Quantification of the health risk associated with wastewater reuse in Accra, Ghana: a contribution toward local guidelines

Razak Seidu, Arve Heistad, Philip Amoah, Pay Drechsel, Petter D. Jenssen and Thor-Axel Stenström

ABSTRACT

Quantitative Microbial Risk Assessment (QMRA) models with 10,000 Monte Carlo simulations were applied to ascertain the risks of rotavirus and *Ascaris* infections for farmers using different irrigation water qualities and consumers of lettuce irrigated with the different water qualities after allowing post-harvest handling. A tolerable risk (TR) of infection of 7.7×10^{-4} and 1×10^{-2} per person per year were used for rotavirus and *Ascaris* respectively. The risk of *Ascaris* infection was within a magnitude of 10^{-2} for farmers accidentally ingesting drain or stream irrigation water; $\sim 10^{0}$ for farmers accidentally ingesting farm soil and 10^{0} for farmers ingesting any of the irrigation waters and contaminated soil. There was a very low risk (10^{-5}) of *Ascaris* infection for farmers using pipe – water. For consumers, the annual risks of *Ascaris* and rotavirus infections were 10^{0} and 10^{-3} for drain and stream irrigated lettuce respectively with slight increases for rotavirus infections along the post-harvest handling chain. Pipe irrigated lettuce recorded a rotavirus infection of 10^{-4} with no changes due to post harvest handling. The assessment identified on-farm soil contamination as the most significant health hazard.

Key words | consumers, farmers, health risk, post-harvest, QMRA, wastewater

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INTRODUCTION

Worldwide, at least 3.5 to 4 million hectares in 50 countries are irrigated with raw, treated/or partially diluted wastewater from domestic and industrial sources (IWMI 2006). In Accra, the capital of Ghana with a population of 2.7 million including its surrounding districts which are growing at 6–9% per annum (Ghana Statistical Service 2002), the use of domestic wastewater for vegetable irrigation has been practiced for more than five decades due to limited access to potable water and freshwater resources (Anyane 1963; Asomani-Boateng 2002; Amoah *et al.* 2006; IWMI 2006; Obuobie *et al.* 2006). The practice provides a livelihood source to a number of poor urban households and contributes to the urban food basket (Keraita & Drechsel 2004; IWMI 2006). However, it is considered highly undesirable by the authorities in Ghana due to the potential health risks associated with it. The question has therefore been how to mitigate the health risks associated with the practice without compromising livelihoods. Abating the health risk associated with the practice demands the development of locally acceptable guidelines for wastewater irrigation based on quantifiable and verifiable health risks (Drechsel *et al.* 2002; WHO 2006).

Over the years, the International Water Management Institute (IWMI) office in Accra with several national and international partners has undertaken a number of studies under its projects CPWF38 and 51, to ascertain and reduce the potential health hazards associated with the practice (Keraita *et al.* 2007; Keraita & Drechsel 2004; Amoah *et al.* 2006, 2007*a*,*b*; Obuobie *et al.* 2006). This work is an extension of the IWMI studies and aims at quantifying the

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health risks associated with the practice using the Quantitative Microbial Risk Assessment (QMRA) approach. It is one of the first times that QMRA is being applied to assess the health risks associated with wastewater irrigation in Sub-Saharan Africa. QMRA has been widely used to establish the health risks associated with wastewater reuse in both developed and developing regions under different scenarios. It has been applied to establish the health risk associated with consuming wastewater-irrigated food crops (Tanaka *et al.* 1998) and vegetables (Shuval *et al.* 1997; Petterson *et al.* 2001; Hamilton *et al.* 2006). Mara *et al.* (2007) have also applied QMRA to assess the health risks for farmers using wastewater under different irrigation and technology regimes. The approach has also been included in the recent WHO guidelines for the safe use of wastewater, excreta and greywater (WHO 2006).

METHODS

The assessment followed the basic methodological framework for QMRA postulated by Haas *et al.* (1999). The microbial data inputs used in the QMRA were largely based on the works from the IWMI CP38 and CP51 projects. Details of the methods used for the microbial enumeration as well as issues regarding quality assurance have been comprehensively presented elsewhere (Amoah *et al.* 2005, 2006, 2007*a*,*b*). In addition a comprehensive literature review of international peer reviewed journals was undertaken to provide inputs for hazard identification, dose-response assessment, exposure assessment and risk characterisation.

Hazard identification

Choice of pathogens and justification

Microbial investigations undertaken so far on wastewater reuse in Accra have focused on the quantification of helminths eggs and faecal coliforms (FC) (Keraita & Drechsel 2004; Obuobie *et al.* 2006; Amoah *et al.* 2006, 2007*a*, *b*). For purposes of our assessment, we chose rotavirus and *Ascaris lumbricoides* as the model organisms. Rotavirus is a major cause of gastroenteritis (Parashar *et al.* 2003; Anderson & Weber 2004; Chandran *et al.* 2006) and has been widely used as a representative organism for enteric viruses in QMRAs of wastewater reuse (Asano & Sakaji 1990; Asano *et al.* 1992; Shuval *et al.* 1997; Hamilton *et al.* 2006). It has also been identified as a major diarrhoeal pathogen in Ghana, accounting for 20% of all diarrhoea cases especially among children (Armah *et al.* 1995). *A. lumbricoides* is the most prevalent parasitic infection worldwide with infection rates ranging from 40–98% in Africa (Freedman 1992). Several studies have established a clear association between *Ascariasis* and wastewater reuse among farmers (Shuval *et al.* 1984; Al Salem & Tarazi 1992; Cifuentes *et al.* 1992; Cifuentes 1998; Peasey 2000; Blumenthal *et al.* 2001) and consumers of wastewater irrigated vegetables (Pound & Crites 1973; Bryan 1997). In Ghana, the prevalence rate of *Ascariasis* is 52% (Hotez *et al.* 2003) with symptoms ranging from abdominal pain, meteorism, nausea, vomiting, diarrhoea and undernourishment (WHO 2006; Jimenez 2007). *Ascaris*, can survive also for months to years under severe environmental conditions (Feachem *et al.* 1983) and has therefore been suggested for QMRAs in developing regions (WHO 2006).

Ascaris and rotavirus levels in irrigation water, contaminated soil and irrigated lettuce

In Accra, irrigation waters used for vegetable farming are sourced mainly from drains, streams and pipes (Gbireh 1999; IWMI 2006; Obuobie *et al.* 2006; Amoah *et al.* 2006, 2007*a*,*b*). We used the *Ascaris* and FC data reported by Amoah *et al.* (2006) and Obuobie *et al.* (2006) for the different irrigation water (drain, stream and pipe) and contaminated soils to assess the health risk for farmers. For the FC concentration in pipe irrigation water, data reported by Gbireh (1999) were used. For consumers' health risk, data on *Ascaris* and FC levels on lettuce irrigated with the different water qualities and sold at the farm, wholesale and retail markets reported by Obuobie *et al.* (2006) and Amoah *et al.* (2007*a*,*b*) were used. The inclusion of the markets was to account for potential effects of post-harvest handling on health risks. For a worse case scenario, we chose lettuce over other vegetables. Lettuce is reported to have a higher *Ascaris* and FC contamination compared with other leafy vegetables irrigated with wastewater in Accra (Obuobie *et al.* 2006) potentially due to its morphology for water retention (Shuval *et al.* 1997).

To account for the rotavirus in our risk assessment models, all reported FC in the above literature sources were converted to rotavirus using a ratio of 1(rotavirus) to 10^5 (FC) applied by Shuval *et al.* (1997). The same approach was followed by Mara *et al.* (2007) but with an assumption of 1 rotavirus to 10^5 *Escherichia coli*. We used the $\log_{10}$normal probability distribution for rotavirus and *Ascaris* in the different irrigation water sources and irrigated lettuce sold at the farm, wholesale and retail markets as shown in Table 1. Applying the same conversion ratio for rotavirus to FC, the FC per 100 g of contaminated soil reported by Amoah *et al.* (2005) was uniformly distributed from 0.039 to 4.1. The *Ascaris* level in the same quantity of soil was also uniformly distributed from 50 to 190 eggs per 100 g of contaminated soil based on Amoah *et al.* (2005). It must be stressed that the FC to rotavirus extrapolation may be an overestimation or underestimation of the rotavirus in both the irrigation water and contaminated soil with a corresponding higher or lower resulting risk of infection. For this, we have accounted for variability in the estimated risk of infection. Field scale investigations are presently underway to establish the most probable level of rotavirus and other pathogenic microorganisms in the above irrigation water and contaminated soil in Ghana.

Exposure assessment

Four exposure scenarios were modelled in the assessment: (a) Accidental ingestion of only *wastewater* by farmers; (b) Accidental ingestion of only *contaminated soil* by farmers; (c) Accidental ingestion of both *wastewater and contaminated* soil by farmers; and (d) Consumption of the different *wastewater irrigated lettuce* collected from the farm, wholesale and retail markets by consumers. The bases for these scenarios are presented below:

Farmers' exposure scenarios

Vegetable farming activities in Accra are labour intensive thus putting farmers who generally do not wear any protective clothes (e.g. boots, mouth covers, gloves etc.) into direct contact with irrigation water and contaminated

Table 1 | Levels of Rotavirus and *Ascaris* in different wastewater sources and irrigated lettuce. The figures in the parenthesis represent the means and standard deviations for the $\log_{10}$normal probability distributions and maximum and minimum for the uniform distribution. Rotavirus data are extrapolated from FC data using the ratio 1(rotavirus) to 10^5 (FC)

			Quality of wastewater irrigated lettuce collected at various post harvest handling points					
	Irrigation water quality		**Farm**		**Wholesale market**		**Retail market**	
Irrigation water source	**Rotavirus (100 ml^{-1})**	***Ascaris**** **(eggs L^{-1})**	**Rotavirus§ (100 g^{-1} wet weight)**	***Ascaris**** **(100 g^{-1} wet weight)**	**Rotavirus§ (100 g^{-1} wet weight)**	***Ascaris**** **(eggs 100 g^{-1} wet weight)**	**Rotavirus§ (100 g^{-1} wet weight)**	***Ascaris**** **(eggs 100 g^{-1} wet weight)**
Drain	$\log_{10}$normal† (−0.11, −3.87)	$\log_{10}$normal (0.48,0.30)	$\log_{10}$normal (−0.75, −4.26)	$\log_{10}$normal (5.7, 1.1)	$\log_{10}$normal (−0.76, −4.14)	$\log_{10}$normal (5.9, 1.2)	$\log_{10}$normal (−0.52, −4.22)	$\log_{10}$normal (5.2, 1.5)
Stream	$\log_{10}$normal 1† (−0.01, −3.88)	$\log_{10}$normal (0.60,0.60)	$\log_{10}$normal (−0.78, −4.34)	$\log_{10}$normal (3.8, 0.9)	$\log_{10}$normal (−0.71, −4.38)	$\log_{10}$normal (3.1, 0.9)	$\log_{10}$normal (−0.71, −4.38)	$\log_{10}$normal (3.9, 1.2)
Piped Water	Uniform (0, $<$0.0001)‡	Uniform (0, $<$0.001)‖	$\log_{10}$normal (−1.56, −4.60)	$\log_{10}$normal (3.2, 0.7)	$\log_{10}$normal (−1.54, −4.57)	$\log_{10}$normal (2.1, 1.2)	$\log_{10}$normal (−1.54, −4.57)	$\log_{10}$normal (3.3, 1.0)

*Based on FC data reported by Obuobie *et al.* (2006); Amoah *et al.* (2006).
†Based on *Ascaris* data reported by Amoah *et al.* (2006); Obuobie *et al.* (2006).
‡Based on FC data reported by Gbireh (1999).
§Based on FC data reported by Obuobie *et al.* (2006); Amoah *et al.* (2007a,b).
‖Based on reported values helminths ova (*Ascaris*) in treated pipe water (Landa *et al.* 1997).

soil. However, the specific doses of irrigation water and contaminated soil accidentally ingested by farmers have not been reported in the literature in Ghana. Therefore, data from other studies with some adjustments were used. The amount of irrigation water ingested was assumed to be uniformly distributed from 1–5 mL per day for a total of 75 days of active irrigation per year. This range is an extension of the 1 ml ingestion level reported by Ottoson & Stenstrom (2003) and it was to account for the predominant use of watering cans for irrigation. A uniformly distributed accidental ingestion of 10 – 100 mg of soil per daily exposure for a total of 150 days per year was also used for the farmers (Haas *et al.* 1999; WHO 2001; Mara *et al.* 2007). For a worse case scenario, we assumed there was no reduction for both rotavirus and *Ascaris* before the ingestion of irrigation water and contaminated soil.

Consumers' exposure scenario

The majority of harvested lettuce in Accra is distributed on farm via wholesale markets to retail markets. Of the total lettuce sold at the wholesale and retail markets, 60% is purchased by some 5000 fast food sellers who daily serve between 130,000 and 150,000 people in Accra with lettuce salads as part of other dishes (Obuobie *et al.* 2006). An additional 38% is sold to canteens and restaurants. Only about 2% is purchased by households (Obuobie *et al.* 2006). Therefore, it was assumed that lettuce salad consumed in Accra is predominantly served by the fast food sellers. To ascertain the combined effect of irrigation water quality and post harvest handling on consumers' health risks, it was assumed that the fast food sellers could buy lettuce irrigated with any of the irrigation waters from either the farm, wholesale or retail distributions points. The amount of lettuce salad consumed was uniformly distributed from 10 to 12 g per single meal (Obuobie *et al.* 2006). This is far lower than the 100 g of lettuce per meal used in other studies (Shuval *et al.* 1997; Mara *et al.* 2007) and reflects the low consumption of lettuce salad in Ghana. The frequency of consumption was taken to be 4 times per week (IWMI 2006; Obuobie *et al.* 2006) giving 208 days of exposure per consumer of lettuce salad per year. For the amount of pathogens ingested by consumers during exposure, we assumed there will be no reductions in rotavirus and *Ascaris* in the fields given that farmers do not cease irrigation for some period before harvesting as they want their lettuce to look fresh at the point of harvest. About 99% of the fast food sellers are reported to wash lettuce with tap water and use disinfectants such as lemon, household bleach and vinegar sparingly during the preparation of lettuce salad (Amoah *et al.* 2007*a*). Reductions due to these practices were therefore considered. According to the WHO (2006) a 1 $\log_{10}$ reduction of pathogens (rotavirus) on lettuce can be achieved through washing with only water. An additional 2 $\log_{10}$ reduction of pathogens is also achievable when a mild disinfectant is used. It was therefore assumed that the combined effect of washing and disinfection during salad preparation would lead to a 3 $\log_{10}$ reduction of rotavirus before ingestion as used by Shuval *et al.* (1997). Amoah *et al.* (2007*b*) have also shown that a 1–2 $\log_{10}$ reduction of *Ascaris* on lettuce can be achieved with the above practice. For this, a uniform distribution of 1–2 $\log_{10}$ reduction was assumed for *Ascaris* on lettuce before ingestion.

Dose response assessment

The ß-poison dose response model was used to estimate the risk of rotavirus infection (Haas *et al.* 1999) while the exponential model was used for *Ascaris* infection (Westrell 2004). In the case of a single exposure, the ß-poison and exponential dose response models are expressed respectively as:

$$P_1(d) = 1 - [1 - (d/N_{50})(2^{1/a} - 1)]^{-a} \quad \text{and}$$

$$P_1(d) = 1 - \exp(-rd)$$

Where P_I (d) is the probability of becoming infected by ingesting d number of organisms, N_{50} is the median infection dose representing the number of organisms that will infect 50% of the exposed population; and a and r are the dimensionless infectivity constants. For rotavirus, N_{50} and a are 6.17 and 0.253 respectively (Haas *et al.* 1999). The exact value of r for *Ascaris* is not yet established in dose-response studies. Therefore, a conservative value of r based on a worse case evaluation was used. For a worse case evaluation, the exact single-hit model $(r = 1)$, which represents the maximum risk curve (Teunis & Havelaar 2000) can be used. The same value has been used by

Westrell (2004) to model the health risk associated with *Ascaris* infection.

Risk characterisation

Given the infection per single exposure above, the annual risk of infection for multiple exposures per person $P_{I(A)}$ was calculated as (Sakaji & Funamizu 1998):

$$P_1(A) = 1 - [1 - P_1(d)^n]$$

Where P_I (d) is as before, the risk of infection from a single exposure to a dose d of organisms; and n being the number of days in a year when a person is exposed to this single dose d. For the scenario of farmers' ingesting both irrigation water and contaminated soil, the combined annual risk of infection was determined by using the relation (Haas *et al.* 1999):

$$\pi_t = 1 - (1 - \pi_i)(1 - \pi_x)$$

Where π_t is the combined annual risk of infection from exposures to wastewater and contaminated soil; π_i is the annual risk of infection resulting from accidental ingestion of irrigation water and π_x is the annual risk of infection resulting from accidental ingestion of contaminated soil.

Monte Carlo Simulations were run using @Risk version 4.5.2 professional edition (Palisade Corporation) added on to Microsoft Excel. Random variables were sampled from the probability distribution functions for the dose of wastewater and contaminated soil (in the case of farmers) and lettuce (in the case of consumers) using the Latin hypercube sampling at 10,000 iterations. The median annual risks of infections were reported for the different scenarios. The 5th and 95th percentiles were also presented to account for variability in the estimated risks. Diarrhoea was used as a proxy for infections related to rotavirus. For comparative analyses, we used the WHO (2006) benchmark for annual tolerable risk (TR) for diarrhoea per person of 7.7×10^{-4} for rotavirus in developing countries. This is extremely conservative given that the incidence of diarrhoeal diseases in developing countries is in the range of 0.8 −1.3 per person per year (Mathers *et al.* 2002). For *Ascaris* infection, a tolerable risk of 1×10^{-2} (Mara *et al.* 2007) was used to account for its high prevalence in developing countries and in wastewater reuse (Hotez *et al.* 2003; WHO 2006).

RESULTS

Farmers health risk

The median annual risk of rotavirus and *Ascaris* infections (including the 5th and 95th percentile range) associated with the accidental ingestion of the different irrigation water and contaminated soil is presented in Figure 1. For rotavirus infections among farmers, there was a descending order of magnitude of risk from drain to stream to pipe irrigation waters with drain water resulting in rotavirus infections above the WHO–TR of 7.7×10^{-4} per farmer per year. The median annual risks of rotavirus infections per farmer for the accidental ingestion of stream and pipe irrigation waters were 3.14×10^{-5} and 7.5×10^{-7} respectively. For *Ascaris*, the median annual risks due to the accidental ingestion of drain and stream irrigation water were of the same order of magnitude at 8.2×10^{-2} and 8.4×10^{-2} respectively and slightly above the TR. For pipe water it was some 3 orders lower than the TR at 9.5×10^{-5} per farmer.

Compared with irrigation water, the accidental ingestion of contaminated farm soils posed the greatest health risk to farmers. Both the median annual risks of *Ascaris* and rotavirus infections for such incidents were above the TRs

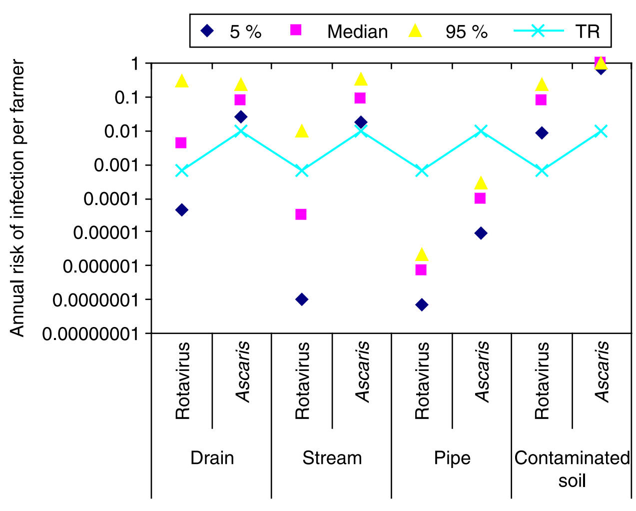

Figure 1 | Farmers' annual risk of rotavirus and *Ascaris* infections associated with the accidental ingestion of different irrigation water and contaminated soil.

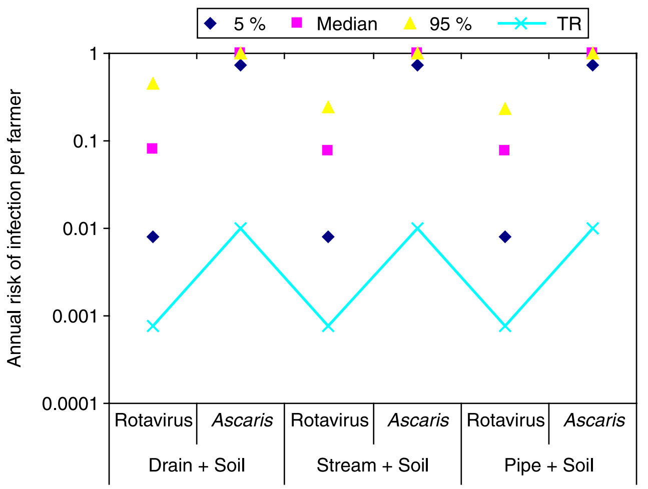

Figure 2 | Farmers' annual health risk associated with the combined accidental ingestion of both wastewater and contaminated soil.

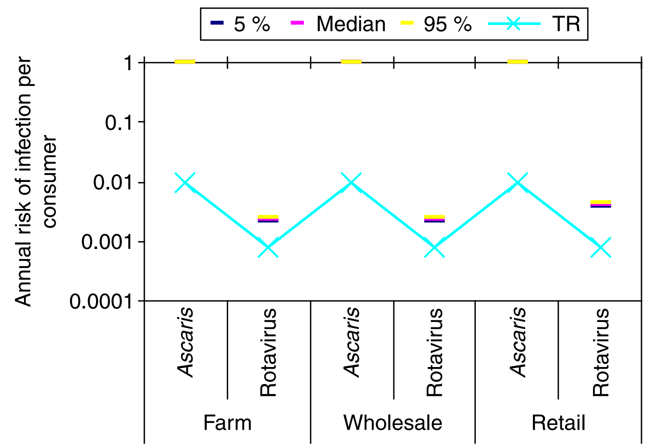

Figure 3 | Annual Rotavirus and *Ascaris* infections associated with the consumption of pipe irrigated lettuce collected from different marketing points.

with the highest risks accounted for by *Ascaris* infection as depicted in Figure 1. For this, the median annual risks of *Ascariasis* and rotavirus infections for the farmers were 0.99 and 7.6×10^{-2} respectively. Mara *et al.* (2007) also reported a median annual risk of rotavirus infection of 9.9×10^{-2} for farmers accidentally ingesting 10–100 mg of soil containing 105–106 *Escherichia coli*/100 g for 150 days.

As mentioned under the exposure assessment, farmers are likely to ingest both irrigation water and contaminated soil. The outcome of such incidents represents the most probable health risks for farmers. For this, the median annual risks of rotavirus and *Ascaris* infections exceeded the annual TR per farmer regardless of the irrigation water quality as depicted in Figure 2. The median annual risk of rotavirus infection was 8.0×10^{-2} for farmers ingesting drain irrigation water and contaminated soil and 7.7×10^{-2} for those ingesting contaminated soil in addition to stream or pipe irrigation water.

For *Ascariasis*, the median annual risk of infection was $\sim 10^{0}$ (i.e. 0.99) for all the irrigation water types given the same dose of contaminated soil as depicted in Figure 2. This shows that even when irrigation water quality meets the standards set for irrigation in the WHO guidelines, as was the case with pipe water (0 − < 10FC/100 mL) in our assessment, tolerable health risk outcomes can still be elusive if farm practices that contaminate soils are still pervasive (Drechsel *et al.* 2000).

Consumers' health risk

Figures 3–5 present the median annual risks of rotavirus and *Ascaris* infections from the consumption of lettuce irrigated with the different irrigation water collected from the farm, wholesale and retail markets. The results indicate that the background irrigation water quality and on farm contamination are the most potential risk factors for consumers of the irrigated lettuce. The effect of post harvest handling through contamination in the markets on health risk was low. As depicted in Figures 3 and 4, the median annual risks of rotavirus infection for consumers of drain

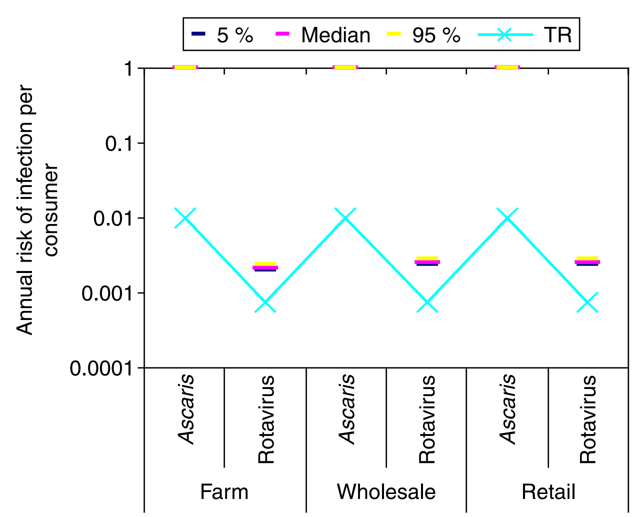

Figure 4 | Annual rotavirus and *Ascaris* infection associated with the consumption of stream irrigated lettuce collected from different marketing points.

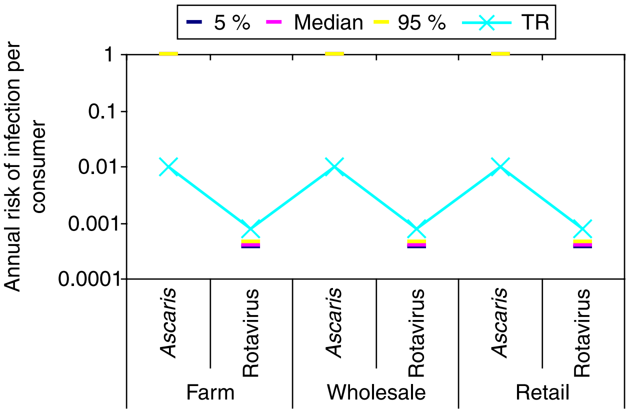

Figure 5 | Annual rotavirus and *Ascaris* infections associated with the consumption of pipe irrigated lettuce collected from different marketing points.

and stream irrigated lettuce were of the same magnitude and increased slightly during post harvest handling. During post harvest handling, the estimated annual risk of rotavirus infection for consumers of drain irrigated lettuce increased slightly from 2.3×10^{-3} per consumer from the farm and wholesale market points to 4.1×10^{-3} for the retail market. For stream irrigated lettuce, it increased from 2.2×10^{-3} for the farm selling point to 2.6×10^{-3} for the wholesale and retail markets. However, the median annual risk of rotavirus infection for consumers of pipe irrigated lettuce was the same for all the selling points at 4.1×10^{-4} as shown in Figure 5. In terms of *Ascaris* infection, the median annual risk of infection was 10° for consumers irrespective of the quality of irrigation water and marketing point as depicted in Figures 3 −5. These risk estimates, are in contrast with the findings made by Ensink *et al.* (2007) where post harvest market handling was identified as a major risk factor for consumers of wastewater irrigated vegetables.

DISCUSSION

A major observation was the increased levels of *Ascaris* and rotavirus infection for farmers due to the accidental ingestion of *contaminated soil* compared to the ingestion of the different *irrigation water*. The elevated hazard posed by soils on-farm could be attributed to the persistence of *Ascaris* and FC in the soils due to several reasons. In contrast to arid and semi-arid regions where the de-activation of *Ascaris* occurs in soils rapidly (Hotez *et al.* 2003), the average annual temperature (27.1°C), relative humidity (81%) and solar radiation (18.6MJ/m^2/day) prevailing in Accra (Agodzo *et al.* 2003) can lead to the persistence of *Ascaris* in the soil. *Ascaris* can embyronate given the above humid and warm conditions and become infectious (Maier *et al.* 2000). Also, farm practices including fertilization of soils with poorly treated manure (Drechsel *et al.* 2000) and cow faeces by farmers in Accra (Amoah *et al.* 2007*b*) explains the high levels of FC in the soil. The FC concentrations in fresh poultry and cow faeces are 1.3×10^6/gram and 2.3×10^5/gram respectively (Geldreich 1978) and when mixed into the soil without proper treatment can persist over a long time given the climatic conditions prevailing in Accra (Byappanahalli & Fujioka 1998). According to Zaleski *et al.* (2005) faecal coliforms and other pathogens have the potential to re-grow and re-colonize in soils amended with poorly treated manure/bio-solids especially during the rainy season. A study by Amoah *et al.* (2006) found the same magnitude of FC and *Ascaris* contamination for soils irrigated with pipe, stream and drain irrigation water indicating the application of untreated manure rather than wastewater was the main cause of soil contamination.

From the foregoing it can be concluded that irrigation water quality alone may not be an appropriate input into the assessment of the health risks for farmers using wastewater for irrigation as was the case in the QMRA of Mara *et al.* (2007) where soil and wastewater were assumed to have the same level of *E. coli* contamination. This also questions the helminths guideline by the WHO, which makes provision for only irrigation water quality of 0.1–1eggs/litre (WHO 2006). As our results indicate, the consumption of contaminated soil may pose a significant health risk above TR levels even when the irrigation water quality meets the WHO guidelines. A combination of irrigation water and soil quality into risk models will thus give a better picture of the health risks for farmers.

Also the initially high contamination of lettuce on farms resulting from the irrigation water and already contaminated soils may explain the risk of rotavirus and *Ascaris* infections among consumers. It is reported that irrigation water is sprayed directly overhead on lettuce by farmers (Amoah *et al.* 2006) using uncapped watering cans and buckets (Amoah *et al.* 2007*a*,*b*). This irrigation practice leads to splashes from the already contaminated soil further contaminating the lettuce on farm. Therefore, a reduction of the splash intensity from the already contaminated soil through proper irrigation practices can significantly reduce health risks on farm. Keraita *et al.* (2007) showed that using watering cans with caps on their spouts reduced the intensity of splashes from already contaminated soil resulting in a correspondingly higher reduction in lettuce contamination compared to uncapped watering cans. The study revealed that by irrigating from a low height of <0.5 m with capped watering cans the thermotolerant coliforms reduced by 2.5 log units and helminthes by 2.3 eggs per 100 g of lettuce compared to irrigating with uncapped watering cans at a height of >1 m. Drip irrigation can also substantially reduce soil splashes and contamination of lettuce with wastewater with a correspondingly significant reduction in health risks. According to Keraita *et al.* (2007), lettuce irrigated with drip kits have, on average, 4 $\log_{10}$ units per 100 g, fewer thermotolerant coliforms than those irrigated with watering cans. These simple but effective on farm risk reduction measures have been adopted by the WHO in its most recent guidelines for wastewater reuse in agriculture. The efficacy and adoptability of these methods as well as other simple on farm, post-harvest handling and household level health risk reduction measures are presently being explored through field scale investigations in Ghana.

The slight increases in the annual risk of rotavirus infection for consumers of drain and stream irrigated lettuce along the distribution chain (farm to wholesale to retail markets) gives an indication of potential contamination from post-harvest handling. Studies have highlighted unhygienic conditions and practices prevailing in these markets as a possible cause of contamination for wastewater irrigated vegetables. In a comparative survey of the contamination of wastewater irrigated lettuce on agricultural fields and in markets, Ensink *et al.* (2007) found a higher level of *E. coli* and helminths contamination in markets compared to on farm. The survey found relatively low concentrations of *E. coli* (1.9 *E. coli* per gram), but relatively high concentrations of helminths (0.7 eggs per gram) on vegetables collected from agricultural fields. Higher concentration of both *E. coli* (14.3 *E. coli* per gram) and helminths (2.1 eggs per gram) were recovered from the vegetables collected from the market. Amoah *et al.* (2007*a*) however found a very low FC contamination of lettuce in the markets in Accra as reflected in our risk estimates. Potential contamination of lettuce in these markets include the use of contaminated water for lettuce re-freshening (Ensink *et al.* 2007) and the display of lettuce under unhygienic conditions (Nyanteng 1998; Drechsel *et al.* 2002). In Accra, for example, sellers display wastewater irrigated lettuce on the bare floor of the market and on tables unprotected from flies and dust. Therefore for a holistic assessment of health risks associated with the consumption of wastewater irrigated vegetables it is pertinent that post harvest handling is factored into models in addition to the irrigation water quality and on farm contamination. This is especially critical in developing countries where poor packing and storage facilities as well as unhygienic conditions might characterize post harvest handling.

The estimated risks of *Ascaris* and rotavirus infections recorded in this assessment have to be interpreted with some caution. For *Ascaris*, our assessment only reports the probability of infection and does not reflect the worm load of the infected farmers and consumers. Therefore, the probability of infection eventhough the same for consumers and farmers, is not tantamount to both groups having the same level of worm load. All things being equal, the level of worm load will be higher for farmers than consumers due to their annual dose of *Ascaris* ingestion. The worm load within the farming as well as the consumer populations will also differ due to the characteristic over-dispersed distribution of *Ascaris* load burden by age among infected populations (Bundy *et al.* 2004). This over dispersed distribution will reflect in children engaged in wastewater irrigation and eating wastewater irrigated lettuce harbouring a disproportionately higher *Ascaris* burden than adults (Bundy 1988). Also, the rotavirus health risks presented here should not be misconstrued as a representative for all the possible enteric virus infections because of the diverse symptoms of enteric virus infections (Westrell 2004). Presently, a WHO funded project in Ghana is investigating the prevalence, distribution and load of *Ascaris* worms and diarrhoea incidence among farmers and children using different wastewater qualities for irrigation and consumers of the irrigated vegetables. The outcome of this study will complement the risk estimates arrived at in this assessment.

The QMRA presented here provides the building block for a quantitatively oriented local guideline for wastewater irrigation in Ghana. The model can be extended to encapsulate the effects of different interventions and their efficacy in reducing the health risks reported here to tolerable levels. However, this will require that more investigations are carried out into the occurrence and concentration of etiological agents of bacteria, viral, parasitic and protozoan origins which are of health significance in Ghana.

CONCLUSION

The assessment has revealed a high risk of *Ascaris* and rotavirus infections above TR for farmers using different irrigation water quality and the consumers of irrigated lettuce. Soils on-farm posed the greatest hazard to farmers for both *Ascaris* and rotavirus infections. For consumers, the already contaminated lettuce collected from the farms had the greatest effect on their levels of *Ascaris* and rotavirus infections. There were minor increases in consumer health risks associated with post-harvest handling at the markets, these increases were however very low.

To abate the health risks for farmers and consumers, conscious efforts have to be made to develop local guidelines based on interventions that are implementable from the short-medium-long term. These local guidelines should reflect different quantifiable tolerable risk levels associated with the reuse of different irrigation water qualities for farmers and consumers. The development of such quantitatively verifiable health risk guidelines could serve as the basis for a fruitful engagement among the different stakeholders concerned with public health issues in Ghana.

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