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HUMAN SYSTEMS

WATER CONTAMINATION IN PUERTO AYORA: APPLIED INTERDISCIPLINARY RESEARCH USING *ESCHERICHIA COLI* AS AN INDICATOR BACTERIA

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Photograph: Noémi d'Ozouville

Water contamination in Puerto Ayora: Applied interdisciplinary research using *Escherichia coli* as an indicator bacteria

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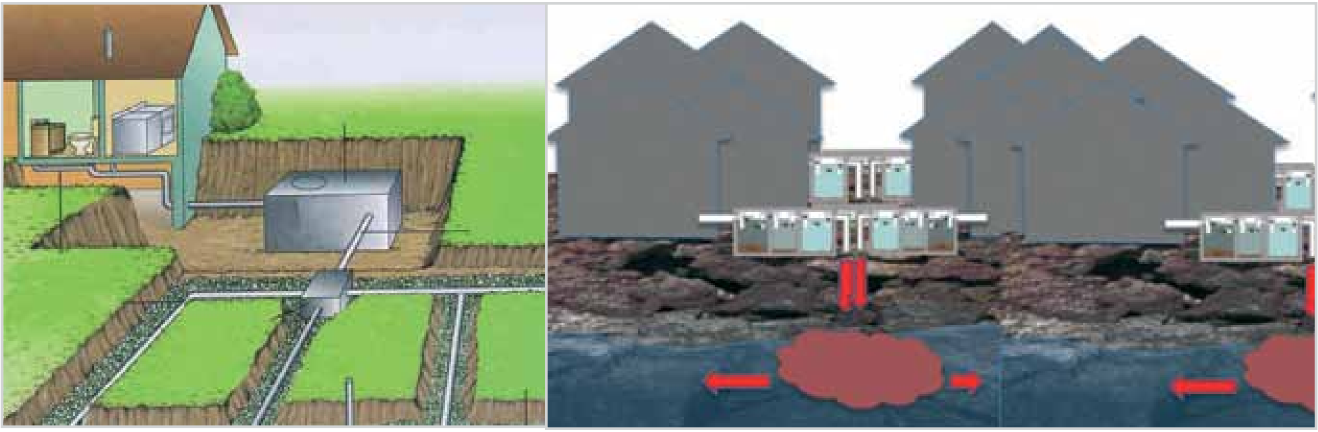
Introduction

*""...from the well there came out **water saltier than that of the sea**; on land they **were not even able to find even a drop of water for two days**…" Tomás de Berlanga, 1535. Letter to his Majesty King of Spain.*

The quality and quantity of freshwater has been an ever-present problem in the Galapagos (d'Ozouville & Merlen, 2007). Of the five inhabited islands, only San Cristóbal has a permanent freshwater source in the form of surface streams. The other islands depend on small-outflow springs (Floreana), extraction from brackish basal aquifers (Santa Cruz and Isabela), or other sources such as transport in and desalinization (Baltra) for their water supply (d'Ozouville, 2007; Guyot-Tephany *et al.*, this volume). Both Santa Cruz and Isabela experience contamination of their groundwater supply due to the location of the basal aquifer beneath dense urban settlements, the lack of effective wastewater treatment, and mixing with seawater (López & Rueda, 2010). Poor water quality has been associated with predominant health problems in those communities (Consejo de Gobierno de Galápagos, 2010).

The municipal water supply in Puerto Ayora is affected by restricted hours of distribution and problems in the piped distribution network (Guyot-Tephany, 2010). Drinking water is dependent on private water purification companies and, for a portion of the population, on precipitation (d'Ozouville, 2008). Water quality is a major concern (INEC, 2011) as high concentrations of *Escherichia coli* in the basal aquifer that supplies Puerto Ayora have repeatedly been identified since the mid 1980s (INGALA *et al.*, 1989; Proctor & Redfern Int, 2003; López & Rueda, 2010). The use of on-site sewage disposal systems in the form of septic tanks (Figure 1) is inadequate for preventing groundwater contamination. They were used initially by the first settlers (1930s) and have persisted through time regardless of changing realities (urban expansion and densification; Sánchez, 2007), primarily due to the prohibitive cost of implementing traditional gravity-fed sanitation in the volcanic ground. In the hope of finding innovative long-term solutions to the problem, small-scale public and private sanitation initiatives are currently underway: the municipality operates two artificial wetlands to treat the effluent from food processing and manufacturing plants, and a hotel and a small highlands urbanization each have a complete sewage treatment system.

This study aims to establish a baseline of bacteriological water contamination and health for Santa Cruz Island, where 17,000 people live (INEC, 2011) and which receives the majority of the 180,000 annual visitors to Galapagos (Dirección del Parque Nacional Galápagos, 2011). *E. coli* is used as an indicator of human contamination because it is easy to measure and can indicate the presence of pathogens that are more harmful to humans but more difficult to detect.



Ideal Septic System:	Currently in Puerto Ayora:
Septic tank + drainage field=	1,500 septic tanks, no drainage fields =
anaerobic + aerobic phase;	high bacteriological load of water exiting tank;
Remote areas, low pop. density;	High population density;
Downstream from water source;	Settlement directly above water source;
Buried in the ground/soil;	Tanks above permeable fractured lava bedrock;
Regular pumping of septic tank.	No regular pumping of septic tank.

Figure 1. Septic Tank Fact Box: comparison between the ideal septic system installation and the current situation in Puerto Ayora, Santa Cruz.

Methods

In addition to the collection of water samples, we examined the water issue from broad social and environmental perspectives, and then narrowed it down to individual knowledge, perception, and practices (Figure 2). Key components included:

1. **Water samples:** Analysis of about 500 water samples, testing for *E. coli* and total coliforms. Samples were collected from various geographical locations within the basal aquifer as well as at strategic locations along the supply route from the source to point of use in households, for both domestic and drinking water. Blank samples were carried out as a control measure on the sampling and analysis process. Results are presented as median values of all samples.

2. **Household surveys:** 150 household surveys were conducted on knowledge, attitudes, and practices regarding water, health, and sanitation. Each household was visited three times: 1) to introduce the project and carry out the survey; 2) to obtain water samples, and 3) to communicate personalized results.

3. **Interviews and information:** Information from labs and hospitals regarding illnesses and analysis results were compiled for the period from November 2009 to October 2010. Interviews with water companies, doctors, laboratories and authorities were conducted.

Basal aquifer

Water was sampled from eight urban and peri-urban crevices ("grietas") (Table 1, Figure 3). Sites within urban limits had higher levels of contamination than those located on the outskirts or several kilometers away from town. Three of the four municipal extraction sites presented low *E. coli* levels (0-10 CFU/100 ml). The Misión crevice presented extremely high levels of contamination and was officially closed by the municipality in October 2011 (D. Sarango, pers. com.). High levels of total coliforms in certain crevices (Figure 4) indicate that they are subject to general environmental contamination and require increased protection.

The results are consistent with the expectation that septic tanks within the densely populated areas are the principal source of fecal contamination. Findings also suggest that water flow within the basal aquifer is still seaward, thus protecting water sources that are located upslope from contamination sources. However, excess pumping could cause flow in the basal aquifer to become landward placing upslope sources at risk. Further inland development could lead to future contamination if no significant precautionary measures of wastewater management are implemented. Of particular concern are housing developments: 1) around the deep well; 2) in the Guayabillo precinct above La Camiseta, and 3) El Mirador, which lies upslope of the INGALA crevice.

[1]**Total coliforms:** indicate environmental contamination from soil, leaves, animals; **Fecal coliforms:** indicate contamination from birds and mammal feces (including humans); ***E. coli*:** indicates contamination from human and other mammal feces. **Units:** Colony Forming Units (CFU)/ml or Most Probable Number (MPN)/ml. **Norms in Ecuador for domestic water:** 600 MPN/ml for fecal coliforms (MPN and CFU are not interchangeable nor can they be inter-converted).

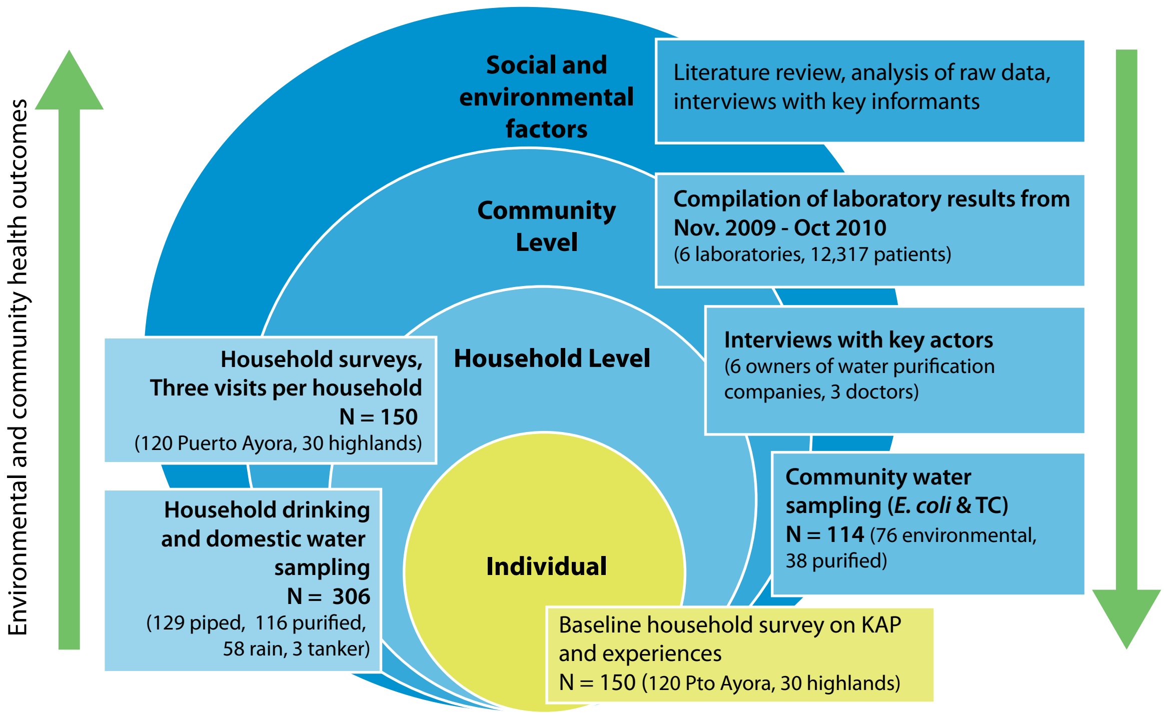


Figure 2. Diagram representing integrated levels methodology.

Domestic water supply

E. coli levels in households, while extremely variable from household to household, were consistently higher than levels detected at their respective source (Figure 5). Previous studies have consistently shown similar patterns of increased contamination when water is stored in the household (Oswald *et al.*, 2007; Brick *et al.*, 2004; Wright *et al.*, 2004). Recontamination can occur in the distribution system, in the household storage system, or due to household practices, such as storing water in a non-sealed container, using a ladle, or pouring to dispense water instead of a spigot. This highlights the importance of behavioral changes at the point-of-use and clean storage options. Central chlorination with cloro-gas as was done in the past does not prevent recontamination. Until uninterrupted water supply is possible, re-contamination will likely continue at a high rate.

Potable water – desalinization and bottling plants

Private purification companies (currently six though there

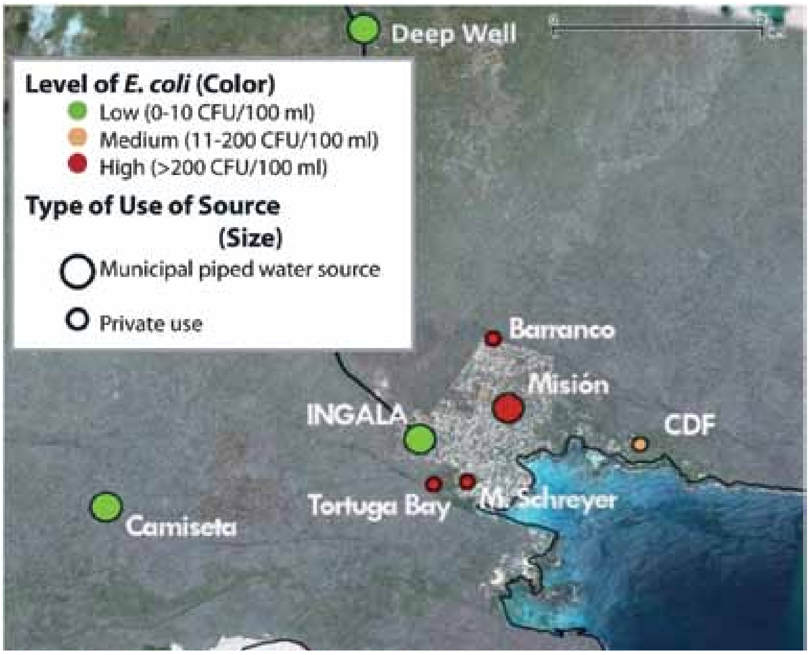


Figure 3. Map of water source and contamination levels for Puerto Ayora.

were only five at the time of the study) provide water for homes, offices, restaurants, hotels, boats, and shops (Figure 6). The majority of water sales occur in Puerto Ayora, with a small percentage going to Bellavista and Santa Rosa. Water is sold in three forms: 1) bulk (~US$30/$m^3$), 2) reusable 5-gallon bottles (~US$100/$m^3$), or 3) new bottles (5 L, 2 L, 500 mL; at ~US$120/$m^3$). An estimated 30 m^3 of desalinized water is sold daily across all water purification companies. According to the owners, there is no on-site storage of production; all the water produced is sold the same day.

Samples of purified water taken immediately after processing showed undetectable *E. coli* levels. Similarly bottled water in sterile 0.5 L and 5 L non-reusable containers showed undetectable levels. In contrast, results

Table 1. Characteristics of water sources for Puerto Ayora.

Source	Vegetation cover	Urban cover	Salinity	Users	Use	Dist. to sea (m)	Altitude (m)
Charles Darwin Research Station	Low	Low	6.8	NGO	Domestic	100	15
Eden cemetery	High	High	--	Private	Domestic	50	5
Misión Franciscana (closed as of October 2011)	None	Very high	2.3	Municipal & private	Distribution network & private desalinization plant	545	20
El Barranco	Low	High	1.4	Private	Tanker trucks	1,200	31
Martin Schreyer A & B	Low	High	--	Private	Desalinization & distribution	280	15
Miguel Cifuentes Center/Tortuga Bay entrance	High	Low	2.8	Private	Desalinization & potable water	500	17
INGALA/Pampas Coloradas	Low	Medium	1.7	Municipal	Local distribution	1,100	23
La Camiseta	High	(National Park)	2.9	Municipal	Local distribution	1,600	34
Deep well	High	Low	0.8	Municipal	Local distribution	4,700	157

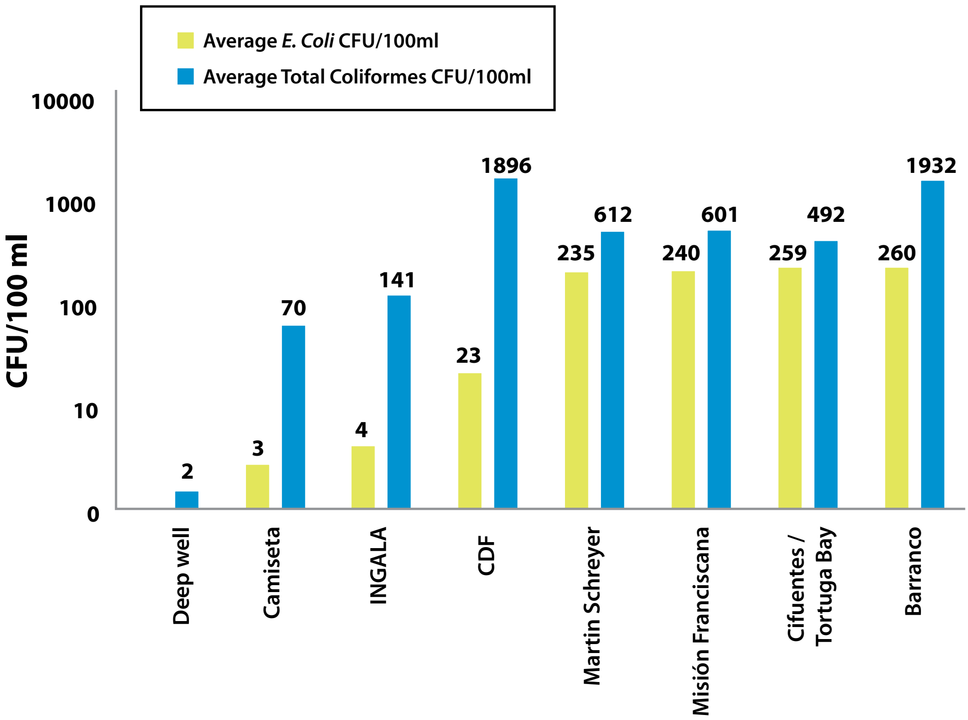


Figure 4. Bacteriological contamination of water sources on Santa Cruz Island: levels of *E. coli* and total coliforms (CFU = Coliform Forming Units).

from bulk water and reusable 5-gallon bottles showed highly variable levels of contamination, independent of the source. Compromised quality of bulk water can be associated with potential sources of contamination during transport and storage. Random and extremely variable contamination of the 5-gallon bottles can be attributed to the absence of a fixed sterilization protocol for the returned jugs and unknown state of storage and transport of jugs between households and purification companies. Thus, although the majority of water sterilization practices are compliant and samples had undetectable levels of *E. coli,* bottling clean water in dirty, reused containers, transportation, and lack of control over clients' home environments are challenges to providing safe drinking water.

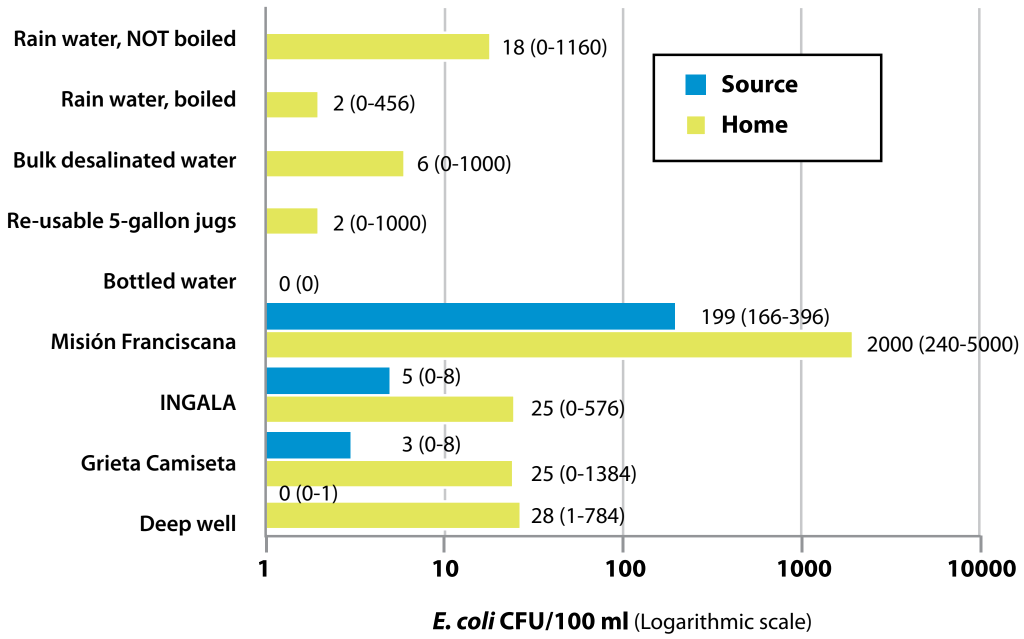


Figure 5. Comparison of level of contamination (*E. coli*/100 ml), at the source and in the home, showing median values and range of all results.

Health and household practices

Biological water contaminants can cause gastrointestinal, respiratory and skin infections, and exacerbate normally healthy flora in urinary and reproductive tracts. Seventy-six percent of the household surveys indicated that at least one family member had one or more of the sickness indicators during the two weeks prior to the survey. Less than 50% of households reported respiratory infection symptoms or a gastrointestinal infection (41% and 40%; Figure 7). Of all respondents, 13.3% reported not feeling well enough to work due to stomach problems. The results from 3541 stool analyses demonstrated the frequency and type of gastrointestinal infections: 64% were positive for parasitosis (Figure 8).

Annual incidence of gastrointestinal parasitic infection in the Santa Cruz population was estimated at 9-13.5% after eliminating an estimated 10-40% of patients who were tourists. Of the surveyed respondents, 81% indicated that they had taken anti-parasitic medications at least once in their lifetime.

Household precautions around water storage and dispensing are important to prevent point-of-use contamination. Although 58% of households kept their drinking water in covered containers, many containers were not seal-tight (e.g., lids on pots, plastic covers on 5-gallon bottles). Method of dispensing drinking water is also associated with *E. coli* contamination levels. Using a spigot is better than using a cup or receptacle to scoop water out of the storage container. Of the surveyed households, 19% of respondents used a spigot.

Multivariate models of socioeconomic factors, household practices, and water characteristics showed that bacteriological quality of domestic water and drinking water did not, in itself, explain the high incidence of water-related illness. Relationships between household practices, level of contamination, and incidence of illness are complex. This can be explained by: 1) occurrence of illness related bacteria that is independent from the degree of *E. coli* contamination; 2) the existence of other fecal-oral transmission pathways from food or lack of hand hygiene; and 3) methods of storing or dispensing potable water that may cause re-contamination.

Conclusions

This study has highlighted that the Municipality of Santa Cruz operates three water sources that present low *E. coli* contamination, but that the current water distribution system and common household practices are increasing the level of contamination. Making potable water a

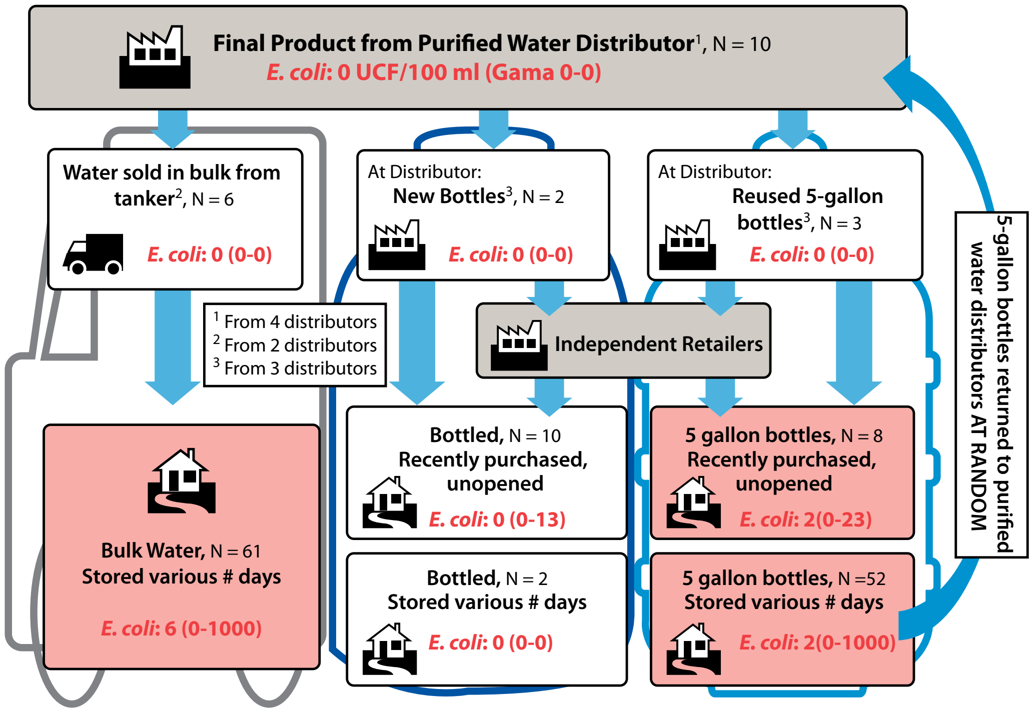


Figure 6. Diagram of water distribution system in Puerto Ayora.

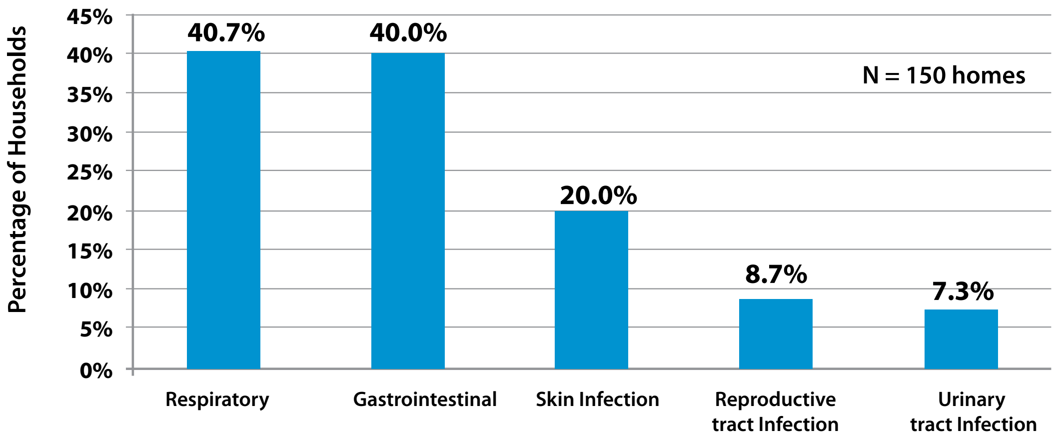


Figure 7. Morbidity of water-related illness in homes in Santa Cruz during the two weeks prior to the survey.

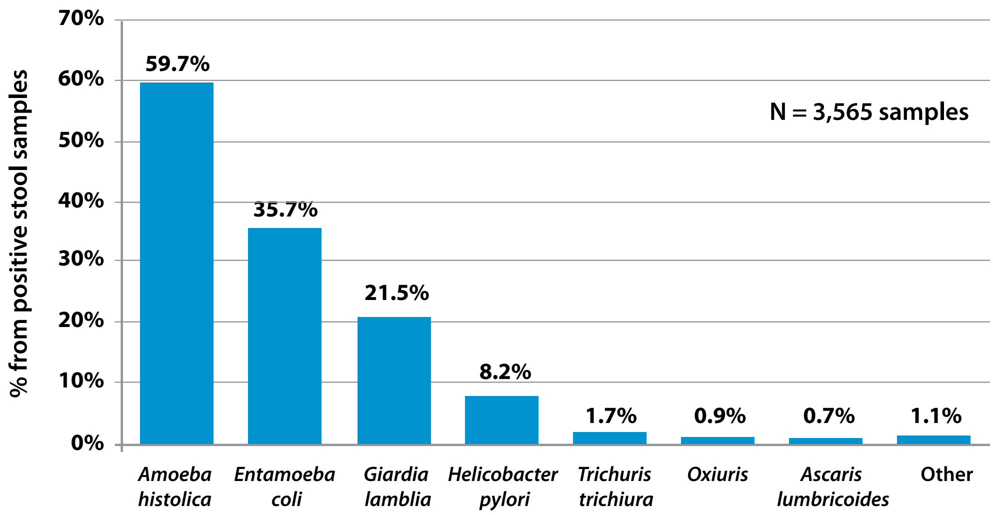


Figure 8. Diagnosed parasitosis rates in Puerto Ayora, October 2009 – November 2010. Parasites identified in stool samples in Puerto Ayora labs; stool samples represented 29% of all exams and 64% were positive.

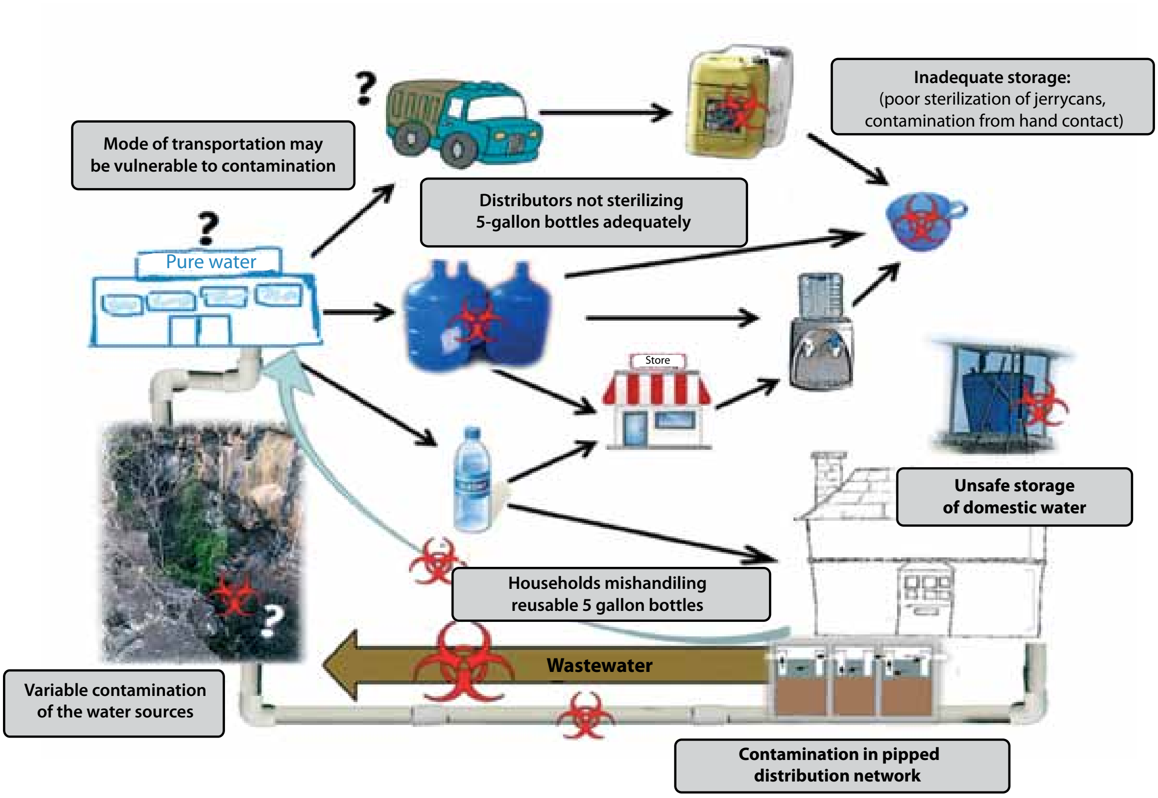


Figure 9. Diagram of the current water flow model for domestic and potable water from source to sink in Puerto Ayora and weak points in the system.

reality for Puerto Ayora must include a complete review of distribution, storage, and household practices (Figure 9). Implementation of a large-scale brackish water desalinization plant will only guarantee safe household water for domestic and drinking use if it is one component of an integral water system.

Furthermore, this study has shown that all levels of the community are at risk from a water-related illness from drinking water due to variable sterilization practices and conditions of reusable water containers. Any given restaurant, household, boat, or hotel could have contaminated bottles, which could have consequences for human health and private businesses.

Lastly, malfunctioning septic tanks have again been shown to greatly compromise water quality. Improving the sanitation system requires immediate attention, as private and clandestine water use in town will continue to tap into a contaminated source.

Recommendations

Based on the results and conclusions of this study, we propose the following recommendations in order to guarantee improved water quality and health of the community in the short and long term:

1. Weekly bacteriological water quality monitoring of municipal water supplies. Analysis should be done in Galapagos in existing laboratories by a trained technician, rather than having samples sent to the mainland.
2. Establishment of a municipal mandate requiring certified sterilization of reusable 5-gallon jugs for drinking water.
3. Immediate closure of any extraction sites with *E. coli* levels above recommended limits.
4. A halt to the use of septic tanks and the implementation of alternative sanitation systems either within individual households (“on-site”) or by collecting waste from individual houses and taking it to an “off-site” treatment plant.
5. Implementation of a community education campaign on how to protect household drinking water and domestic use water from contamination.

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