Review Paper

Microbial contamination of non-household drinking water sources: a systematic review

Lydia Abebe, Andrew J. Karon, Andrew J. Koltun, Ryan D. Cronk, Robert E. S. Bain and Jamie Bartram

ABSTRACT

Drinking water in non-household settings (e.g. schools, health care facilities (HCFs), restaurants, and mass gatherings) that is free of contamination is important for human health, especially in settings with vulnerable populations who are more at risk from the use of unsafe drinking water, such as immunocompromised patients in HCFs and children at school. Few studies have characterized water quality in non-household settings. We examined the quality of drinking water in non-household settings using studies identified through a previous systematic review. This review evaluated the quality (*Escherichia coli*, thermotolerant coliforms, and total coliforms) of drinking water in non-household settings. We found that drinking water in non-household settings is often non-compliant with health-based standards as defined by the World Health Organization. More research is necessary to determine the extent to which drinking-water quality in non-household settings differs from community settings to better understand how to effectively and appropriately address their challenges unique to safe water in non-household settings. This is of particular relevance to public health since people spend much of their day outside the home where they may consume unsafe water.

Key words | *E. coli*, fecal indicator bacteria, health care facilities, restaurants, schools, water quality

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INTRODUCTION

Contamination of drinking water, particularly fecal contamination, is a grave public health concern and is associated with diarrheal diseases (Hodge *et al.* 2016). Exposure to unsafe drinking water can occur in household and non-household settings. Examples of non-household settings are health care facilities (HCFs), schools, temporary use settings (restaurants, markets, accommodations, transit hubs, places of worship) and workplaces, which are private or public locations where populations spend a significant amount of time but do not typically reside in long-term (Cronk *et al.* 2015). Non-household settings can also include locations where people reside for short- or long-term durations due to displacement as a result of conflict and other circumstances, such as refugee and internally displaced person camps, prisons, and orphanages. There is little evidence describing the quality of water sources in these settings. Neglecting water quality and its monitoring in non-household settings may have substantial public health consequences.

Recent studies and national and global estimates have shown that access to these basic services in schools and HCFs is a concern when water availability in these settings

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is low, sources and systems are unsafe, and services are inequitably distributed (UNICEF 2015; WHO & UNICEF 2015; Cronk & Bartram 2018). The safety of water systems in these settings is also important, especially in settings with vulnerable populations, such as immunocompromised patients in HCFs and young children at school. A lack of safe drinking water in non-household settings can contribute to intra-household inequalities. For example, immunocompromised persons or pregnant mothers with access to safe drinking water at the household level may be put at increased risk by consuming unsafe water in non-household settings such as health facilities, and transmission of infectious disease in non-household settings has the potential to facilitate larger epidemics as compared to household settings (VanDerslice & Briscoe 1995; Cairncross *et al.* 1996).

Evidence suggests water sources are often contaminated and an estimated 1.8 billion people drink from fecally contaminated water sources (Bain *et al.* 2014a, 2014b; Shaheed *et al.* 2014; Kostyla *et al.* 2015; Shields *et al.* 2015; Williams *et al.* 2015). In 2015, an estimated 1.3 million people died from diarrheal diseases, 499,000 of which were children younger than five years old. Poor water quality is linked to causing inflammation, anemia, and stunting in early childhood development (Ngure *et al.* 2014). An estimated 502,000 diarrheal deaths each year are associated with contaminated drinking water (Prüss-Ustün *et al.* 2014). One modelling study suggests that the health gains from the provision of an improved water source may be wiped out when users revert to an unprotected water source (such as surface water) when their improved source is not available (Hunter *et al.* 2009). People may have safe water access at home or in community settings, yet the health gains provided from those sources may be compromised when children attend school, adults go to work, or ill patients visit a health care facility with unsafe drinking water.

The Sustainable Development Goals (SDGs) call for universal access to drinking water, which implies access in the household and also in settings beyond the household such as schools, HCFs, workplaces, and markets (Lanata *et al.* 2013; Ngure *et al.* 2014; Hodge *et al.* 2016). The language of Sustainable Development Goal 6 of 'universal access to safe and affordable drinking water' carries tremendous importance for human health. Surveying literature on non-household water quality is important to inform how to effectively and appropriately address the unique challenges to achieve the goal of universal access and complement reviews on monitoring households, such as Cronk *et al.* (2015). Additionally, we can refer to literature to guide research agendas that address the need for – and current lack of – a body of evidence to examine the status of drinking water quality (DWQ) in a given setting and compare water quality across multiple settings.

We examined the quality of drinking water in non-household settings using studies identified through a previous systematic review (Bain *et al.* 2014b). The following questions were considered: (i) what is the status of DWQ in non-household settings, (ii) what are the research gaps in water quality studies in non-household settings, and (iii) what are the implications for monitoring and practice priorities based on the evidence from water quality studies in non-household settings?

METHODS

Search strategy

Studies analyzed in this paper were identified from a systematic review on fecal contamination of improved and unimproved drinking water sources in low- and middle-income countries (Bain *et al.* 2014b). Bain *et al.* (2014a, 2014b) included studies if they involved water quality sampling in non-household settings. A limited number of non-household studies met the inclusion criteria of the earlier review ($n = 17$). We re-reviewed the 6,586 articles identified through database searches and 1,274 reports from grey literature and correspondence by Bain *et al.* (2014a, 2014b) with less stringent inclusion criteria to determine if they reported water quality results for non-household settings. Only papers in English were reviewed.

Inclusion and exclusion criteria

This review expanded the inclusion criteria of Bain *et al.* (2014a, 2014b) by including studies on non-household settings and imposed no requirement for minimum number of samples. Bain *et al.* (2014a, 2014b) excluded studies

which did not have a minimum of 10 samples from a given supply type.

Data extraction

The following information was extracted from studies: (i) setting type (school, health care facility, workplaces, temporary gatherings, mass use settings, and displaced populations); (ii) compliance (percent of samples 10 mL or larger free of *Escherichia coli* (*E. coli*), thermotolerant coliforms (TTC), or total coliform (TC), (iii) location (urban or rural as defined by the authors of the original study, or both if the geography of the study area was mixed or unclear); (iv) study country; (v) year of publication; and (vi) study design. Compliance with respect to microbial contamination included *E. coli* and TTC (known as fecal indicator bacteria (FIB)) and also total coliforms (indicators that are not specific to fecal contamination). Included studies were grouped by setting and classified as urban, rural, both, or unclassified, according to text identifiers from each study. Studies in which water samples were analyzed in multiple types of non-household settings were counted as an individual study for both settings. If a study analyzed microbial water quality for both household and non-household samples and differentiated between these in reporting, it was classified only as the corresponding non-household setting. The number of water samples tested for *E. coli* and/or TTC, along with the number of these samples that found the indicator bacteria present, were extracted from each included paper. The WHO Drinking Water Quality Guidelines (DWQG) for *E. coli* or thermotolerant coliform levels were used to evaluate compliance. The WHO guidelines identify a tolerable level of *E. coli* and TTC as <1/100 mL.

RESULTS AND DISCUSSION

Search results

Figure 1 depicts the flowchart for the screening process. Of the 6,586 studies identified in Bain *et al.* (2014a, 2014b), 149

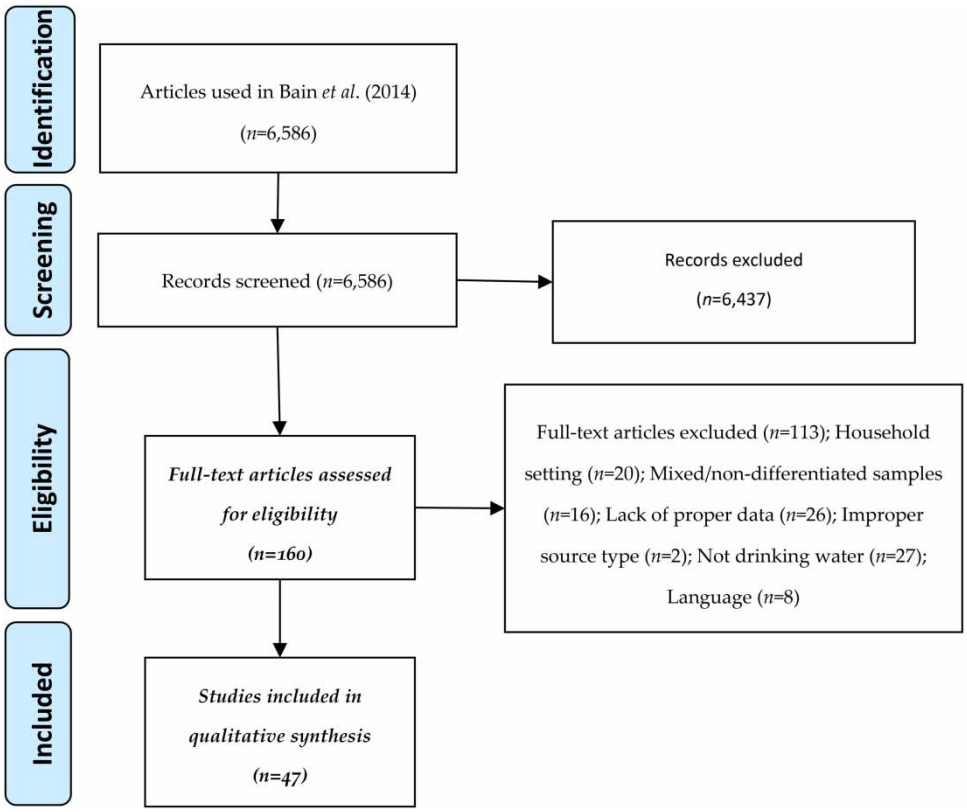

Figure 1 | Flowchart for review of water quality studies in non-household settings.

studies were initially identified as documenting fecal contamination of drinking water in non-household settings. Of these, 47 studies met our criteria for inclusion and were included in this review.

Studies included

Table 1 characterizes the 47 studies included for qualitative synthesis by country, SDG sub-regions, country income level classification (as determined by the World Bank), rural/urban setting, study design, and non-household setting type. Most studies were conducted in sub-Saharan Africa ($n = 16$, 34%) or South Asia ($n = 17$, 36%); and in low-income ($n = 18$, 38%) or lower middle-income ($n = 18$, 38%) countries. The majority of studies took place in urban settings ($n = 19$, 40%), while fewer studies took place in rural settings ($n = 14$, 30%) and the remaining 30% were not specified. Most studies were cross-sectional ($n = 35$, 59%). The final column in Table 1 indicates the range of non-household settings represented in this study. The majority of the settings are self-explanatory; however, accommodation implies private facilities that provide accommodation for patrons, heritage site refers to places of social or historical significance, and water stations are water that was transferred from a source to a station in a public place for public consumption.

Characteristics of included studies

Table 2 summarizes the number and extent of included studies according to a previously developed typology of non-household settings (Cronk *et al.* 2015). The largest proportion of included studies were conducted in schools ($n = 13$, 22%; e.g. Agatemor & Okolo 2007). The second greatest proportion ($n = 10$, 17%) concerned healthcare facilities (e.g. Mendoza *et al.* 1992). However, by number of samples, internally displaced persons (IDP) camps was the most-represented setting type ($n = 8{,}402$ samples, 63%) (Roberts *et al.* 2001; Godfrey *et al.* 2003; Doocy & Burnham 2006; Guthmann *et al.* 2006; Steele *et al.* 2008; Baig *et al.* 2012). This finding was due to one study that reported testing 7,562 water samples for TTC evaluation in drinking water in IDP camps (Godfrey *et al.* 2003).

The number of studies in non-household settings by urban or rural classification is shown in Figure 2. A majority of studies on water quality in schools ($n = 7$, 50%), HCFs ($n = 6$, 60%), and restaurants ($n = 5$, 71%) were conducted in urban settings. In studies of IDP camps, rural settings outnumbered urban settings. In all setting groups except restaurants, a number of studies were unclassified as either urban or rural setting.

Microbial water quality testing

The number of water quality samples in non-household settings are shown in Figure 3. Across most settings, there were more *E. coli* samples ($n = 2{,}627$, 75% of all samples) than TC ($n = 518$, $n = 15\%$) and TTC ($n = 339$, 10%) samples. There were more *E. coli* samples than TC/TTC samples in studies of schools (e.g. Pathade *et al.* 2003), restaurants (e.g. King *et al.* 2000), and IDP camps (e.g. Furusawa *et al.* 2008). In studies of healthcare settings, no single indicator dominated (Figure 3): TC represented 35.5% of samples ($n = 219$) compared with $n = 200$, 32.4% for *E. coli* and $n = 198$, 32.1% for TTC).

By compliance

Thirty-two of the 47 included studies (68%) evaluated bacteriological data for compliance with DWQG for *E. coli* or thermotolerant coliform levels. These 32 studies were conducted in the following settings: schools ($n = 10$, 31%), HCFs ($n = 10$, 31%), restaurants ($n = 7$, 22%), and IDP camps ($n = 5$, 16%). Figure 4 shows compliance by setting. Of the included studies, schools held the greatest proportion of compliant samples ($n = 1{,}076$, 31%). Restaurants had the lowest compliance ($n = 64$, 10%).

DISCUSSION

This is the first review that summarizes the status of DWQ in non-household settings. We summarized study country, setting type, urban/rural classification, water quality parameters, and compliance with WHO guidelines. Based on our summary we identified priorities for research, and for monitoring and practice.

Table 1 | Characteristics of studies ($n = 47$) included in review of water quality in non-household settings

Author name and year	SDG sub-region[a]	Country	Country income level	Urban/rural[b]	Study design[c]	Setting[d]
An & Breindenbach (2005)	EA	South Korea	High	R	CS	Recreation
Sung *et al.* (2010)	EA	Taiwan	High	–	CS	School
Ferreira (2004)	LAC	Brazil	Upper middle	U	L	HCF
Grosso & Oliveira (2007)	LAC	Brazil	Upper middle	U	CS	School
Echeverry Ibarra *et al.* (2008)	LAC	Colombia	Lower middle	R	I	HCF
Mendoza *et al.* (1992)	LAC	Mexico	Upper middle	U	CS	HCF
Hassanean *et al.* (2012)	NA	Egypt	Lower middle	U	CS	HCF
Khalifa *et al.* (2007)	NA	Libya	Upper middle	U	CS	Mosque
Furusawa *et al.* (2008)	O	Solomon Islands	Low	R	CS	Public water supply
Alam *et al.* (2006)	SA	Bangladesh	Low	U	L	Restaurant
Moniruzzaman *et al.* (2011)	SA	Bangladesh	Low	U	CS	Restaurant/street vendor
Agarkar & Thombre (2005)	SA	India	Lower middle	–	CS	School
Agarkar & Thombre (2006)	SA	India	Lower middle	R	CS	School
Chatterjee *et al.* (2007)	SA	India	Lower middle	U	CS	Restaurant/street vendor
Goel *et al.* (2007)	SA	India	Lower middle	–	L	HCF
Gupta *et al.* (2011)	SA	India	Lower middle	–	CS	Restaurant
Kasar *et al.* (2009)	SA	India	Lower middle	U	CS	Transportation hub
Manonmani & Christina (2001)	SA	India	Lower-middle	U	CS	Accommodation
Pathade *et al.* (2003)	SA	India	Lower middle	U	CS	Accommodation
Prajapati & Raol (2006)	SA	India	Lower middle	–	CS	Transportation hub
Roy & Thakuria (2007)	SA	India	Lower middle	U	CS	School
Tambekar & Banginwar (2005)	SA	India	Lower middle	U	CS	Hotel, restaurant
Tambekar *et al.* (2006)	SA	India	Lower middle	U	CS	Hotel, restaurant
Baig *et al.* (2012)	SA	Pakistan	Low	R	CS	IDP
Shar *et al.* (2009)	SA	Pakistan	Low	–	CS	Accommodation
Siddiqui *et al.* (2010)	SA	Pakistan	Low	U	CS	School
Gupta (2007)	SEA	Indonesia	Low	–	CS	Transportation vehicle
Phattharangrong *et al.* (1998)	SEA	Thailand	Upper middle	R	CS	Places of worship
Wiwanitkit & Suwansaksri (2008)	SEA	Thailand	Upper middle	R	CS	Places of worship
Godfrey *et al.* (2003)	SSA	Angola	Low	U	I	IDP
Barnes & Barnes (2009)	SSA	Ghana	Low	–	CS	School, HCF
King *et al.* (2000)	SSA	Ghana	Low	–	CS	Restaurant/street vendor
Daniels *et al.* (1999)	SSA	Guinea-Bissau	Low	U	CS	HCF
Doocy & Burnham (2006)	SSA	Liberia	Low	–	I	IDP
Roberts *et al.* (2001)	SSA	Malawi	Low	R	I	IDP

(*continued*)

Table 1 | continued

Author name and year	SDG sub-region[a]	Country	Country income level	Urban/ rural[b]	Study design[c]	Setting[d]
Agatemor & Okolo (2007)	SSA	Nigeria	Low	U	CS	School
Nkere *et al.* (2011)	SSA	Nigeria	Low	R	CS	Restaurant
Vos & Cawood (2010)	SSA	South Africa	Lower middle	R	CS	Heritage sites
Esterhuizen & Fossey (2012)	SSA	South Africa	Lower middle	R	L	Workplace
Momba *et al.* (2004)	SSA	South Africa	Lower middle	R	CS	School
Otieno & Adeyemo (n.d.)	SSA	South Africa	Lower middle	R	CS	School
Samie *et al.* (2011)	SSA	South Africa	Lower middle	–	CS	School
Guthmann *et al.* (2006)	SSA	Sudan	Low	U	CS	IDP
Hammad & Dirar (1983)	SSA	Sudan	Low	U	CS	School
Steele *et al.* (2008)	SSA	Uganda	Low	R	I	IDP
Akturk *et al.* (2012)	WA	Turkey	Lower middle	–	L	Public drinking fountain
Mashat (2010)	WA	Saudi Arabia	Upper middle	U	L	Places of worship
Mihdhdir (2009)	WA	Saudi Arabia	Upper middle	U	CS	Water station

[a]SDG subregion: Eastern Asia (EA), Sub-Saharan Africa (SSA), Latin America and the Caribbean (LAC), Oceania (O), South Asia (SA), South-eastern Asia (SEA), and Western Asia (WA).
[b]Urban (U) and Rural (R).
[c]Study design: Cross-sectional (CS), Intervention (I), and Longitudinal (L).
[d]Setting: Internally Displaced Persons (IDP), Health Care Facilities (HCF).

Table 2 | Characteristics of studies included in the fecal contamination of drinking water sources in non-household settings review

Setting type	Number of studies (%)	Number of samples (%)
Schools	13 (22)	1,440 (11)
Health care facilities	10 (17)	622 (5)
Workplaces	2 (3)	156 (1)
Temporary use settings		
Restaurants	7 (12)	632 (5)
Accommodation	5 (8)	579 (4)
Transport hubs	2 (3)	12 (0)
Vehicles	2 (3)	288 (2)
Markets	0 (0)	–
Places of worship	6 (10)	281 (2)
Public WaSH facilities (e.g. water station)	4 (7)	143 (1)
Mass gatherings	–	–
Dislocated populations		
Internally displaced person camps	7 (12)	8,402 (63)
Refugee camps	1 (2)	700 (5)
Prisons	–	–
Orphanages	–	–

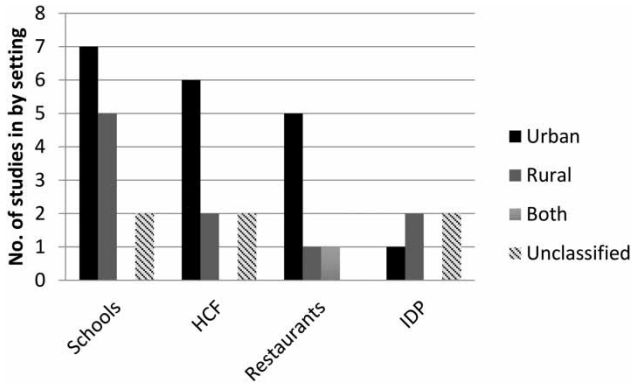

Figure 2 | Number of studies in urban, rural, both or unclassified settings by type of non-household facility. Studies were conducted in the following non-household settings: schools, health care facilities (HCFs), restaurants, and internally displaced persons (IDP) camps.

Water quality studies in non-household settings

A majority of studies on water sources in schools (50%, $n = 7$), healthcare facilities (60%, $n = 6$), and restaurants (71%, $n = 5$) all focused on urban settings. A few studies ($n = 6$, 10%) could not be classified as urban or rural as they did not report the type of setting, preventing analysis of the association of water quality with urban/rural environments.

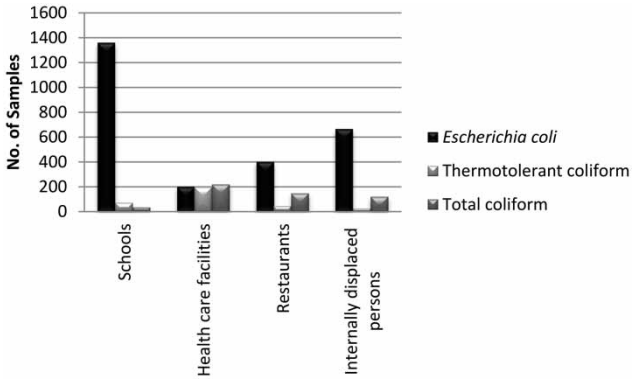

Figure 3 | Number of samples based on water quality parameter evaluated by type of non-household facility. Studies were conducted in the following non-household settings: schools, health care facilities (HCFs), restaurants, and internally displaced persons (IDP) camps.

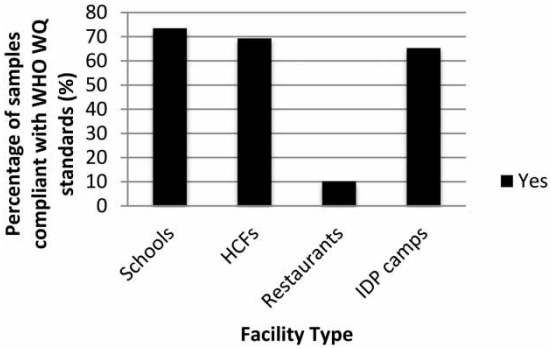

Figure 4 | Percentage of water samples compliant with WHO WQ Guidelines by facility type. Water samples were taken in studies that examined water in the following settings: schools, health care facilities (HCFs), restaurants, and internally displaced persons (IDP) camps.

These include prisons, markets, and orphanages where vulnerable populations can face significant exposure to waterborne disease. This is a notable oversight as these locations house under-protected constituents such as prisoners and orphans who are being overlooked, which presents an equity problem.

Fecal contamination in drinking water in non-household settings

We documented the type of water quality parameters that were used in the studies, and found *E. coli* samples were far more prevalent than TC or TTC samples with the exception of HCFs. *E. coli* samples represented 75% of all samples within the study set. While *E. coli* represented the majority of FIB samples, wide variations remain – especially in healthcare facilities – in which two types of FIBs and total coliforms are used to evaluate compliance, therefore limiting comparability. The implications for the use of TC versus *E. coli* or TTC are notable especially in HCFs as these settings necessitate health-related parameters to ensure health protection. Finally, data shows that samples compliant with the WHO DWQGs are more common than non-compliant samples in all settings except restaurants. Seventy-one percent of all samples were compliant, and compliance by setting type exceeded 60% in every setting except restaurants, where compliance was much lower (10% of samples compliant). These alarming rates of non-compliance support the need for further investigation to better understand levels and sources of contamination, and develop strategies for improvements that are context-specific.

Priorities for research

Additional research is needed to understand the status of water quality in non-household settings and generate evidence to inform monitoring of the current status of water quality and support the need for improvements in the water quality status in non-household settings. These types of studies are necessary as they provide evidence to generate policies and allocate funding on local, national, and international levels. They can also be used as advocacy to encourage better regulation and monitoring of water quality in non-household settings and water supplies that serve these types of shared spaces, particularly because evidence has shown that the absence of regulation and enforcement of water quality testing is a major barrier to water quality monitoring. Additionally, these studies are needed to encourage responsible ministries (e.g. Education, Health, Local Government) to address this issue in non-household settings. Water quality studies in non-household settings can be used to inform the public about health risks outside of the home which can be leveraged to apply pressure to privately run businesses used by the public (including privately run schools, health facilities, restaurants, etc.) to ensure safe water management and storage and encourage external water quality testing.

These types of studies can also be used for secondary data analysis, such as modelling studies and assessing country performance toward the improvement of DWQ (Hunter *et al.* 2009; Bain *et al.* 2014a; Luh *et al.* 2016). Examining exposure to poor water quality holistically provides insights on risks and allow for the development of appropriated responses to manage risks of exposure. Of these non-household settings, some (e.g. schools and healthcare facilities) have been modestly studied despite the obvious needs in those settings, and others (e.g. prisons and orphanages) have been overlooked. There is a need to better understand the drivers of water quality and likely points of contamination in non-household settings, especially in the settings that have been understudied. Overall, many of the studies that we reviewed lacked critical information for understanding how drinking water may have become contaminated, such as a description of associated water distribution systems or whether water treatment had taken place. Future studies should be sure to include this type of information. Furthermore, it would be very useful to compare community level data with data at these extra-household sources in future studies to understand if water contamination in these settings is a localized issue or one that is widespread in the geographic area.

It is clear there is a large deficit in evidence regarding DWQ in many non-household settings (Table 2) and the available data indicates that many of these settings will not be compliant with global water quality standards (Figure 4). Additionally, research is recommended to elucidate which setting types are most accessed among both the general population and the immunocompromised, and how this varies by setting. Studies in this area establish the importance of understanding the water quality in non-household settings for burden of disease estimates and clarify the relationships between exposure and health outcomes.

Priorities for monitoring and practice

The evidence synthesized in this review was collected to inform water facility and utility operators, WaSH practitioners and researchers, and WaSH policy makers of the nature and scale of water quality issues and examine what research has been conducted to date on non-household water quality. As water service providers are devising mechanisms to mitigate the risk of microbial water contamination, they should be aware of its applicability to non-household settings and incorporate these settings into any safety and monitoring plans. WaSH researchers and practitioners should recognize the evidence presented in this paper in addition to the lack of evidence for specific types of institutions (e.g. prisons, orphanages, mass gatherings, markets, etc.) when targeting water and water quality programs and research projects. Water policy stakeholders should also be cognizant of the risk that drinking water in public settings can pose when devising monitoring guidelines and health interventions.

While indicators such as FIBs and total coliform allow evaluation of compliance with DWQG, the inconsistent use of indicators may prevent research and monitoring bodies from pooling and evaluating the severity of contamination and estimating burden of disease. As such, quantification of FIB leading to estimates of contamination severity and disease burden is needed in monitoring protocols. There is particular need for more complete water quality monitoring in public settings, given these sources are at higher risk for fecal contamination given their wide usage and potential diffusion of responsibility for maintenance and therefore susceptible to oversight. Evidence from previous reviews suggests sampling should occur at both the source and from stored water, which is often more contaminated (Shields *et al.* 2015). Where possible, sampling should occur in the wet and dry seasons to account for seasonal variation of FIB (Kostyla *et al.* 2015). Use of mobile survey tools may facilitate improved data collection from field-based water quality studies (Fisher *et al.* 2016). Integrating water quality testing into monitoring, evaluation, and learning studies of non-household settings may enable analysts to identify the complex pathways and factors that contribute to sustainable, safe water service delivery (Fisher *et al.* 2015).

Given the increased scale of water quality monitoring that including public settings could portend, there is a need for collaboration across the water sub-sector to enable it to happen and to ensure the appropriate actors take the necessary steps to address the inevitable water quality deficiencies that will be found. In order to adequately mitigate the risk of drinking water contamination in public use settings, precautions will need to be incorporated to safety standards for the wide array of settings presented in

this paper. This will require collaboration across many branches of government and innovative programming from development partners. It will be important to engage the private sector in ensuring water quality in these settings by implementing their own safety procedures. The private sector could also help fill the role of providing water quality testing services at an increased number of settings.

Understanding varying levels of fecal contamination in drinking water and exposure in these non-household settings will inform practice through generating evidence for evidence-based water safety plans for non-household settings, such as schools and HCFs. It is also worth exploring and applying the principles of these plans to other settings, such as restaurants and hotels. While the UN seeks universal access to clean water through its SDGs, sufficient monitoring for evidence is needed to inform decision-making in prioritizing and monitoring interventions.

Limitations

This study was conducted to present a high-level overview of the status of water quality in non-household settings. An existing systematic review on fecal contamination in drinking water was re-reviewed to identify and highlight studies from non-household settings as these settings have gained prominence in the SDG agenda. We used this approach because search terms, classifications of settings, and groupings to categorize all non-household settings would be difficult to conduct. Therefore, some studies may have been excluded in our review. Future systematic reviews may be conducted for specific settings and explore an expanded range of contaminants.

Data collected in the current review are too incomplete to enable robust water quality comparison – within or across setting types such as urban and rural differences in water quality for prisons, markets, and orphanages. Several gaps in evidence prevent such comparison of differences in water quality analysis methodology – including study design, parameters and analytical approach – and constrain comparison of water quality between settings and investigation of explanatory factors within them. These inconsistencies underscore the need for international standardization in testing and reporting.

Nonetheless, while the current study's data is insufficient for robust comparisons, several trends within and across settings do emerge. At the level of reported outcomes, our review depended heavily on the proportion of non-compliant samples. Many included epidemiological studies relied on cross-sectional study designs rather than longitudinal designs. When such sampling does not meet established standards for minimum sampling frequency, reported outcomes may overstate compliance. Lastly, the review did not contain studies published in languages other than English, and few studies from certain regions of the globe, especially Oceania and Central Asia. Such types of limitations in our review prevent our set of included studies from being universally applicable.

CONCLUSIONS

This review supports the importance of understanding water quality in non-household settings through investigating the literature to identify research opportunities and implications for practice and policy. Improving our understanding of non-household setting water quality allows identification of research gaps that can inform monitoring and practice in order for facility operators, practitioners, and policy makers in the environment and health sector to reduce exposure. Additional research is necessary to strengthen monitoring systems to ensure coverage of surveillance reaches all non-household settings and disaggregation allows for analysis of exposure risks.

AUTHOR CONTRIBUTIONS

Robert Bain and Ryan Cronk conceived and designed the review. Andrew J. Karon extracted the data from the literature, and Lydia S. Abebe and Andrew J. Koltun summarized the data in tabular and graphical form and wrote the manuscript. Jamie Bartram provided comments and feedback on the interpretation of the results and reviewed the manuscript. All authors read and approved the final manuscript.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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