factors that farmers and consumers face. Also the ex-ante modelling of microbial risk (QMRA) is only a tool and the quality of its estimates has to be verified in the local context as it uses dose-response functions from other parts of the world with other actors and, for example, immunity levels.

In other words, we have very sound indications of health risks and can probably rank some risks according to priority, but more research is needed to actually verify the occurrence of disease. This is also important as according to farmers' perceptions (see chapter 10 for details and a related discussion) their risks are low.

In view of heavy metals, the few studies available indicate that chemical contamination of vegetables is generally within permissible limits. Compared with previous studies on the same sites, the data show that the risk from chemical contaminants in general, i.e. including pesticides and other organic chemicals, like the so-called emerging contaminants, appears possible but currently is less significant compared to microbial (pathogen) contamination. Nevertheless, continuous monitoring is needed in view of poor pesticide management practices (Ntow et al. 2006), vehicle exhaust (Pb) and the prospective growth of the industrial sector in Ghana as well as oil discoveries near the coastline. Importantly estrogens were present in the analyzed vegetables although concentrations and occurrence varied among plant types. It appears from the limited data in literature that most hydrophobic emerging contaminants are adsorbed by soil organic matter and are therefore not expected to translocate into and accumulate in harvested plant parts. However, the number of studies across Africa is very limited and more are needed for any sound conclusions on uptake mechanisms and associated human health risks from emerging contaminants.