GLOBAL WATER PATHOGEN PROJECT
PART FIVE. CASE STUDIES

DISEASE BURDEN DUE TO GASTROENTERITIS INFECTIONS AMONG PEOPLE LIVING ALONG WASTEWATER REUSE SYSTEM IN HANOI, VIETNAM

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Summary

Highlights

- Reuse and management of wastewater is increasing in low- and middle-income countries
- QMRA was applied alongside sanitation safety planning tests in Asia
- Describes wastewater system from source to reuse in urban and peri-urban areas
- Exposures and risks for farmers, sanitation workers and flooding events are estimated
- Gastrointestinal infections are compared to WHO reference levels and GBD estimates
- Identifies management options to reduce health risks important to achieve SDG 6

Graphical abstract

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Risk Management Objective

To investigate the safety of people living and working along the major wastewater recovery and reuse system in Hanoi, Vietnam.

Location and Setting

The case study was located along Hanoi's main wastewater conveyance and treatment system, where as many as 700,000 farmers are estimated to reuse wastewater. In the urban and peri-urban areas around Hanoi, wastewater reuse in agriculture and aquaculture creates important livelihood opportunities and is a valuable source of fresh vegetables, livestock and fish.

Description of the System

The focus was on four population groups exposed to wastewater: (i) workers maintaining the wastewater treatment systems; (ii) community members in urban areas exposed to flooding events; (iii) urban farmers using wastewater from To Lich River; and (iv) peri-urban farmers, where Red River water is used for agriculture.

Outcome and Recommendations

The disease burden for these different population groups were several thousand-fold above the tolerable risk benchmark. Urban farmers, sanitation workers and rural farmers are at risk for diarrhoeal disease burdens that are 6 to 3 times higher than the estimates from the Global Burden of Disease study 2010 for an average Vietnamese (0.002 DALYs pppy). This could be addressed by:

- Additional **treatment**. (i) improve the treatment efficiency of septic tanks together with faecal sludge treatment; and (ii) upgrade the existing sedimentations ponds to functional waste stabilisation ponds with anaerobic, facultative and aerobic treatment together with appropriate retention times
- Additional improvements of **public health programs aimed at reducing exposure** (i) continue school-based helminth and education programs; (ii) provide specific training and education programs for rural communities, while anticipating further urbanization of the rural areas; and (iii) promote non-technical control measures and awareness campaigns on safe work practices

Introduction

In Southeast Asian cities, such as Hanoi, large quantities of insufficiently treated effluents contaminate surface waters and soils, resulting in high concentrations of pathogenic organisms and toxic chemicals (Kuroda et al., 2015; Fuhrmann et al., 2016a). This is explained by the fact that most of the 6.7 million people living in Hanoi rely on flush toilets directly connected to septic tanks, that discharge (partially treated effluents) into a complex network of drainage channels. These channels also receive effluents from industries (Fuhrmann et al., 2016c). In addition, faecal sludge from septic tanks is often informally discarded into the environment; in many cases directly into agricultural fields or ponds used for aquaculture (Bassan et al., 2015). In response, wastewater flows have been largely controlled by channelization of the main urban rivers, water gates and sedimentation pond systems to prevent flooding and to treat wastewater before use in agriculture and aquaculture (Nguyen and Parkinson, 2005; World Bank, 2013).

In a recent water quality assessment we found that, despite efforts to improve Hanoi's wastewater conveyance and treatment systems, water deriving from the wastewater channels being used in agricultural fields for irrigation is heavily contaminated with total coliforms (TC), *Escherichia coli* and *Salmonella* spp. (Fuhrmann et al., 2016a). Observed values were up to 110-fold above Vietnamese discharge limits for restricted agriculture and up to 260-fold above the World Health Organization (WHO)'s tolerable safety limits for unrestricted agriculture (Fuhrmann et al., 2016a). Additionally, a cross-sectional

epidemiological survey revealed high prevalence of intestinal parasite infections in peri-urban and urban farmers (up to 30%), general communities (up to 10%) and workers maintaining the wastewater channels (10%) (Fuhrmann et al., 2016c). In the aforementioned study, the prevalence of self-reported diarrhoea episodes (recall period: 2 weeks) in adults in peri-urban communities, urban farmers and sanitation workers was 8-12%. These observations suggest that treatment efficacy of Hanoi's wastewater management system is insufficient in preventing microbial contamination. Consequently, people exposed to wastewater are at risk of gastrointestinal infection. However, prior research does not provide an estimate of the magnitude of the disease burden caused by specific pathogenic organisms (Katukiza et al., 2013; Machdar et al., 2013).

Here we present a quantitative microbial risk assessment (QMRA) with three specific objectives: to estimate the disease burden due to gastroenteritis resulting from exposure to water-borne pathogens along the major wastewater system in Hanoi; to validate model estimates with findings obtained from a cross-sectional epidemiological survey (Fuhrmann et al., 2016c); and to compare disease burden estimates with national and international standards.

Problem Formulation

The scope was defined through sanitation safety plan testing in Hanoi:

Hazard identification: Viruses (rotavirus and norovirus), bacteria (*E. coli*, *Campylobacter* spp., *Salmonella* spp), protozoa (*Cryptosporidium* spp.) and helminths (*Ascaris lumbricoides*).

Exposure pathways: Potential for accidental direct ingestion of contaminated water (e.g. splashes while working on the field or while maintaining a wastewater treatment systems) due to flooding, working and farming (urban and peri-urban) were considered.

Health outcome: The risk was quantified as the number of cases per year, DALYs pppy and total DALYs per year (according to published burden estimate for gastroenteritis and fatality rates and adapted to the average life expectancy of 72 years in Vietnam (Salomon et al., 2012; Gibney et al., 2014).

A schematic of Hanoi's main wastewater system, with indication of the four exposure scenarios considered in the study is shown in Figure 1.

Figure 1. Schematic flow of Hanoi's main wastewater system, with indication of the four exposure scenarios within the study area ($S_{flooding}$, $S_{working}$, $S_{farming}^U$ and $S_{farming}^{PU}$ and potential exposure outside the scope of this study (i.e. contact to Nhue River water and vegetable consumption). (Image reproduced with permission of Elsevier <https://www.sciencedirect.com/science/article/pii/S0309170816307850>)

Exposure Assessment

The exposure scenarios included in the assessment are illustrated in Figure 2.

Figure 2. Exposure scenarios (S_{flooding} , S_{working} , S_{farming}^U and S_{farming}^{PU}) considered in the quantitative microbial risk assessment (QMRA) to estimate the burden of norovirus, rotavirus, *Campylobacter* spp., *Escherichia coli* O157:H7, *Salmonella* spp., *Cryptosporidium* spp. and *Ascaris lumbricoides* along the major wastewater system in Hanoi. (Image reproduced with permission of Elsevier <https://www.sciencedirect.com/science/article/pii/S0309170816307850>)

Source: Water quality was tested for the indicator organism *E. coli*, total coliforms, *Salmonella* spp. and helminth eggs between April and June 2014 (Fuhmann et al., 2016a). The ratio between measured pathogens and *E. coli* is assumed to vary between 10^{-6} and 10^{-5} (rotavirus, norovirus and *Campylobacter* spp.) or between 10^{-7} and 10^{-6} (*Cryptosporidium* spp.). The ratio between pathogenic and non-pathogenic strains of *E. coli* and *Salmonella* spp. was assumed to vary between 7.6×10^{-4} and 1×10^{-2} (Shere et al., 2002; WHO, 2006; Soller et al., 2010; Barker et al., 2014; Hynds et al., 2014). For *Ascaris* spp. it was assumed that each egg detected represents an *A. lumbricoides* (not considering the occurrence of other helminth species such as, for example, *A. suum*) (Mara and Sleight, 2010).

Barriers/controls: The effect of barriers or controls was not included in the assessment.

Exposure: Four exposure scenarios along the three selected study areas were developed and assumptions about exposure groups, number of people exposed, exposure frequency and volume of ingested water were made (see Figure 2).

Exposure to water from To Lich River:

Scenario 1 (S_{flooding}): Urban communities (all age groups) in Bang B and Tam Hiep living in close proximity to the To Lich River are prone to flooding events. For instance, 5% of the people living in these communities reported to be at risk of flooding events (i.e. 795 out of 15,900 people) (Fuhmann et al., 2016c). According to HSDC, four flooding events occurred during the rainy season in 2013; the year previous to our epidemiological survey (Fuhmann et al., 2016c). During a flooding event, ingestion of water due to unintentional immersion was assumed to range between 10 and 30 mL (McBride et al., 2013).

Scenario 2 (S_{working}): There are 450 registered workers employed by the HSDC who are in charge of the maintenance of the To Lich River and the operation of the wastewater treatment plants (Yen Son). On average, a worker is on duty 322 days per year. Most of the workers wear gloves (91%), which can be seen as a proxy for the level of awareness and preparedness to avoid accidental ingestion of

contaminated water (WHO, 2006a; Fuhrmann et al., 2016d). It was assumed that the worst case scenario (an accidental ingestion of 10-50 mL of wastewater per working day) was reduced to ingestion of 0.9-4.5 mL per working day (WHO, 2006a; Labite et al., 2010; Mara and Bos, 2010).

Exposure to water use from To Lich River in agriculture fields of urban farming communes in Hanoi:

Scenario 3 ($S_{farming}^U$): Urban farmers living in Bang B village or Tam Hiep commune using wastewater from To Lich River were selected for the model. One third of the community (an estimated 5,300) are involved in urban farming (mainly rice, morning glory, neptunia and watercress) or aquaculture. Thus, the likelihood of accidental ingestion of water was expected to be high. On average, farmers in Bang B village and Tam Hiep commune reported to work 338 days per year in flooded agricultural fields and they are in contact with irrigation water on a daily basis. Three out of four workers (74%) wear gloves, which can be seen a proxy for the level of awareness and preparedness to avoid accidental ingestion of contaminated water (WHO, 2006a; Fuhrmann et al., 2016d). It was assumed that the worst case scenario (an accidental ingestion of 10-50 mL of wastewater per working day) was reduced to ingestions between 2.6 mL and 13 mL

per working day (WHO, 2006a; Labite et al., 2010; Mara and Bos, 2010).

Exposure to water used from Red River in agriculture fields of peri-urban farming communes in Hanoi:

- **Scenario 4 ($S_{farming}^{PU}$):** A typical peri-urban farming community living in Duyen Ha commune, 10 km away from the outskirts of Hanoi. Farmers using the irrigation water from Red River, wells or local drains, which are not contaminated with the city's wastewater but may be contaminated with household effluents. About 38% of the people work in agriculture (i.e. 580 urban famers). On average, farmers reported to work 338 days per year, though, fields are irrigated only every second day. 82% of the workers wear gloves, which can be seen a proxy for the level of awareness and preparedness to avoid accidental ingestion of contaminated water (WHO, 2006a; Fuhrmann et al., 2016d). It was assumed that the worst case scenario (an accidental ingestion of 10-50 mL of wastewater per working day) was reduced to ingestions between 1.8 mL and 9 mL per working day (WHO, 2006a; Labite et al., 2010; Mara and Bos, 2010).

Health Effects Assessment

The assumptions used for the health effects assessment are summarised in Table 1.

Table 1. Health effects assessment assumptions used in the QMRA

Reference pathogen	Dose-response			Probability of illness		DALYs per case*
	model	parameter values	reference	Pinf inf	reference	
<i>A. lumbricoides</i>	Beta Poisson approx	a=0.0104; N50=859	(Mara and Sleight, 2010)	0.39	(Mara and Sleight, 2010)	0.0029
<i>Campylobacter</i> spp.	Beta Poisson approx.	a=0.145; N50=896	(Medema et al., 1996)	0.3	(Machdar et al., 2013)	0.0053
<i>Cryptosporidium</i> spp.	Exponential	r=0.0042	(Haas et al., 1999)	0.79	(Machdar et al., 2013)	0.0022
<i>E. coli</i> O157:H7	Beta Poisson approx	a=0.49; N50=596,000	(Teunis et al., 2008a)	0.35	(Machdar et al., 2013)	0.0013
Norovirus	Beta Poisson exact	a=0.04; β =0.055	(Teunis et al., 2008b)	eta=0.00255; r=0.086	(Teunis et al., 2008b)	0.0008
Rotavirus	Beta Poisson approx	a=0.253; N50=6	(Teunis and Havelaar, 2000)	0.5	(Barker, 2014)	0.0032
<i>Salmonella</i> spp	Beta Poisson approx	a=0.3126; N50=23,600	(Haas et al., 1999)	1	Amha et al., 2015	0.0719

*Calculated in the study, various references, see Table 2 of <https://www.sciencedirect.com/science/article/pii/S0309170816307850>

Risk Characterization

The results are illustrated in Figure 3. The combined estimated incidence for gastroenteritis episodes per year due to exposure to contaminated water was highest for urban farmers and sanitation workers who were estimated to

suffer, on average 2 and 1 gastroenteritis episodes per person per year. Incidence estimates were considerably lower for people exposed to flooding events and peri-urban farmers (>0.1 episodes per person per year for both groups). Most episodes were caused by rotavirus (1.5 episodes per year), *E. coli* (0.6 episodes per year), *Campylobacter* spp (0.4 episodes per year) and *Cryptosporidium* spp (0.4 episodes per year).

Figure 3. Estimated number of cases, annual incidence of gastroenteritis per year (Inc py), disability-adjusted life years (DALYs) per year (py) and per person per year (pppy); (a) and (b) showing estimates of the respective outcomes per *S*_{flooding}, *S*_{working}, *S*_{farming}^U and *S*_{farming}^{PU}; (c) and (d) are indicating the contribution of individual pathogens and scenarios, respectively, to the total estimated numbers per outcome along the major wastewater system in Hanoi, Vietnam. (Image reproduced with permission of Elsevier <https://www.sciencedirect.com/science/article/pii/S0309170816307850>)

Risk Management

Our estimated gastrointestinal disease burden among urban farmers and sanitation workers who are exposed to wastewater were 5.6- and 2.8-fold higher than the diarrhoea burden estimates for the average Vietnam citizen (0.002 DALYs pppy) (Institute for Health Metrics and Evaluation, 2015), and more than hundred times above the revised WHO tolerable level of 0.0001 DALYs pppy. The high number of cases and the resulting burden due to *E. coli*, rotavirus and *Campylobacter* spp. together were estimated to cause most of the disease burden (88%). This study showed evidence that exposure to wastewater around Hanoi has considerable public health implications for these population groups and calls for action, especially to bring down the burden due to *E. coli*, rotavirus and *Campylobacter* infections. This could be achieved by:

Additional treatment. (i) improve the treatment efficiency of septic tanks together with faecal sludge treatment; and (ii) upgrade the existing sedimentations ponds to functional waste stabilisation ponds with anaerobic, facultative and aerobic treatment together with appropriate retention times

Additional improvements of public health programs aimed at reducing exposure (i) continue school-based helminth and education programs; (ii) provide specific training and education programs for rural communities, while anticipating further urbanization of the rural areas; and (iii) promote non-technical control measures and awareness campaigns on safe work practices

Evaluation of the QMRA

The model included a range of uncertain assumptions that can influence the quantitative results. A sensitivity analysis of the QMRA model has been presented by Fuhrimann et al. (2016d). There was an effect of different volumes of water accidentally ingested on the risk estimates. Such accidental ingestion may not be very accurate, as it is highly dependent on individual behaviours, which are influenced by age, sex, educational attainment and socioeconomic status (WHO, 2006; Haas et al., 2014). In addition, pathogen to indicator ratios for rotavirus, *E. coli* and *Campylobacter* have shown a considerable effect on the total number of gastroenteritis cases. The actual ratio between indicators and pathogens depends on the source of microbial contamination, and this contamination varies between seasons in urban wastewater systems (Ensink, 2006; Katukiza et al., 2013; Fuhrimann et al., 2015, Fuhrimann et al., 2016a). It is important to note that *E. coli* is excreted by humans and animals continuously, whereas pathogens are excreted only by infected people. This *E. coli* to pathogen ratio is therefore highly uncertain and will change over time (Mara, 2004; Haas et al., 2014).

Nevertheless, employing a QMRA approach, we found very high risk estimates for urban farmers in Hanoi who use wastewater in agriculture and aquaculture. The measured faecal indicator concentrations, together with the assessment of human behavioural practises, were effectively combined and translated into a health outcome metric, allowing for the implications of sanitation related water contamination to be clearly investigated.

Against this background, health-based targets should be set according to local idiosyncrasies after validation with epidemiological findings. For example, as a first step towards setting local targets could be the consideration of estimates provided by the Global Burden of Disease study 2010. These findings are especially interesting in the frame of the Sustainable Development Goals (SDGs), as they address sustainable and safe wastewater reuse and recovery systems, from the point of generation to the point of disposal and (re)use for minimising adverse health impacts associated with water-borne disease, while maximising gains from safe wastewater use in agriculture and aquaculture in LMICs.

The full paper can be found here: <https://www.sciencedirect.com/science/article/pii/S0309170816307850>

and the related PhD thesis providing a more detailed discussion on QMRA and sanitation safety planning under following link: <https://edoc.unibas.ch/55439/>

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