Water, sanitation, and hygiene (WASH) interventions are key to reducing the burden of disease associated with outbreaks, and are commonly implemented in emergency response. However, there is a lack of summarized evidence on the efficacy and effectiveness of these interventions. We conducted a systematic review of published and grey literature by developing theory of change models, developing inclusion criteria, conducting the search, selecting evaluations for inclusion, assessing the quality of the evidence, and analysing the included evaluations. Overall, 15,026 documents were identified and 51 evaluations from 47 studies met inclusion criteria. Interventions from 19 countries were included, primarily in response to cholera (86 per cent). Most included evaluations (70 per cent) were at high risk of bias and nearly half were from grey literature (49 per cent). We found that WASH interventions consistently reduced both the risk of disease and the risk of transmission in outbreak contexts; however, programme design and beneficiary preferences were important considerations to ensure WASH intervention effectiveness. Critical programme design characteristics included simple interventions that were appropriately timed, community-driven, and had linkages between relief and development. Beneficiary preferences, barriers, and facilitators to WASH interventions in outbreak response were taste and smell of water treatment, communication methods, inaccurate perception of efficacy, and trust/fear. Research on commonly implemented but severely under-researched WASH interventions is recommended. It is also recommended that responders implement interventions that are: efficacious, simple, well-timed, community-driven, link relief and development, and address barriers and facilitators to use with communities.

Keywords: WASH, disease outbreaks, evidence, systematic review

An outbreak occurs when disease cases increase above expected levels in a defined community, geographical area, or season (Gideon, 2016). Between 1980 and 2013, the number and diversity of disease outbreaks globally increased significantly...
(Smith et al., 2014). These increases are attributed to microbial adaption of pathogens, changing human susceptibility, climate change, changing human demographics, economic development, breakdowns in public health, war, famine, poverty, and social inequality.

In low- and middle-income countries (LMIC), cholera, Ebola virus disease (Ebola), and hepatitis E are outbreaks of current concern. The number of cholera cases is increasing globally, and currently there are more than 2.8 million cholera cases that led to more than 90,000 deaths worldwide (Ali et al., 2012; WHO, 2016a; Gaffga et al., 2007). The West African Ebola outbreak that began in 2014 was unprecedented in scale, impacting the entire global community with 28,626 cases and 11,323 deaths (WHO, 2016c). Hepatitis E can cause acute liver failure, particularly in pregnant women, and currently causes 70,000 deaths and 3,000 stillbirths annually (Rein et al., 2012). Hepatitis E outbreaks have recently become more common in displacement camps (Boccia et al., 2006; Hakim et al., 2016).

Water, sanitation, and hygiene (WASH) interventions play a critical role in preventing disease outbreaks by breaking transmission routes. More specifically, WASH interventions can prevent and control outbreaks of waterborne diseases, diseases transmitted through the faecal-oral route (i.e. cholera and hepatitis E), and diseases transmitted by direct contact (i.e. Ebola) (Sphere Project, 2011; JMP, 2014; Watson et al., 2007). Water interventions aim to increase water quantity and/or improve water quality; sanitation interventions aim to isolate faeces from the environment; hygiene interventions aim to prevent transmission through hands, and more broadly, promote awareness among affected populations on the disease and equip these populations to act; and environmental hygiene interventions reduce risks by disinfecting household objects or reducing environmental transmission risks, for example by managing rubbish. WASH interventions in outbreaks are not necessarily intended to provide long-term sustainable access, but instead provide rapid relief to minimize the impact or spread of disease (Sphere Project, 2011). In addition to the three diseases detailed above, hepatitis A, acute (watery) diarrhoea, typhoid, and dysentery (shigellosis) are also diseases of current concern that can be prevented or controlled by WASH interventions.

WASH interventions are commonly implemented as part of outbreak response activities by United Nations (UN) agencies, local governments, and emergency responders. While the ability of WASH interventions to disrupt disease transmission is well established through laboratory experiments and development contexts, there is little evidence on the effectiveness in outbreak and humanitarian emergency situations (Blanchet et al., 2013; Ramesh et al., 2015; Brown et al., 2012; Taylor et al., 2015). Establishing an evidence-base is challenging in outbreak and emergency situations because responders prioritize response activities over research, in addition to the inherent difficulty of using rigorous research methods in unstable outbreak and emergency settings (Spiegel et al., 2007). Responders also note there is a lack of technical knowledge related to data collection, lack of personnel to collect data, and lack of clear goals for how to use the information that is collected (Vujcic et al., 2015). While randomized control trials (RCTs) are robust evaluation designs and considered the ‘gold standard’ for
health research, conducting RCTs in emergencies is hindered by the complex and dynamic conditions (Mayne, 2011; Victora et al., 2004). Less robust, higher bias, and more flexible evaluation designs – such as cross-sectional evaluations – are more often used in emergencies by responding agencies, but challenge the term evidence considering the high likelihood of bias.

In 2015, a systematic review on the efficacy of WASH interventions for cholera response (Taylor et al., 2015) and another on the health impact of WASH interventions in emergencies (Ramesh et al., 2015) concluded that there is a lack of data to establish firm evidence for implementing WASH interventions in outbreaks and emergencies. As Taylor et al. (2015) only included published studies and Ramesh et al. (2015) only included manuscripts documenting health impacts, neither review included the most prominent information sources or variety of evaluation methods and outcomes available for WASH interventions in outbreak contexts. Ideally, a synthesis of WASH evidence would include both published and grey literature, as well as quantitative and qualitative information on outcomes, impacts, and influencing contextual factors that contribute to programme effectiveness, in order to fully encompass the evidence base (Brown et al., 2012).

Objectives

The objective of this systematic review was to assess the outcomes and impacts of WASH interventions during disease outbreaks in LMIC. By including both published and grey literature, the aim was to investigate a broader set of contextual factors that may shape intervention effectiveness. We intended to address four specific research objectives in WASH interventions during outbreak response:

1. What are the health impacts of WASH interventions in disease outbreaks?
2. What are important WASH programme design and implementation characteristics in disease outbreaks?
3. What is the cost-effectiveness of WASH interventions in emergency outbreak situations?
4. What are the population-related barriers and facilitators that affect WASH interventions in disease outbreaks?

Methods

To address these research questions, we conducted a systematic review of published and grey literature, including development of: 1) theory of change models; 2) search strategy; 3) inclusion criteria; 4) selection and processing strategy; 5) quality of evidence appraisal; and 6) analysis plan. Please note that efforts were made to follow the protocol and procedures with standard systematic review procedures outlined by the Cochrane Review (Higgins and Green, 2011), including the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist; however, due to the acceptance of low-quality manuscripts, grey literature, and the wide variety of outcome measures beyond health outcomes, strict adherence to these procedures
was not appropriate. The full systematic review protocol was peer-reviewed and made publicly available before conducting the review (Yates et al., 2015a). Each step of the systematic review process is summarized below.

**Theory of change model development**

A theory of change model was developed for each WASH intervention to describe the theoretical route from intervention activities to outputs, outcomes, and impacts, while also identifying influencing factors and assumptions. We developed a model for each of the eight WASH activities anticipated in the review: increasing access to water, source-based water treatment, household water treatment (HWT), temporary or permanent latrines, latrine alternatives, hygiene promotion (including handwashing), distribution of soap and/or hygiene materials/kits, and environmental hygiene. Theory of change diagrams for each intervention can be found in the protocol (Yates et al., 2015a).

**Search strategy**

A search strategy was developed to identify published and unpublished grey literature. Individualized search terms and strings were developed for each of the eight WASH interventions from their associated theory of change, and included keywords and outcome and impact measures specific to that intervention. The search strings were used in a total of nine peer-reviewed databases and 10 searches, in English (7), French (2), and English/Spanish (1) including: Cochrane Library, Google Scholar, IDEAS, LILACS, Ovid Medline (PubMed), Scopus, Web of Science, Academic Search Premier (English and French), and ArticleFirst. Searching took place in November and December 2015, and was re-run in September 2016. Six journals identified as most likely to have relevant research and reference lists of included evaluations and reviews identified in the searches were screened by hand. Responder websites were also searched with keywords, including: non-governmental organizations (NGO), UN, and other relevant websites. Additionally, solicitation for relevant documents was carried out through email and personal contacts. Requests for information were sent to the international community via the Global WASH Cluster in September 2015 and February 2016, and to the International Network on Household Water Treatment and Safe Storage in September 2015. Overall, more than 75 organizations were contacted through email. Personal solicitations, online posts, and international conferences were also used to collect relevant information.

**Inclusion criteria**

Inclusion criteria were established according to the populations, interventions, comparisons, outcomes, and study types (PICOS) framework (Yates et al., 2015a).

**Populations.** All age, gender, and socioeconomic populations in LMIC were eligible for inclusion. Populations must have also been affected by an outbreak of: cholera, Ebola, hepatitis E, hepatitis A, acute (watery) diarrhoea, typhoid, or dysentery (shigellosis). An outbreak was defined in accordance with WHO definitions (WHO, 2016b).
Interventions. A WASH intervention was eligible for review if it targeted prevention, or control of, one or more included diseases and was carried out within 12 months of the start of the outbreak. Interventions must have been field-based. Laboratory research and health-focused interventions (i.e. clinic or hospital interventions) were excluded.

Comparisons. No specific comparisons were required for inclusion.

Outcomes. Evaluations were included if at least one intermediate outcome (use of service or non-health outcomes) or final impact (disease reduction or cost-effectiveness) was reported. Use of service includes three specific indicators: self-reported use, confirmed use, and effective use. Self-reported use is beneficiary reported use without additional verification. Confirmed use is when an evaluator tests or observes the use or service in some way (testing free chlorine residual (FCR) in chlorine-based water treatment programmes). Effective use is a measure of improving quality of contaminated water requiring confirmed use and microbiological testing. Cost-effectiveness included economic analyses investigating cost-benefit, cost-utility, cost per beneficiary, and cost per disability adjusted life-year averted. Disease reduction data were included if beneficiary morbidity and mortality impact were self-reported or clinically measured. Non-health outcomes of preferences from the population on use of interventions (e.g. ease of use, taste, or smell of water), quality of life improvement (e.g. feeling safer, time savings), and agency preferences for interventions were included.

Study types. Experimental, quasi-experimental, non-experimental, mixed-methods, and qualitative methodological study type designs were eligible for review.

Dates for inclusion were 1995–2016. Both peer-reviewed and unpublished grey literature documents were eligible. Personal blogs, diaries, newspaper articles, magazine articles, website postings, poster abstracts, and legal proceedings/court documents were not included. Review documents were not included, but individual references in review documents were screened for inclusion.

Selection and processing
Identified studies were screened first by titles, then by abstracts and then by full texts. From abstract to final inclusion, studies were independently double screened by two of the authors. Any discrepancies were discussed with a third author for final decision. Throughout the screening process, references were managed with Endnote X7 (New York, NY, USA) and Microsoft Excel 2010 (Redmond, WA, USA). Data collection was completed with a detailed coding sheet using Microsoft Excel 2010, and included author and publication details, type of intervention, context of the intervention, study design, study quality, effect estimation, outcomes and impacts, and barriers and facilitators to implementation. Data collection was completed and double screened by four research assistants.

Quality of evidence
Each included evaluation was assessed for the potential risk of bias. For quantitative studies, the bias assessment tool was based on the Cochrane Handbook.
‘Risk of bias’ tool and adjusted similarly to Baird et al. (2013) (Higgins and Green, 2008, Baird et al., 2013). The risk of bias was assessed through five categories: selection and confounding; spillover effects and contamination; incomplete outcome; selective reporting; and other risks of bias. For qualitative studies, four appraisal categories were adapted from Spencer et al. (2003): design; bias; data collection; and clarity of findings. Each category was scored as ‘low risk’, ‘high risk’, or ‘unclear’. The summary risk of bias for a study was based on the number of ‘low risk’ assessments across the four or five categories depending on research design.

To establish the summary quality of evidence from multiple studies of varying qualities and study designs for each WASH intervention, a protocol was developed based on the Grading of Recommendations Assessment, Development and Evaluation (GRADE) of evidence outlined in Cochrane Review Standards (Higgins and Green, 2011). The baseline was determined by the study design of the evaluation, then downgraded or upgraded considering biases, effect size, consistency, and generalizability. The summary of evidence was then described through four categories (Oxman and GRADE Working Group, 2004): high evidence as further research is very unlikely to change confidence in the estimate of effect or accuracy; moderate evidence as further research is likely to have an important impact on confidence in the estimate of effect or accuracy and may change the estimate; low evidence as further research is very likely to change the estimate; and very low evidence as any estimate of effect or accuracy is very uncertain.

Analysis plan

Considerations for missing data and meta-analysis techniques were described in the protocol; however, the low-quality research designs identified and included in the review undermined the relevance of meta-analysis and therefore most contingency measures were not utilized. Formal heterogeneity analysis with $I^2$ could not be completed, as reported outcomes were too different for direct comparison.

A narrative synthesis approach was used to summarize the information gathered. A summary of all included evaluations is first presented with descriptions of outbreaks by country, disease type, intervention type, published or grey literature, risk of bias assessment, and evaluation methodology. Then, for each WASH intervention, a description of the intervention is presented, followed by information on the number of studies identified, risk of bias, outcomes and impacts, and summary of evidence. Results were summarized in general tables, described with an evidence map then stratified by objective.

Please note that based on included evaluations, the original eight WASH intervention categories were modified to 10 categories: well disinfection, source-based treatment, household water treatment with chlorine-based options, household water treatment with other options, community-driven sanitation, hygiene promotion, social mobilization, hygiene kit distribution, jerrican disinfection, and WASH package (a term for when multiple interventions were delivered in the same response).
Results

Overall, 15,026 documents were identified in the systematic review process. After applying the three selection filters, 47 studies describing 51 evaluations were included (Figure 1). Each included study is detailed in the full report (Yates et al., 2017).

The included evaluations described WASH interventions in 19 countries, with the highest frequency of evaluations from Zimbabwe (8/51, 16 per cent) and Haiti (7/51, 14 per cent). Cholera was the most researched and discussed disease, representing 86 per cent (44/51) of the diseases responded to in the included evaluations; Ebola (2/51, 4 per cent), acute watery diarrhoea (3/51, 6 per cent), shigellosis (1/51, 2 per cent), and typhoid fever (1/51, 2 per cent) accounted for the remainder of the diseases.

Water interventions represented the largest grouping of included evaluations (n = 22, 43 per cent), followed by hygiene (n = 15, 29 per cent) and WASH package (n = 12, 24 per cent). Sanitation-specific interventions were represented by two evaluations (4 per cent).

A near equal number of evaluations were identified from the peer-reviewed (26/51, 51 per cent) and grey literature (25/51, 49 per cent). Most evaluations (38/51, 70 per cent) had a high risk of bias (Figure 2). The quantitative studies were mostly completed on water interventions, were more likely to be in the peer-reviewed literature, and had less risk of bias. For example, 47 per cent of published water evaluations had a low risk of bias (9/19), while 4 per cent (2/32) of the other interventions had a low risk of bias result. The WASH package evaluations were primarily field commentaries in the unpublished grey literature, with a high risk of bias.

![Figure 1 Screening process](chart)

**Table 1**

<table>
<thead>
<tr>
<th>Removed:</th>
<th>Count</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Databases</td>
<td>13,586</td>
<td>No outbreak: 103</td>
</tr>
<tr>
<td>Websites</td>
<td>1,060</td>
<td>Policy document/manual: 15</td>
</tr>
<tr>
<td>Emails/NGOs</td>
<td>333</td>
<td>No clear WASH intervention: 84</td>
</tr>
<tr>
<td><strong>Total Removed</strong>:</td>
<td><strong>15,984</strong></td>
<td>No outcome of relevance: 43</td>
</tr>
<tr>
<td><strong>Final Inclusion</strong>:</td>
<td><strong>47</strong></td>
<td>Outside scope: 36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Repeated research: 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Timing (13+months): 14</td>
</tr>
<tr>
<td></td>
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<td>Review document: 37</td>
</tr>
</tbody>
</table>
Overall, 14 per cent of the included studies (7/51) had a control group and less than 4 per cent (2/51) were RCTs. Health impacts were measured in 12 per cent (6/51) of the evaluations; a measure of use was evaluated most frequently for HWT interventions (31 per cent, 16/51).

**Results by intervention**

**Well disinfection.** A common outbreak response intervention is to disinfect a contaminated well with chlorine, the objectives of which are to reduce microbiological contamination and/or maintain FCR in the well. Five evaluations of high (3) and low (2) risk of bias were identified that described four slightly different approaches to well disinfection with chlorine (note two studies evaluated multiple methods): 1) a shock dose of liquid chlorine (bleach) added directly to the well; 2) pot chlorination where powdered chlorine, sand, and gravel in a pierced jerrican were inserted into wells, intended to slowly disperse chlorine and treat water over time; 3) pot chlorination with locally pressed chlorine tablets in a perforated container; and 4) floating pot chlorinator (commercial plastic devices used in swimming pools).

One-time shock chlorination did not provide FCR protection for more than a few hours and did not reduce microbiological contamination. Traditional pot chlorination inconsistently maintained measurable FCR for 1–4 days. Floating pot chlorinators could be effective, but materials needed to be imported and required specialized tablets. Finally, in comparative evaluations, albeit with inconsistent methods, pressed HTH tablets with a pot chlorination approach maintained FCR for 3–4 days and were the preferred mode of well disinfection by responders. Microbiological impact of treatments was not assessed. An important programmatic consideration identified was communication with community members, as: 1) well
disinfection interventions were often perceived to maintain water safety for longer than it was actually maintained; and 2) communities unnecessarily doubled the chlorine dose by also treating water in the home with chlorine-based options.

Source-based treatment. Source-based treatment is water treatment that occurs at the point of collection. Evaluations were identified in the review only for the intervention of chlorine dispensers; bucket chlorination, where a person is stationed near a water source and adds a dose of chlorine directly into the recipient’s water collection container, was described as an activity but not evaluated. A chlorine dispenser programme includes hardware installed next to a water source that dispenses chlorine solution, a local promoter who refills the dispenser and conducts community education, and a supply chain of chlorine refills. Users treat water by turning a valve that dispenses a controlled amount of chlorine solution into their water collection container.

Dispensers were used in three different cholera contexts, Haiti, Sierra Leone, and Democratic Republic of Congo (DRC), with three different responders presented in one low risk of bias manuscript (Yates et al., 2015b). Results varied over two acute evaluations (2–8 weeks after installation) and three sustained evaluations (4–7 months after installation) for reported use (26–75 per cent acute, 31–75 per cent sustained), confirmed use (11–34 per cent acute, 5–18 per cent sustained), and effective use (10–28 per cent acute, 0–10 per cent sustained) metrics. Spillover effects from other water treatment options were present and helped to explain the results, as the local municipal water system in DRC was functional in the sustained evaluation and 32 per cent of households in Haiti reported using chlorine tablets as an alternative treatment. With regression analysis of household survey data, factors consistently associated with higher use across contexts were: speaking to the promoter within the last month; and collecting water from a source with a dispenser. A fourth case study in the same evaluation was conducted in a non-outbreak situation, and had much higher results (>79 per cent reported use, confirmed use, and effective use in initial and sustained evaluations). The three implementing organizations gathered at project end and reflected on factors leading to success. These included: appropriate source selection; chlorine solution quality and supply chain; dispenser hardware installation and maintenance; integration into a larger WASH programme; promoter recruitment and remuneration; experienced programme staff; partnering with local organizations; conducting ongoing monitoring; and having a sustainability plan.

Household water treatment. HWT products (also called point-of-use water treatment products) are interventions used in the home to improve the microbiological quality of household drinking water. These may be distributed as a stand-alone intervention or included as one of several items in a hygiene kit. Distributions also sometimes include hygiene promotion.

HWT was the most studied intervention, with 16 evaluations and a mixture of high, medium, and low risk of bias. For analysis, HWT interventions were separated by chlorine-based products (chlorine tablets, liquid chlorine, flocculant/disinfectants) and other products (filters, solar disinfection (SODIS), safe storage, and boiling). Please note several contexts included more than one HWT product.
HWT: chlorine-based products. The most common HWT products distributed in emergencies were chlorine products; this was particularly true in cholera response, because they effectively inactivate most bacterial and viral pathogens, lead to residual protection, are low cost, and are easy to use and transport (Lantagne and Clasen, 2012). Chlorine-based HWT products were separated into three sub-categories: chlorine tablets, liquid chlorine, and flocculant/disinfectants:

Chlorine tablets. Sodium dichloroisocyanurate chlorine tablets (e.g. Aquatabs®), used to treat 1–20 L of water, were evaluated in six contexts with mixed risk of bias. The distributed tablets (67–167 mg) were freely distributed through hygiene kits and intended to treat 10–20 L of water. The reported use ranged between 8 and 31 per cent (n = 5), while confirmed use ranged between 7 and 87 per cent (n = 6) with one noticeable outlier; without the outlier the range was 7–31 per cent (n = 5). Effective use was identified in one study (5.3 per cent, n = 1). The taste and smell of chlorine tablets was reported as a barrier to use in five contexts within three countries (ACF, 2009; Lantagne and Clasen, 2012; Imanishi et al., 2014; Ruiz-Roman, 2009). Overdosing may have led to strong smells/taste, as some beneficiaries did not have the appropriate water storage container for the tablet size distribution (Imanishi et al., 2014; ACF, 2009). Knowing a HWT method before the outbreak and ease-of-use were indicators for use in Zimbabwe (Imanishi et al., 2014) and Nepal (Lantagne and Clasen, 2012).

Liquid chlorine. Small bottles of 1–1.25 per cent sodium hypochlorite (e.g. WaterGuard, sized so one cap treats 20 L of water) and commercial bleach (where the dosage is generally in drops) were evaluated in four contexts in three countries with mostly high risk of bias. Reported use ranged between 20 and 88 per cent (n = 4), confirmed use ranged between 12 and 69 per cent (n = 3), and effective use was not assessed. Some of the heterogeneity could be explained by the active promotion of liquid chlorine before the outbreaks in the two studies with higher use rates in the DRC (Tokplo, 2015) and Madagascar (Mong et al., 2001). Cost to the beneficiary may explain the low use in Madagascar (Dunston et al., 2001) as the free distribution of the same product had higher use rates in the same outbreak (Mong et al., 2001). Excessive dosing was observed in Madagascar (FCR >3.5 mg/L) (Mong et al., 2001) and taste was noted as a hindrance to use in Nepal (Lantagne and Clasen, 2012). Liquid chlorine was linked to long-term development approaches, including promotion (ACF, 2014b), cost-recovery and social marketing (Dunston et al., 2001), local production (Date et al., 2013), and vouchers (ACF, 2014b). These development programme strategies were used with liquid chlorine programming, and not described in other HWT interventions. Liquid chlorine was also more regularly used in endemic situations, where responses can be scaling up existing ongoing development interventions.

Combination flocculant/disinfectants. Flocculant/disinfectant sachets (e.g. P&G Purifier of Water® ‘PuR®’) are most often used to treat turbid water. Users add the contents of one sachet to 10 L of water, stir for five minutes, wait five minutes for the solids to settle, filter the water through a cloth into a second bucket, and wait 20 minutes before drinking. PuR was measured in three evaluations; two were low
risk of bias and one was high risk of bias. Reported use ranged between 6 and 78 per cent (n = 2), while confirmed use ranged between 4 and 95 per cent (n = 2). Effective use was measured in one evaluation at 2 per cent (n = 1). Household knowledge may explain some variability. High use was attributed to high knowledge of correct use in South Sudan and when households were also provided all materials necessary to use PuR at no cost, received extensive training, and were visited weekly in Liberia (ACF, 2014a; Doocy and Burnham, 2006). On the other hand, in Kenya, PuR was distributed through an NFI (non-food items) distribution with minimal promotion, resulting in only 2.3 per cent of households able to describe correct use; ultimately translating to similarly low reported use of 6 per cent and confirmed use of 4 per cent (Lantagne and Clasen, 2012). Health impact was reported in one evaluation (with high use, in Liberia) where PuR reduced diarrhoea incidence by 67 per cent (adjusted RR 0.33; 95 per cent CI 0.30–0.37) and diarrhoea prevalence by 77 per cent (adjusted RR 0.23; 95 per cent CI 0.21–0.25) (Doocy and Burnham, 2006).

**HWT: other products.** Fewer non-chlorine HWT interventions were identified in the review and all were implemented in non-acute endemic outbreak contexts. The quality of evaluation design was higher than that of chlorine or PuR studies, but was not generalizable to other contexts without multiple studies of the same intervention. Other HWT products were separated into four sub-categories: filters, solar disinfection (SODIS), safe storage, and boiling.

**Filters.** In an endemic cholera area in Bangladesh, two simple filters (a small nylon screen of 150 µm mesh size and a folded piece of sari cloth) were used in intervention groups and compared with a control group in a large, low bias evaluation (Colwell et al., 2003). More than 90 per cent of households reported following the filtering instructions, and cholera morbidity was reduced by approximately 40 per cent in both the nylon and sari cloth filter groups (nylon filter RR: 0.59; sari cloth RR: 0.52). In a follow-up medium bias study, reported use of the sari cloth filters was 35 per cent five years after intervention and the protective reduction in morbidity was also seen in neighbours of users (Huq et al., 2010).

**SODIS.** SODIS was evaluated in one high risk of bias study in a development context in Kenya that led into an outbreak evaluation when cholera began in the project area (Conroy et al., 2001). SODIS was effective at reducing self-reported diarrhoea rates by 88 per cent in children younger than six (OR = 0.12; 95 per cent CI 0.02–0.65; p = 0.014), but impact was inconclusive with older children and adults.

**Safe storage.** Two evaluations isolating safe water storage were identified in the review; both were low bias. The control group in the PuR evaluation in Liberia received jerricans, and this alone significantly reduced diarrhoea rates by 16 per cent from the preceding week (OR = 0.84, 95 per cent CI 0.82–0.86) (Doocy and Burnham, 2006). The second evaluation was from an ‘improved bucket’ intervention with a spout and a permanent partial lid preventing hands from entering the bucket (Roberts et al., 2001). Diarrhoea rates were reduced by 31 per cent in children under 5 years and 8 per cent overall for the intervention group; however, neither reduction was statistically significant (p = 0.06 and p = 0.26).
The community preferred the improved buckets to chlorination, as chlorine was associated with a bad taste and smell.

**Boiling.** Only one high risk evaluation included in this review promoted boiling as a response intervention as part of a hygiene campaign for cholera in Guinea-Bissau (Einarsdottir et al., 2001). After the campaign, 40 per cent of households reported boiling water; however, 66 per cent reported using lemon to treat water, no households reported consistent use of either method, and no confirmed use evidence was collected.

Overall, these less common HWT interventions were consistently reported to be simple, sustainable, and accepted by the communities. However, the overall evidence for each individual intervention is weak.

**Sanitation.** While latrine building was commonly listed as an activity, no evaluations of latrine building were identified in the review. Sanitation was indirectly addressed in evaluations of two community-driven interventions: one community led total sanitation (CLTS) which was shown to have significantly reduced cases of Ebola (Meyer Capps and Njiru, 2015), and one participatory hygiene and sanitation transformation (PHAST) (Waterkeyn et al., 2005). Both intervention strategies aimed to educate and motivate communities to address their own needs with minimal external support.

**Community-driven sanitation.** A CLTS programme in Liberia was implemented for five years before Ebola erupted and the intervention continued throughout the outbreak. In a medium risk of bias study, households in villages that achieved ‘open defecation free’ status through CLTS were found to be 17 times less likely to have cases of Ebola than non-CLTS communities (OR = 0.06, p<0.001) (Meyer Capps and Njiru, 2015). Additionally, villages that were triggered by CLTS but had not yet achieved open defecation free status had eight times fewer Ebola cases than communities not in the project (Waterkeyn et al., 2005).

A PHAST approach with community health clubs was trialled in the midst of a cholera outbreak in a Ugandan internally displaced persons camp (Waterkeyn et al., 2005). The evaluation was a high risk of bias field commentary, but reportedly reached more than 15,000 people while constructing more than 8,000 latrines and 6,000 bath shelters in less than four months. Group cohesion and peer pressure were noted as effective behaviour change mechanisms.

**Hygiene.** Hygiene messages educate affected populations on disease risks and transmission routes. Often in emergencies, hygiene promotion is condensed to key messages, such as handwashing at critical times. Promotion can be at schools, in large community groups, or at the household level. Social mobilization includes strategies for engaging and facilitating communities to address identified risks with local solutions (e.g. CLTS as described above). There was no direct evaluation of hygiene practices identified for the review; however, there were eight evaluations of hygiene promotion and six social mobilization evaluations identified, although all were medium and high risk of bias.
Hygiene promotion. In five hygiene promotion evaluations, interpersonal communication was highlighted as positively received by beneficiaries (Williams et al., 2015; Matemo, 2014; Contzen and Mosler, 2013; Date et al., 2013; Einarsdottir et al., 2001; Wall and Chéry, 2011). Additionally, material demonstrations (i.e. instruction on HWT), visits by community health workers, and conversations with friends and family were consistently reported as positively received by beneficiaries. Radio communication was also consistently preferred or trusted by communities. Delivering simple, clear messages was a notable challenge in four studies. Different and conflicting messages undermined the response in the Haiti cholera and Liberia Ebola response (Wall and Chéry, 2011; Meyer Capps and Njiru, 2015). It was unclear if hearing a message on the radio translated to action or a realistic understanding of the local situation (Wall and Chéry, 2011). There were also noted difficulties with dialect differences (Einarsdottir et al., 2001) and errors in printed information (Neseni and Guzha, 2009). Other impacts from hygiene education included a reported decline in morbidity and diarrhoea rates (WHO, n.d.; Williams et al., 2015), confirmed increase in HWT use (Date et al., 2013), and self-reported changes in behaviour by reducing physical contact (i.e. hugs, shaking hands) during a cholera outbreak (WHO).

Social mobilization. In a mix of research methods, including quantitative, qualitative, and field commentary, there were six medium and high risk of bias evaluations describing some version of social mobilization. Compared with a purely educational campaign that is ‘top-down’, designed to deliver or extract information (Contzen and Mosler, 2013), community mobilization (engagement) approaches were reported to have positive impact on programmes by NGOs: listening to communities, dispensing fears and stigmas, and learning how to adapt to the context. For example, a ‘dialogue-based’ approach by NGOs led to an improved understanding of the community, leading to a better response as viewed by the community (Wall and Chéry, 2011). Moreover, stronger community relationships were also described in three of the social mobilization evaluations described with ‘community ownership’, ‘trust’, and ‘group cohesion’ (Wall and Chéry, 2011; Waterkeyn et al., 2005; ACE, 2015). Social mobilization was also qualitatively reported in high risk of bias studies to reduce disease transmission better than disease case management (ACE, 2015; Rees-Gildea, 2013; Neseni and Guzha, 2009), while the CLTS programme in the Liberia Ebola response (described above) had a strong and significant reduction in disease risk (Meyer Capps and Njiru, 2015).

Hygiene kit distributions. The goal of most hygiene kit distributions was to deliver HWT products and/or support hygiene activities addressed in other intervention categories. Hygiene kit distributions were mentioned in 17 mixed risk of bias evaluations. HWT products, soap, and safe water storage containers were most commonly included in the kits. Barriers and facilitators of hygiene kits were described throughout studies described within other interventions (e.g. HWT and WASH package below) most often noting the importance of pre-positioning and timely distribution of supplies (Simpson et al., 2009; DeGabriele and Musa, 2009; Neseni and Guzha, 2009; Ruiz-Roman, 2009; Lantagne and Clasen, 2012; ACE, 2007).
Environmental hygiene. Environmental hygiene interventions were identified as jerrican disinfection and spraying household surfaces with a chlorine solution or disinfection kit distribution.

Jerrican disinfection. Jerrican disinfection was investigated in three high risk of bias evaluations, all in camp settings, and all assessed with no beneficiary input. All three jerrican cleaning methods were assessed to reduce disease risk with very weak evaluation methods. Chlorine concentration reduction was noted in all three documents (Steele et al., 2008; Walden et al., 2005; Roberts et al., 2001). One-time disinfection did not have a long-term impact on recontamination.

Household spraying. Household spraying was mentioned as an activity in five documents but not evaluated (Neseni and Guzha, 2009; Gauthier, 2014; Grayel, 2011, 2014; Dunoyer and Sudre, 2012). A known outbreak activity, household or community spraying was noted to have several potential drawbacks such as stigmatizing households, limited resource availability, a false sense of protection, and limited impact considering 80–85 per cent of people infected with cholera are asymptomatic (Grayel, 2011). Household spraying is currently not recommended for responders to carry out by the UNICEF Cholera Toolkit (UNICEF, 2013); however, it is recommended that families should thoroughly clean the house with soap and chlorine solution. Other environmental hygiene evaluations were few in number and are not described herein. In an example from the Ebola response in West Africa, household spraying was described as ‘incomplete’ and likely ineffective (Nielsen et al., 2015). In alignment with the UNICEF recommendations, an NGO provided family members of cholera patients with household disinfection kits during the cholera outbreak in Haiti. After a group hygiene session, kits were given to the patient or caretaker, including: 0.5–1 kg of soap, a 14 L bucket, a 10 L jerrican, 3.8 L of bleach, a cloth, a scrubbing brush and an instruction book (Gartley et al., 2013). Self-reported use of hygiene kit contents was high (>90 per cent) in a high risk of bias evaluation.

WASH package. WASH interventions are regularly implemented in combination to address multiple possible transmission routes and provide comprehensive protection to beneficiaries. Overall, 13 WASH package evaluations from eight countries were identified in this review; all 13 were high risk of bias grey literature documents, with 11 field commentary documents. Well rehabilitation, NFI kit distributions, and hygiene promotion were the most frequently included individual interventions in these WASH package interventions; meanwhile water trucking was slightly less common and sanitation was rarely present – mirroring the findings above. These qualitative field commentaries had a high risk of bias but consistent descriptions of anecdotal health impacts and non-health behaviour change impacts. Expert staffing and rapid response timing were consistently identified as critical factors for programme success.

Cost-effectiveness. Cost-effectiveness and economic outcomes could not be assessed. Only cost-related outcomes – not cost-effectiveness – were commented on in nearly half of evaluations (45 per cent, 23/51), but were too heterogeneous for analysis. For example, an acute chlorine HWT intervention reportedly cost about $1/day for a household with confirmed FCR in Nepal and Kenya (Lantagne and Clasen,
WASH interventions in outbreak response

2012), whereas in a different HWT intervention in Madagascar, a bottle of chlorine solution able to treat 1,000 L cost about $0.46 (Dunston et al., 2001); however, this price did not include promotion and indirect cost and was estimated to have 46 percent cost recovery. The lack of clear and consistent reporting of economic outcomes eliminated the ability for any usable comparison.

Summary of evidence

Summaries of findings and assessment of evidence are presented in Table 1 and Table 2. Overall, the quality of evidence is low; this was attributed to weak study designs that lacked control groups and had high likelihood of spillover effects. As can be seen in Figure 3, well disinfection, source-based treatment, and HWT had more evaluations, better evidence, and were assessed more quantitatively. Hygiene, sanitation, and WASH package interventions were assessed with lower quality and more qualitative studies.

No intervention had high quality of evidence. While most of these evaluations were poor quality with high bias, the strength of evidence comes from the consistency of reported outcomes and impacts.

Through this review, we identified breakages along the causal chain in each of the WASH interventions. All interventions evaluated could be ‘efficacious’, with documented potential to have positive impact on WASH conditions; however, it is noted that the efficacy of household spraying is unclear. Well and jerrican disinfection were evaluated without beneficiary involvement, thus the ‘effectiveness’ – how well the intervention worked in the context – depended on how the intervention was carried out by the responding agency in the particular context. The effectiveness of the remaining interventions was influenced by beneficiary factors such as taste/smell and their knowledge of correct use.

Discussion

We collected and assessed the stated evidence of WASH interventions in specific disease outbreaks investigating four objectives: health impacts, project designs, cost-effectiveness, and population barriers and facilitators.

Objective #1: Health impacts of WASH interventions in disease outbreaks

WASH interventions that evaluated health impact through a measured change in diarrhoeal disease rates were rarely conducted in outbreaks, as only six health impact evaluations were identified in the review. Five were with less commonly implemented HWT interventions – one with PUR (Doocy and Burnham, 2006), two with simple filters (Colwell et al., 2003; Huq et al., 2010), one with SODIS (Conroy et al., 2001), and two with safe storage (Roberts et al., 2001; Doocy and Burnham, 2006). All five studies reduced diarrhoeal disease rates. In the sixth evaluation, a long-running CLTS intervention implemented before and during the Ebola outbreak had a large and significant reduction in diarrhoeal disease risk (Meyer Capps and Njiru, 2015).
Table 1 Water intervention summary of evidence

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Number of studies</th>
<th>Quality of outcomes</th>
<th>Summary of findings</th>
<th>Overall evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Health</td>
<td>Use</td>
<td>Non-health</td>
</tr>
<tr>
<td>Well disinfection</td>
<td>5</td>
<td>Not assessed</td>
<td>Not assessed</td>
<td>Moderate</td>
</tr>
<tr>
<td>Source-based treatment</td>
<td>3</td>
<td>Not assessed</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>HWT: chlorine-based products – chlorine tablets</td>
<td>6</td>
<td>Not assessed</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>HWT: chlorine-based products – liquid chlorine</td>
<td>4</td>
<td>Not assessed</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>HWT: chlorine-based products – flocculant/disinfectants</td>
<td>3</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>HWT: other products – filtration, SODIS, safe storage and boiling</td>
<td>6</td>
<td>Low</td>
<td>Very low</td>
<td>Low</td>
</tr>
</tbody>
</table>
### Table 2 Sanitation, hygiene, and WASH package intervention summary of evidence

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Number of studies</th>
<th>Quality of outcomes</th>
<th>Summary of findings</th>
<th>Overall evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community-driven Sanitation – CLTS/PHAST</td>
<td>2</td>
<td>Low, Not assessed</td>
<td>Limited number of interventions, but strong positive health and social aspects from community-led interventions.</td>
<td>Low</td>
</tr>
<tr>
<td>Hygiene promotion</td>
<td>8</td>
<td>Low, Very low</td>
<td>Consistently, personal communication and radio are preferred and trusted by the community. Use and health reportedly improved.</td>
<td>Low</td>
</tr>
<tr>
<td>Social mobilization</td>
<td>6</td>
<td>Low, –</td>
<td>Limited assessments but anecdotal health impact. Community trust and ownership important factors.</td>
<td>Low</td>
</tr>
<tr>
<td>Hygiene kit distribution</td>
<td>8</td>
<td>Not assessed, Not assessed</td>
<td>Consistent factor of influence through materials, quantity, timeliness. Low quality evaluations, HWT primary investigation of hygiene kits.</td>
<td>Low</td>
</tr>
<tr>
<td>Environmental hygiene</td>
<td>4</td>
<td>Very low, Very low</td>
<td>With weak evaluations, jerrican disinfection consistently reported to reduce disease transmission risk and chlorine concentration monitoring was necessary. Household consistently spraying not recommended for responders.</td>
<td>Very low</td>
</tr>
<tr>
<td>WASH package</td>
<td>12</td>
<td>Very low, Not assessed</td>
<td>Weak evaluations had consistent anecdotal descriptions of disease reductions, behaviour adjustments, and psychosocial support; staffing and timing also important factors.</td>
<td>Low</td>
</tr>
</tbody>
</table>
More common than diarrhoeal disease reduction evaluations, interventions that evaluated the risk of diarrhoeal disease transmission included: well disinfection (Rowe et al., 1998; Libessart and Hammache, 2000; Garandeau et al., 2006; Guevart et al., 2008; Cavallaro et al., 2011), chlorine dispensers (Yates et al., 2015b), and HWT (liquid chlorine (Mong et al., 2001, Dunston et al., 2001; Lantagne and Clasen, 2012; ACF, 2014b), chlorine tablets (Imanishi et al., 2014; Lantagne and Clasen, 2012; ACF, 2009; Tokplo, 2015; ACF, 2014a), and flocculant-disinfectants (Doocy and Burnham, 2006; Lantagne and Clasen, 2012; ACF, 2014a)). Environmental hygiene interventions using chlorine to clean jerricans also reduced short-term transmission risk (Steele et al., 2008; Walden et al., 2005; Roberts et al., 2001).

WASH interventions consistently reduced both the risk of diarrhoeal disease and the risk of transmission in outbreak contexts; however, programme design and beneficiary preferences were important considerations to ensure WASH interventions reached their potential.

**Objective #2: Important WASH programme design and implementation characteristics**

Four programme design and implementation characteristics were consistently reported as positive programme characteristics identified through a mixture of research designs and across risk of bias assessments, including simple interventions that were appropriately timed, community-driven, and had linkages between relief and development. Some of the most basic interventions, such as simple cloth filters, nylon screen, safe storage with a jerrican or bucket, or hygiene kit provision, had a clear positive impact (Roberts et al., 2001; Colwell et al., 2003; Huq et al., 2010; Gartley et al., 2013). These interventions required
little to no promotion and led to incremental improvements that reduced the
risk of diarrhoeal disease. Prepositioned stock, quick release of funds, and early
triggers for rapid scale up were important factors of a positive response, parti-
cularly with hygiene kit and HWT interventions (Simpson et al., 2009; DeGabriele
and Musa, 2009; Neseni and Guzha, 2009; Ruiz-Roman, 2009; Lantagne and
Clasen, 2012). Engagement in the community empowers and builds trust, and
community-driven interventions can increase awareness, trigger behaviour
change, and identify local solutions (Waterkeyn et al., 2005; Neseni and Guzha,
2009; Rees-Gildea, 2013; Meyer Capps and Njiru, 2015; ACF, 2015; Wall and
Chéry, 2011). Linking with pre-existing programming builds upon recipient
population familiarity, and having a sustainability plan encourages better cultural
understanding and improves emergency response programmes (Meyer Capps and
Njiru, 2015; Dunston et al., 2001; Tokplo, 2015; Imanishi et al., 2014; Lantagne
and Clasen, 2012; WHO, no date).

Objective #3: Cost-effectiveness of WASH interventions in
emergency outbreak situations

Cost-effectiveness of WASH interventions in outbreaks could not be assessed as
there were only minimal, and disparate, economic outcomes in the evaluations
identified in the review. There were no consistent reporting measures, despite cost
or economic considerations from nearly half of the included studies. While inter-
ventions should not be solely compared by cost-effectiveness, some effort acknowl-
edging the need for efficiency of funds should be considered.

Objective #4: Population-related barriers and facilitators that affect WASH
interventions in disease outbreaks

In the review, four community perceptions and preferences that consistently affected
the success of WASH outbreak interventions were identified across the mixture of
evaluation methods and risk of bias assessments. Taste and smell of HWT products
may hinder use (e.g. chlorine treatments can have an off-putting smell or taste)
(ACF, 2009; Lantagne and Clasen, 2012; Imanishi et al., 2014; Ruiz-Roman, 2009)
or facilitate use (e.g. filters and flocculant disinfectants improved taste) (Doocy
and Burnham, 2006; Colwell et al., 2003; Huq et al., 2010). Radio and face-to-face
communication were consistently reported as ‘most trusted’ or ‘most valued’ for
hygiene communication (Einarsdottir et al., 2001; Date et al., 2013; WHO, no date;
Contzen and Mosler, 2013; Matemo, 2014; Williams et al., 2015; Wall and Chéry,
2011). Community understanding of some interventions overestimated the effec-
tiveness and risk reduction (i.e. household spraying and well disinfection) (Grayel,
2011; Rowe et al., 1998). Social mobilization and open communication between
the community and NGOs built trust and greater community cohesion (Wall and
Chéry, 2011; Waterkeyn et al., 2005; ACF, 2015).

Previous systematic review efforts reported only on health impacts (Ramesh
et al., 2015), have been limited by the narrower scope (Taylor et al., 2015;
Ramesh et al., 2015) and therefore few of the lessons learned were reported. The wide
The scope of this review permitted a greater quantity of lower quality, less technical studies with a similarly large variety of outcomes than is traditional for systematic reviews. This undermined the potential for detailed analysis at the intervention level, but enabled broader lessons to be learned that were applicable to the global emergency WASH community. Also, the inclusion of grey literature allowed more additional intervention barriers and facilitators that were not described in other reviews.

In conducting the review, it was more difficult than expected to assess: whether the WASH intervention was in the same geographic location as the outbreak; compare interventions conducted at different times in the outbreak; clearly suggest impact without suitable control groups to compare; and search and extract information from grey literature. Despite these limitations, the strength of this review is in its broad inclusion criteria and assessment of intermediary outcomes and final impacts, which led to a comprehensive review of available evidence that is policy-relevant and actionable.

Gaps
It is clear from the results of the review that some of the most commonly implemented WASH interventions in outbreaks are severely under-researched. We need additional research for: well rehabilitation, water trucking, bucket chlorination, household spraying, handwashing, latrine building, environmental clean-up, and formal economic analysis. Additionally, there was a disparity between what was researched and published in the literature and what was implemented by responders and written up as grey literature: water treatment interventions were most commonly researched and published by academics, while combined WASH package interventions were commonly implemented and reported for a narrow audience by responders.

Limitations
There were several limitations to this research. Most organizations that submitted documents to the review provided only a select handful of reports, and it is likely that the provided reports were limited to those with favourable outcomes or innovative approaches. Self-reported data (such as diarrhoea disease incidence or use of HWT products) was subject to both recall and courtesy bias, which would likely over-estimate positive outcomes. FCR, diarrhoea incidence, and *Escherichia coli* microbiological results are proxies for the outcomes and impacts of disease outbreaks. Outcomes were reported inconsistently. For example, confirmed use of an HWT intervention was the clearest outcome measured (using FCR); however, reporting thresholds varied by: ‘detectable’, >0.0 mg/L, >0.1 mg/L, ≥0.2 mg/L, and ≥0.5 mg/L, which precluded comparative analysis. Furthermore, database searching was completed primarily in English; keywords searched may not have captured all relevant studies with variations of intervention names or names in local languages. There was difficulty in securing non-published studies from known responding agencies, likely influencing the results. And lastly, only WASH interventions implemented in outbreak settings were included, likely excluding interventions derived from other sectors or development approaches.
Recommendations

To improve the evidence on WASH interventions in emergencies, clear reporting with consistent evaluation methods and common and robust methods is needed. Well-designed non-experimental and qualitative studies can be used to increase the evidence base and should include indicators beyond diarrhoeal rates. Consistent and thorough cost-effective evaluations of WASH interventions are also needed. Additionally, evaluations should be conducted at the beneficiary level, to better understand impact on the household rather than presume impact through community coverage. Publishing results, while not necessary, does offer transparency and an additional sharing platform for the humanitarian community.

Conclusion

A systematic review process was used to identify more than 15,000 documents; ultimately, 51 evaluations of WASH interventions in outbreaks were included in the review. Across the wide breadth of scope of this review, we found that WASH interventions consistently reduced both the risk of diarrhoeal disease and the risk of transmission in outbreak contexts; however, program design and beneficiary preferences were important considerations to ensure that full WASH intervention effectiveness could be reached. Some of the most commonly implemented WASH interventions in outbreaks were found to be severely under-researched, such as the impact of hygiene promotion, distribution of hygiene kits, or bucket chlorination. Further research investigating outcomes and impacts of specific interventions is recommended since diarrhoeal disease impact is just one of many outcomes relevant to WASH interventions. It is also recommended that responders implement efficacious, simple interventions that are appropriately timed, community driven, and have linkages between relief and development. Considering the large funding gaps, defining cost-effective expectations relative to the scale and timing of the outbreaks is needed. Finally, responders should work in collaboration with the recipient communities to address barriers and facilitators to use while acknowledging the differences in community perception and local knowledge.

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