GLOBAL WATER PATHOGEN PROJECT

PART FIVE. CASE STUDIES

TIERED APPROACH FOR INTEGRAL ASSESSMENT OF SANITATION, WATER SUPPLY AND HYGIENE HEALTH RISKS IN RURAL BRASIL

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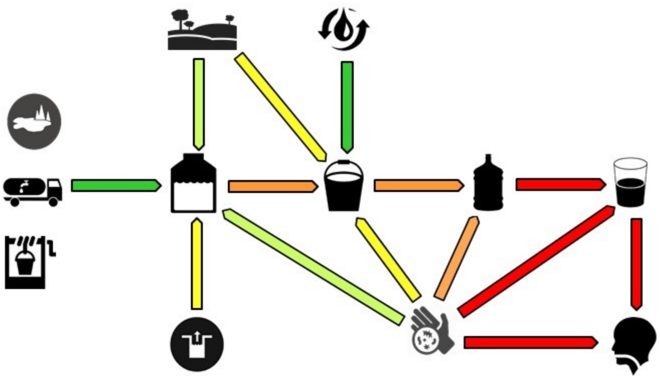
Summary

Highlights

- Health risks from excreta-borne pathogens come from may exposure routes in rural Brazil
- A tiered approach was developed for a holistic assessment of the risk via sanitation, drinking water and hygiene
- Excreta-borne exposure pathways have a high cross-contamination potential in the domestic environment
- Hand-to-mouth and drinking water both posed a relatively high risk of infection (by Salmonella spp., Giardia lamblia and norovirus)
- Raising awareness of the important (cross-contaminating) exposure pathways may improve the health in these communities

Graphical abstract



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Introduction

People living in rural communities located in the semi-arid region of North East Brazil, face several health issues, common to those living in many other low-income communities around the globe. Water scarcity, combined with lack of awareness about the need for 'safe' handling, storage of drinking water and poor hygiene appear to contribute significantly to the microbial contamination of water from source-to-mouth. Contamination may occur at several critical-points within the domestic environment within these communities. Understanding the contribution of the different routes of exposure is necessary to support effective risk management. The consumption of drinking water containing pathogens can lead to numerous diarrheal diseases and is one of the leading causes of childhood mortality and morbidity in the world (WHO, 2017). The following case study illustrates how a tiered approach to Quantitative Microbial Risk Assessment (QMRA) can be applied to provide objective information with which to identify priority areas for risk management of multi-sourced rural water supply systems.

Problem formulation

The purpose of the QMRA was to provide an evidence-base for effective management of the health risk associated with the different water contamination routes in this rural community. The specific risk assessment objective was to:

- Assess the risk of infection posed by multi-source drinking water supplies and hand-to-mouth routes to the population living in rural communities in the semi-arid Sertao region of North East Brazil.

The scope of the study was defined by the following steps:

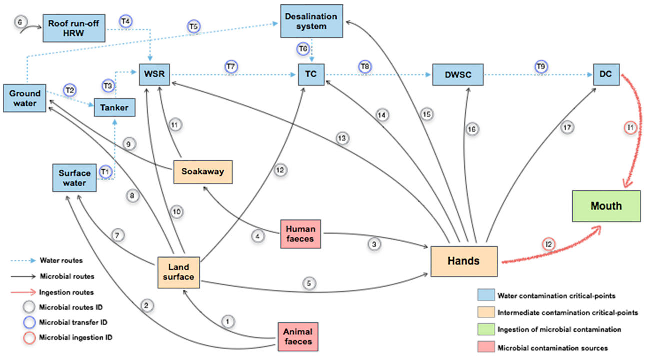
Hazard identification: Norovirus, *Salmonella* spp. and *Giardia lamblia* were selected in this assessment because these pathogens presented higher prevalence levels in feces of patients with symptomatic and asymptomatic diarrheal infections in rural Brazil. It is important to mention that both *Salmonella* spp. and *Giardia lamblia* can also be shed and spread by several domestic and wild animals, which were also common in the rural settings studied. All selected pathogens presented high health significance and moderate-to-long persistence in water supplies.

Exposure pathways: Drinking water originated from multiple sources, including tankered water (from both surface water and groundwater sources), rainwater, and desalinated water (groundwater), which was stored in water storage reservoirs (cistern) and/or within household drinking water storage containers. Treated (as reported by residents) and untreated waters were also evaluated during the study.

Health outcomes: Annual probability of infection.

Exposure assessment

Information relating to the water supply system, sanitation and hygiene was gathered through questionnaires, which were conducted face-to-face with the residents. Sanitary surveys were also conducted during the field survey. Data provided by the Brazilian health authorities, as well as from the literature were also used during the formulation of the exposure assessments. A monitoring program was also developed to quantify the level of fecal contamination through the detection and enumeration of *E. coli*. Figure 1 illustrates the conceptual scenario model developed, including the water, microbial and ingestion routes identified in this study.



WSR = water storage reservoir; TC = transport container; DWSC = in-house drinking water storage container; DC = drinking container.

3.1. Drinking water (I1) and hand-to-mouth (I2) exposure

The exposure dose for the drinking waters (I1) from different sources was estimated based on *E. coli* concentrations, and was described with triangular distributions (Table 1). The first and third quartiles of *E. coli* counts observed at each step of the water supply chain (origin, water storage reservoir and in-house drinking water storage container) were used to represent the minimum and maximum values, whereas the median was assumed to be the mode of the distribution. For the hand-to-mouth route (I2), a triangular probability density function (PDF) was created for the microbial load on both hands, based on a study undertaken by Pickering et al., (2010).

Table 1. Probability Density Functions (PDF) to represent *E. coli* levels on hands and in water within water storage reservoirs and household drinking water storage containers

Water Quality at Different Stages of the Water Supply Chain[b]	PDF Parameters[a]
Hands	(3.5;309;3162) (CFU)
HRRW at WSR	(1;10;42.5) (CFU/100 mL), n = 59
TW at WSR	(6.5;31;194) (CFU/100 mL), n = 35
HRRW + TW at WSR*1	(3;5;31) (CFU/100 mL), n = 25
HRRW + TW at WSR*2	(1;10;37) (CFU/100 mL), n = 21
HRRW + TW at WSR*3	(2;10;51) (CFU/100 mL), n = 17
DW at DWSC	(1;9;79.5) (CFU/100 mL), n = 12
HRRW at DWSC	(1.75;6.5;35) (CFU/100 mL), n = 20
TW at DWSC	(3;14;24) (CFU/100 mL), n = 5
HRRW + TW at DWSC*1	(2;8;34) (CFU/100 mL), n = 25
HRRW + TW at DWSC*2	(1;4;29) (CFU/100 mL), n = 21
HRRW + TW at DWSC*3	(1;1;1) (CFU/100 mL), n = 17

[a]CFU = Colony Forming Unit; [b]DW = Desalinated Water; HRRW = Harvested Roof run-off Rain Water; TW = Tankered Water; WSR = Water Storage Reservoir; DWSC = in-house Drinking Water Storage Container.

These *E.coli* concentrations were translated to concentrations of the target pathogens in the different drinking waters and on hands by the formulas and data described in the annex.

3.2. Intake and dose

In the household, hygiene during taking of water from the storage container to drink (microbial pathways 17 and T9) were considered to contribute to the microbial contamination of drinking containers, and therefore, to the final ingestion dose through the drinking water route. Most of research in the literature reported that the mean intake of water per person varies between 1.10 and 1.50 liters per day (Williams et al., 2001). However, a higher volume was adopted in this study because it was expected that people in the semi-arid region would drink more water. Moreover, based on the fact that people normally drink water at various intervals throughout the day and the contamination of drinking containers (DC) was considered in this assessment, the risk of infection was based on the ingested dose per event rather than the daily intake of water. The ingestion dose for the drinking water and the hand-to-mouth routes were estimated based on the formulas 1 and 2, respectively.

$$ID(TP) = (CTP_{DWSC} \times V_{DC} \div 100) + NTP_{hands} \times PMC_{Hands-DC} (1)$$

ID (TP) = ingestion dose of a certain target pathogen (n); CTP_{DWSC} = concentration of target pathogens at the in-house drinking water storage container; NTP_{Hands} = number of target pathogens on hands (n/two hands); $PMC_{Hands\text{-}DC}$ =

proportion of microorganisms' contribution from hands to drinking containers (%).

The number of hand-to-mouth touching events per day was assumed to be ten, based on the findings of a recent research undertaken in rural Accra, Ghana (Antwi-Agyei et al., 2016). However, another triangular PDF was created to include uncertainty on the daily number of events that someone consumes water in this analysis. This PDF was assumed to have a minimum of one, maximum of ten and mode of six events per day.

$$ID(TP) = NTP_{Hands} \times PTPTE_{Hands-mouth} \times PTTPT_{Hands-mouth} \quad (2)$$

ID (TP) = ingestion dose of a certain target pathogen (n); NTP_{Hands} = number of target pathogens on hands (n/two hands); $PTPTE_{Hands-mouth}$ = proportion of target pathogens transferred per event; $PTTPT_{Hands-mouth}$ = Percentage of times that hands transfer target pathogens to the mouth.

Health effects assessment

A Beta-Poisson model was used to assess risk posed by *Salmonella* spp. and norovirus, whereas risk of infection posed by *Giardia lamblia* was performed using the exponential dose-response model. The dose-response models and their respective parameters were adopted from the Centre for Advancing Microbial Risk Assessment (CAMRA, 2015), and are summarized in Table 2.

Table 2. Selected parameters for dose-response models

Host type	Agent Strain	Route	Best Fit Model	Optimized Parameter(s)	LD50/ ID50[a]	Reference
Mice	*Salmonella meleagridis* strain I	Oral	Beta-Poisson	α^b = 3.89E-01, N50 = 1.68E+04	1.68E+04	McCullough and Eisele, 1951
Human	Norovirus	Oral	Beta-Poisson	α = 1.11E-01, N50 = 1.70E+04	1.70E+04	Leak et al., 2011
Human	*Giardia lamblia* from an infected human	Oral	Exponential	K^c = 1.99E-02	3.48E+01	Rendtorff, 1953

[a]LD50/ID50 = Lethal Dose 50 / Infectious Dose 50 = The amount of microorganisms that is sufficient to kill 50% of a population; [b]α = parameters of the beta-Poisson distribution; [c]K = survival probability, N50

Risk characterization

The probability of infection per person per year was stochastically estimated by combining the ingestion dose for each scenario variant with the dose-response model and performing simulations with 10,000 iterations using the Latin hypercube sampling technique.
The risk assessment applied to all water sources identified in the rural communities, considering the proportional volume of use of each source, resulted in a high risk of infection for all TP: *Salmonella* spp. (4.0×10^{-2}), *Giardia lamblia* (6.2×10^{-2}) and norovirus (one), compared to the maximum level of risk (10^{-4}) suggested by the US-EPA guidelines. The hand-to-mouth route was observed to pose a slightly lower risk compared with the drinking water route for *Salmonella* spp. (1.1×10^{-2}), *Giardia lamblia* (3.7×10^{-2}) and norovirus (8.0×10^{-1}), but still represented a significant level of risk to human health.

The assessment of the three most used water sources for drinking (desalinated water, harvested roof run-off rainwater and tankered water) indicated a moderate to high risk for all microorganisms assessed in this study (as shown in Table 3). Unexpectedly, desalinated water presented higher risk for both *Salmonella* spp. and *Giardia lamblia* compared to harvested roof run-off rainwater (HRRW) and tankered water (TW). This was very likely caused by the inadequate transportation, handling and storage of drinking water.

Table 3. Median annual risk of infection per person for the population consuming the various available water sources in the rural communities studied

Target Pathogen	Desalinated Water Users	Harvested Roof Run-Off Rainwater Users	Tankered Water Users
Salmonella spp.	7.3E-02	5.1E-02	6.8E-02

Target Pathogen	Desalinated Water Users	Harvested Roof Run-Off Rainwater Users	Tankered Water Users
Giardia lamblia	2.7E-02	1.9E-02	2.2E-02
Norovirus	1	9.9E-01	1

The risk assessment of the different types of drinking water treatment (reported by consumers) showed that consumers using ceramic candle filters had a significantly lower risk of infection by *Giardia lamblia* and a slightly lower risk for both *Salmonella* spp. and norovirus, when compared to users consuming non-treated or chlorinated water (Table 4). Although it was expected that *Salmonella* spp. and norovirus would be removed more effectively by chlorination compared to ceramic filtration, it was observed that users that reported to use chlorine tablets to treat their drinking water prior consumption were inadequately applying it (or not using it at all), mainly because of taste and/or odour issues.

Table 4. Median annual risk of infection per person for the population consuming non-treated and treated (chlorination and filtration) drinking water in the rural communities studied

Target Pathogen	Non-Treated Water Users	Chlorinated Water Users	Filtered Water Users
Salmonella spp.	5.4E-02	4.7E-02	2.5E-02
Giardia lamblia	2.0E-02	1.7E-02	8.1E-03
Norovirus	1	9.9E-01	9.7E-01

Risk management

The QMRA outcomes were very helpful for identifying the most useful and appropriate risk management strategies for use within the rural communities in semi-arid regions of Brazil. The high risk of infection (especially for norovirus) observed in this study, even in desalinated water stored within the drinking water container showed that microbial contamination was happening at the household level and that was nullifying the effect of water treatment. So more effort should be directed towards raising awareness among local inhabitants with regards to water, sanitation and hygiene issues within the domestic environment.

It was also recommended that the use of ceramic candle filters should be promoted because of their high level of social acceptability, observed efficacy in reducing microbial contamination of drinking water and consequently in reducing the risk of diarrheal disease. Moreover, it was recommended that these filters should include an activated carbon component to enhance the social acceptability of a previous chlorination step within the water storage reservoir. Finally, the study also suggested that the Brazilian health authorities need to do more to direct efforts to raise awareness and educate local residents with respect to water, sanitation and hygiene.

Evaluation of the QMRA

The approach to risk assessment performed in this study provided valuable quantitative information to suggest that rural populations living in the semi-arid region of North East Brazil were at a high risk of infection by locally relevant pathogens, independently of the water source used. This assessment showed that even desalinated water can be highly contaminated by the time it reaches the drinking water storage container, and therefore, that the transportation, handling and storage of drinking water should be done carefully and safely. Finally, the QMRA approach adopted here helped facilitate understanding of a complex water supply system, in which consumers often received water from multiple sources.

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