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Adopting a Preparatory Strategy to Respond to Water Security Issues Arising from Geo-Hazards

E. McBean[1], AiLi Yang[2], Huiyan Cheng[2], YiCheng Wu[2], Zheng Liu[2], ZhiNeng Dai[2], Haiyan Fu[2], Munir Bhatti[1,*]

[1]School of Engineering, University of Guelph, Guelph, Ontario, Canada

[2]School of Environmental Science and Engineering, Xiamen University of Technology, Xiamen, Fujian Province, China

**Corresponding author's email: munirabhatti [AT] gmail.com*

ABSTRACT---- ***'Geo-hazards' is a collective term to describe hazards causing huge problems with human settlements, where the hazards are many and varied, including earthquakes, floods, windstorms, and drought, all of which are intensifying over time in large part due to climate change and population growth. In particular, issues of availability of 'safe' water are major disruptive elements frequently causing widespread incidence of diarrheal diseases both during and post, geo-hazard events. In response, arguments are described which demonstrate ceramic water filters (CWFs) have credible potential to effectively remove E.-coli (and, by similar attribute characterization), are effective in the removal of cholera. Field experience in terms of removal have been demonstrated as 94.7% removal of E-coli and all users in some applications have expressed interest in continuing use of ceramic filters beyond the trial period. Arguments are put forth, for CWFs as a Point-of-Use (POU) technology by which they can be stored and rapidly disseminated given occurrence of geo-hazards, thereby providing the opportunity to respond quickly. CWFs can be effectively stored without deterioration, are inexpensive, and easy to train recipients for their post-geo-hazard occurrence.***

Keywords--- *E.-coli*, Cholera, Point-of-Use, geo-hazards, Clay Water Filter, Column Filter Emergency response

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1. INTRODUCTION

'Geo-hazards' is a collective term for a wide array of events, including earthquakes, floods, windstorms, and drought. Since the world is facing geo-hazard disasters at an unprecedented scale, including unfortunately, the likelihood of this incidence rate continuing, CWF options have significant potential to be made quickly available to help impacted and displaced people.

Geo-hazard disasters are intensifying over time for reasons including climate change and population increases, where people are living in increasingly precarious locations. While geo-hazards are attributable to many causes, climate change and environmental degradation are exacerbating the intensity and frequency of weather-related hazards, resulting in escalating economic and human losses.

Issues of geo-hazards are intensifying but a single dimension which is common to virtually all, is the disruption of water supply in what are typically very challenging conditions. Given the above evidence of widespread and intensifying impacts of geo-hazards, the world community needs to be preparing for onset of geo-hazard events. This includes the need to be prepared, to use appropriate and inexpensive water treatment technologies.

In particular, the available literature on disasters indicates that epidemics of communicable diseases do not always occur after geo-hazards but, if they do, it is frequently not the geo-hazard itself causing the major impacts, but the secondary effects of the disasters. The destruction of water, sanitation and health care services, overcrowding and population displacement into artificial, crowded refugee communities with limited water and sanitation facilities, that lead to infectious disease outbreaks [1,2,3,4,5].

Overcrowding of displaced people and lack of availability of healthcare services, along with limited water supplies and inadequate hygiene and sanitation, are all contributing factors known to increase the incidence of diarrhea, respiratory infections, and other communicable diseases. All of these interact within the context of the local disease ecology to influence the risk of spread of communicable diseases and death in the affected populations.

The need for immediate action to provide a reliable system of safe water supply is apparent. Further, adequate quantities of safe water are preferable to small amounts of very high quality water in these circumstances. More specifically, each person must receive a minimum of 15 to 20 L of safe water per day for their domestic needs [6,7]. Unfortunately, it has been demonstrated that it is frequently difficult to provide even these minimum quantities of safe water to disaster-affected populations. One of the response options is to implement an effective Point-of-Use (POU) technology, implemented quickly, along with the necessary training needed to ensure performance of the technology by the users.

2. THE MERIT OF POINT-OF-USE (POU) WATER TREATMENT TECHNOLOGIES

The most frequently observed increases in communicable diseases post geo-hazards are directly attributable to faecal contamination of water. Examples of microbial pathogen sources include (i) sediments due to erosion of soils; (ii) nutrients from animal wastes and sewage-treatment plants; (iii) animal wastes from livestock husbandry and septic systems; and, (iv) human wastes. Geo-hazards (e.g., storm, flooding and landslides) bring about not only gravitational movements, but also intense and concentrated erosion along streams and slopes denuded of their vegetative cover; it follows that this process causes an over-accumulation of sediment and pollutants into the waterbody.

Displaced populations in camp settings are at particularly high risk of infectious diseases due to the secondary effects of the geo-hazards indicated above. Death rates of 60-fold over baseline have been recorded in refugee camps and internally-displaced people, with over three-quarters of these deaths caused by communicable diseases [8,1]. Epidemic-prone diseases in refugee settings are diarrheal diseases, respiratory infections, measles, and meningitis. In refugee camp situations, diarrheal diseases have accounted for more than 40% of the deaths in the acute phase of an emergency, with over 80% of these deaths occurring in children aged less than two years [1].

Outbreaks of cholera are some of the worst aftermaths of geo-hazard events. Cholera is a waterborne disease which is particularly relevant in post geo-hazard events where *Vibrio cholerae* (*VC)* infections result from ingestion of the organism. Cholera is an acute intestinal disease caused by the bacterium *VC O1* or *O139* (the two pathogenic strains are abbreviated henceforth, together, as '*VC*'). Depending on the vulnerability of the person who has been exposed, the incubation period for *VC* infection ranges from 12 to 72 hours [9]. In patients with severe *VC* infection, the volume of small intestine fluid reaching the colon far exceeds the maximum re-sorptive capacity of the colon, which is six liters/day. This causes profuse watery diarrhea [10].

During cholera outbreaks, people of all ages may contract the disease. Vomiting commonly accompanies the diarrhea, particularly early in the illness with the purging causing severe dehydration in patients recognizable by: increases in pulse rate and decreases in pulse volume; hypotension; an increase in respiratory rate; sunken eyes and cheeks; dry mucous membranes; decrease in skin turgor; a decrease in urine output, lethargy, weakness, irritability, and thirst.

Cholera remains a global threat to public health and an indicator of inequity and lack of social development. Researchers have estimated that every year, there are roughly 1.3 to 4.0 million cases, and 21 000 to 143 000 deaths worldwide due to cholera [11, 12].

Ceramic Water Filters as Effective POUs

As implied above, the provision of adequate quantities of safe water is a key prevention strategy to reduce the spread of cholera. When normal water supplies are interrupted or compromised due to geo-hazards, affected populations are often encouraged to boil or disinfect their drinking water to ensure its microbiological integrity. While chlorine can be very effective, its availability in times of geo-hazards makes the potential for chlorine use rather limited. The result is that treatment must be done at the POU level by one or more of boiling, disinfecting, filtering, etc.

The result is important merit for considering a POU as an effective measure to protect against bacterial diseases in the post geo-hazard situation. POU water treatment technologies include any of a range of devices or methods used for purposes of treating water in the home. A number of POU options are available as emergency options, including sodium hypochlorite, flocculant/disinfection powder, solar disinfection (SODIS), ceramic water filter (CWF), and biosand filtration. Criteria for determining the most effective POU include:

1. Effectiveness in Removing Pathogens – Key biological contaminants are *E-coli* and *VC*. POU filtration technologies include membrane filters, porous ceramic filters and granular media filters. Traditional membrane technologies [13] are generally expensive and therefore largely unknown for small-scale drinking water treatment systems in developing countries. Cloth filters such as those using sari cloth, have been recommended for reducing *VC* but these cloths will not significantly retain dispersed bacteria not associated with copepods, other crustaceans, suspended sediment, or large eukaryotes because the pores of the cloth fabric (>20 μm) are sufficiently small to exclude high percentages of bacteria. Since *VC* is frequently associated with zooplankton,

Colwell [14] described a simple filtration method involving a sari cloth folded four-to-eight times is capable of removing zooplankton and particulates >20 µm, effectively achieving 99% removal (2 log) of *VC*. This study was completed in 65 rural villages in Bangladesh involving approximately 133,000 individuals from September 1999 through July 2002 and resulting in a 48% reduction in cholera. Hence, this technology will work in theory, however, this approach is somewhat elaborate and not feasible in many locations due to the availability of saris. Consequently, sari cloth filtration can have significant beneficial health impacts but not universally.

A study by Berney [15] determined the effectiveness of SODIS for enteric pathogens, including *VC*, finding that bacteria are very susceptible to SODIS. *VC* were determined to be not resistant to sunlight and highly susceptible to mild water temperatures (above 40°C) for the entero-pathogenic strains studied. Nevertheless, the most interesting POU is the ceramic water filter (CWF) because of its many advantages. Several designs of CWFs are available, with one scenario being in Figure 1, as depicted in schematic form. This type of CWF is typically constructed of clay and milled rice husk and/or coffee grounds; the mixture is separated into 7-8 kg balls and pressed into cylindrical pot form (24cm x 34cm) (height X diameter), where the CWF is shown as inserted into a plastic and functional receptacle as shown in Figure 2 which serves as a reservoir for the safe (filtered) water. This technology allows adequate transmittance of water (1- 3 L/h) as indicated in Figure 1. Lantagne [16] reported pore diameters ranging from 0.6 to 3 µm while van Halem [17] reported a pore size distribution ranging from 0.02-200 µm, with a predominant pore size of 14 µm.

An alternative form of CWF is a column filter, where an alternative approach to CWF is utilized where the treatment tank is filled with source water, and the water treatment passes through the filter and the treated water is collected in the effluent receptacle, with the latter serving as a storage receptacle. CWFs in this form have been demonstrated as successful at removing *E-coli* [18] and also have the utility for allowing less frequent need to add water since the reservoir of source water is much larger than the clay pot. CWFs have been shown to effectively remove *E-coli* from drinking water (e.g. [19,20,18]). Bacteria generally range in length from 1-50 µm and rod-shaped bacteria (including *E-coli*) are 0.3-1.5 µm in diameter and 1-10 µm in length [13]. *E-coli* is gram-negative, flagellated, facultative bacillus about 2-4 µm long and 0.6-1.0 µm in diameter [21]. As a result, the considerable majority of *E-coli* are filtered from the source water during CWF operation. In addition to filtration, the development of a biofilm on the surface of the CWF during operation of the filtration device, aids in the removal of pathogens. The combination of filtration and biofilm development have demonstrated the ability of CWF to result in significant removals of microorganisms from source water during CWF operation.

Additional significance of the effectiveness of ceramic water filters has been provided by Mohamed [22] who assessed the microbiological effectiveness of several household water treatment and safe storage (HWTS) options in-situ in Tanzania and found that ceramic pot filter improved microbial water quality by reducing thermo tolerant (TTC) coliforms by 99.5%. Further, Guerrero-Latorre [23] reported that CWF that was fired in a reductive atmosphere presented virus and bacteria removal efficiencies greater than 3.0 log and 2.5 log, respectively and ceramic characterization of the selected filters, which were fired in a reductive atmosphere, showed that a larger specific surface area than those of control filters and higher fraction of a positive Z-potential fraction are the most likely explanations for this increase in virus removal.

2. <u>Cost Is Important in the Selection of the POU</u> - There are a number of such POU options, with prices that vary from a few dollars to substantial amounts. For example, ‘Lifestraw’ is also possible but the technology is expensive (175$) [24]. The purchase price of the ceramic water filter is typically around 6-8 $ US.

3. <u>Ease of Technology Transfer</u> - There is also the issue of technology transfer, meaning the training of users to properly use the technology. While it can be more difficult to conduct in emergencies, training is a necessary component of the emergency implementation strategy. User preference and transfer of technology should be considered when deciding which POU technology to implement. User acceptance and training have been identified as one of the most difficult factors in implementation of a POU [25]. Equally important, it is straightforward to train a user in the use of the CWF. Cleaning is accomplished by a simple brushing of the surface of the filter to remove sediments [26].

   In field studies, as apparent from Figure 4, the *E-coli* removal efficiency associated with individual CWFs studied during field trials in Longhai, China. Farrow [27] reported field removal (i.e. by the villagers in Longhai), efficiencies of *E.-coli* ranging from 75-100% (as opposed to laboratory studies where removal efficiency was observed to range from 97.7-99.9%), with average *E.-coli* removal efficiencies in the field, and lab *E- coli* observed to be 94.7% and 99.5% respectively. The differences (field versus lab) in removal efficiency are attributed to contamination of the filter element and receptacle when employed in the field (as would be expected also in post geo-hazard conditions) indicating the importance of training of the users of a low tech water treatment technology, to ensure adequate performance during field use by end-users. Attaining 94.7% removal findings is very powerful in terms of positive ramifications for human health protection.

In the development context, the higher levels of user adoption have been documented when POU technologies are promoted in schools or health clinics and when motivational interviewing and social marketing are employed as "behavior change communications strategies" [28]. Training was identified as a factor contributing to the high usage of CWFs in both the Sri Lanka tsunami and Dominican Republic flooding interventions. Although the training was not extensive, and follow-up visits were not needed to ensure continued usage, some training at the outset on operation and maintenance of the CWFs was identified as "vital" [29, 30, 27]. It is necessary that all recipients be provided with all the materials necessary to use and maintain the CWFs including the filter element, plastic receptacle, brush for cleaning the element, etc. In the development context, POU water treatment technology interventions need to select culturally appropriate options, distribute the products reliably, and work with trusted local community educators to encourage healthy water practices. These factors translate into the emergency context, and it is recommended that materials be developed specifically for the emergency context to assist organizations in conducting the training necessary to ensure project success [28]. Continued use of CWFs post-emergency as well as beyond, may occur (where villagers in Longhai specifically requested to be allowed to continue to use the CWFs [27].

Additionally, the importance of access to replacement CWF parts for recipients in post-emergency situations depends on the project goals of the organization and the type of emergency, and therefore may be considered either unimportant or vital. In the instances where the goal is to provide emergency relief that translates into long-term development interventions, establishing a replacement part supply chain is necessary for the sustainability of use of the technology. In these cases, CWFs should only be implemented if the necessary materials to manufacture replacement parts are locally available. A benefit of products that are locally available prior to emergencies is that if adequate stocks are maintained, the filters can be deployed quickly and efficiently. Further, while the CWF performance does deteriorate over time during use, the performance can be maintained for the emergency situation (see [18, 26]). This capability, along with the modest expense, makes the CWF option very interesting as an approach for geo-hazard conditions.

If the above-mentioned factors are implemented in emergency interventions, continued use of the POU technology may also occur 'post-emergency'. In follow-up studies conducted in communities where CWFs were distributed, it was found that in one Sri Lankan tsunami response community, 23% of people were using the ceramic filter three months after distribution, in the Dominican Republic, 48.7% of households were correctly operating filters 16 months after distribution with 54% of water samples from operating filters (26.1% of total) free of thermo-tolerant coliform [29, 30]. Ehdaie [31], reported that 63% ceramic water filter-treated samples had < 1 CFU/100mL of *E-coli* after 1 year. Average percent reduction of *E-coli* among ceramic water filter households declined to 60% after 52 weeks, which is lower than what has previously been seen in long-term ceramic water filter studies.

In other cases, for example, in Haiti, users expressed a desire to continue using the filter [32] as well as in Longhai, China where 100% of the users expressed interest in the opportunity to continue to use the ceramic filter [27]. These studies highlight that a one-time distribution of CWF accompanied with training may lead to the long-term usage of POU water treatment.

4. <u>No Deterioration in Effectiveness Occurs During Storage</u> – The CWF technology doesn't deteriorate with time during periods of storage i.e. could be stored in an 'as-ready' condition and be distributed at times of emergency. The weight of the CWF is approximately 6 kg, ensuring availability for manufacturing and storage (see Figure 2), available for use in the event of an emergency as the CWF is based primarily upon the physical removal mechanism. Products such as the CWFs that can be locally made and hence locally available prior to emergencies is that if adequate stocks are maintained, the filters can be deployed quickly and efficiently. CWFs can also be highly effective after the acute emergency has passed when recipients are moving from transitional to more permanent living structures. A sense of permanency allows for more time and receptivity to training on the operation and maintenance of the filters.

3. CONCLUSIONS

Concerns with geo-hazards are increasing as they becomes increasingly disruptive. One of the most important consequences of geo-hazards is the displacement of people and the circumstances of water needs, post geo-hazard. Disease burden arising from exposure to being without safe water and developing illness may be profound, post geo-hazard.

POU water treatment technologies structured around use of a ceramic filter is an effective strategy in response to a geo-hazard emergency. The filters are inexpensive, able to be stored without deterioration and hence easily available for distribution in post-emergency situations, feasible to manufacture in a developing country, and easily introduced/transfer of technology to recipient populations for their effective use. Further, the technology assessment shows that CWFs will be effective at removal of *E-coli H157O7* and *VC*.

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Appendix

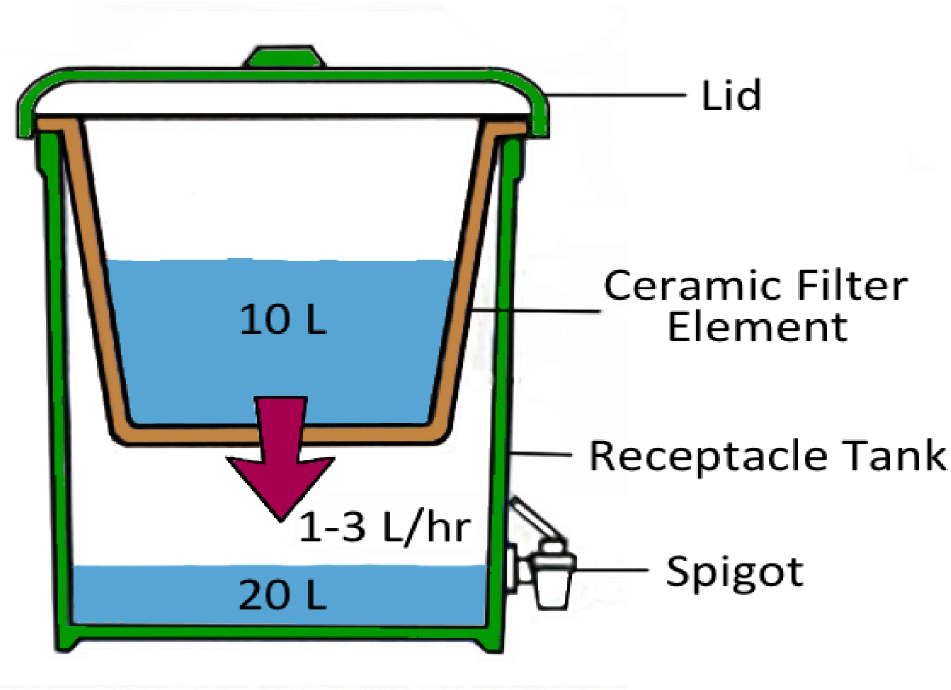

Figure 1. Ceramic Water Filter Schematic

Figure 2. Two CWFs inside their plastic casements where the plastic provides protection as well as a resevoir for the safe water

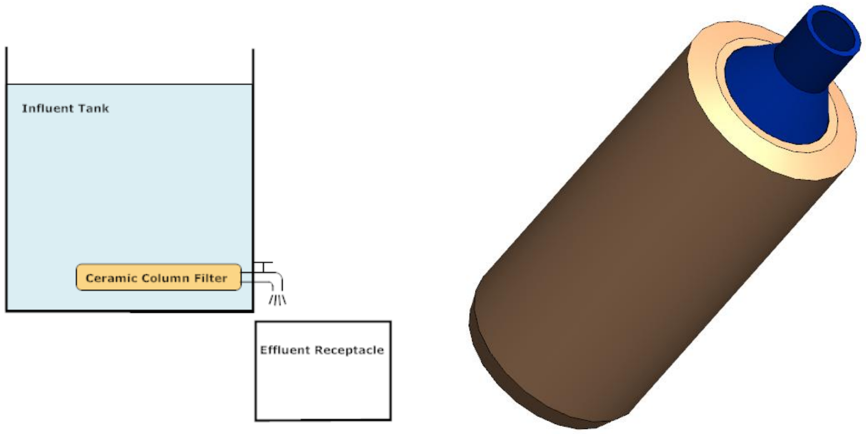

Figure 3. Column CWF Filter (see Brown et al., 2018)

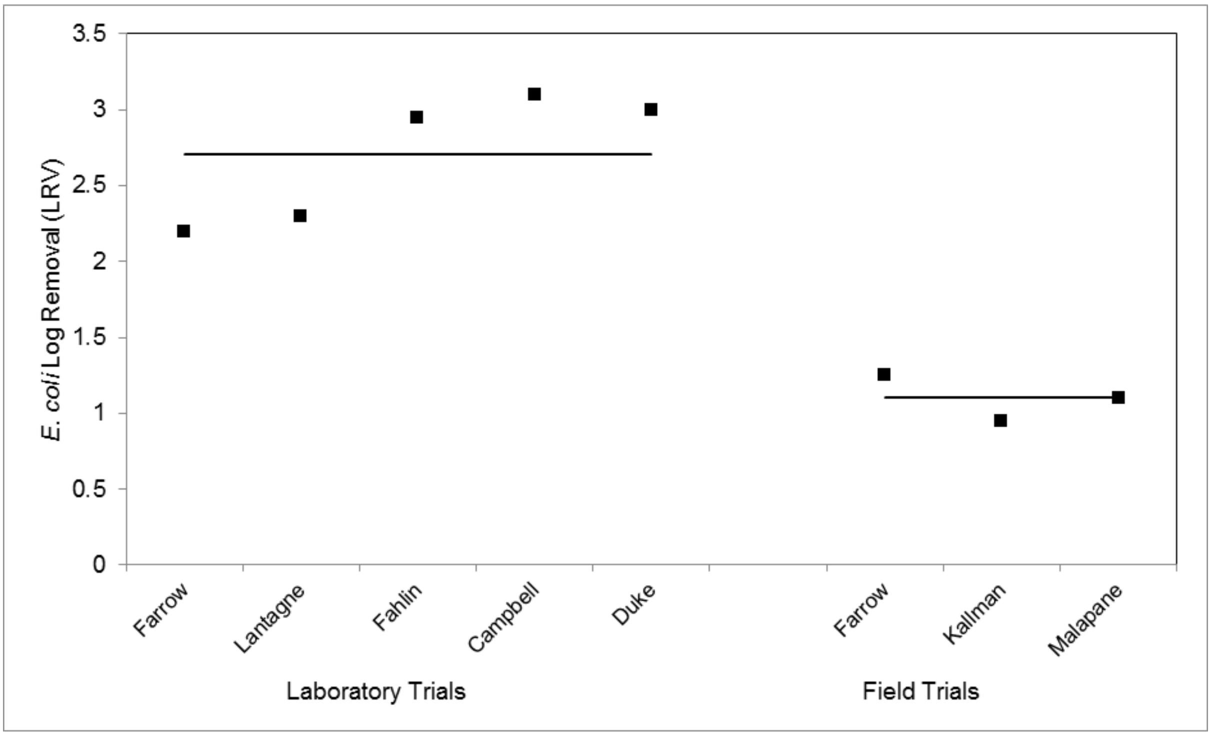

Figure 4: Removal efficiencies of *E.-coli*: comparison between laboratory and field trials (Farrow [27]; Lantagne [33]; Fahlin [34]; Campbell [35]; Duke [36]; Kallman [37]; Malapane & Hackett [38])