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Water quality for guest health at remote Amazon ecotourism lodges

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ABSTRACT

Remote rainforest lodges are a growing part of the ecotourism industry. They can provide benefits through employment, environmental protection, and opportunities for scientific research. Lodges are vulnerable to income interruptions which put these benefits at risk. Authors identified water-related health crises as a potential interruption. Four lodges in lowland rainforest of southeastern Peru were visited to assess water quality, hygiene practices, and the relationship between water quality and guest experience. Thermotolerant coliforms (fecal bacteria including *E. coli*) were measured in drinking, tap, and river water. All treated drinking water contained coliform bacteria. River bacteria indicated possible unsafe swimming conditions. Through interviews with lodge staff, guests and regional stakeholders, a concerning picture developed. National law banned chlorine bleach, management relied upon the TripAdvisor website which did not accurately represent illness rates, and an international accreditation scheme discouraged chemical water treatment. Culture, law, and practice interact to affect bacterial contamination.

1. Introduction

Ecotourism can be a major income generator and support local economies (C. A. Kirkby et al., 2010) in one case offering nearly the double the income of existing opportunities (Hunt, Durham, Driscoll, & Honey, 2015). Conservation scientists note the positive effects of ecotourism beyond building local economic capacity. Ecotourism businesses can reduce threats to the environment such as logging and the hunting of local wildlife, and in some instances, the continued survival of individual animals or species is contingent upon the presence of ecotourism (Buckley, Castley, de Vasconcellos Pegas, Mossaz, & Steven, 2012). In addition, eco-tourism can provide research stations and funding for scientific research that furthers conservation as a science (Brightsmith, 2004). However, remote tourism lodges may have relatively small profit margins and relatively high fixed expenses (C. A. Kirkby et al., 2011). This can make remote ecotourism lodges susceptible to income interruptions.

Preventing remote rainforest ecotourism failure is increasingly important to local economies and ecosystems as the number of lodges increase. Remote rainforest tourism is a growing form of ecotourism. (Torres-Sovero, González, Martín-López, & Kirkby, 2012). A simple search on TripAdvisor.com for "rainforest camp" returned the website's maximum display of 1020 locations. These accommodations typically involve a camp or lodge setting in intact forest located outside of traditional utility grids. Being "off-grid" requires highly technical management to produce potable water for guests and managing use of local water bodies. Without careful management, diseases acquired from drinking, bathing, and swimming, can have direct effects on economic development (World Health Organization, 2013) and severely impact these remote lodges. A fundamental global practice to reduce disease in water is chlorination. When water is underchlorinated, disease microbes can exist and reproduce in the water (WHO, 2011). Though many developed countries have water quality standards in place, many of the countries in the Global South are still lacking necessary support to chlorinate water (Bhalotra, Diaz-Cayeros, Miller, Miranda, & Venkataramani, 2017).

The World Health Organization (WHO) considers small community-managed water sources, such as those utilized in remote ecotourism, especially prone to contamination (WHO/UNICEF Joint Water Supply & Sanitation Monitoring Programme, 2014). The most common illness acquired by tourists to the developing world is traveler's diarrhea (TD) (Connor & Riddle, 2013). Bacteria are thought to account for 80%–90% of TD cases (Connor & Riddle, 2013), which are often thought to be *E. coli.* When caused by *E. coli* bacteria, TD will usually clear spontaneously but in some cases it can cause some serious or fatal diseases, including hemorrhagic colitis, hemolytic-uremic syndrome, and long

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term disease such as irritable bowel syndrome (Connor, 2017; Nataro & Kaper, 1998; Noris & Remuzzi, 2005). Some destinations can have illness rates up to 70% for tourists (Connor & Riddle, 2013). Tourists from the developed world may expect a greater than 50% chance of becoming ill. (May, 1989).

In the context of ecotourism, guest health should be central to destination management in order to ensure the sustainability of tourism (Musa, Hall, & Higham, 2004; WHO, 2011). Ill guests can cause many difficulties for individual companies. When guests become sick they may change their itineraries, (May, 1989), and even brief bouts illness may lead to costly litigation such as in the case of a lodge's settlement of $10,000 per guest (Pineiro-Zucker, 2016). A severe disease outbreak can affect the industry through bad publicity and loss of revenue (Marti, 1995). In Mexico, an H1N1 flu outbreak in 2009, caused an estimated loss of 2.8 billion USD (Rassy & Smith, 2013). Tourists can return home carrying water-acquired diseases with them, causing international disease outbreaks, such as the case of hotels in the Canary Islands which shared an unsafe well. Guest of these hotels returned to four countries, bringing with them 15 cases of Vero cytotoxin-producing *E. coli* O157. (Pebody et al., 1999).

Overall, the tourism literature has limited discussion of tourist health. A "lack of research" connecting health and tourism was noted during the 1992 conference on Food Protection and Tourism (Spivack, 1994). Over the last 25 years, arguably little advancement on the subject has taken place: Our search of the leading tourism journals (*Journal of Travel Research*, *Tourism Management*, *Journal of Sustainable Tourism*, *Annals of Tourism Research*, and *Journal of Ecotourism*) using terms, "*E. coli*" and "traveler's diarrhea" returned only 11 results. While papers mentioned *E. coli* in various contexts, there was not a focus on tourist health despite this being an extremely common tourist ailment.

The general water sanitation literature shows that relatively simple treatments remove the risk of waterborne disease (WHO, 2011). Typically, large particles are removed through settling if the water is not clear. Once visually clear, water is put through a nanopore filter to remove larger organisms, such as parasite eggs. Then, the water is chlorinated to inactivate bacteria and viruses. Enough chlorine is added so that after inactivating microorganisms there is still extra chlorine ("residual chlorine") to prevent re-contamination of stored water by hands or utensils (Centers for Disease Control, 2014). When combined with hygiene of hands, drinking cups, and used water bottles (Rufener, Mäusezahl, Mosler, & Weingartner, 2010) most sources of illness can be eliminated.

When caused by water, as opposed to foods, TD is not always caused by the drinking supply. Natural water bodies can also be a source of disease. The water ingested while swimming (Dufour, Evans, Behymer, & Cantu, 2006) or boating (S. Dorevitch et al., 2011) can cause illness. A study showed 1.5% of those who engaged in limited contact freshwater activities in natural water, such as kayaking or fishing, became ill afterwards (S. Dorevitch et al., 2012), whether or not the water body was directly impacted by sewage. Exposure to disease causing organisms can increase when the shoreline or bottom are disturbed during recreation (Heaney et al., 2009;Whitman and Nevers, 2003). The lodges in the Madre de Dios region of Peru are heavily studied, with over 700 papers mentioning ecotourism in the region. The frequent publication makes the region a model for remote rainforest ecotourism. We visited four lowland tourism lodges within Madre de Dios, to collect information about lodge utilization of chlorination, guest education, guest health tracking, and hygiene.

We tested drinking water, tap water, and rivers for fecal bacteria. We also interviewed lodge staff about water issues and investigated health issues through anecdotal tracking of our own group participants and through online guest reviews.

2. Methods

2.1. Study area

The study was conducted in the watershed of the Madre de Dios region in the lowlands of southeastern Peru in the areas surrounding the city of Puerto Maldonado (12° 35.226′ S, 69° 11.820′ W). Areas of forest are grouped into reserves (SERNANP, 2018), most notably Manu National Park, (1 716 295 ha), Tambopata National Reserve (274,690 ha) and Bahuaja-Sonene National Park (1,091,416 ha). The region contains lowland tropical rainforest, with average annual rainfall up to 3000 mm (Brightsmith, 2004; Vuohelainen, Coad, Marthews, Malhi, & Killeen, 2012). Certain charismatic megafauna can be reliably observed by visitors, including three large macaw species (genus *Ara*), giant river otters (*Pteronura brasiliensis*), five monkey species (suprafamily Ceboidea), and caiman species (subfamily Caimaninae). The region is also home to a form of strip mining along rivers to attain gold rich silt which encroaches upon protected lands (Gardner, 2012). The study area was visited during a 22-day period in May 2015. Three authors were present for the travel, DJB, AMV, and CJW. CJW took and incubated samples, AMV interviewed Spanish-speaking lodge and protected area staff. DJB oversaw research activities and made introductions for interviews.

2.2. Lodges

Four lodges with different primary owners were included in this study. Each lodge required access via river boat and was off the traditional utility grids. As a result, all lodges provided their own electric, water, and sewage. Lodges could accommodate an approximate range of 10–50 guests per night. Per night stay cost between $40 and $160. To help ensure anonymity of the lodges who allowed us to test their water, the names and exact locations of lodges are withheld. The site descriptions are based on private tours and interviews with onsite managment and staff and may reflect imperfect communication or staff knowledge. For example, a former manager who reviewed this reviewed this manuscript for accuracy stated that chlorination occurs at lodge D, and also at lodge B. However, on site, staff did not include chlorination as part of their water treatment.

Lodge A was a newly constructed primitive forest camp with an open, roofed dining and cooking area. Commercially bottled "water cooler" style bottles were hauled in by boat and not re-used. Wastewater treatment was a commercial biodigester. It was located at the intersection of a river and a tributary creek. The creek water was the source for the lodge's washing water system. The creek was also used for swimming and occasional bathing. This was the only lodge with an open kitchen, all others had screening.

Lodge B was a high-end, resort-style lodge blending some features of a primitive camp with high-end vacationing, such as open-air structures with limited satellite internet, and an on-call masseuse. A well supplied the water used for washing and showers. The stored well water was filtered, ozonized and placed in reusable water cooler style dispensers for drinking water. Biodigesters processed wastewater. The lodge was adjacent to a major river, river swimming by guests was apparently possible, but discouraged by the company, and was not seen during the visit. This lodge was accredited through the Rainforest Alliance Certification Services for Tourism Businesses.

Lodge C was a bed-and-breakfast style accommodation built on a lake inland from the river system with a totally enclosed kitchen. Lake water was used for washing and showering. The lake water was treated with chemical tablets, placed in reusable dispensers, and offered as drinking water. Wastewater treatment was through a series of connected cesspits. The lake was utilized for boating, wading, and swimming.

Lodge D was a high-end lodge. a well was used for washing and showers. The stored well water was filtered and ozonized, placed in reusable water-cooler style dispensers, and offered as drinking water.

Table 1
Fecal coliform bacteria in lodge water samples from southeastern Peru. Total fecal coliforms per liter were calculated as a count of the number of bacterial colonies that grew from 1 ml of water. The EPA goal of zero colony forming units per liter is provided for comparison ...

Measurement	Fecal coliform bacteria per 1 ml	*E. coli* per 1 ml	Source	Total fecal coliform bacteria per 1 ml	*E. coli* per 1 ml
EPA Maximum Contaminant Level Goal per liter (EPA 2013)	0	0	Lodge A commercially bottled drinking water	0	0
Lodge An untreated tap water	7	1	Lodge B ozonated and filtered drinking water cooler	9	0
Lodge B untreated tap water	0	0	Lodge C tablet treated and filtered drinking water cooler	44	6
Lodge C untreated tap water	0	0	Lodge D ozonized and filtered room pitcher	2	0
Lodge D untreated tap	20	13	Lodge D ozonized and filtered drinking cup	11	0
Port city municipal tap	0	0	Port city municipal source in a restaurant drinking cup with ice	5	0

Two biodigesters processed wastewater. The kitchen area was screened. The lodge was adjacent to a major river. River swimming occurred during the visit. This lodge was accredited through the Rainforest Alliance Certification Services for Tourism Businesses.

2.3. Sample collection

With permission from the lodge management, samples were taken from lodge water sources and the river access near each lodge. Samples were also collected from the river near Puerto Maldonado. Due to portable incubator size limitations, a single measurement was taken for each category. For tap water collection, researchers ran the faucet for 30 s then collected 50 ml water samples in sterile test tubes. Drinking water samples were collected in similar tubes directly from water coolers or water pitchers depending upon how they were offered at each lodge. River samples were obtained by boating to the center of the river, and dipping a sterile collection tube into the water, swirling the tube under water, and then capping the tube immediately.

2.4. Indicator bacteria enumeration

Water samples were chilled in a cooler on ice or refrigerated within 4 h of collection to reduce bacterial die-off (Flint, 1987) and incubated within 30 h of acquisition following US EPA guidelines for holding water test samples (EPA, 2013). pH of the samples was checked, because the process depends on acidity of the sample.

Utilizing 3M Petrifilm product instructions for sampling and incubating, 1 ml amounts were taken from each sample using a sterile-tipped micro-pipette and spread on 3M Petrifilm *E. coli*/Coliform Count Plates. All pipetting was done adjacent to a burning candle or large grilling lighter to draw in falling dust and prevent particles settling on the plate during pipetting. For incubation, a Jameson brand portable field incubator was used for 24 h at 44.5 C, using 12-V car batteries when electricity was not available. Incubated plates were photographed and counts carried out. The types of bacteria identified were fecal bacteria and a type of fecal bacteria called *E. coli*, as based on their color and gas production.

2.5. Anecdotal human health

To understand if people were becoming sick with TD or other ailments associated with poor water quality, authors spoke with staff members at each lodge. Authors spoke with lodge owners, lodge managers, two trail guides, a research director, and a staff member that supervised special multi-week stays. The authors were travelling with a group of 18 people and noted the health status of their own group throughout the trip.

2.6. TripAdvisor methodology

In order to determine the incidence of disease self-reported by tourists, the researchers read all relevant reviews on TripAdvisor.com from for each of the four study lodges. At the time of data collection, January 2015, this included 391 reviews from 2007 onward. For each review, any mention of illness, gastrointestinal issues, or drinking water quality was recorded. Lodge A was new and did not have a TripAdvisor profile at the time of data collection, so no reviews were available.

2.7. Practice and beliefs

In order to determine local knowledge and practice regarding water quality, AMV and CJW, spoke with six lodge tour guides, three field scientists, two lodge managers, two lodge owners, one park system guard, and one park system administrator. Discussions were open-ended about water, guest health, and relevant laws and rules. Discussions lasted approximately 15 min and were transcribed.

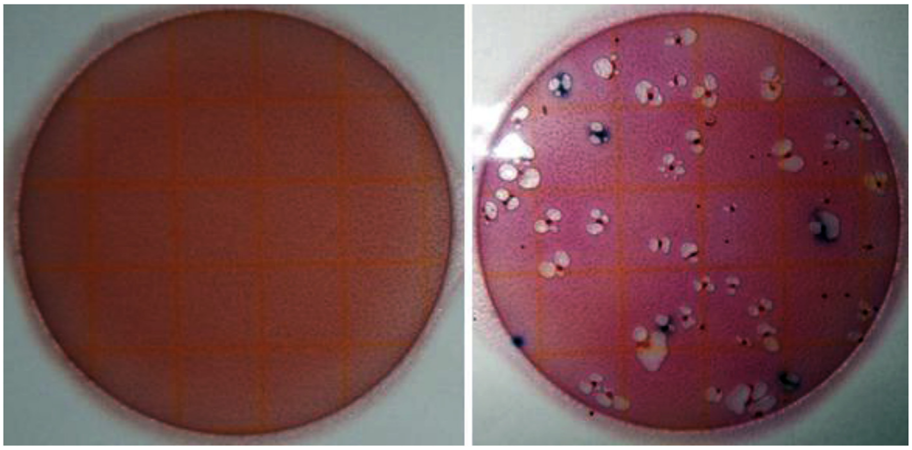

Fig. 1. Incubated samples from lodge C. 3M Petrifim dishes, 5 cm wide, inoculated with 1 ml of untreated tapwater (left) and chemically treated tap water from the water cooler (right) after 24 h of incubation at 44.5 C. In the image on the right, blue colonies with gas indicate *E. coli*, red colonies with gas indicate coliform bacteria. The count in treated water was 44 total colony forming units, six being *E. coli*. This increase in bacteria may indicate re-contamination during handling and storing of water. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

3. Results

3.1. Drinking water

Of the nine 1 ml lodge water samples tested, several showed the presence of fecal bacteria (Table 1). The treated drinking water offered by three lodges contained measurable numbers of fecal coliform colony forming units (mean 16.5, standard deviation ± 18.7, n = 4 samples). At lodges B and C, total coliform counts were zero in the untreated water from the tap but higher in the treated drinking water (9 and 44 respectively). In Lodge D fecal coliforms were higher in the tap water (33) and lower in the treated water (2 and 11, Table 1). The only lodge where coliform bacteria were not discovered in the drinking water was Lodge A which provided commercially bottled water for drinking (see Fig. 1).

3.2. Lodge practice

No lodges were observed treating the tap water ($N = 4$), no lodges were equipped to test their water for microbes on site ($N = 4$), each lodge manager and owner was confident of high drinking water quality ($N = 4$), and one lodge (C) used water treatment tablets in their water. The high-end lodges (B and D) utilized nanopore and ozone treatment for drinking water. A former manager from lodge D stated that residual chlorination, the global standard for water treatment (WHO, 2011), was utilized, as was the case for lodge B, along with quarterly water testing where samples where carried out in cold packs. However, the coliform bacteria in water in the provided drinking cups and room cups may indicate unsuccessful chlorination.

No lodge was observed using sanitizing soaks on their water storage containers. Lodge B was observed swishing a water storage jug with soapy water and rice, using the rice to "scrub" away contamination.

Alimentary (eating and drinking) education was provided to new guests at all four lodges. Guests were instructed to drink only from water coolers and served drinking vessels. Guests were not provided with a way to wash their personal water bottles nor encouraged to do so ($N = 4$). No lodge offered a telemedicine solution or on-site health worker to address guest illness. The two higher-end lodges (B and D) had small plaques in the showers reminding guests that the washing water was not treated ($N = 2$). At lodge D a no-rinse sanitizing dip (Oasis® 146 Multi-Quat Sanitizer) was used after washing dishes. However, this dip made water and food distasteful which lead to some staff rinsing off their dishware with tap water to remove the flavor.

3.3. Septic systems

All lodges used bacteria to break down sewage, either using commercially-purchased biodigesters ($N = 3$), or a series of primitive cesspits connected by a buried pipe ($N = 1$). Managers at lodges with biodigestors were concerned that adding chlorine to the water could inactivate the bacteria in their septic systems.

3.4. Practice and beliefs

Lodge staff, park and reserve staff, and scientists working under research permit all indicated that the use of chlorine bleach was "banned" at the lodges ($N = 6$ individuals across the four lodges). This included the director of Bahuaja Sonene National Park, as well as a guard from the Tambopata National Reserve. Some suggested it was because the lodge owners forbid it due to the damage it could cause to the septic systems, some said it was banned by the ecotourism accreditation agency because of its potential damage to the environment, and others stated it was banned by Peruvian law because it was a chemical used in the making of illicit drugs. However, no one could offer precise clarity about the legal basis of the ban or what group enforced it.

Further research by the authors after completion of field work identified some of the drivers behind these perceived prohibitions. The law behind the "bleach ban" is Peruvian Law Number 29037 for regulated chemicals and controlled substances. The law strictly regulates chemicals associated with the production of cocaine and heroin. As translated by the authors, the list included the active ingredient in household bleach, sodium hypochlorite, in "any amount, shape, or presentation" (Chapter 1, article 4.). The law requires registration, rigorous daily record keeping, and immediate reporting of quantity changes such as accidental spills. As multiple individuals in the lodge system avoided bleach to a widely known but vague "ban," the law has appeared to have negative effects on the use of liquid chlorine bleach for sanitation in the remote lodges.

There may have been additional influences for not using chlorination based on a Global Sustainable Tourism Council (GSTC) accreditation criteria (The Global Sustainable Tourism Council (GSTC), 2016 "Criteria for Hotels", 2012). These guidelines require that "the use of harmful substances," including "swimming pool disinfectants, and cleaning materials, is minimized, and substituted when available, by innocuous products or processes." A suggested companion performance indicator to the GSTC is that "There has been a review of each chemical used to identify available alternatives which are more environmentally innocuous." The regional accrediting body uses a GSTC aligned criteria according to their website, and following such guidelines could logically lead to a reduction of chlorination.

3.5. River fecal bacteria

The 1 ml river water samples all contained *E. coli* colony forming units (Average 6.5 standard deviation ± 6.3 per ml, N = 5 samples,

Table 2
Natural water body fecal bacteria counts, with scaled EPA water quality criteria. The 2012 quality criteria is the geometric mean of *E. coli* colony forming units per 100 ml. This level causes 23 illnesses per 1000 people (EPA 2012). Scaled from "colony forming units" of 100 cfu/100 ml to 1 cfu/1 ml for comparison to the 1 ml mobile water test size used by the authors. Similarly, the 1986 total coliform criteria has been scaled from 200 cfu/100 ml to 2 cfu/ml. The 2012 criteria do not include total coliforms.

Measurement	*E. coli*	Total Coliforms
Scaled 2012 US EPA Recreational Water Quality Criteria for *E. coli*, and 1986 criteria for total coliforms.	1	2
Port city river center.	3	6
Upriver of port city.	3	2
River tributary in reserve.	3	1
Upstream of river tributary in reserve.	13	9
Most upstream tributary within reserve, farthest from port city.	16	13

Table 2). which is comparably above the 100 cfu per 100 ml recreational water body limit set by the United States Environmental Protection Agency (EPA, 2012), which uses *E.coli* only, and not total coliforms for its guidelines.

3.6. Health anecdotes

During the 18-day trip conducted by the researchers, six of the ten travelling companions self-reported having acquired a diarrheal illness. Some illness were debilitating, requiring bed rest. One of the authors required medical attention as the illness did not clear after 10 days. The long-term guest supervisor reported that all the research assistants from the USA who stayed at lodge D for more than two weeks acquired some sort of diarrheal illness during their stay. Staff reported that relatives visiting lodge employees also became ill. A trail guide at lodge B did not drink from the lodge water explaining it was not healthful. The guide instead drank from a hillside seepage by a trail behind the lodge.

3.7. TripAdvisor results

Each lodge manager identified TripAdvisor.com as a major source of reviews and feedback regarding their facility ($N = 4$). The newly built primitive camp lodge did not yet have a TripAdvisor listing and management were eager to create one. Of the 391 TripAdvisor reviews that were examined for the three lodges, only four posts mentioned illness associated with lodge stays ($\sim$1% of reviews). Only one was obviously related to a gastrointestinal issue, referring to a "stomach bug" picked up "somewhere in Amazonia" ($\sim$0.3%). By comparison, five posts mentioned water being clean and safe to drink.

4. Discussion

4.1. How guests are exposed to the bacteria that cause illness

Lodge water and river water exposed guests to fecal bacteria, including *E. coli*. These levels appear to be above the safety levels suggested by the EPA in the United States. Exposure began during the boat ride to the lodge, where tourists were lightly and occasionally heavily sprayed with water from the bow splashes for up to seven hours. Upon reaching a lodge, the tourists could refill their personal bottle or cup and self-contaminate due to their drinking vessel being unclean, a situation in common with other South American locations (Rufener et al., 2010). When lodges processed water for guests, in a cooler, at the dining table, or a jug in the room, there was more exposure to bacteria. Hand washing before a meal or after use of the bathroom would put hands in contact with bacteria in the tap water. At meals, lodge processed drinking water provided further exposure, as would any items that were made with water but not cooked enough to kill bacteria, such as juice mix. During showering, untreated tap water would further expose guests. During any river baths, wading, or swimming, guests would again be exposed. The only drinking water free of fecal contamination was purchased bottled water in a non-reusable jug.

4.2. Health anecdotes

Through conversations with staff, and observing travelling companions, it became apparent that guest illness was common. However, the majority of guests only stayed at each lodge for a short duration (2–4 days). As illnesses like TD can occur as much as 2 weeks after ingesting bacteria, guests might not develop an illness until days after leaving the lodge (Connor, 2017) making it difficult for tourism companies to know the full extent of the illness acquired at their lodges.

Managers thought their purification systems worked. They responded with surprise when we shared the bacterial counts. Staff, researchers, and long-term guests seemed to expect illness during their extended stays but there was not an obvious understanding that these common illnesses could pose a health risk or that a more dangerous illness could be spread the same way TD was being spread.

4.3. TripAdvisor

The TripAdvisor reviews, which are heavily utilized by lodge managers, appear to provide an unreliable story with respect to guest health. The lack of discussion of illness in the reviews seem to provide an inaccurate recounting of guests' experience. Months after our trip, our companions did not write about their experiences despite the majority becoming ill, not even the companion who was bedridden with violent vomiting for two days while at a lodge. We expect that other guests, like our companions, may choose not to report their illnesses. In this way, TripAdvisor may mask health problems as the platform is not designed to report guest health.

Guest satisfaction may remain high despite illness. In a mountain adventure tourism study, where illness rates were known, 92.9% of the 448 people surveyed were satisfied with their experience. This was despite 89.4% of surveyed guests reporting illness (Musa et al., 2004). High guest satisfaction and positive reviews do not indicate the guests are healthy.

4.4. Natural water

All river samples tested during this study were comparably above EPA guidelines for recreational water.

Counts of 100 *E. coli* per 100 mL of water are associated with 32 illnesses per 1000 people (EPA 2012). These *E. coli* guidelines are part of a number of factors used by the EPA to help U.S. state governments determine when and where to close beaches.

In our study, the highest *E. coli* count was from the sample taken the furthest upstream close to the mountains, flowing from a protected area which is basically uninhabited and off-limits to tourism. As samples from further up-river contained more, not less bacteria, there is a contrast with the purity narrative that water from a 'virgin ecosystem' far from polluting civilization is more healthful and desirable (Wilk, 2006). This purity narrative was echoed in the statements to the authors from experienced visitors who suggested that the authors engage in natural water baths while at the lodges. River bathing was conveyed as entirely positive, being "cleansing," and "life changing," as well as hygienic, by other guests. Authors did not encounter cautions against the realities of diarrhea or gastritis. Guests may be arriving at lodges with a cultural belief system that encourages contact with untreated water, without knowledge of the consequences. Frequent televised and internet-based marketing for bottled water has focused on the commodification of nature as a way to deliver purity. This is referred to as a "modern medicine show" (Gleick, 2010) due to the false claims associated with the purity narrative.

4.5. Lodge practice and barriers to best practice

During our visits no lodge staff described utilizing residual chlorination techniques for water treatment. This seems to have been the product of a complex mix of practice, beliefs, guidelines, regulations, and other cultural elements that are worthy of consideration. As an important note, during manuscript revision, a manager from lodge D reviewed this document to help us with accuracy. He expressed that he thought chlorinators were present at Lodge D and lodge B as well. He could not immediately describe how chlorine in the water was monitored. This highlighted differences in staff knowledge observed by the authors.

During initial interviews and discussions, lodge staff stated and believed that their current drinking water quality and handling was adequate and for that reason likely saw no reason to improve water treatment. This belief was supported by TripAdvisor which did not suggest gastrointestinal illness was common. The aforementioned purity narrative also supports the assumption that the rainforest environment is pure and healthful.

Many of the lodge staff did not come from highly developed urban areas. For some employees, reliable running water might not be present at home and rural staff may have reduced access to best hygiene practices such as on-demand access to laundering with detergent, heat or chemical sanitizing of dishes, and unlimited soap, hot water, or alcohol sanitizer. As a result, fecal contamination is common in rural Peruvian homes (Lanata, Ochoa, Lozada, Pineda, & Verastegui, 2014). Lodge employees we encountered were not well-versed in the technical maintenance of sanitation and water treatment. It is likely that an interaction of beliefs and culture downplayed recognition of TD and other ailments and removed the perceived need for improving water treatments.

If the lodge staff wanted to improve water treatment there were factors that would work against them. While there is indication that lodges B and D utilized chlorine, most lodge staff had the beliefthat chlorination would cause undue harm to the biodigesters. In personal communication with three U.S. based water treatment companies, we learned that use of some chlorine is not incompatible with a biodigestor, and need for high concentrations of chlorine can be dealt with successfully. The use of chemicals appears to be discouraged through the publicly available language of accreditation, which suggests finding "alternatives" to sanitary chemicals. This type of language would likely reinforced managers' fears that chemicals would inactivate the biodigestor systems or cause other unwanted harm. In addition, Peruvian law functionally banned all use of bleach at these remote sites, eliminating the easiest and most common water treatment method. Without training in water quality chemistry, the average person would not know how to substitute related chemicals associated with swimming pool maintenance nor could they do so safely. The combination of beliefs, guidelines and regulations probably had a cumulative effect, leading to a state of "chemonoia" (Ropeik, 2015). Chemonoia is a psychological and cultural phenomena where people reject the use of chemicals despite evidence that the chemicals are safe and improve quality of life. These factors, combined with the warm and humid rainforest setting, likely led to the contamination we found in this study and create a "perfect storm" that could lead to a major health crisis.

4.6. Limitations

The situation surrounding water in remote rainforest lodges is complex and not well characterized. Our study provides only single sample snapshots of a small area utilizing very small samples of water. Additional studies across a wider area and longer time frame are needed to better assess the extent, causes and potential consequences of the water quality problems we discovered here.

4.7. Recommendations

We suggest that water chlorination, with daily residual chlorine level testing, become a norm for all lodges. Multiple staff members should be trained to create support and awareness for water quality and help avoid the confusion we saw where different managers had different knowledge about the same site. Low cost bacterial testing such as the Aquagenx brand portable test bags could empower staff to see firsthand the efficacy of their treatment and allow for onsite weekly testing, or daily during a quality control period. By having some testing on site, testing can become an educational and awarensss tool for staff. When chlorine bleach use is in doubt, calcium hypochlorite, an alternative to sodium hypochlorite, could avoid the "bleach ban." Higher concentrations of chlorine used to soak dishes and water bottles (as is done in restuarants) could be safely poured out onto gravel away from the biodigestors allowing for inexpensive sanitation that is safe for biodigestors. Guest hygiene and education can be evaluated, inlcuding personal water bottle and drinking cup sanitation. A suggested hygiene area to address is the practicality of handwashing by guests and staff. For example, the authors observed a case where guests did not handwash due to stinging bullet ants eating the soap bar. An alcohol sanitizer pump might increase hygiene if insects are attracted to soap.

Regarding natural water bodies, during the boat ride to the lodge, a curtain behind the pilot's seat could block spray from contacting guests. Discouraging river baths or swimming are potential tools to avoid natural water body-related health issues. Lodge managers might consider "closing" access to natural water bodies if the waters consistently have high levels of indicator bacteria. Guest education about natural water related illness risks as part of the initial welcome education talk may be useful. The tourism community may need to be aware of and reevaluate "green" attitudes in accreditation or certification for remote sites. As part of an accreditation process, increasing the site staff's understanding of water quality theory and practice, chlorination, hygiene, and water quality testing would be ideal. Sustainability depends on healthy guests and staff. The agency could help each lodge create a plan to carry out water quality activities. During the inspection period, the accrediting agency could count bacteria in tap, drinking, and natural water bodies for lodges and have an all-hands meeting where all staff review how chlorination and sanitation work. Understanding of water issues occuring onsite may help overturn misconceptions created by unreliable TripAdvisor reviews.

CRediT authorship contribution statement

Constance J. Woodman: Conceptualization, Methodology, Investigation, Writing – original draft, Data curation, Writing – original draft. **Amelia A. Min-Venditti:** Data curation, Formal analysis, Writing – original draft. **Kyle M. Woosnam:** Formal analysis, Writing – original draft. **Donald J. Brightsmith:** Supervision, Resources, Writing – review & editing.

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