humanitarian innovation fund

WASH in Emergencies
Problem Exploration Report

Water Treatment

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Preface

The Humanitarian Innovation Fund (HIF) is a programme of ELRHA, and we are here to support organisations and individuals to identify, nurture and share innovative and scalable solutions to the challenges facing effective humanitarian assistance.

The HIF has a dedicated fund to support innovation in water, sanitation and hygiene (WASH) in all types of emergencies, from rapid onset to protracted crisis. WASH is a broad theme with serious consequences in many other areas such as health, nutrition, protection and dignity. In the absence of functioning toilets, clean water systems, effective hygiene practices, and safe disposal of waste, pathogens can spread rapidly, most commonly causing diarrheal and respiratory infections which are among the biggest causes of mortality in emergency settings.

Despite this, there is a significant gap between the level of WASH humanitarian assistance needed and the operational reality on the ground. This is why the HIF works closely with multiple stakeholders from across many humanitarian agencies, academia and private sector to understand and overcome practical barriers in the supply and demand of effective solutions.

Over the past three years the HIF has been leading a process to identify the key opportunities for innovation in emergency WASH. Fundamental to this is having a strong understanding of the problems that need to be solved. We note that many innovations focus on improving technology because the problems can often be clearly defined, compared to more complex problems with supply chains, governance or community engagement.

Our problem research began with an extensive Gap Analysis (Bastable and Russell, 2013) consulting over 900 beneficiaries, field practitioners and donors on their most pressing concerns. From these results we prioritised a shortlist of problems including water treatment. However drawing lines between where one problem ends and another starts is difficult given the feedback loops within each system. For example reducing waste from plastic bottle usage relies on the availability of other safe water options which in turn is linked to environmental sanitation and hygiene.

This report is one of a series commissioned by ELRHA to explore priority problems in emergency WASH. The researcher selected for each report was asked to explore the nature of the challenges faced, document the dominant current approaches and limitations, and also suggest potential areas for further exploration.

The primary purpose of this research is to support the HIF in identifying leverage points to fund innovation projects in response to the complexity of problems. We seek to collaborate closely with those already active in these areas, avoid duplication of efforts, build on existing experiments and learning, and take informed risks to support new ideas and approaches.

In publishing these reports we hope they will also inform and inspire our peers who share our ambitions for innovation in emergency WASH. In addition to engineers and social scientists who are crucial to this work we hope to engage non-traditional actors from a diverse range of sectors, professions and disciplines to respond to these problems with a different perspective.

The content of this report is drawn from a combination of the researcher's own experiences, qualitative research methodologies including a literature review that spanned grey and published literature and insights from semi-structured interviews with global and regional experts. The report was then edited and designed by Science Practice.

We would like to thank the members of our WASH Technical Working Group for their ongoing guidance: Andy Bastable (Chair), Brian Reed, Dominique Porteaud, Mark Buttle, Sandy Caincross, William Carter, Jenny Lamb, Peter Maes, Joos van den Noortgate, Tom Wildman, Simon Bibby, Brian Clarke, Caetano Dorea, Richard Bauer, Murray Burt, Chris Cormency, and Daniele Lantagne.

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The report was edited and designed by Science Practice.

Abbreviations

CDC	The Centers for Disease Control and Prevention
DRC	The Democratic Republic of the Congo
FRC	Free Residual Chlorine
HHWT	Household Water Treatment
IDP	Internally Displaced Person
IFRC	The International Federation of Red Cross and Red Crescent Societies
MF	Membrane Filtration
MSF	Médecins Sans Frontières (Doctors Without Borders)
NGO	Non-governmental Organisation
NTU	Nephelometric Turbidity Units
OCHA	The United Nations Office for the Coordination of Humanitarian Affairs
ORP	Oral Rehydratation Point
R&D	Research and Development
RO	Reverse Osmosis
UN	United Nations
WASH	Water, Sanitation, and Hygiene
WHO	World Health Organisation
WSP	Water Safety Plan
WTU	Water Treatment Unit

Glossary

The terms listed in this glossary are defined according to their use in this report. They may have different meanings in other contexts.

Backwashing — A form of preventive maintenance so that a filter media can be reused. Backwashing consists of reversing the flow of water so that it enters from the bottom of the filter bed, lifts and rinses the bed, then exits through the top of the filter tank.

Brackish Water (or Briny Water) — Water that has more salinity than fresh-water, but not as much as seawater. It may result from mixing of seawater with freshwater, as in estuaries, or in salt-bearing formations.

Faecal Coliforms — A group of facultatively anaerobic, rod-shaped, gram-negative, non-sporulating bacteria. Coliform bacteria generally originate in the intestines of warm-blooded animals and are used as an indicator of human faecal contamination of water.

Flocculation — The process by which fine particles are caused to clump together into a floc. The floc may then float to the top of the liquid (creaming), settle to the bottom of the liquid (sedimentation), or be filtered from the liquid.

Free Residual Chlorine (FRC) — Residual chlorine content of water that exists in uncombined form and is composed of hypochlorite ion and hypochlorous acid (see Residual Chlorine). The presence of free residual chlorine in drinking water is correlated with the absence of disease-causing organisms, and thus is a measure of the potability of water.

Grey literature — Operational and/or research documents produced by organisations that are not published or disseminated externally by commercial or academic publishing and distribution channels.

Hydrocyclone — A static device that applies centrifugal force to a liquid mixture so as to promote the separation of heavy and light components.

Influent Water — A general name for the water entering a treatment plant.

Internally Displaced Person (IDP) — A person who is forced to flee his or her home but who remains within his or her country's borders.

Nanofiltration — A membrane filtration process providing nano-scale exclusion for the removal of undesirable particles.

Refugee — A person who has been forced to leave their country in order to escape war, persecution, or natural disaster.

Residual Protection — The ability of an agent to continue to prevent or inhibit the growth of harmful bacteria in water after initial treatment.

Reverse Osmosis (RO) — A water purification technology that uses a semipermeable membrane to remove larger particles from drinking water under a pressure differential.

Safe Water — Water that is palatable and of sufficient quality to be drunk and used for cooking and personal and domestic hygiene without causing risk to health.

Sphere Project — Launched in 1997, the aim of the Sphere Project is to develop a set of minimum standards in core areas of humanitarian assistance, improve the quality of assistance provided to people affected by disasters, and enhance the accountability of the humanitarian system in disaster response.

Total Residual Chlorine — The total chlorine content of water following chlorine-based water treatment.

Vector-based disease — Infection transmitted by the bite of infected arthropod species, such as mosquitoes, ticks, triatomine bugs, sandflies, and blackflies.

Water Safety Plan (WSP) — A plan to ensure the safety of drinking water through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer.

Executive Summary

The provision of adequate quantities of safe water is a basic necessity in emergencies. Inadequate provision of clean water is linked to the transmission of infectious diseases including hepatitis E, cholera, and other diarrhoeal diseases. The spread of waterborne pathogens is of particular concern during population displacements (due to war, famine, or natural disaster), major floods, and faecal-oral disease outbreaks.

To achieve water quality targets mandated by the industry-standard Sphere Project, humanitarian workers have relied upon bulk chlorination to inactivate pathogens present in clear water and provide residual protection against recontamination. In the case of high turbidity source waters, additional pre-treatment steps to reduce turbidity, often in the form of assisted sedimentation, are common. More recently, a number of new technologies, some operating at the household level, have been utilised as well.

Despite the advances that have been made in coordination and professionalisation of water treatment in emergencies, there remain considerable knowledge gaps in field practice. These gaps range from operational concerns, to the lack of evidence-base for commonly applied interventions, to technological limitations.

The present report puts forward three key areas which would benefit from innovations and research to improve the provision of safe water in emergency contexts.

Better Operational Tools: There is a need to develop operational tools to help humanitarian aid workers improve their decision-making processes. These tools should be able to support agencies in assessing a new emergency situation, or select context-specific water treatment interventions.

A Robust Evidence-Base: A more robust evidence-base for the effectiveness of commonly used treatment technologies in emergencies is needed. Ideally, research in this area would employ epidemiological methods in the field during an emergency situation. Specifically, research looking into the effectiveness of household water treatment (HHWT) solutions would be valuable, together with the development of relevant training materials to help facilitate behaviour change.

Technological Innovations: Although there have been significant technological innovations in the area of water treatment, solutions looking to improve the usability and reliability of currently used systems, such as those for assisted sedimentation and disinfection, would be very beneficial.

Part 1: The Challenge of Water Treatment in Emergencies

The provision of adequate quantities of safe water is a basic necessity in emergencies. Inadequate provision of clean water is linked to the transmission of infectious diseases including hepatitis E, cholera, and other diarrhoeal diseases (Fewtrell and Colford, 2004; Gundry, Wright, and Conroy, 2004; Guthmann et al., 2006). The spread of waterborne pathogens is of particular concern during population displacements (due to war, famine, or natural disaster), major floods, and faecal-oral disease outbreaks (Watson, Gayer, and Connolly, 2007; Lemonick, 2011; Cann et al., 2013).

To harmonise responses to emergencies, humanitarian agencies came together in 1997 to establish the Sphere Project. This put forward a common humanitarian charter as well as minimum standards and best practices for core areas of emergency response including water, sanitation, and hygiene (WASH); food security and nutrition; shelter, settlements, and non-food items; and health services.

Sphere guidelines for water supply stipulate that at least 15 l/day/person should be provided, with water quality at point of delivery with turbidity <5 NTU (nephelometric turbidity units), zero faecal coliforms per 100 ml, and free residual chlorine of 0.5 mg/l (in the case of piped water or diarrhoeal disease outbreaks). The water should also not present long-term health risks due to chemical contamination (Sphere Project, 2011).

The Sphere guidelines recommend that sanitary surveys be carried out to assess conditions and practices that may constitute a public health risk including sources of water contamination at source, during transport, and in the household in order to identify ameliorative strategies. In order to protect the safe water chain (i.e. going from point of delivery to point of consumption), the Sphere guidelines specify that water collection/storage containers used for distribution should have narrow mouths and/or covers that are easy to clean and can thus limit unhygienic contact with stored water (Sphere Project, 2011).

Achieving water quality standards without similarly achieving water access and quantity targets is not sufficient to satisfy the Sphere guidelines for water supply nor protect public health.

In order to achieve water quality targets, humanitarian workers have traditionally relied on bulk chlorination to inactivate pathogens present in clear water (both for groundwater and surface waters). In the case of high turbidity source waters (often surface waters), an additional pre-treatment step to reduce turbidity of assisted sedimentation (commonly using aluminium sulphate - alum) is indicated. Alum flocculation and chlorination are widely used in the humanitarian sector because materials are widely available, they are simple to use and relatively low cost, and importantly, because chlorination provides residual protection against recontamination (Reiff, 2002). While this approach to water treatment has been dominant, particularly in large displacement camps, the increasing sophistication of WASH response has also resulted in the diversification of approaches to water treatment in emergencies. Though the focus of the present document is on water treatment, it is important to note that achieving water quality standards without similarly achieving water access and quantity targets is not sufficient to satisfy the Sphere guidelines for water supply nor protect public health. A number of field manuals have been produced by WASH agencies that provide essential technical guidance on current best practices for emergency water treatment (Médecins Sans Frontières, 2010; Davis and Lambert, 2002; Oxfam GB, 2001).

Advances have been made in coordination and professionalisation of WASH service delivery in emergencies, however there remain, as with all aspects of humanitarian response, considerable knowledge gaps in field practice (Evidence Aid, 2013; Brown et al., 2012; Blanchet and Roberts, 2013; Bastable and Russell, 2013). This report aims to identify key knowledge gaps on water treatment in emergencies.

A note on scale

Generally speaking, emergencies are dynamic, chaotic, and spatially and temporally variable, entailing that a range of approaches may be required across all aspects of response. Temporally, humanitarian crises have different levels of acuity, each with its own requirements and limitations:

Acute	The first weeks
Transitional	The first few months
Stabilised	A few months to one year
Sustained	On-going emergencies

Spatially, emergencies occur at a range of geographic scales entailing dense or dispersed displacements in urban or rural areas in widely varying geographic contexts. Given such spatial and temporal variability, emergency interventions, whether targeting water quality improvement or other aspects of response, are not one-size-fits-all. Often solutions implemented during the acute phase of an emergency would be considered unacceptable in a stabilised or sustained context. Spatial scale also has a specific resonance with water treatment as technical approaches are fundamentally conditioned by process scale. Though not perfect, a useful classification scheme for levels at which water treatment can be applied is as follows:

Household	In individual homes	Small-scale: 10s–100s of litres per day
Community or “Semi-Centralised”	At a “neighbourhood” level serving a cluster of multiple households	Medium-scale: 1000s–10,000s of litres per day
Centralised	En masse at a single point serving a town-size settlement (urban, village, large refugee/IDP camp)	Large-scale: 100,000s–1,000,000s of litres per day

Throughout this report, water treatment approaches are considered at distinct temporal and spatial scales.

Part 2: Current Approaches and Limitations

This section is divided into five key thematic areas developed through an inductive approach, emerging from interviews with key experts and a review of grey and published literature. The section begins with an overview of some of the key contextual challenges of water treatment in emergencies, and continues with a presentation of current water treatment practices according to their scale, ranging from household-level solutions, to semi-centralised and centralised solutions. Finally, the challenges posed by chemical water pollution are briefly discussed.

Each sub-section herein discusses the current state of practice, R&D work presently under way to advance practice (if any), and questions/knowledge gaps that may be the subject of future R&D activity.

2.1 Contextual Challenges

One of the cross-cutting themes that emerged from the expert interviews was that too often emergency responders do not adequately consider the local context before designing and launching safe water interventions. Failure to do so often leads to poor intervention performance and/or wasted resources. This failure calls for a more sophisticated approach to emergency water treatment. Such an approach should entail developing operational support tools that can help responders incorporate the contextual information needed to design an appropriate safe water strategy.

2.1.1 Adapting the Water Safety Plan Approach to Emergencies

For one, the focus for water treatment presently is at the point of distribution. An immediate contextual challenge is considering what happens to the quality of water as it moves along the pathway from distribution to consumption as recontamination of treated water is a continuous challenge in emergency contexts. One approach may be to translate the Water Safety Plan approach advocated by the WHO to the emergency context. Water Safety Plans embody a comprehensive risk assessment and management approach that examines all possible points of recontamination from catchment to consumer (Davison et al., 2005). There has been little work in this regard in emergencies and such work may be especially valuable following the acute phase as emergencies transition to a stabilised or sustained situation.

The risk of water recontamination from catchment to consumer is an important contextual challenge often forgotten.

2.1.2 Disaster Preparedness — Water Supply Baseline

The urgency of emergency situations makes integrating context particularly challenging, especially in acute situations. However as one interviewee pointed out, certain areas of the world are more prone to emergencies (earthquakes, floods, and other natural disasters) and it would be useful to develop clear contextual information before an emergency occurs that might help ensure a successful response. Such research would need to clearly document what is currently happening to assure adequate supplies of safe water (in the case of water quality), who the primary actors are in this arena (e.g. private vendors, community based systems), and what technologies are already familiar to stakeholders. This information will promote the design and deployment of safe water interventions that better suit their local context.

Figure 1.
Refugees collect water from a tapstand in the Jamam refugee camp, South Sudan. (Source: Syed Imran Ali, UC Berkeley)

Innovations in safe water provision need to take place at an institutional level. There is a need for clarity and consensus when it comes to best practices.

2.1.3 Operations and Knowledge Management

Overall, there was a common feeling that, in the case of water quality challenges, there is a need to go beyond further technological development and to explore some of the institutional challenges to the provision of safe water. Water system performance remains hugely variable from site to site highlighting the centrality of operational standards and quality assurance. Another challenge is the proliferation of often contradictory information concerning best practices in the field. While there is a huge volume of written information – mostly in grey literature – there is a general lack of clarity. As a result, water quality strategies are developed in one context and applied to another, different context, with mixed success. Related to this concern, and perhaps one of the reasons for the apparent problem, is that many emergency-response institutions lack adequate systems for knowledge management and preserving institutional memory.

2.1.4 Process Metrics vs. Public Health Impacts

Another institutional challenge is the over-reliance on descriptive checklists in emergency situations. The focus on checklists and discrete metrics – while certainly valuable – at times draws attention away from whether or not achieving any given metric actually improves water quality at the point of consumption in a sustainable manner. For example, a heavy focus on the distribution of chlorine sachets doesn't ensure that they are used properly, or may even happen without confirming that this is in fact the most important intervention. Embedded in this second issue is a desire to ensure that interventions are effective, a theme that comes up repeatedly in this research.

The tension between conducting research and accomplishing operational goals is ever-present in emergency contexts. The 'tyranny of emergency' often trumps the focus on long-term improvements. While some interviewees noted that the rigorous approaches to research in academia are needed in the field, others noted that while this is true, the institutional structures within academia are not well suited for field research in emergencies.

There is clearly a need to design creative mechanisms for the inclusion of academic-quality research in field settings without compromising operational priorities.

The topics of particular interest included: epidemiological studies, operational research, and anthropological research to better understand the needs of beneficiaries and how practitioners might better meet those needs.

CASE STUDY – The Need for a Robust Evidence Base

During the 2012–13 Maban County refugee crisis in South Sudan, a major hepatitis E outbreak gripped the camps. Hep E is a viral disease for which there is no cure and which is transmitted by the faecal-oral pathway. In response to the outbreak, humanitarian agencies sought to improve WASH service levels in the camps in order to limit the spread of the disease. For water quality, agencies strove to meet Sphere guidelines for free residual chlorine (FRC) at camp tapstands. However, it was soon observed that even when FRC levels were on point at tapstands, water stored in households often had little chlorine protection.

Surveys in the Jamam refugee camp showed that 40% to 58% of households that collected water from chlorinated tapstand sources had no detectable FRC in their stored household water (Oxfam, 2012; CDC, 2013), while another study demonstrated the presence of human adenovirus in stored household water, indicating faecal contamination (Guerrero-Latorre, Gonfa, and Girones, 2013).

The reason for the observed failure of the Sphere FRC guidelines to realise safe water at the point of consumption comes down to the source of the FRC conventions. They are based on the WHO Guidelines for Drinking-Water Quality (WHO, 2008) which emerge from experience with municipal piped-water systems — that is, from conditions that are vastly different from refugee/IDP camps.

Across multiple areas of water treatment, and WASH more generally, the evidence base underlying much of current field practice is radically deficient. Rigorous operational research in the field is required to understand how current practices actually fare and and how they can be improved.

2.1.5 Beyond Water Treatment

A final area of concern that came up in numerous interviews was the need to consider issues beyond water quality. Some interviewees argued that water quality is not the main problem and that instead, research should focus on sanitation solutions. Others echoed this idea by making the point that more broad-based solutions that take into account the interrelationships between water, sanitation, hygiene, and behaviour change efforts are needed to improve WASH requirements in an emergency situation.

2.2 Household Water Treatment (HHWT) Solutions

2.2.1 Background and Context

The training and adherence of household members is key to ensuring that the public health benefits of HHWT are met.

HHWT technologies are deployed as bench-scale systems that bring physical and/or chemical water treatment processes to the household level. Physical methods for HHWT include boiling, solar disinfection, UV irradiation, plain sedimentation, filtration, and aeration. Chemical methods include coagulation-flocculation, chemical precipitation, adsorption, ion exchange, chlorination, ozonation, chlorine dioxide, iodination, acid/base treatment, and silver/copper contact. Additionally, there are HHWT options that combine physical and chemical processes including combined flocculant-disinfectant products and systems integrating coagulation-flocculation, filtration, and disinfection (Sobsey, 2002). Some of the more common types of HHWT include combined flocculant-disinfectants (e.g. PuR, WaterMaker), chlorination (e.g. Aquatabs, CDC Safe Water System), rapid and slow sand filters (e.g. ceramic filters, biosand filters), solar disinfection (e.g. SODIS), and ultraviolet disinfection (Sobsey et al., 2008; Lantagne, Quick, and Mintz, 2011; Brownell et al., 2008).

Because they are carried out at the household level where they primarily serve the drinking water needs of an individual family, HHWT typically produce on the order of 10s-100s litres per day. HHWT options are often coupled with safe storage interventions in the recognition that treatment alone is not sufficient to ensure safe water supply and safe storage to protect water from recontamination is also essential (Ahmed, Hoque, and Mahmud, 1998; Brick et al., 2004; Levy et al., 2008; Baker et al., 2013; Clasen and Bastable, 2003; Gunther and Schipper, 2013).

As water treatment processes are carried out by household members themselves, training is an essential component of HHWT deployments. Approaches vary from intensive one-on-one training to the passive distribution of written or pictorial instructional materials. It has been observed that while HHWT have high levels of efficacy in laboratory trials, their field effectiveness levels are generally much lower due to challenges with incomplete compliance (Enger et al., 2013). Brown and Clasen (2012) similarly found that high adherence is required on the part of households if the public health benefits of HHWT are to be realised.

Since HHWT solutions came to prominence in the early 2000s, there has been a proliferation of both lab-based studies assessing the water treatment efficacy of traditional and novel HHWT options as well as numerous field-based randomised controlled trials and quasi-experimental studies to assess HHWT's epidemiological and water quality effects. There have been a series of meta-analyses and systematic reviews (Fewtrell et al., 2005; Clasen et al., 2007; Waddington and Snilstveit, 2009; Gundry, Wright, and Conroy, 2004) which, as Clasen (2015) summarises, generally suggest a positive, albeit highly heterogeneous, public health benefit with HHWT in development contexts.

This position is not shared unanimously across the sector however. Schmidt and Cairncross (2009) similarly reviewed HHWT health outcome trials and found evidence to suggest that HHWT may reduce diarrhoea by 30-40%. They note however that many of these trials are unblinded leading to a fundamental problem of bias in reported findings. When the authors included only blinded studies in their meta-analysis they found the reported health effect to vanish and concluded that current evidence does not exclude the possibility that the reported

There is considerable disagreement on the health effectiveness of HHWT. While some unblinded trials suggest a positive health benefit, blinded studies have not confirmed this health effect.

benefits of HHWT are largely or entirely due to bias. Engell and Lim (2013) in their meta-analysis similarly found that HHWT interventions had no observable effect once blinding was taken into account. Overall, there is considerable disagreement on the health effectiveness of HHWT.

The application of HHWT, together with its associated controversies, has in recent years entered into the humanitarian sector as well. HHWT has been advanced as a potential approach to safe water supply in emergencies, specifically in contexts where traditional batch water treatment and distribution or water trucking will not work (i.e. in dispersed displacements or displacements into existing urban areas), or as a short-term intervention when piped or point-source water supplies are potentially contaminated and a disease outbreak is occurring. The International Federation of Red Cross and Red Crescent Societies (IFRC) has published a manual on household water treatment and storage in emergencies that describes popular, simple HHWT approaches and includes a simple decision tree on how to choose the best approach in a given context. This takes into account several factors such as the water source and available resources (IFRC, 2008). The Sphere Guidelines now also include a decision tree for emergency HHWT that builds upon the IFRC version (Sphere Project, 2011).

2.2.2 Current Approaches

Recent interest on HHWT in emergencies has led multiple WASH agencies to begin experimenting with them in the field. A number of experiences were reported throughout the expert interviews conducted for this report. Key lessons that emerged for specific HHWT products are summarised:

Chlorine tablets (e.g. Aquatabs) — This is the most widely utilised HHWT product deployed in emergencies, and also one of the simplest. Field experiences suggest that despite its apparent simplicity, incorrect and/or inconsistent use remains common, leading to doubts around its real public health value. For additional information, see: Enger et al. (2013); Brown and Clasen (2012); Pickering et al. (2015).

Combined flocculant-disinfectants (e.g. PuR) — Overall, interviewees had a poor prognosis for PuR in emergencies. Field experiences suggest it is too complex to use correctly consistently. There have been attempts to simplify the use of combined flocculant-disinfectants by combining them in an effervescent tablet (i.e. no longer requiring stirring for flocculation), but these attempts have largely failed.

LifeStraw — The handheld version of this filtration system was widely criticised by interviewees on the basis of its poor technical performance and high cost.

Ultrafiltration Devices (e.g. Aquafilter, Lifesaver Jerrycan/cube) — These membrane filtration devices, which can reliably remove viruses, may have some potential in emergencies as they are relatively easy to use and because their price point is coming down. However they offer no residual protection, and depending on the influent water quality, may require excessive backwashing. Oxfam and Médecins Sans Frontières (MSF) have had limited trials using these but no agency is as yet stockpiling them for widespread deployment. For additional information, see: UKAID, Solidarites International, and Grifaid Aquafilters (2015).

Figure 2.
HHWT products such as this ceramic filter in a refugee camp household in Jordan face a number of challenges that may limit them to specific niche roles. (Source: Syed Imran Ali, UC Berkeley)

Ceramic Filters (e.g. Fairey Ceramics and Berkefeld) — While still relatively expensive, these filters may have potential to be deployed in emergencies as they are high quality ceramic filters that can be shipped safely. Tulip filters have gone to scale in some development contexts and may also have potential in emergencies. As they are manufactured in Malawi and are relatively cheap, the Dutch Red Cross has started distributing these products, suggesting that they may be applicable in emergencies as well. Fairey Ceramics are now being included in IFRC Oral Rehydration Point (ORP) kits and Berkefeld ceramic filters remain an essential part of clinic and base kits for MSF and other agencies.

The public health benefits of the above HHWT options in emergencies have not been investigated by any epidemiological studies. However some smaller scale studies focusing on household water quality have been carried out; for instance, on the impact of distributing LifeStraw in the Democratic Republic of Congo by Médecins Sans Frontières.

Building upon two important studies by Lantagne and Clasen (2012a; 2012b) as well as the expert interviews, below are some of the key factors that influence the effective use of HHWT technologies in emergencies:

- In acute emergencies, introducing users to unfamiliar HHWT technologies is ill-advised; instead HHWT may be best suited to non-acute emergencies with a dispersed population and high diarrhoeal disease risk;
- HHWT should be considered as one strategy of many for safe water in emergencies;
- Prioritising user preferences and HHWT options that users are already familiar with, and taking into account contextual specificity helps facilitate successful implementation;
- Training and material availability (i.e. replacement parts) is essential for user uptake;
- Long-term access to HHWT products should be considered at outset.

Overall, current work suggests HHWT may have a role in emergencies but may be best deployed in targeted interventions to households having poor water quality that cannot otherwise be reached by water tankers or at-source water treatment.

CASE STUDY — The Role of Rebranding

One example of a successful emergency HHWT application comes from Mozambique with the provision of Certeza. Certeza is a diluted sodium hypochlorite solution that users add to disinfect their drinking water. It was launched in 2004 in Mozambique by Population Services International and was sold in 150 ml bottles at subsidised prices through the private sector.

Following the cholera outbreak in 2004, emergency responders sought a readily available, easy to distribute, and locally recognised treatment technology that would enable those affected by the outbreak to treat their own drinking water. As Certeza was available on the local market and people knew how to use it prior to the outbreak, this product seemed an appropriate choice for distribution in the wake of the crisis.

To differentiate the product so that affected people would know that it was available for free during the period of the emergency, responders had the branding of the Certeza product changed from the normal, commonly recognised blue packaging to a new green packaging. This rebranding was key - it helped indicate that a familiar consumer product was now available for free during the period of the emergency.

There are however considerable concerns about the viability of HHWT in emergencies, even in the limited cases indicated. While HHWT may be useful in dispersed displacements where centralised water systems are not feasible, numerous logistical and technical challenges remain including product distribution, training, supervision, and resupply. As it stands, even the simplest HHWT options (i.e. chlorine tablets) are not regularly used correctly in emergencies. The 'one size fits all' approach to water quality and treatment of many HHWT options may also not be suitable for all water types. In addition there is often the problem of the daily or at least seasonal changes in the chlorine demand of most surface water sources which affects the efficacy of disinfection. Finally, if not consistently practised correctly, HHWT may fail, allowing people to fall sick while apparently practising HHWT, possibly leading to rejection of further safe water interventions.

CASE STUDY — The Need for Training

In Myanmar, following a flood, Aquatabs and PuR sachets were distributed to people living in affected areas. However when aid workers later returned to the affected areas, they found boxes unopened and disinfectants unused. Workers quickly realised that, while adequate supplies had been distributed, there had been no training on how to use the disinfectants. Moreover, those who had tried to use them did not like the taste of chlorinated water, and opted to forego the treatment. While the PuR sachets and Aquatab tablets were technically sound, the combination of inadequate implementation and user taste/perception prevented uptake. This experience suggests a need to develop more rigorous operational protocols and, more fundamentally, the need for a rigorous evidence base to support decision-making.

In the Lake Turkana region of Kenya, an international agency distributed PuR tablets and sachets to compare how well they work in the field. They found very limited success rates for both (3-4% and 7-8% respectively). The lack of success was attributed to large-scale, rapid product distribution without the appropriate training.

In another case, an NGO working in Mozambique realised that following distribution of PuR sachets users had mistaken them for flour, sugar, and oral rehydration packets leading to dangerous misuse. These cases point to the importance of clear, contextually appropriate training and support for HHWT technologies.

While technical concerns abound, these are not the only, or even the most pressing, challenges levelled at HHWT by critics. While an oft-reported benefit of HHWT is that it shifts treatment closer to the end user and therefore limits the opportunities for recontamination, there are major problems with this approach.

First, user adherence to proper use is a persistent problem limiting its field effectiveness (Brown and Clasen, 2012; Bradol et al., 2011). The correct interpretation of written instructions by recipients may be erroneously taken for granted by program implementers (e.g. cultural and educational differences in the interpretation of icons, outright language barriers). Moreover the time and effort involved in treating water in the household, or concerns about taste (particularly with chlorination) have been barriers to uptake in field experiences.

HHWT brings water treatment closer to the end user. While this limits the opportunities for recontamination, it also places the burden of water treatment on vulnerable individuals.

Second, at a larger socio-political level, HHWT shifts the burden of water treatment to individuals and households, which may already have limited capacity especially during times of crisis. In doing so, they are likely to exacerbate existing inequalities by burdening people who may have specifically limited capacity including people with disabilities, the elderly, children-headed households, single or working women, and other vulnerable groups.

Therefore, there is always a prerogative to centralise water treatment as much as possible. Not only is centralisation more efficient and less expensive, it also moves the burden away from the end user. As one interviewee noted, it is not empowering to be forced to treat one's own water.

2.3 Semi-Centralised Water Treatment Solutions

There are a number of technical approaches, some commonly used and some considered as potential future technologies, that came up during expert interviews and in the literature review. The current state of the art with each of these approaches will be discussed in the individual sub-sections below.

Many of these technologies operate most commonly at semi-centralised, or community levels. As with HHWT, there are proponents of the semi-centralised approach and there are critics. Proponents argue that semi-centralised systems bring the responsibility toward the beneficiary population, but only to a few designated, trained, and appropriately incentivised operators (i.e. dozens of people instead of thousands). At this level, effective supervision is still possible and the distribution of materials is simplified. Critics suggest that this model doesn't fit into existing operational frames of emergency agencies being either too small for a refugee/IDP camp, or too big for a dispersed displacement that may call for HHWT.

2.3.1 Bucket Chlorination

This is a method that is widely practised in emergency contexts. The basic process is that as beneficiaries collect water from a source (often a hand-pump or a natural surface water source), a trained attendant stationed there directly doses chlorine solution into their collection vessels. Though this approach is widely practised in emergencies there needs to be a great deal of research to build the evidence base around it. Along similar lines, there are also simple manually-operated chlorine dispensers that people collecting water can use to release a pre-fixed dose into their containers as they fill them.

Currently, there are major discrepancies on what the dosing should be at the source in order to achieve an adequate level of protection at the household level (often many hours post-distribution). There are no peer-reviewed papers on whether this approach actually works or not to deliver residual chlorine (and therefore safe water) at the point of consumption (Branz et al., 2015).

The effectiveness of bucket chlorination to obtain safe water at the point of consumption depends on the chlorine product, its stability and strength, as well as the water quality and volume.

Anecdotal evidence related in interviews suggests that, in some cases, less than 5% of households receiving water treated by bucket chlorination may have free residual chlorine at follow-up. In addition to this, existing guidance on this method is not really usable as it states a uniform rule for how much chlorine should be dosed. Because there is so much variability in all parts of the water treatment and transmission chain such a uniform treatment rule is useless. Examples of varying factors may include the stability of the chlorine product, its effective strength, the container volume, the quality of water used to make the chlorine solution, including its own turbidity and chlorine demand.

Figure 3.
WTUs often rely on assisted sedimentation pre-treatment and would be improved if continuous clarifiers were integrated into the package water treatment plant. (Source: Syed Imran Ali, UC Berkeley)

2.3.2 Package Water Treatment Units (WTUs)

To provide large quantities of safe water in traditional camp settings, assisted sedimentation centring on alum flocculation in large tanks followed by chlorination of clarified water was standard. These systems had high typical production rates of around 15,000 l/h or higher. However, trends towards smaller camps led also to water supply shifting to smaller water treatment units that could produce higher quality water at moderate levels of production (2,000-5,000 l/h).

In 1993 ICRC held a water treatment 'fair' and invited commercial firms to present their package treatment units (WTUs) to humanitarian agencies for possible uptake. The specifications were rigorous: WTUs had to be portable (movable by 4-6 people); use only a single energy source (i.e. one pump); and should not be mounted on a trailer. None of the options on offer met organisational specifications.

To address this need, multiple agencies including MSF-Belgium and others began to develop their own WTUs that came to form part of their emergency response kit in the mid-90s. The majority of these systems essentially built upon assisted sedimentation by integrating a rapid granular media filtration stage after in-line flocculation in order to improve finished water quality. These systems however are designed to handle only up to 200-300 NTU and are not effective beyond that turbidity level; they are also run as batch processes. There has been some work done to develop pre-treatment units for WTUs including work by Oxfam and their Field Up-flow Clarifier Kit (Figure 4), an inclined plate settler system that can reduce influent water of up to 1,000 NTU down to 50 NTU (Dorea et al., 2009).

Figure 4.
The Field Up-flow Clarifier Kit allows for continuous flocculation and clarification of water prior to filtration. (Source: Caetano C. Dorea, Université Laval)

However, these systems require longer to transport and setup, and are therefore more appropriate after the acute phase of an emergency has passed. Improvement of these systems is desirable, as their limitations have prevented wider use in emergencies.

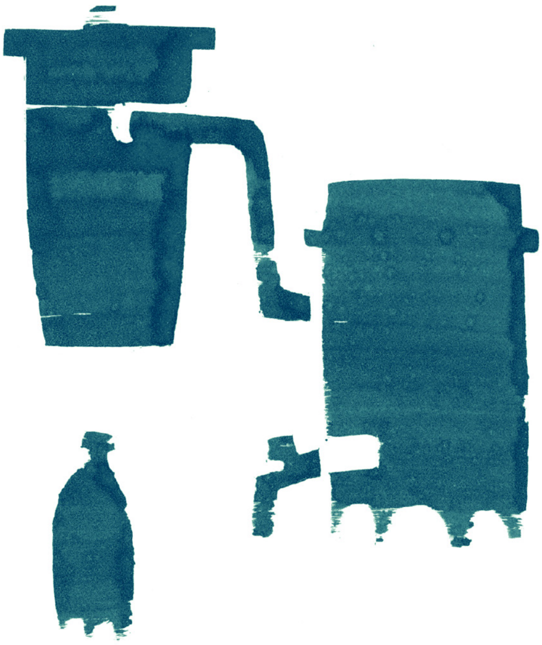
2.3.3 Semi-Centralised Assisted Sedimentation and Chlorination

There have also been attempts to develop a semi-centralised assisted sedimentation-chlorination system that can be implemented at a medium-scale (1,000s of litres) by community-members themselves (Dorea and Jalaber, 2014). One company, Aquasure, has developed a 1m^3 combined flocculation and disinfection system consisting of a small onion tank, pump and hose, and large effervescent tablets for chlorine tablets and flocculants that can be dispatched on a motorcycle. The key to this innovation was the use of dishwashing tablet technology to make the tabs effervescent (not requiring constant stirring) and to delay the release of chlorine until after the flocculent had been released.

One concern with assisted sedimentation is that flocculants may leave high residual iron and aluminium concentrations, up to ten times the maximum guideline level recommended by the WHO. High concentrations of iron result in unpalatable water (Preston et al., 2010), and while still inconclusive, some research has indicated that long-term exposure to aluminium may be related to long-term health risks. However when properly used, residual aluminium concentrations arising from flocculants are generally not considered a health concern (Dorea, 2009). With WTUs that feature a sand filtration step, aluminium and iron residual levels can be brought down within WHO limits.

2.3.4 Mechanical Separation

One way to get around the use of chemicals for flocculation is mechanical separation – using centrifuges to clarify water. One example of this approach utilises a hydrocyclone – a compact, simple to operate system that relies on water pressure to create multiple vortexes in which dirty water leaves one outlet while cleaner water leaves another. In laboratory testing, however, these systems were unable to lower water turbidity levels (Reed, 2011). Such mechanical approaches may have potential at the community level, however it is important to note that with mechanical systems, disinfection will still be needed after clarification.

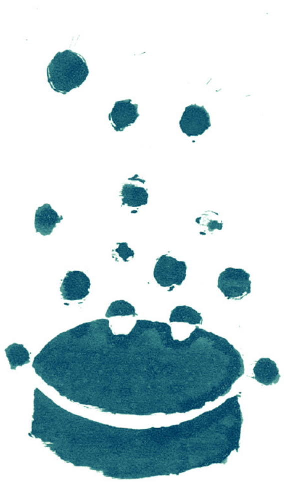


2.3.5 Membrane Filtration (MF)

Membrane filtration systems have also emerged as a possibility for water treatment at the community level. MF is usually very fragile, however some companies have developed stronger membranes that require fewer chemical inputs (though they still need acids for cleaning). Backwashing, the use of electric pumps, and the need for pre-treatment as well as spare parts are serious barriers to MF use in emergency contexts. In addition, membrane filtration systems do not offer the residual protection that can result from chlorination.

2.3.6 Direct Well Chlorination

The practice of direct well chlorination in emergencies can sometimes be effective, but it is often not done correctly, instead becoming a site of political theatre. The appropriate method entails daily doses added directly to the well by trained personnel, based on either an evidence-based daily dose or daily jar tests. However, this more laborious approach is relatively mundane, and cuts out the spectacle of politics, making it less attractive to political actors. Godfrey et al. (2003) describe an effective use case of this method in Angola.



CASE STUDY — The Politics of Well Chlorination

One technique for improving water quality is direct well chlorination. While potentially effective, the requirements for this technique are commonly misunderstood and it is often the site of political grandstanding. The actual disinfection process is relatively simple, and involves either regular shock chlorination or a slow-release system (e.g. submerged or floating pot chlorinators). With either of these techniques, chlorine addition must be tailored to the specific well parameters (volume, water quality) and both techniques require regular treatments. During acute waterborne disease outbreaks (e.g. cholera outbreaks), direct well chlorination is often looked to as a way to stem disease transmission at its source. While some authors point to the potential effectiveness of well chlorination (Godfrey et al., 2003; Garandeau et al., 2006) others have reported poor experiences (Rowe et al., 1998; Luby, Islam, and Johnston, 2006; Cavallaro et al., 2011).

Perhaps most concerning is that there are numerous reports of spurious chlorination of wells for political purposes during emergencies. In these cases a well is chlorinated, often by local government officials or NGOs, to create the appearance that the water is now treated and safe to drink. This treatment, however, is highly ineffective: the water simply gets a chlorine shock which then dissipates rapidly leaving no residual chlorine. As a result the water in the well remains susceptible to contamination. What is worse is that such practices can lead users to believe that their water is safe to drink and dissuade them from using other disinfection methods. This is just one of many examples demonstrating the need to link potentially effective technologies to robust operational procedures that take into account local politics.

2.4 Centralised Water Treatment Solutions

2.4.1 Water Tankering

Water tankers are widely used to deliver safe water to affected populations especially in the acute phase of emergencies. There are however questions that require further research including how to appropriately dose chlorine in order to ensure water safety at the point of consumption.

Moreover, in practice truckers often avoid UN stations that put HTH chlorine into their tankers as chlorine may corrode their water tanks. Traditionally it has been the case that NGOs will hire all the tanker drivers in a given locale, driving up the prices so that other customers/locations end up being ignored or dropped. There are implications for the economics of water supply as well as equity that arise in these situations.

Figure 5.
Water tankers are commonly used to transport water during the acute phase of an emergency as seen here in the Jamam refugee camp, South Sudan 2012.
(Source: Syed Imran Ali, UC Berkeley)

2.4.2 Failed Municipal Water Systems

Presently, much of the emergency guidance is centred on classic displacement scenarios in large-scale refugee/IDP camps. Overall, there is relatively little documented experience and guidance on how to respond in situations where high-level municipal infrastructure already exists but has failed. This is a pressing issue in countries with more advanced treatment systems as well as less advanced systems.

What is the best method for dealing with situations like the 2008 cholera outbreak in Zimbabwe, where good infrastructure was present but the country was struggling economically and had stopped chlorinating its municipal drinking water?

Under disaster circumstances, aid workers often set up alternative water delivery systems that cost far more than repairing a centralised system. While some basic guidelines do exist (WHO, 2013) more research is needed on how to respond to emergencies in these settings.

2.4.3 Emergencies in Slums and Unplanned Urban Settlements

Another pressing contemporary question is how to deal with emergencies in a context of rapid urbanisation and expanding slums. Slum settings may have decentralised water supply with a great mix of sources: with so many different sources, how might practitioners ensure good water quality? These settings are already complex, fractured, and the site of multiple ad hoc and/or failing systems, so when disasters occur, they present multiple challenges that may magnify one another.

One approach that has arisen in many urban areas is kiosk systems. Presently there is very little data on how well kiosks are functioning to deliver safe water at the point of consumption. A recent study in Port-au-Prince, albeit not during an acute emergency, found that these systems do deliver good quality water at least at the kiosk level (Patrick et al., 2014).

2.5 Growing Challenges — Chemical Water Pollution

Ten to fifteen years ago practitioners were not worried about chemical pollution aside from natural salinity in groundwater sources. However, with expanding industrial development and agriculture, chemical pollution is getting worse, just as salinity is worsening with groundwater depletion in many places. More chemical quality related diseases are being seen in the field during emergencies (e.g. benzenes in water from rubber production in Liberia; boron in Afghanistan).

The application of Reverse Osmosis technologies in crises situations is limited due to its complexity and high cost.

The usual answer to these problems is reverse osmosis (RO) - a water purification technology that uses a semipermeable membrane to remove larger particles from water. However, this solution is high tech and expensive. Generally speaking, a good company making a good machine will ask for a full profile of the chemical water quality and then design a custom system for that specific water quality; obviously such a device is not rapidly deployable in an emergency.

On the other hand, off-the-shelf equipment that is not designed for specific water quality generally does not work well. Moreover, RO doesn't work if the water is turbid. Many agencies have found RO too complicated to use effectively in the field.

Ultimately, this means agencies see RO as having limited potential in emergencies given its cost, technical complexity, and relatively low rates of production. A simpler alternative to RO could be nanofiltration, which can, to a certain degree, handle salinity and certain types of chemical pollution. Appropriate technologies could also have a role in chemical water treatment: filtration with different media types, activated carbon, and different coagulants may all have a role to play in removing certain chemical contaminants.

Part 3: Areas for Further Exploration

This section draws together key questions and observations that have emerged from this gap analysis research and offers directions for further exploration.

There is an urgent need to devise new ways to integrate research into operations.

At a broader level, one of the most important suggestions that came out of the expert interviews was the urgent need to devise new ways to integrate research into operations. Current institutional structures make rigorous research difficult in emergency settings, as field staff are regularly stretched beyond their limits. As a result, insufficient time is available for practitioners to engage in research with long-term benefits. Related to this, practitioners need to write and publish more. Within the field there is an immense amount of often contradictory anecdotal evidence, and creating time for those focused on operations to publish their accumulated knowledge would enable a more complete picture of what works and what doesn't work, as well as where and how.

It is worth mentioning again in this section that several of the experts interviewed argued that water treatment innovations should be considered as part of a broader approach to improving WASH requirements in an emergency situation. While the provision of safe water is a basic necessity in emergencies, innovations in this area should complement developments in other essential WASH areas such as sanitation.

Three suggested areas that would benefit from further exploration and innovation include: Operational Tools, Field Effectiveness Studies and Technological Innovations.

3.1 Operational Tools

3.1.1 Qualitative Decision Support Tool

To support responders in assessing a new emergency situation, more sophisticated operational tools are required. These could be based upon a set of guiding questions designed by collating existing information on water treatment deployments at different levels. Pertinent questions may include:

- What did the affected population use for water supply before the emergency?
- Was this water source safe or chlorinated?
- How was the supply of water affected by the emergency?
- How was the quality and safety of the water affected by the emergency?
- What is the timeline for getting back to pre-emergency situation? For example, if there was a three-day flood, then a three-day treatment needs to be provided. If the event was longer, then responses need to be designed appropriately.
- What are the options (i.e. level of treatment, technology) that we can use to fill this gap?
- Are there options related to what people had before and are familiar with? What is available locally or through organisational supply channels?
- What kind of treatment technology does the water quality of the source demand?
- How to transition water treatment along the emergency-development continuum?

Such an approach is particularly important for displacements outside of traditional camp settings, including in existing urban communities. To compile such a tool, research focusing on integrating lessons learned from past implementations in varied contexts should be used to inform algorithms that guide operational decision-making. Current guidance, such as in the Sphere Project, is somewhat basic and decontextualised. There is a strong need to build upon existing decision support tools by bringing in field effectiveness data and further decision criteria from real-world implementations. Some work has been done in this vein (cf. Steele and Clarke, 2008; Szántó et al., 2015) which may provide a basis for further development.

3.1.2 Technical Decision-Making Toolkit

Emergency responders would benefit from the development of a tool that would help them to select context-specific water treatment interventions. This tool would bring together quantitative and qualitative aspects bearing on water treatment selection from water quality, to institutional capacities, to logistical constraints and cost.

As a part of this toolkit, it would be beneficial to develop a catalogue of different filter media and coagulants, activated carbon, pH adjustments, aeration and other simple treatment elements that can handle specific chemical contaminants (including pH variations) so that WASH workers can identify chemical parameters of concern, select appropriate treatment options, and design a treatment system.

3.1.3 Adapting the Water Safety Plan Approach to Emergencies

How can we adapt current approaches to emergency situations so that vulnerabilities in the safe water chain can be found and addressed?

How might the Water Safety Plan (WSP) approach be adapted to emergency contexts so that it can allow for the identification of vulnerabilities in the safe water chain, and the development of strategies to ameliorate these risks?

Current practice for water quality in emergencies centres on achieving water quality targets at the point of distribution. However, major risks to water safety in an emergency setting often arise post-distribution. Therefore, a shift is needed from monitoring quality (i.e. Sphere Project) to managing risks (i.e. Water Safety Plans) (Bradol et al., 2011). This applies to water treatment systems at any level - household, community, or centralised - and requires extensive operational research to bring development-oriented WSPs into emergency contexts.

Such a tool would help practitioners recognise which situations call for the prioritisation of water treatment versus those that would be best served prioritising other hazards. Such a WSP approach would involve a higher surveillance standard and hazard control than the current water treatment focus. Water treatment may be prioritised where there is high risk of waterborne outbreaks including displacements, floods, etc. Other disasters may not always present serious waterborne disease risks (e.g. some earthquakes, assuming pipe breakages haven't created risks of waterborne diseases) so water treatment can be de-prioritised in these situations. Research is required to review previous field experiences and identify which emergencies present the greatest waterborne disease threats and the opportunities for water treatment interventions.

3.2 Field Effectiveness Studies

All of the emergency water treatment interventions currently used in practice need to undergo rigorous evaluation as the evidence base underlying them is thin. Moreover, currently there is very little evidence-based decision making, and instead most practice follows individual practitioner experience and institutional norms. To fill this knowledge gap, more research studies - ideally epidemiological studies - are called for. The majority of studies that have been completed measure surrogates (using survey data) as opposed to actual diarrhoeal incidence, and while measuring incidence is certainly more challenging, doing so would provide a more solid evidence base for decision-making.

There are lingering questions on the field effectiveness of PuR sachets, chlorine tablets (i.e. Aquatabs), and bucket chlorination with respect to both *E. coli* and turbidity control, especially with natural waters that have varying turbidity and quality. Despite being widely practiced, these interventions lack an evidence base on the technical performance of residual chlorine over time and therefore the overall effectiveness of the strategy.

Similarly, there are multiple questions that need to be addressed regarding kiosk systems in urban emergencies. While kiosks have been extensively studied in development literature, it is not clear how the specific, unique circumstances found in emergency contexts will affect them. Research is required on how to effectively regulate and manage kiosk providers to ensure water quality in emergencies where they exist.

3.2.1 HHWT Knowledge Gaps

A particular area that would benefit from further field studies is that of understanding the effectiveness of HHWT in emergencies. While the technical efficacy of currently available HHWT systems has been well established in laboratory studies, there is little rigorous evidence on the effectiveness of HHWT in emergencies. Therefore, future field implementations of HHWT systems should be combined with research studies to build an evidence base.

Figure 6.
Chlorine decay studies are required in the displacement camp setting to better understand water quality changes between distribution and consumption, Rwanda 2015. (Source: Syed Imran Ali, UC Berkeley)

Such implementations should be specifically targeted to households having poor water quality that cannot otherwise be reached by water tankers or at-source water treatment during non-acute emergencies where there is a high diarrhoeal disease risk (e.g. endemic cholera). Studies would ideally employ epidemiological methods assessing diarrhoeal disease impact or, if not possible, then effective use studies looking at household water quality (as a proxy for health impact).

In addition, one critical operational knowledge gap with HHWT is how to encourage user adherence and uptake (i.e. behaviour change). This may entail the development of comprehensive guidelines and manuals on how to do the intensive household training and health promotion required to ensure consistent and correct use. One approach may be to adapt the ‘bed net’ model of traveling from house to house to train users to use HHWT systems effectively. Although time and labour intensive, this model has been used to successfully distribute and ensure uptake of malaria-preventing bed nets.

3.3 Technical Innovations

The area of water treatment has benefitted from a wide range of technological innovations. While technical concerns are still common, they are rarely seen as the most pressing challenges. However, innovation in specific processes could make these systems more effective and reliable in emergency contexts.

For example, standard assisted sedimentation and disinfection practices work well in general, but there are some contexts where they could use improvement. Overall, the sustainability of bulk water supply (i.e. moving from batch to continuous process, making it easier to operate) is a neglected area. Assisted sedimentation could use further improvement in contexts with highly turbid water or chemical contamination (especially with long-term consumption). Moreover, the development of a continuous flocculation-sedimentation-disinfection process would greatly improve the usability of these commonly implemented systems.

References

Ahmed, S. A., B. A. Hoque, and A. Mahmud. 1998.
"Water Management Practices in Rural and Urban Homes: A Case Study from Bangladesh on Ingestion of Polluted Water." *Public Health* 112 (5): 317–21.
Available online at: http://www.ncbi.nlm.nih.gov/pubmed/9807928.
[Accessed 23 October 2015]

Ali, S. I., S. S. Ali, and J. Fesselet. 2015.
"Effectiveness of Emergency Water Treatment Practices in Refugee Camps in South Sudan."
Bulletin of the World Health Organization 93 (8): 550–58.

Baker, K. K., S. Sow, K. L. Kotloff, J. P. Nataro, T. H. Farag, B. Tamboura, M. Doumbia, et al. 2013.
"Quality of Piped and Stored Water in Households with Children Under Five Years of Age Enrolled in the Mali Site of the Global Enteric Multi-Center Study (GEMS)."
The American Journal of Tropical Medicine and Hygiene, July. doi:10.4269/ajtmh.12-0256.

Bastable, A., and L. Russell. 2013.
Gap Analysis in Emergency Water, Sanitation and Hygiene Promotion.
London: Humanitarian Innovation Fund.

Blanchet, K., and B. Roberts. 2013.
An Evidence Review of Research on Health Interventions in Humanitarian Crises.
London: London School of Hygiene and Tropical Medicine.

Bradol, J., F. Diaz, J. Léglise, and M. Le Pape. 2011.
Is Humanitarian Water Safe to Drink?
Paris: Médecins Sans Frontières.

Branz, A., M. Levine, A. Bastable, W. Carter, D. Bloom, S. I. Ali, K. Kadir, L. Lehmann, T. Yates, and D. Lantagne. 2015.
"Chlorination of Water in Emergencies: Review of Knowledge, Recommendations for Implementation, and Research Needed."
Unpublished manuscript.

Brick, T., B. Primrose, R. Chandrasekhar, S. Roy, J. Muliyil, and G. Kang. 2004.
"Water Contamination in Urban South India: Household Storage Practices and Their Implications for Water Safety and Enteric Infections."
International Journal of Hygiene and Environmental Health 207 (5): 473–80.
Available online at: http://www.ncbi.nlm.nih.gov/pubmed/15575563.
[Accessed 23 October 2015]

Brown, J., S. Cavill, O. Cumming, and A. Jeandron. 2012.
"Water, Sanitation, and Hygiene in Emergencies:
Summary Review and Recommendations for Further Research."
Waterlines 31 (1): 11–29.

Brown, J., and T. Clasen. 2012.
"High Adherence Is Necessary to Realize Health Gains from Water Quality Interventions."
PLOS One` 7 (5): e36735. doi:10.1371/journal.pone.0036735.

Brownell, S. A., A. R. Chakrabati, F. M. Kaser, L. G. Connelly, R. Peletz, F. Reygadas, M. J. Lang, D. M. Kammen, and K. L. Nelson. 2008.
"Assessment of a Low-Cost, Point-of-Use, Ultraviolet Water Disinfection Technology."
Journal of Water and Health 6 (1): 53–65.

Cavallaro E.C., Harris J.R., da Goia, M.S., dos Santos Barrado, J.C., da Nobrega, A.A., de Alvarenga Junior, I.C., Silva, A.P., Sobel, J., and E. Mintz. 2011.
"Evaluation of pot-chlorination of wells during a cholera outbreak, Bissau, Guinea-Bissau."
Journal of Water and Health, 9(2): 394–402.

Cann, K. F., D. Rh. Thomas, R. L. Salmon, a. P. Wyn-Jones, and D. Kay. 2013.
"Extreme Water-Related Weather Events and Waterborne Disease."
Epidemiology and Infection 141: 671–86. doi:10.1017/S0950268812001653.

CDC. 2013.
Final report: Hepatitis E outbreak investigation: results from the knowledge, attitudes and practices (KAP) survey, environmental investigation and seroprevalence survey in Jamam and Yusuf Batil camps, Upper Nile, South Sudan.
Atlanta: Centers for Disease Control and Prevention.

Clasen, T. F., and A. Bastable. 2003.
"Faecal Contamination of Drinking Water during Collection and Household Storage: The Need to Extend Protection to the Point of Use."
Journal of Water and Health 1 (3): 109–15.

Clasen, T., W. P. Schmidt, T. Rabie, I. Roberts, and S. Cairncross. 2007.
"Interventions to Improve Water Quality for Preventing Diarrhoea: Systematic Review and Meta-Analysis."
British Medical Journal 334 (7597): 782–85. doi:10.1136/bmj.39118.489931.BE.

Clasen, T. 2015.
"Household Water Treatment and Safe Storage to Prevent Diarrheal Disease in Developing Countries."
Current Environmental Health Reports 2 (1): 69–74.
doi:10.1007/s40572-014-0033-9.

Davis, J., and R. Lambert. 2002.
Engineering in Emergencies: A Practical Guide for Relief Workers.
London: ITDG Publishing.

Davison, A., G. Howard, M. Stevens, P. Callan, L. Fewtrell, D. Deere, and J. Bartram. 2005.
Water Safety Plans: Managing Drinking-Water from Catchment to Consumer.
Geneva: World Health Organization.

Dorea, C. C., and V. Jalaber. 2014.
"The Potential of a Semi-Decentralised Bulk Water Treatment Approach for Emergency Relief."
Journal of Water, Sanitation and Hygiene for Development 4 (4): 709. doi:10.2166/washdev.2014.043.

Dorea, C. C., R. Luff, A. Bastable, and B. A. Clarke. 2009.
"Up-Flow Clarifier for Emergency Water Treatment."
Water and Environment Journal 23 (4): 293–99. doi:10.1111/j.1747-6593.2008.00142.x.

Dorea, C. C. 2009.
"Aluminium Residuals in Emergency Water Treatment: What You Wanted to Know, but Never Asked."
Waterlines 28 (2): 161–73. doi:10.3362/1756-3488.2009.016.

Engell, R. E., and S. S. Lim. 2013.
"Does Clean Water Matter? An Updated Meta-Analysis of Water Supply and Sanitation Interventions and Diarrhoeal Diseases."
The Lancet 381 (June): S44. doi:10.1016/S0140-6736(13)61298-2.

Enger, K. S., K. L. Nelson, J. B. Rose, and J. N. S. Eisenberg. 2013.
"The Joint Effects of Efficacy and Compliance: A Study of Household Water Treatment Effectiveness against Childhood Diarrhea." *Water Research* 47 (3). Elsevier Ltd: 1181–90. doi:10.1016/j.watres.2012.11.034.

Evidence Aid. 2013.
"Prioritization of Themes and Research Questions for Health Outcomes in Natural Disasters, Humanitarian Crises or Other Major Healthcare Emergencies."
PLoS Currents, 1–9. doi:10.1371/currents.dis.c9c4f4db9887633409182d2864b20c31.

Fewtrell, L., and J. M. Colford Jr. 2004.
Water, Sanitation and Hygiene: Interventions and Diarrhoea: A Systematic Review and Meta-Analysis.
Washington, D.C.: World Bank.

Fewtrell, L., R. B. Kaufmann, D. Kay, W. Enanoria, L. Haller, and J. M. Colford Jr. 2005.
"Water, Sanitation, and Hygiene Interventions to Reduce Diarrhoea in Less Developed Countries:
A Systematic Review and Meta-Analysis."
The Lancet Infectious Diseases 5: 42–52.

Godfrey, S., L. Mccaffery, A. Obika, and M. Becks. 2003.
"The Effectiveness of Point-Source Chlorination in Improving Water Quality in Internally Displaced Communities in Angola."
Water and Environment Journal 17 (3): 149–51.

Garandeau, R., Trevett, A., and A. Bastable. 2006.
"Chlorination of hand-dug wells in Monrovia."
Waterlines, an international journal of water, sanitation and waste, 24(3): 19-21.

Guerrero-Latorre L., Gonfa, A.H., Girones, R., 2013.
Environmental investigation in Maban, South Sudan (April 2013): preliminary results.
Barcelona: University of Barcelona WADHE Project.

Gundry, S., J. Wright, and R. Conroy. 2004.
"A Systematic Review of the Health Outcomes Related to Household Water Quality in Developing Countries."
Journal of Water and Health 2 (1): 1–13. http://www.ncbi.nlm.nih.gov/pubmed/15384725.

Gunther, I., and Y. Schipper. 2013.
"Pumps, Germs, and Storage: The Impact of Improved Water Containers on Water Quality and Health."
Health Economics 22: 757–74.

Guthmann, J., H. Klovstad, D. Boccia, N. Hamid, L. Pinoges, J. Nizou, M. Tatay, et al. 2006.
"A Large Outbreak of Hepatitis E among a Displaced Population in Darfur, Sudan, 2004:
The Role of Water Treatment Methods." *Clinical Infectious Diseases* 42: 1685–91.

IFRC (International Federation of Red Cross and Red Crescent Societies). 2008.
Household water treatment and safe storage in emergencies.
[Online] Available at: https://www.ifrc.org/Global/Publications/disasters/142100-hwt-en.pdf
[Accessed 23 October 2015]

Lantagne, D., and T. F. Clasen. 2012a.
"Point-of-Use Water Treatment in Emergency Response."
Waterlines 31 (1&2): 30–52.

Lantagne, D., and T. F. Clasen. 2012b.
"Use of Household Water Treatment and Safe Storage Methods in Acute Emergency Response:
Case Study Results from Nepal, Indonesia, Kenya, and Haiti."
Environmental Science & Technology 46 (20): 11352–60. doi:10.1021/es301842u.

Lantagne, D. S., R. Quick, and E. D. Mintz. 2011.
*Household Water Treatment and Safe Storage Options in Developing Countries:
A Review of Current Implementation Practices*.
Washington, D.C.: Wilson Center.

Lemonick, D. M. 2011.
"Epidemics After Natural Disasters."
American Journal of Clinical Medicine 8 (3): 144–52.

Levy, K., K. L. Nelson, Al. Hubbard, and J. N. S. Eisenberg. 2008.
"Following the Water: A Controlled Study of Drinking Water Storage in Northern Coastal Ecuador."
In *Environmental Health Perspectives*, 116:1533–40.

Luby, S., M. S. Islam, and R. Johnston. 2006.
"Chlorine Spot Treatment of Flooded Tube Wells, an Efficacy Trial."
Journal of Applied Microbiology 100 (5): 1154–58. doi:10.1111/j.1365-2672.2006.02940.x.

Médecins Sans Frontières. 2010.
Public Health Engineering in Precarious Situations.
Brussels: Médecins Sans Frontières. http://refbooks.msf.org/msf_docs/en/public_health_en.pdf

Oxfam GB. 2001.
Oxfam Guidelines for Water Treatment in Emergencies.
[Online] Available at: http://reliefweb.int/report/world/guidelines-water-treatment-emergencies.
[Accessed 23 October 2015]

Oxfam. 2012.
PH monthly monitoring report (Jamam Refugee Camp, November 2012).
Oxford: Oxfam GB.

Patrick, M., M. Steenland, A. Dismer, J. Murphy, A. Kahler, B. Mull, H. Bien-Aime, et al. 2014.
“Assessment of Private Sector Water Kiosks in Port-Au- Prince, Haiti.”
Presentation at UNC Water and Health Conference, no. August.

Pickering, A. J., Y. Crider, N. Amin, V. Bauza, L. Unicomb, J. Davis, and S. P. Luby. 2015.
“Differences in Field Effectiveness and Adoption between a Novel Automated Chlorination System and Household Manual Chlorination of Drinking Water in Dhaka, Bangladesh: A Randomized Controlled Trial.”
PloS One 10 (3): e0118397. doi:10.1371/journal.pone.0118397.

Preston, K., D. Lantagne, N. Kotlarz, and K. Jellison. 2010.
“Turbidity and Chlorine Demand Reduction Using Alum and Moringa Flocculation before Household Chlorination in Developing Countries.”
Journal of Water and Health 8 (1): 60–70.

Reed, R. A. 2011.
“Emergency Water Treatment Using Hydrocyclones.”
Water Practice & Technology 6 (2): 1–2. doi:10.2166/wpt.2011.037.

Reiff, F. M. 2002.
“Chlorination for International Disasters.”
Proceedings of the Water Environment Federation 13. Water Environment Federation: 439–51.

Rowe, A. K. 1998.
“Chlorinating Well Water with Liquid Bleach Was Not an Effective Water Disinfection Strategy in Guinea-Bissau.”
International Journal of Environmental Health Research 8 (4): 339–40. doi:10.1080/09603129873444.

Schmidt, W., and S. Cairncross. 2009.
“Household Water Treatment in Poor Populations: Is There Enough Evidence for Scaling up Now?”
Environmental Science & Technology 43 (4).

Sobsey, M. D. 2002.
Managing Water in the Home: Accelerated Health Gains from Improved Water Supply. Geneva: World Health Organization.

Sobsey, M. D., C. E. Stauber, L. M. Casanova, J. M. Brown, and M. A. Elliott. 2008.
“Point of Use Household Drinking Water Filtration : A Practical, Effective Solution for Providing Sustained Access to Safe Drinking Water in the Developing World.”
Environmental Science & Technology 42 (12): 4261–67.

Sphere Project. 2011.
The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response.
[Online] Available at: http://www.sphereproject.org/handbook/ [Accessed 23 October 2015]

Steele, A., and B. Clarke. 2008.
“Problems of Treatment Process Selection for Relief Agency Water Supplies in an Emergency.”
Journal of Water and Health 6 (4): 483–89. doi:10.2166/wh.2008.059.

Szántó, G. L., I. van Kinderen, A. Pelgrim-Adams, and J. Heege. 2015.
“Expanding preparedness - integrating emergency response with water sector development in the S(P)EEDWater tool.”
38th WEDC International Conference.

UKAID, Solidarites International, and Grifaid Aquafilters. 2015.
“Safe Water at Field Level: Improvement of a Grifaid Community Aquafilter.”
38th WEDC International Conference.

Waddington, H., and B. Snilstveit. 2009.
“Effectiveness and Sustainability of Water, Sanitation, and Hygiene Interventions in Combating Diarrhoea.”
Journal of Development Effectiveness 1 (3): 295–335. doi:10.1080/19439340903141175.

Watson, J. T., M. Gayer, and M. A. Connolly. 2007.
“Epidemics after Natural Disasters.”
Emerging Infectious Diseases 13 (1): 1–5. doi:10.3201/eid1301.060779.

WHO, 2008.
Guidelines for drinking-water quality - Volume 1: Recommendations.
[Online] Available at: http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/
[Accessed 27th October 2015]

WHO, 2013.
Rehabilitating Water Treatment Works after an Emergency.
Technical Notes on Drinking-Water, Sanitation, and Hygiene in Emergencies.
Geneva: WEDC.

About the HIF

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