Influencing factors for household water quality improvement in reducing diarrhoea in resource-limited areas

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ABSTRACT

Background and Objectives: Water and sanitation are major public health issues exacerbated by rapid population growth, limited resources, disasters and environmental depletion. This study was undertaken to study the influencing factors for household water quality improvement for reducing diarrhoea in resource-limited areas.

Materials and Methods: Data were collected from articles and reviews from relevant randomized controlled trials, new articles, systematic reviews and meta-analyses from PubMed, World Health Organization (WHO), United Nations Children’s Fund (UNICEF) and WELL Resource Centre For Water, Sanitation And Environmental Health.

Discussion: Water quality on diarrhoea prevention could be affected by contamination during storage, collection and even at point-of-use. Point-of-use water treatment (household-based) is the most cost-effective method for prevention of diarrhoea. Chemical disinfection, filtration, thermal disinfection, solar disinfection and flocculation and disinfection are five most promising household water treatment methodologies for resource-limited areas.

Conclusion: Promoting household water treatment is most essential for preventing diarrhoeal disease. In addition, the water should be of acceptable taste, appropriate for emergency and non-emergency use.

Key words: Diarrhoea, household water treatment, hygiene and sanitation, water quality

INTRODUCTION

Water and sanitation are the major public health concerns in developing countries. Safe water supplied together with good water management and hygienic sanitation are fundamental to health. Almost 10% of the global disease burden could be prevented by access to safe drinking water, sanitation, hygiene and appropriate water management to reduce risks of waterborne infectious diseases.[1] In addition, safer drinking water could prevent 1.4 million child deaths from diarrhoea and 860 000 child deaths from malnutrition annually.[2]

Diarrhoea is commonly linked to water and sanitation. About 4 billion cases annually account for 5.7% of the global burden of disease with diarrhoeal disease as the third highest cause of morbidity and sixth highest cause of mortality.[3] Generally, safe water is important in preventing diarrhoeal diseases. For promoting safe water supply, the World Health Organization (WHO) sets guidelines for water quality, which express no detectable level of pathogenic organism in the water intended for human consumption.[4] However, it is not always possible to follow standard guidelines for water quality. Furthermore, waterborne pathogens can also be
transmitted via ingestion of contaminated food and other beverages, by person-to-person contact and by direct or indirect contact with infected faeces.

United Nations Millennium Development Goal (MDG 7) ‘Environmental Sustainability’ includes use of improved drinking water source asking world leaders to support universal access to clean water. In 2010, the United Nations General Assembly declared that safe and clean drinking water and sanitation is a human right that is essential to the full enjoyment of life and all other human rights, voicing deep concern that almost 900 million people worldwide do not have access to clean water. In 2008, 13% of the world’s population (884 million people) still rely on unimproved water sources (surface water from lakes, rivers, dams or unprotected dug wells or springs) for drinking, cooking, bathing and other domestic activities.

MDG aims to halve by 2015 the proportion of people without sustainable access to safe drinking water; one-half of 1.5 billion people without sustainable access to improved water supply by the year 2015. Providing safe piped disinfected water, to each household is the best solution to diarrhoea and waterborne disease. However, this solution would require an investment of tens of billions of dollars each year for infrastructure, which is not available in the developing world. Most of the developing world lacks sufficient conventional water supply infrastructure, and is home to substantial proportions (as high as 50%) of the total urban population and (nearly 90%) of the rural population. Therefore, resource-limited areas especially rural populations need other immediate approaches in improving existing water quality. Interventions to treat and maintain the microbial quality of water at the point-of-use are among the most promising of these alternatives. The cost of treating water at the point-of-use can be dramatically less than the cost of conventional water treatment and distribution systems. It has been reported that developing countries will need US$42 billion for new coverage in water supply and US$322 billion for maintaining existing water supply services. Furthermore, only 57% of the global populations get their drinking water from a piped connection in the user’s dwelling, plot or yard. Moreover, when demand exceeds supply in a piped water system due to intermittent and unreliable supply services, it results in inconvenience to users and increased risk of compromised water safety. This situation is most acute in Bangladesh, India and Nepal, which each have an average continuity of service of less than 10 hours a day compared with 22 hours in Latin America and in the Caribbean.

There is an immediate need for resource poor communities to innovatively develop cost effective water treatment methodology before universal water supply and safe water pipe is provided.

This study reviewed the impact of different water sanitation programmes in reducing diarrhoea morbidity and mortality. Further analysis was extended to identify household water treatment in preventing diarrhoea and health impact.

**MATERIALS AND METHODS**

Relevant literature was obtained through a rigorous search from databases of the WHO, World Bank, UNICEF, Cochrane Library, PubMed, Medline, EMBASE, Water, Sanitation and Hygiene and WELL Resource Centre. All studies relating to water quality, diarrhoea, household water treatment, and hygiene and sanitation were searched. After reviewing titles, 316 studies between 1980 and 2011 were reviewed for abstract. Finally 31 articles were selected. Studies from developing countries were given priority in this review. All the studies collected were reviewed, collated, categorized and reported for all relevant and important findings.

**RESULTS**

Earlier studies about water and sanitation showed better results for sanitation and hygiene than water quality. Esrey et al. reported lower percentage of median reduction in diarrhoea morbidity by water quality intervention than sanitation and hygiene. The study reported that percentage of median reduction in diarrhoea morbidity as follows:

(i) Water quality and quantity (two rigorous studies) (17%); (ii) Water quality (four rigorous studies) (15%); (iii) Water quantity (five rigorous studies) (20%); (iv) Water and sanitation (two rigorous studies) (30%); (v) Hygiene (six rigorous studies) (33%) and (vi) Sanitation (five rigorous studies) (36%).

However, better evidence for water quality was found in the World Bank report [Table 1] indicating water supply with house connection has a 63% reduction in diarrhoea and 2.7 relative risk.

In another finding, water collection distance is also important for fullest use of water. In Figure 1, Caincross and Feachem showed that household water consumption declined to less than half of connected households at more than 5 minutes water collection distance.

**DISCUSSION**

In this review, we explored and identified water quality including different water treatment methods affecting diarrhoea morbidity and mortality. Some findings show that household-based approaches to water treatment may
be more efficient and cost-effective means of preventing diarrhoeal disease than conventional treatment at the source.

Household-based chlorination is the most cost-effective method followed by solar disinfection, which is only slightly less cost-effective. Conventional source-based interventions have a mean cost per disability-adjusted life year (DALY) averted of about twice that of chlorination and solar disinfection. In Africa (high adult and high child mortality region), the cost per DALY averted by household chlorination is US$46, by household solar disinfection is US$54, by source-based interventions is US$106, by household ceramic filtration is US$125 and by household flocculation/disinfection is US$415 [Appendix 1]. However, the study reviewed endemic diarrhoea only and also could not include economic value of other benefits (including time savings) or diseases related to unsafe water such as typhoid, hepatitis A and E and polio. Those diseases are transmitted by the ingestion of unsafe water and food but their pathology does not consist of diarrhoea.

In addition, according to the Caincross model, household water consumption declined to less than half of connected households at more than 5 minutes water collection distance, no change between 5 and 30 minutes and reduced again after more than 30-minute distances. Calculating benefit and quality improvement of water; equity in access and social disparity are additional dimensions to be considered. In almost three-quarters of households without access to drinking water on premises, women and girls have the primary responsibility for collecting water; in some countries the proportion is more than 90%. This is a very significant burden for women, especially when the time taken to collect water is considerable.

Furthermore, the relation between water quality and diarrhoea was lower than sanitation and diarrhoea in most scientific publications during the late 20th century. Esrey et al.'s review on previous studies – interventions at the point of distribution, such as protected wells and springs – reported (15-17%) reduction in diarrhoeal disease. In contrast, improving microbial safety of water immediately before consumption (at point-of-use) could reduce 39% diarrhoea risk and water quality interventions, on average, effect a 42% relative reduction in child diarrhoea morbidity. WHO also estimated 45% reduction in diarrhoea morbidity from household water treatment and 65.9% reduction in diarrhoea morbidity (7.6 billion diarrhoea episodes) from universal piped and regulated water supply. Furthermore, it is well known that even uncontaminated source water becomes contaminated before use, that is, post-source contamination. Post-source contamination could be collection, transport, storage and drawing in the home. Moreover, additional studies about benefit of point-of-use water treatment are: household-based chlorination is the most cost-effective method to prevent diarrhoea in the absence of universal piped and regulated water supply, and point-of-use water treatment comprising disinfection, safe storage and community education reduce 44% diarrhoeal episodes. Moreover, better effectiveness of water supply was reported in the World Bank report; water supply with house connection is almost two times greater than sanitation in diarrhoeal reduction and also better than hygiene and greater cost-effectiveness.

Diarrhoea, acute or persistent, is a broad term and effect of household water treatment should be analysed in comprehensive health impact. Accordingly, health impact of treating water at the point of consumption is not absolute. Except in the case of Vibrio cholerae, point-of-use water quality or a reduction in waterborne pathogens is not clearly associated with a reduction in diarrhoea. Many studies could not produce consistent protective effect of water treatment; more than two dozen studies have shown
household water treatment to be protective for diarrhoea but the range of effects is quite broad.\textsuperscript{[31]} Furthermore, one of the only blinded trials by Kirchoff et al.,\textsuperscript{[20]} has not demonstrated any statistically significant reduction in diarrhoea. Those heterogeneous results from various interventions may possibly be related to a wide range of conditions such as diverse risk settings, the different methodological rigour of the studies, negative externalities from unhygienic practices and other socioeconomic factors.

Lastly, microbial contamination of stored water has been influenced by many factors including storage times.\textsuperscript{[21‑23]} Storage duration of 1-2 days in rural Bangladesh has 10-fold higher cholera rate; however, storage duration of 4 hours in South Africa has no effect for increased diarrhoea and cholera, although it increased the coliform level. Storage containers are also important in improving water quality. Usually, containers with narrow opening or appropriate covers to prevent filling and containers designed for water treatment and directly stored for household use are preventive measures of microbial contamination. In contrast, increase faecal coliform and diarrhoea were found in following studies:

1. Rural Malaysia – higher diarrhoea rate in wide-neck container.\textsuperscript{[25]}
2. Kolkata, India – four-fold increased cholera in wide mouth container.\textsuperscript{[26]}
3. Trujillo, Peru – higher coliform and increase cholera risk in wide mouth storage container.\textsuperscript{[27]}
4. Rural Trinidad – increased faecal coliform in open storage vessels.\textsuperscript{[28]}

**Household water treatment for resource-limited area**

Treating water at the point-of-use, household water treatment is the best option for the resource-limited area. The WHO is exploring effectiveness in improving and maintaining microbial water quality, health impact, simplicity, accessibility, cost, acceptability, sustainability and potential for dissemination.\textsuperscript{[29]} The studies were further reviewed by Thomas,\textsuperscript{[3]} who reported the five most promising household water treatments.

**Chemical disinfection**

It is most common at the community level and in emergency. Liquid sodium hypochlorite or solid calcium hypochlorite is commonly used and mostly affordable methodology. At doses of a few milligrams/litre and contact time of about 30 minutes, free chlorine inactivates more than four logs of enteric pathogens, the notable exceptions being Cryptosporidium and Mycobacterium species.

**Filtration**

Household filters can operate at any temperature, pH and turbidity and have no effect upon taste and odour. There are three types:

2. Slow-sand filters.

**Thermal and solar disinfection**

Boiling or heat treatment of water is most effective against the full range of microbial pathogens. Similarly, solar disinfection by using thermal and ultra violet (UV) radiation reduce diarrhoeal morbidity of attributable risk fraction by 16% among children.\textsuperscript{[30]} Treatment of water with solar radiation was practiced in ancient India for more than 2000 years ago,\textsuperscript{[29]} which controls waterborne microbial contaminants by exposure to sunlight.

The ‘SODIS’ system, developed and promoted by the Swiss Federal Institute for Environmental Science and Technology treat low turbidity (<30 NTU) water in clear plastic bottles through aerating to increase oxygenation and exposing the bottles to the sun. Exposure times vary from 6 to 48 hours depending on the intensity of sunlight.\textsuperscript{[5]} Thermal and solar disinfection does not provide residual protection against recontamination.

**Combined flocculation and disinfection**

Turbidity, a common problem in household-based water treatment, can reduce by simple sedimentation or flocculation/coagulation using additives such as alum. Assisted sedimentation has been shown to reduce the levels of certain microbial pathogens, especially protozoa, which are resistant to chemical disinfectants. However, disinfection is still required in most cases for complete microbial protection. Field studies have demonstrated that use of home water treatment with flocculant-disinfectant decreased the incidence of diarrhoea.\textsuperscript{[31]}

However, prevalence of such appropriate household water treatment methodologies is not very common in developing countries. Generally, practices like straining water through a cloth or letting it stand and settle are not considered appropriate methods. There is a need for appropriate strategies to scale up to poorer households.

Beyond the importance of methodological complexity, additional factors are needed to achieve full utilization of household water treatments by communities. Accessibility, taste and quality of water are the most important factors. Public–private partnership (PPP) and social marketing will be further options for promoting household water treatment. Supporting private sector and local small and medium enterprise for the promotion of household water treatment could be the sustainable solution for resource-limited communities.
RECOMMENDATIONS

Currently, five types of household water treatment methods are most effective and applicable to rural and resource-limited settings and areas where water is unable to be universally piped in. Regarding requirements of proper utility and storage methods related with human behaviour, we recommend further research about household water treatment among rural populations. While there is considerable research to support the microbiological effectiveness and promising, although not definitive health impact, there is relatively little evidence about the potential uptake of such interventions. Acceptability, affordability, long-term utilization and sustainability need further exploration, particularly in programmatic settings. Moreover, hardware development will have an exponential impact when there is software for changing people's behaviour and acceptance. The possible policy option for promoting behaviour and acceptance among communities is social marketing through PPPs. The private sector has advantages in marketing and mobility to reach communities. Quality assurance by various research of the public sector can be assisted by private sector assistance in marketing and promotion of utility.

CONCLUSIONS

Promoting household water treatment is most essential in preventing diarrhoea disease and reducing diarrhoea death among patients. Although there are different methodologies so far, issues such as taste and quality (most acceptable), appropriateness to all situations (both emergency and non-emergency) and costing (affordability) will ultimately help to determine the potential role of household water treatment in preventing diarrhoea.

REFERENCES


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Appendix 1: WHO Cost-effectiveness Study (USD per DALY averted)

<table>
<thead>
<tr>
<th>WHO epidemiological sub-regions by mortality</th>
<th>Source-based interventions (stand post, bore hole, dug well)</th>
<th>Chlorination</th>
<th>Ceramic filtration</th>
<th>Solar disinfection</th>
<th>Flocculation disinfection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa (high adult, high child)</td>
<td>106</td>
<td>46</td>
<td>125</td>
<td>54</td>
<td>415</td>
</tr>
<tr>
<td>Africa (very high adult, high child)</td>
<td>123</td>
<td>53</td>
<td>142</td>
<td>61</td>
<td>94</td>
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<td>America (low adult, low child)</td>
<td>1930</td>
<td>744</td>
<td>2005</td>
<td>861</td>
<td>6656</td>
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<tr>
<td>America (high adult, high child)</td>
<td>469</td>
<td>190</td>
<td>508</td>
<td>218</td>
<td>1687</td>
</tr>
<tr>
<td>Eastern Mediterranean (low adult, low child)</td>
<td>1511</td>
<td>510</td>
<td>1375</td>
<td>590</td>
<td>4565</td>
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<tr>
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<td>90</td>
<td>695</td>
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<tr>
<td>European (low adult, low child)</td>
<td>2254</td>
<td>978</td>
<td>2637</td>
<td>1132</td>
<td>8754</td>
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<td>South-East Asia (high adult, high child)</td>
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<td>South-East Asia (low adult, low child)</td>
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<tr>
<td>Western Pacific (low adult, low child)</td>
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Source: Reference[13]; DALY - Disability-adjusted life year