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Wastewater-irrigated vegetables: market handling versus irrigation water quality

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Summary OBJECTIVE AND METHODS Vegetables irrigated with untreated domestic wastewater were, at the time of harvest, analysed for the presence of the faecal indicator, *Escherichia coli*, and helminth eggs in Faisalabad, Pakistan. Vegetables from the same harvested batch were collected approximately 12 h later from the local market.

RESULTS 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.

CONCLUSIONS The results of the survey suggest that unhygienic post harvest handling was the major source of produce contamination. Interventions at the market, such as the provision of clean water to wash produce in, are better ways to protect public health and more cost effective than wastewater treatment.

keywords wastewater, *Escherichia coli,* helminths, irrigation, Pakistan, vegetables

Introduction

Urban agriculture is promoted as a way to reduce urban poverty, improve food security and enhance the urban environment through the creation of green 'spaces'. The cultivation of produce close to urban markets reduces transport, handling and production costs, making the food products readily available to the urban poor. The shorter time between harvest and consumption results in improved nutritional quality (Klein 1987; Shewfelt 1990). In many developing countries, as a result of rapid urbanisation and the absence of wastewater treatment facilities, urban farmers often use wastewater either directly from sewage drains or indirectly through wastewater-polluted irrigation water. Wastewater use in agriculture is common practice and is increasing as a result of the rising water scarcity worldwide (Scott *et al.* 2004). But the use of wastewater for agricultural purposes can pose a significant occupational and public health risk (Blumenthal & Peasey 2002).

In Pakistan, an estimated 25% of Pakistan's vegetable production is irrigated with wastewater (Ensink *et al.* 2004). Pakistan's total population is expected to grow by 65% in the next 25 years; its urban population is expected to grow by a staggering 140% (UNPD 2005). Water is already scarce in Pakistan and this situation is likely to deteriorate (Seckler *et al.* 1998). With increasing population pressure and water scarcity, the use of (untreated) wastewater is likely to become more and more important and with it the potential for foodborne disease outbreaks.

Little information is available on the quality of agricultural produce from wastewater-irrigated fields and/or its quality at local markets, although it is evident that the use of wastewater in agriculture is common in Pakistan. Here, we present the results of a yearlong, wastewater and produce quality investigation in the city of Faisalabad.

Methods

Study site

Faisalabad is the third largest city in Pakistan. A detailed description of the city and its wastewater use practices is given by Ensink *et al.* (2005). The study site was situated next to Faisalabad's only wastewater treatment plant (WTP), where approximately 500 hectares of agricultural land are irrigated with untreated wastewater. Farmers grow predominantly fodder and vegetable crops.

Agricultural and marketing practices

Farmers at the site pay an annual fee to the local drinking water and sanitation authority (WASA) for the use of untreated and partially treated wastewater. This fee ranges from 620 rupees (US$ 10) to 3700 rupees (US$ 62) per hectare per year depending on the amount and the quality (nutrient content) of wastewater. The highest fees are paid for untreated wastewater. Farmers grow vegetables on ridges and apply wastewater through furrows. Other crops such as wheat, sugarcane and fodder are grown using the basin irrigation technique, by which fields are flooded in a controlled manner by opening and closing of a bund. Spinach and cauliflower are the vegetables most commonly irrigated with wastewater, and for part of the year may occupy more than 80% of the cultivated area.

Vegetables are harvested in the late morning or early afternoon and sold either to wholesalers or directly to local retailers. Because of physical proximity, vegetables irrigated with wastewater from the study site are sold to one of the government-sanctioned markets. This market is the second largest in Faisalabad with approximately 120 shops. Trading starts at 6 am, when consumers and shopkeepers from all over the city arrive to buy their vegetables. The average time between harvest and retail is estimated to be 12 h.

Wastewater sample collection and analysis

Vegetable and wastewater samples were collected from April 2004 to March 2005. Composite wastewater samples were collected every 2 weeks from the main sewerage drain just before entry into the WTP. The daily mean *Escherichia coli* concentration was chosen for sample collection; the time was determined in a yearlong evaluation of WTP performance. Five 1-l samples were collected between 11 and 12 o'clock 20–30 cm below the water surface, mixed and analysed following the modified Bailinger method for the presence of helminth eggs (Ayres & Mara 1996). Another sample was collected and analysed for *E. coli* by the membrane filtration technique using a selective and indicative medium for *E. coli* (m-ColiBlue24®, HACH, Colorado, USA).

Vegetable sample collection and analysis

Produce samples were collected from two farms each with an approximate area of 3 hectares. Farm fields were situated approximately 500 m from the main sewerage drain and were representative in both crops grown and irrigation practices of the larger field site. From April 2004 to March 2005, we collected samples of all vegetables that were cultivated and ready for harvest in these fields every 2 weeks. The samples were analysed for *E. coli* and helminth eggs. Special care was taken to prevent any contact with soil during sample collection. Sample bags were stored on ice in a cool box and analysed within 3 h after collection.

Differences in coliform concentrations exist between low-growing leafy vegetables and vegetables with a smooth, waxy outer surface such as tomatoes and aubergines (Rosas *et al.* 1984; Armon *et al.* 1994). Vegetables were, therefore, grouped into three categories: leafy vegetables, cauliflower and smooth surface vegetables. Depending on the seasonal availability, one to three vegetables were obtained during each field visit.

Vegetables were always sold to the same market salesman who was visited the next morning at his market stall. Here, vegetables from the same harvest batch as sampled the previous day were purchased and analysed for *E. coli* and helminth eggs. Produce samples were bought at the market between 8 and 10 am to allow sufficient market handling of the produce. Vegetables irrigated by river water were not cultivated in the close proximity of Faisalabad.

In the local WASA laboratory, vegetable samples were washed following a standard protocol (Schwartzbrod 1998). Briefly, approximately 100 g in case of spinach or another leafy vegetable were washed in 1 l of sterile phosphate buffered water. Non-leafy vegetables were weighed and washed whole. Wash water was settled, centrifuged and analysed for helminth eggs using the Bailinger method (Ayres & Mara 1996). Depending on the turbidity, various volumes of wash water (100, 50 or 10 ml) were analysed for *E. coli* using the same method as for wastewater.

Data analysis

Data analysis were analysed with STATA 7.0 (STATA Corporation, TX, USA). Basic arithmetic means and 95% confidence intervals (CI) were calculated for helminth egg and geometric means, with corresponding 95% CI for *E. coli* concentrations. Differences in *E. coli* and helminth egg concentrations between samples collected at field and market were compared using a paired, double-tailed Student *t*-test, in which a *P*-value of <0.05 was considered significant.

Results

Wastewater quality

The fortnightly collections and analyses of wastewater samples showed high concentrations of *E. coli* (1.8×10^7 CFU/100 ml) and helminth eggs (968 eggs per litre). Hookworm was the predominant helminth in untreated wastewater, followed by *Ascaris lumbricoides* and

Table 1 *Escherichia coli* and helminth egg concentrations in untreated wastewater in Faisalabad during the period April 2004–March 2005

Pathogen	Unit	Geometric mean	95% CI	Range
Escherichia coli	CFU/100 ml	1.8×10^7	$1.2\ 10^7$–2.7×10^7	2.0×10^6–8.9×10^7
Hookworm	Eggs per litre	724	179–1268	100–5218
Ascaris lumbricoides	Eggs per litre	172	111–233	13–672
Trichuris trichiura	Eggs per litre	10	3–17	0–62
Total nematode eggs	Eggs per litre	906	312–1499	156–5627
Hymenolepis nana	Eggs per litre	60	34–85	0–276
Taenia spp.	Eggs per litre	2	0–4	0–8
Total cestode eggs	Eggs per litre	62	37–88	0–276
Total helminth eggs	Eggs per litre	968	353–1582	175–5903

Hymenolepis nana. Concentrations of *Trichuris trichiura* and *Taenia* spp. eggs were relatively low (Table 1).

Produce quality

In the course of the survey, 110 vegetable samples were collected; 55 at wastewater-irrigated fields and 55 at the local market. Eight different vegetables were tested for *E. coli* and helminth eggs. Of the 55 vegetable samples collected in the field, only 4 samples (7.3%) were free of *E. coli*. The geometric mean of *E. coli* concentrations on the different types of vegetables collected in the field was 1.9 *E. coli* per gram (95% CI: 1.1–3.4). Low-growing leafy vegetables (Figure 1) carried the highest *E. coli* concentrations (4.6 *E. coli* per gram; $P < 0.001$).

Vegetables from the market harboured higher *E. coli* concentrations with a (geometric) mean concentration of 14.3 *E. coli* per gram (95% CI: 10.0–20.1) than vegetables from the field. This difference was highly significant for all three types: leafy vegetables ($P = 0.001$), cauliflower ($P = 0.002$) and smooth surface vegetables ($P = 0.009$).

Helminth egg concentrations on vegetables collected from the field were high: on average 0.7 eggs per gram of vegetable (95% CI: 0.4–1.0). Leafy vegetables (Figure 2) showed the highest concentrations (1.1 eggs per gram; $P < 0.004$), followed by cauliflower (0.1 eggs per gram; 95% CI: 0.0–0.2), whereas smooth surface vegetables were found to be free of helminth eggs. The vegetable samples from the market contained on average three times more helminth eggs than vegetables from the field, although this difference was borderline non-significant ($P = 0.07$). The difference in helminth concentrations between market and field was only significant for leafy vegetables ($P = 0.04$).

Discussion

This survey in Faisalabad found high concentrations of *E. coli* and helminth eggs in wastewater used in agriculture. However, these concentrations in irrigation water did not

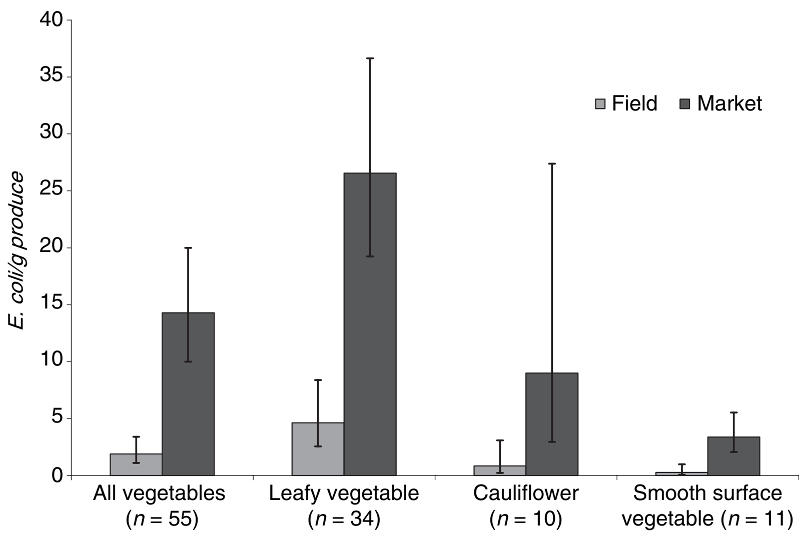

Figure 1 Mean *E. coli* concentrations on different types of vegetables collected at fields and at a market in Faisalabad during the period April 2004–March 2005 (error bars represent 95% CI).

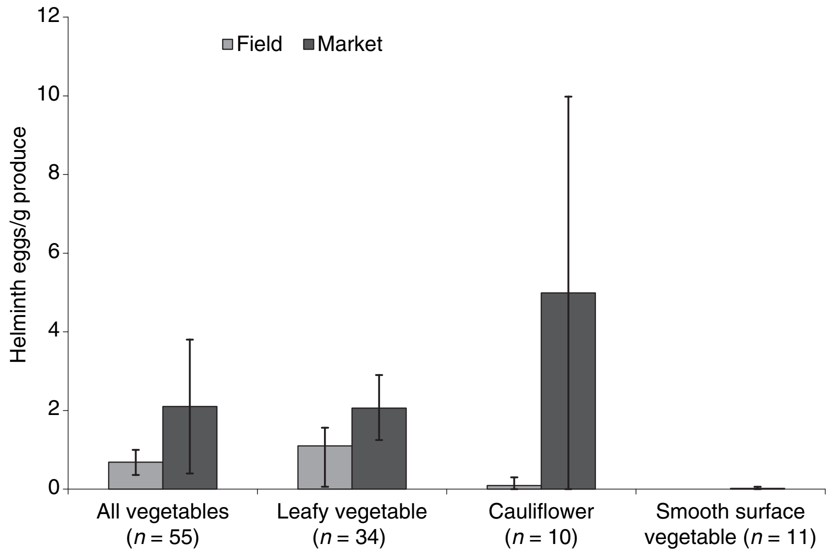

Figure 2 Mean helminth egg concentrations on different types of vegetables collected at fields and at a market in Faisalabad during the period April 2004–March 2005 (error bars represent 95% CI).

translate to high *E. coli* and helminth eggs concentrations on wastewater-irrigated vegetables collected from the fields. The same vegetables collected from the local market consistently contained higher concentrations of *E. coli* and helminth eggs than vegetables collected from the fields.

Wastewater quality and produce quality at field level

Although high concentrations of *E. coli* were found in wastewater, relatively low concentrations of *E. coli* were found on irrigated produce. Studies in Ghana, Israel and Mexico found faecal coliform concentrations at least 100 times higher than those in Faisalabad (Rosas *et al.* 1984; Armon *et al.* 1994; Amoah *et al.* 2005). The irrigation water application method likely played a pivotal role, as in these past studies wastewater was applied from above through sprinklers or watering cans, whereas in this study wastewater was applied through furrows, minimising contact between plant and wastewater. Further, high daily temperatures (up to 50 °C in summer) combined with low humidity promote rapid die-off of *E. coli*, which can be as high as 2 $\log_{10}$ per day (WHO 2006).

Helminth egg concentrations in Faisalabad's untreated wastewater were high, but typical for untreated domestic wastewater in a developing country setting (Feachem *et al.* 1983). We found smooth surface vegetables to be free of helminth eggs, which confirms the findings of past studies reporting no or very low (0.002 eggs per gram) concentrations of helminth eggs on wastewater-irrigated tomatoes (90–2000 eggs per litre; Rhallabi *et al.* 1990; Stien & Schwartzbrod 1990; Ayres *et al.* 1992). In Faisalabad, leafy vegetables contained on average 1.1 eggs per gram, which was similar to concentrations found on wastewater-irrigated lettuce (0.4–2.7 eggs per gram) in Ghana (Amoah *et al.* 2005). However, in Ghana, wastewater was of considerably better quality (0–15 eggs per litre) but applied from above with the help of watering cans, which promotes the accumulation of helminth eggs on lettuce. The findings in Faisalabad, therefore, confirm that the mode of irrigation application and crop type are key determinants for produce quality and consumer risk.

We did not test the viability of helminth eggs on produce, which is a major limitation in determining the public health risk to consumers of wastewater-irrigated produce in Faisalabad. Hookworm eggs are unlikely to survive for more than a couple of days on produce (Brooker *et al.* 2004), whereas *Ascaris lumbricoides* eggs can remain viable for several months or years in soil (Shuval *et al.* 1986) although often less than 2 months on produce (WHO 2006).

Post-harvest handling and produce quality at the local market

With significantly higher *E. coli* and helminth concentrations found on market produce, unsanitary handling post-harvest seems to have caused greater faecal contamination than wastewater irrigation. This is confirmed by the presence of helminth eggs on cauliflower and smooth surface vegetables, which were free of helminth eggs at the field site. In Portugal, Vaz da Costa Vargas *et al.* (1996) attributed an increase in faecal bacteria concentrations from field to market to the use of contaminated water to refresh the produce at the market, a practice which was common in Faisalabad too. Farmers and market salesmen also washed their produce in wastewater drains. Contact with wastewater-irrigated soil, where *E. coli* and in particular helminth eggs can survive for prolonged periods (Feachem *et al.* 1983), is another potential risk factor for pathogen transmission. More detailed investigations are needed to assess the relative importance of risk factors.

Public health impacts and intervention measures

To protect farmers and consumers from the potential adverse health impact of wastewater use in agriculture, the WHO has set a helminth guideline of ≤1 egg per litre (WHO 2006). Based on this guideline, the wastewater in Faisalabad was clearly unfit for use in agriculture, as confirmed by the results of a cross-sectional study conducted at the same site, which found an increased risk of hookworm and *Giardia intestinalis* infection in farming families exposed to untreated wastewater (Ensink *et al.* 2005, 2006).

The quality of vegetables collected from the field and market was satisfactory by United Kingdom microbiological guidelines (<20 *E. coli* per gram; Gilbert *et al.* 2000). Hence, potential negative health impacts based on *E. coli* indicator concentrations, e.g. bacterial enteric pathogens, can be expected to be minimal. But helminth concentrations on the collected produce are a reason for concern. Although almost all vegetables grown at the study site are consumed cooked, handling of agricultural produce could in itself be a major source of direct transmission and cross-contamination of foods with helminths and other pathogens.

Interventions to protect consumer health

The main methods put forward in the new WHO guidelines to minimise the health risk of wastewater irrigation to consumers are wastewater treatment and crop restrictions (WHO 2006). However, this survey indicates that post-harvest and market interventions to reduce faecal pollution may be more effective, in regard to both cost and health protection. Suitable interventions could be better availability of clean water and promoting hygienic food-handling practices. The availability of clean water could be improved by providing extra (drinking) water posts, which would give farmers and market salesmen the opportunity to wash their produce with good quality water. The use of plastic sheets or other materials to prevent contact with contaminated soil during harvest could be promoted through agricultural and water user associations. Future studies should assess the impact of these and other relevant interventions in reducing faecal pollution of wastewater-irrigated produce along the field-to-market chain.

Conclusion

This survey found relatively low faecal pollution levels of vegetables irrigated with untreated wastewater containing high concentrations of *E. coli* and helminth eggs. This was mainly because of the use of bed and furrow irrigation techniques, which cause relatively little faecal contamination. Significantly higher concentrations of the faecal indicators were found on the same produce collected from the local market. This indicates that irrigation water contributes significantly less to faecal pollution of produce purchased at markets than the faecal pollution taking place post-harvest. Points of faecal pollution on the way from field to market need to be assessed and addressed by effective interventions.

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Conflicts of interest

All authors declare no conflicts of interest.

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