The Application of Participatory Research to Optimize a Household Water Treatment Technology in a Poor and Marginalized Community of Chennai, India

by

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ABSTRACT

THE APPLICATION OF PARTICIPATORY RESEARCH TO OPTIMIZE A HOUSEHOLD WATER TREATMENT TECHNOLOGY IN A POOR AND MARGINALIZED COMMUNITY OF CHENNAI, INDIA

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University of Guelph, 2013

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This research provides an authoritative perspective on the importance of collaborative innovation for the development of sustainable household water treatment and safe storage (HWTS) in Mylai Balaji Nagar, a low-income, peri-urban community in Chennai, India.

The use of HWTS to improve drinking water quality and reduce the burden of diarrhoeal diseases in poor and marginalized communities in the developing world has received considerable attention. However, the technologies proposed by foreign researchers and engineers are often designed without the involvement of local people, and often neglect the cultural heterogeneity of the low income communities they’re intended for. Participatory action research (PAR) encourages a two-way exchange of information that promotes collaborative learning and increases the likelihood of sustainable development. This research employed a PAR
framework to promote community control and stimulate local participation in a user-centered approach to HWTS design. Complementary evidence is presented on the importance of appropriate technology that places greater emphasis on the social determinants of user satisfaction.

A twelve month randomized controlled trial of the collaboratively designed HWTS revealed significant reductions of indicator bacteria in intervention household drinking water, with mean log reductions of 1.54 (95% CI: 1.35 – 1.73) for E. coli and 1.92 (95% CI: 1.76 – 2.08) for total coliforms. Bacterial concentrations in treated water were higher during the monsoon season than the dry season, indicating that water quality may vary according to seasonality in tropical countries with monsoon rains. Additionally, survey data established that households with high perceptions of treated water taste, colour, and odour were more than three times more likely to comply with treatment instructions than were households with very low perceptions. These findings merit further study, as it appears that HWTS products that produce aesthetically appealing water receive greater compliance, and therefore present greater potential for achieving the desired health outcomes. The results of this research promote PAR as a powerful tool for developing contextually appropriate and culturally sensitive HWTS in poor and marginalized communities as a way to improve drinking water quality.
”Under the current model of globalization, everything is for sale. Areas once considered our common heritage are being commodified, commercialized and privatized at an alarming rate. Today, more than ever before, the targets of this assault comprise the building blocks of life as we know it on this planet, including freshwater, the human genome, seeds and plant varieties, the air and atmosphere, the oceans and outer space. The assault on, and defence of, the commons is one of the great ideological and social struggles of our times.”

- Maude Barlow
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I am particularly indebted to Prof. Kevin Hall, who profoundly influenced my life when he invited me to conduct my doctorate under his guidance and supervision. His unconventional decision to recruit me, someone without a traditional background in engineering, inspired me and gave me the confidence to tackle this international and multidisciplinary project. Thank you for being the impetus in my professional awakening. Additionally, I am most appreciative of Prof. Kristan Aronson for her passion in focussing the research, providing constructive criticism, and for her valued feedback. Committee members, Prof. Ed McBean and Prof. Paul McNicholas, whose insights and recommendations helped refine this dissertation and advance my own professional development. Appreciation also goes to Prof. Rumina Dhalla, Prof. Sally Humphries, and Prof. Michelle Edwards who supported and assisted me during the writing and analysis stage. I feel honoured to have had such a gifted committee and support network. Thank you.

This dissertation and the research it reports was made possible with funding from the International Development Research Centre (IDRC), Ottawa, Canada, as well as student funding from the National Science and Engineering Research Council of Canada (NSERC), and the
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The two years I spent living and working in Chennai, India were two of the most exciting, fulfilling, and overwhelming years of my life. I acknowledge and deeply appreciate my Indian partners, who welcomed me into their country and invited me to perform meaningful but challenging work as part of a talented research team. Prof. Ligy Philip, Prof. Prema Rajagopalan, and Prof. B. S. Murty — thank you for your ongoing support and patience. I will never forget the warmth you showed me or the conversations we shared over masala chai. Thank you all for your commitment and boundless support to myself and the project.

To my project staff in India, I owe a debt of gratitude that can never
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List of Abbreviations

AMESH  adaptive methodology for ecosystem sustainability and health

BIS  Bureau of Indian Standards

CFU  colony forming units

COD  chemical oxygen demand

FSWQC  Five Star Water Quality Centre

HiH  Hand in Hand India

HWTS  household water treatment and safe storage

MBN  Mylai Balaji Nagar

NaDCC  sodium dichloro-isocyanurate

NGO  non-governmental organization

NTU  nephelometric turbidity units

PAR  participatory action research

PoU  point of use
UN United Nations

UNICEF United Nations International Children's Fund

WHO World Health Organization
Chapter 1

Introduction

Alternative water treatment is urgently needed in the peri-urban (PU) slums of Chennai, where the water crisis has gone from bad to worse. The population is fast approaching 10.6 million, 3 million of which are located in the PU areas. Assuming 100 litres per capita per day (lpcd), the WHO standard for optimal access to water, the city’s public water demand is estimated to be 1060 mld with an additional 250 mld required for industry. Fresh water yield from municipal reservoirs and groundwater extraction totals approximately 425 mld in a given year, leaving the city in a current water deficit of 885 mld (Butterworth et al., 2007; WHO, 2003). In response to this shortfall, Metro Water imposes periodic water cuts across the city in an attempt to conserve this limited resource. Poor and marginalized communities that are not legally recognized as slums by the municipal government, such as Mylai Balaji Nagar, may not be guaranteed consistent water provision. With the emergence of water as an economic good, it will become increasingly difficult for the urban poor to afford this fundamental right, forcing them to seek drinking water in polluted and unprotected environments. This water is high in both chemical and biological contaminants, unfit for human consumption. If the drinking water goes untreated, the individuals consuming it risk serious illness and death. Alternative
water treatment technologies provide end-users with the means to purify their own drinking water, empowering them, and making them less dependent on centralized systems.

At a United Nations Summit in 2000, the international community established the Millennium Development Goals (MDGs), of which goal four aims to reduce the under-five child mortality rate by two-thirds by 2015. In a recent analysis of global child mortality rates, it was discovered that the diarrhoeal diseases remain one of the leading causes, implicated in the deaths of more than 750,000 children worldwide (Liu et al., 2012). Goal seven is set to halve by 2015 the proportion of people without sustainable access to safe drinking water and sanitation, since the transmission of diarrhoeal disease is primarily attributable to contaminated water and inadequate sanitation (UN, 2002; WHO, 2002). For the estimated 780 million people who lack access to improved water sources and the millions more drinking microbiologically unsafe water from improved water sources, the WHO declared point-of-use household water treatment and safe storage (HWTS) to be one of the most cost-effective approaches for achieving the MDGs (UN, 2012; WHO, 2002, 2011).

1.1 Research Motivation

India is rapidly gaining traction and influence on the world stage, while making significant improvements to the living conditions of its rural and urban poor. The rate of extreme poverty in India fell from 60% in 1990 to 16% in 2005, and again to 13% in 2008 (UN, 2012). In 2010, the UN made further efforts to reduce global poverty by declaring access to safe and clean drinking water as a fundamental
human right. Access to safe drinking water enables people to rise out of poverty by preventing diarrhoea and other waterborne illnesses, creating the time and good health to increase their economic situation. A recent report from the UN indicates that since 1990, an additional 457 million and 522 million people received access to safe drinking water in China and India, respectively. This increase accounts for nearly half of all global progress towards achieving goal seven of the MDGs, which the world has accomplished five years ahead of schedule (UN, 2012). If accessibility to safe water sources continues to grow at the same rate, 92% of the global populations is expected to receive coverage by 2015.

In order to extend coverage, India is relying heavily on groundwater. Currently, 7% of India’s fresh water demand is for domestic use, and 80% of this comes from groundwater sources (UNICEF, 2013). With the emergence of water as an economic good, groundwater extraction has reached a national high, with over 20 million private extraction sites, resulting in the unregulated and unsustainable exploitation of groundwater resources (UNICEF, 2013). Consequently, Chennai, India is suffering from some of the country’s greatest water scarcity; where the average citizen receives only 32 lpcd, and the average household receives running water for only 1.5 hours per day (UNICEF, 2013). Tragically, it’s often the poorest residents who don’t receive access to safe and reliable water, and are forced to rely on unprotected surface water sources of unknown quality. Currently, there are 783 million people worldwide without access to an improved source of drinking water, and millions more drinking microbiologically unsafe water from improved water sources (UN, 2012). A recent analysis of global child mortality found that half of all child deaths in 2010 occurred in India, Nigeria, Democratic Republic of Congo, Pakistan, and China, with over 1.6 million child deaths in India alone; the second
leading cause of death in children under five is diarrhoea, with over 750,000 deaths annually (UN, 2012; Liu et al., 2012). The WHO suggests that diarrhoeal diseases are over 80% preventable by interrupting transmission pathways with better access to safe water, sanitation and hygiene (WHO, 2002). Point-of-use water treatment technologies represent one of the leading strategies for extending the coverage of safe water access to poor and marginalized communities, in order to achieve immediate health gains.

Recent literature suggests that modern point-of-use technology may be more effective than the treatment of water at-source. A systematic review and meta-analysis by Fewtrell et al., investigated by subgroup the results of 38 intervention studies (Fewtrell et al., 2005). Findings revealed water treatment immediately prior to consumption was of principle importance for the reduction of diarrhoea. However, the majority of intervention studies are of too short duration to accurately capture the impact of temporal variability on treatment effectiveness. Researchers have noted that failure to report on at least 12 months of data collection may influence the observed effect (Blum and Feachem, 1983; Clasen et al., 2007; Crump et al., 2004). Historically, studies involving household water treatment and safe storage (HWTS) have been primarily interested in the technology’s effectiveness within the first six months, with little understanding of their capacity for sustainability (Altherr et al., 2008; Quick et al., 1999, 2002). More long term studies are needed to judge the effectiveness of HWTS products, and determine their ability to provide consistent high quality water under the harsh environmental conditions commonly encountered in the field.

With the implementation of HWTS in multiple countries around the world, the importance of contextual appropriateness and user satisfaction cannot be over-
stated. While some studies have demonstrated a greater concern for intervention sustainability by investigating the factors predicting their use (Altherr et al., 2008; Brown et al., 2008; Firth et al., 2010), and longitudinal follow-up studies designed to determine the rates of continued application (Luby et al., 2001; Rose et al., 2006), few studies have investigated the complex interaction between HWTS technologies and the people they're intended for. Given the cultural heterogeneity of low income communities throughout the developing world and the considerable difficulties of their contexts, more research is needed to understand the factors that result in either the success or failure of HWTS programs.

1.2 Research Objectives

The research described in this document was performed as part of the Alternative Water Systems Project (AWSP), a collaborative effort between the University of Guelph (Ontario, Canada), Queen’s University (Ontario, Canada), and the Indian Institute of Technology Madras (Chennai, India). With funding from the International Development Research Centre (IDRC), the overall objective was to develop an alternative water treatment option for safe water provision in a peri-urban slum and to reduce the burden of diarrhoeal disease within the community. Ultimately, this research is intended to assist program implementers in making informed choices regarding the selection, implementation, and sustainability of alternative water treatment technologies in different parts of the developing world. Specific research objectives included:

1. Assessment of the effectiveness of the PoU water treatment system for its removal of waterborne pathogens in field conditions;
2. Assessment of the potential health impact of the PoU safe water system within the study community by measure of diarrhoeal disease prevalence between intervention and control households;

3. Determining the level of acceptability of the PoU safe water system by observing the degree of participant compliance;

4. Developing an appropriate operations and management (O & M) framework for the PoU system to promote ongoing sustainability; and

5. Identifying and addressing challenges to the long-term sustainability of the PoU system in the study community.

1.3 Project Timeline

The *Alternative Water Systems Project* was a collaborative research effort to investigate the participatory design of a household water treatment technology, its effectiveness in the field, and its appropriateness to context. The total duration of the project was three years, conducted between June 1, 2009 and May 31, 2012. The research presented in this thesis was conducted by Morgan MacDonald, between September 2010 and May 2012, as a module of the larger project. The following table gives a rapid overview of the project timeline, sequence of events, and program development. Greater detail is offered in subsequent chapters. Please note, two of the events listed below are marked with an asterix (*) to indicate that they were not performed by Morgan MacDonald, but by another member of the research team.
Table 1.1: Project Timeline

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<td>All stakeholders forum*</td>
<td>December 1, 2009</td>
<td>The forum was called to address the issue of water poverty faced by the residents of MBN. Community members, project researchers, local government officials, and representatives from local NGOs were in attendance. Drinking water quality was identified as a major community concern in need of development.</td>
</tr>
<tr>
<td>Baseline data collection*</td>
<td>January 28, 2010 to January 23, 2011</td>
<td>The baseline study involved the collection of social and environmental data in an effort to understand vectors of disease transmission.</td>
</tr>
<tr>
<td>Evolution of the study design to accommodate a water quality outcome measure</td>
<td>January 2011</td>
<td>The baseline data revealed diarrhoeal prevalence was unexpectedly low. Consequently, I transformed the study from that of an epidemiological design, to that of water quality assessment. The new design required the routine monitoring of bacterial concentrations in household drinking water.</td>
</tr>
<tr>
<td>Community census</td>
<td>February 10 to 21, 2011</td>
<td>I and the research team performed a community-wide census to determine the number of households eligible to participate in the study. Of the 181 households that met the inclusion criteria, we were able to recruit 124.</td>
</tr>
<tr>
<td>Laboratory assessment of the SWS</td>
<td>December 5, 2010 to February 3, 2011</td>
<td>The SWS was tested for its treatment efficacy. We dosed the system with 20 litres of raw lake water for 28 days to assess reductions in turbidity, organic matter, and bacterial indicators.</td>
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<td>Intervention implementation and project launch</td>
<td>April 23, 2011</td>
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<tr>
<td>Community outreach and door-to-door program maintenance</td>
<td>April 23, 2011 to May 30, 2012</td>
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<tr>
<td>Water sample collection and survey administration</td>
<td>April 23, 2011 to May 30, 2012</td>
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<td>SWS recall and refurbishment</td>
<td>Mid July, 2011</td>
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<td>Sports day to promote WASH awareness in school</td>
<td>August 14, 2011</td>
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<td>Free medical camp</td>
<td>November 6, 2011</td>
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<td>Street theatre for WASH awareness</td>
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Formation and development of the Five Star Water Quality Centre (FSWQC) | October 2, 2011 to May 30, 2012 | Once a week, I and the research staff would meet with members of the FSWQC to design an operations and management framework. These efforts were intended to enhance the sustainability of the SWS following completion of the research project.

First filter workshop with the FSWQC | January 24, 2012 | Members of the FSWQC were invited to attend a half-day workshop at IIT Madras on the general principles of filter construction, the tools and materials involved, and their practical importance to the silter’s efficacy.

Second filter workshop with the FSWQC | February 6, 2012 | A second filter workshop was held in MBN to reinforce skills previously learned at IIT. It was also intended to demonstrate how the SWS could be constructed in MBN, without any special tools only available to the research staff at IIT.

Project completion ceremony and distribution of SWS to control households | March 10, 2012 | Completion of the project was celebrated with the gathering of study participants, the research team, and local government officials. Guests were entertained with dancing and street theatre; snacks and lunch were provided. At this time, participants from the control group received an SWS for their participation in the project.

### 1.4 Thesis Organization

The structure of this thesis follows a manuscript style, where a single published or unpublished paper is presented in the form of a chapter. Copyright agreements and approvals from publishers to include these papers in this thesis can be found in Appendix A. This thesis consist of seven chapters including this one. Each chapter is outlined below.
Chapter 2 Literature Review

This chapter reviews the current literature on the state of water poverty and related health concerns in developing countries, as well as available point-of-use water treatment options.

Chapter 3 Collaborative innovation for the development of contextually appropriate water treatment technology in a marginalized, low-income, South Asian community

This chapter discusses the participatory design of the Safe Water System (SWS) during phase one of the project. It explores the concepts of appropriate technology, participatory action research, iterative design, and sustainability. Furthermore, it demonstrates that complex development problems are more effectively solved by utilizing collective knowledge and problem-focused dialogue than by top-down reductionist and prescriptive methods. Finally, the paper reflects on lessons learned from this experience and suggests possible improvements to the current methodology. This paper has been published in The International Journal of Technology, Knowledge, and Society:


Chapter 4 The impact of rainfall and seasonal variability on the bacteriological removal effectiveness of a point-of-use drinking water treatment intervention in Chennai, India

Chapter four presents water quality results from phase two of the research project, following the design and implementation of the SWS. Phase two involved
a longitudinal water quality monitoring program, as part of a randomized controlled trial of 124 households in Mylai Balaji Nagar. Households were visited once every two weeks over a twelve month data collection period; survey data was collected once every two weeks, while water samples were collected once every month. This chapter compares the water quality findings of intervention-treated, intervention-untreated, and control water samples. The chapter also investigates the influence of seasonal weather variability on treatment performance, and the resulting water quality. This paper has been prepared for submission to the journal of Water Science and Technology, to be considered for publication. The authors are delaying the submission of this paper until a second complementary paper can be written, and the two can be submitted together.

Chapter 5 Predicting Participant Compliance with Point-of-Use Water Treatment: The Implications of Improving Water Aesthetics

Chapter five presents data from Phase two of the research project, conducted in India to determine the appropriateness of the SWS for application in poor and marginalized communities of South India. This chapter examines the technical, social, and institutional factors affecting participant compliance, by examining longitudinal survey data on water treatment and provisional practices in 69 intervention households over the 12 month data collection period. Lastly, the paper concludes by emphasizing the importance of certain design considerations for developing HWTS, to optimize compliance and increase the potential of achieving the desired public health outcomes. This paper has been submitted to the American Journal of Tropical Medicine and Hygiene, to be considered for publication (Submitted on May 22, 2013).

Chapter 6 Applying an Extended Ladder of Participation for the De-
development of a Community-Managed Safe Water System in a Marginalized South Asian Community

This chapter addresses the issue of program sustainability for research based development projects, following the withdrawal of the researchers (or project implementers). It describes the application of Bruns’ “Extended Ladder of Participation” and how it was used to guide the transfer of decision-making power from project implementers to local communities via institutional reform and user participation. The chapter concludes by addressing the benefits of such a model for guiding program strategy and tailoring development activities to fit an appropriate level of community involvement.

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Chapter 7 Conclusions and Recommendations

This section summarizes community health and sociological findings, as well as those from the water quality monitoring program, and finally findings and insights on program development and sustainability. The section concludes with recommendations for future research to improve our understanding of HWTS technology performance in the field, reduce performance variability, improve user satisfaction, and promote sustainability.
Chapter 2

Literature Review

2.1 Problem and Justification

Water-related diseases are the single leading cause of death and morbidity in the developing world. They account for some 750,000 child deaths each year, 88% of which are attributable to diarrhoea resulting from inadequate water, sanitation and hygiene (Liu et al., 2012; World Health Organization, 2002). Infective bacteria, parasites, protozoa and viruses form a collective group of pathogenic microorganisms known as the diarrhoeal diseases; they are typically transmitted by ingestion of contaminated water or food. Of the six billion people who inhabit the Earth, 780 million do not have access to clean drinking water while an additional 2.5 billion lack access to basic sanitation (UN, 2012; WHO, 2002, 2011). The majority of these underserviced communities exist in the developing world, placing diarrhoeal disease amongst the most pressing challenges faced by marginalized communities today. Children often bear the brunt of diarrhoeal disease because of compromised immune systems, made vulnerable to infection by malnutrition and inadequate
healthcare. Diarrhoea accounts for 10% of deaths in children under the age of 5 living in developing countries (Liu et al., 2012). An estimated 400 children under the age of 5 die every hour due to waterborne bacterial diseases. In India, an estimated 2,402,000 children under the age of five died in the year 2000 alone (Black et al., 2003). Should present trends continue undisturbed, the children of South Asia will suffer from increased incidence of acute diarrhoea and enteric pathogen infection.

The following section reviews the current literature on the state of water poverty and related health concerns in developing countries. It highlights the challenges faced by poor and marginalized communities in South India, with specific attention paid to the issue of water scarcity faced by the peri-urban poor of Chennai, India. It revisits the Millennium Development Goals, our progress in achieving them, and obstacles which remain to be overcome. Finally, the section concludes with an examination of four alternative water treatment options, their strengths and weaknesses, and circumstances under which they can achieve optimum health benefits.

2.2 The Urban Slum Environment in South Asia

India has the second largest urban population in the world next to China (Fry et al., 2002). Rural India, which composes approximately 68% of the country’s population, has demonstrated an increasing trend of migration to urban centres. Upon arrival, migrants from the countryside seeking employment and an improved quality of life are encountered with limited opportunity for employment and a high cost of living. They are often forced to seek shelter in illegal slums and settlements
on the outskirts of cities in peri-urban (PU) areas. PU communities have been described as areas in transition from being predominantly rural to obtaining features and services typical of urban centres (Allen et al., 2004). As the city increases in size and population the PU areas are absorbed by the municipality and provided with public services. This process is however unhurried, leaving the urban poor with inadequate access to clean water and sanitation. Inhabitants of urban slums are easily identified by several predictive factors including marginalization, illiteracy, gender, and class or caste. Families of urban slums often fall into three categories:

1. those who are no longer able to afford the expense of living in the inner city and are forced to move to the outskirts;

2. young families in the process of saving money to enter into a subsidized housing program; and

3. migrant families unprepared for the expense of urban life (Solo et al., 1993).

Currently, 30% to 40% of India’s urban population live in poverty (Fry et al., 2002).

With the exponential growth in India’s urban population, it becomes increasingly difficult for adults to find employment and for children to pursue an education. India’s urban population increased by 31.2% between 1991 and 2001, with the number of urban poor reaching 61.8 million (Bouselly et al., 2006; Indian Government, 2001). The majority of these people live in slums or resettlement colonies. PU communities are typically characterized by low socio-economic status and low household income. While investigating the effects of the 2004 Tsunami on two Chennai city slums, Bunch et al. found approximately half of residents to be unemployed. The average monthly household income varied from Rs. 1450 (USD
$33) to Rs. 1800 (USD $41); less than two dollars per day (Bunch et al., 2005). Men living in slums are commonly employed as labourers, fisherman, rickshaw drivers and street vendors while women often work in domestic services and retail jobs. Approximately 70% of India’s poor are women and children. In order to pay for food, water and shelter roughly 27% of children under the age of 16 must work to supplement the family income (Bunch et al., 2005). They are commonly employed by the informal economic sector, working the lowest paying jobs in the most dangerous environments.

Poor quality water and inadequate sanitation are endemic to South Asian slums. It is therefore the marginalized poor which endure the greatest suffering inflicted by disease and common infection. These communities are littered with garbage, debris and human waste, polluting the physical environment and attracting pests which bring with them new dangers. Children under the age of 5 years, without immunity to ubiquitous pathogens bear the brunt of diarrhoeal disease. With greater access to good quality drinking water and improved sanitation, the international community can prevent approximately 88% of these deaths by stemming the source of infection (World Health Organization, 2002). The medical community continue their end of the fight by providing curative therapy with only nominal success. Only preventative intervention will result in significant change and help the international community achieve the Millennium Development Goals.

2.3 Public Health and Medical Care

Healthcare systems in urban slums are characteristically overburdened and commonly suffer from resource shortage. Private practitioners, government hospitals
as well as local and international NGOs are the primary avenues for healthcare provision. Private practitioners are expensive and accessible only to those households with financial means (Das and Hammer, 2007). Services provided by NGOs are contingent upon funding and are only intermittently available. Hospital care is provided by the government nearly free of charge to the patient; however these resources are stretched far too thin with consequences to quality of care. The investigation of 168 infant deaths in Delhi slums found evidence of inappropriate medical practice among both modern and indigenous systems of medicine (Bhandari et al., 2002). Only 48% of infants with severe diarrhoea were prescribed oral rehydration solution, while none of the 7 neonates and only 6 of the 25 older infants in the study, who had both diarrhoea and critical malnutrition were given antibiotic injections. The same study found that nearly half of all admitted infants died during their stay in hospital. Of those infants who were discharged, 23% died within the first 48 hours and 62% died within their first week of homecoming. Despite the shortcomings of governmentally funded hospitals and dispensaries, slum inhabitants do benefit from access to relatively free medical care. Abelson (1996), studying the effects of slum improvement programs in Visakhapatnam, India found the proportion of children receiving immunizations rise from 25% to 83% over the course of one year (Abelson, 1996). Furthermore, Burra et al. found that 98% of pregnant women in Chennai slums had received at least one medical check-up prior to giving birth, improving the rate of successful deliveries (Burra et al., 2003).

Despite the availability of medical resources the number of untreated illnesses in slums remains quite high. Early recognition of illness and utilization of healthcare services remain two of the greatest factors effecting child morbidity in India. Of 1,000 respondents from 32 slum clusters and 8 resettlement colonies in Chennai,
70% claimed to have access to a government hospital within two kilometres (Bhandari et al., 2002; Burra et al., 2003). Of those resettlement colonies, which are typically located further away from the downtown core, 62% claimed to have access to a dispensary. Several predictive factors such as distance, education, income, gender and caste or tribe are considered important determinants of whether or not a slum inhabitant will seek the medical attention of government hospitals (Bhandari et al., 2002; Burra et al., 2003; Fry et al., 2002).

The high cost associated with private medical care can put households at serious risk of indebtedness; hospital bills can comprise between 20% and 60% of the per capita income (Krishnan, 1996). Irrespective of low household income, between 45% and 77% of slum dwellers prefer to seek medical attention from private practitioners and private hospitals (Burra et al., 2003). For many households unable to afford private healthcare, the alternative is often no treatment at all. The proportion of untreated illnesses show an acute decrease from 13.2% to 3.4% between households of low (<Rs 1000) and high (>Rs 5000) monthly incomes (Burra et al., 2003).

Patient compliance with prescribed medical treatment is typically low in poor communities where the quality of healthcare and medicine is highly variable. The most common excuse for neglecting an illness and failing to seek medical attention is the belief that the illness was, "not serious" (Burra et al., 2003). One study found that 61% of deaths in the first week of life occurred within 24 hours of illness recognition. In only 57% of these cases did caregivers seek medical attention (Bhandari et al., 2002). Of those children referred to a hospital only 40% of neonates and 54% of older infants were taken there by their caregivers. Reasons for non-compliance included: a noted improvement in the child’s condition; an inability
to leave the home; a family member advised against such actions; and financial expense (Bhandari et al., 2002). Marginalized communities are often untrusting of public hospitals and practitioners due to a negative previous experience. Bhandari et al. (2002), found that 15% of infants taken to the hospital were refused admission, of which 7% were refused treatment because the physician felt they would die anyways. Consequently, the urban poor are often suspicious of public medical facilities and avoid what few medical services they have access to.

2.4 Diarrhoeal Diseases and the Millennium Development Goals

On account of environmental health hazards and nominal public healthcare, certain infectious diseases are the leading cause of child mortality in the developing world (Liu et al., 2012). Of these, the single greatest health threat faced by people living in urban slums are waterborne diseases, the most ubiquitous of which is diarrhoeal disease (Graf et al., 2008). A multitude of viral, bacterial and protozoan pathogens constitute the diarrhoeal diseases for which the primary symptom is diarrhoea. Disease vectors originate in human and animal excreta, transmitted via contaminated food and drinking water (Prüss et al., 2002). Water plays a critical role in the transmission of waterborne pathogens and resulting community health (Leclerc et al., 2002). Commonly associated with malnutrition, diarrhoeal diseases can have lasting effects on a child’s physical and cognitive development. Evidence of growth stunting and impaired cognitive ability in later childhood have been linked to diarrhoeal infections in infancy with greater risk to those children.
suffering multiple episodes (Baqui et al., 1993; Berkman et al., 2002). Children living in South Asian slums suffer on average between 3.2 and 19.4 diarrhoeal episodes each year (Gupta et al., 1998; Kosek et al., 2003).

Diarrhoeal disease is profoundly endemic, disproportionately effecting young children in developing countries deprived of municipal services. Studies conducted in the 1950s, 60s and 70s estimated over 4.5 million annual deaths due to diarrhoea in children under the age of 5 (Snyder and Merson, 1982). More recent investigations however, suggest this number to be closer to 3.3 million (Bern et al., 1992). Based on studies conducted between 1992 and 2000, Kosek et al. (2003) estimate that 2.5 million children died each year during the 1990s as a result of diarrhoeal infection Kosek et al. (2003). International development efforts have, however, had a marked effect on child mortality worldwide. For children under one year of age, mortality fell from 23.3 deaths per 1000 children per year in 1982 to 8.2 in 2002. The drop in mortality was less significant in children between the ages of one and four, from 4.6 to 3.8 per 1000 children per year in 1982 and 2002 respectively (Kosek et al., 2003). Children under 1 year are still at greater risk of death from diarrhoea due to an acute susceptibility to dehydration (Rahaman et al., 1979). The acute reduction in child mortality rates over the last two decades may be attributable to the widespread use of oral rehydration therapy (ORT) for the treatment of diarrhoea. The percentage of diarrhoeal infections treated with ORT is estimated to have risen from 15% in 1984 to 40% in 1993 (Victora et al., 2000). While advances in curative medical therapy for diarrhoeal diseases are noteworthy, preventative measures for the interruption of water- and food-borne pathogen transmission have greater potential health benefits. By impeding the spread of infection, intervention technologies are capable of reducing the degree of
life lost, as well as the duration of life lived with disability. Global health would benefit from more attention paid to such preventative measures.

Marginalized communities continue to suffer the greatest burden of infectious disease. In 2001, Subsaharan Africa and South Asia together bore 45% of the global disease burden (Lopez et al., 2006). Not only do urban slum dwellers living in underserved and disenfranchised communities face shorter life expectancies they live a greater portion of their lives in ill health. Ten years ago, the international community agreed upon a vision for the global improvement of health, education, safer environments, longer life expectancies and equal opportunity for both girls and boys. These ideas were manifest in the UN Millennium Development Goals (MDGs) and agreed upon by leaders from every country (UN, 2008). Each of the eight MDGs identifies a time-bound target by which progress can be monitored and used to direct international efforts for the achievement of a common goal. Ensuring environmental sustainability, the MDGs aim to reduce the burden of diarrhoeal disease by halving the number of people without basic sanitation and sustainable drinking water by the year 2015 (Goal 7). A second target under the same goal means to achieve a significant difference in the lives of at least 100 million slum dwellers by the year 2020. Since diarrhoeal diseases are currently one of the major causes of childhood mortality, Goal 4 aims to fortify the UNs commitment to the reduction of diarrhoeal prevalence within the developing world by reducing the under-five mortality rate by two thirds. Recent evidence suggests India is making progress, as under-five mortality has decreased from 150 deaths per 1,000 live births in 1990 to 74 per 1,000 in 2005-06 (Khetrapal-Singh, 2011). However, at this rate, it is unlikely that India will achieve the target of 50 deaths per 1,000 live births in under-fives set forth by MDG Goal 4. Children of the developing world are
more susceptible to water related hazards afflicting their health, productivity and physical safety. Since, diarrhoea is the end-point of a long chain of causal factors, it is only by improving drinking water and sanitation that we stand a chance of reducing the global prevalence of diarrhoeal diseases.

2.5 Water, Sanitation and Public Health

The key to controlling the prevalence of diarrhoeal disease exists in the interruption of pathogen transmission. Unhygienic environments, such as peri-urban slums add considerable complexity to disease prevention strategies. The transmission of bacterial pathogens is commonly enabled by person-to-person contact, the ingestion of contaminated food or water, and indirect contact with infected feces. In essence, diarrhoeal disease is almost entirely preventable with the appropriate application of transmission barriers. They are responsible for 10% of child deaths in the developing world and account for 5.7% of the global disease burden (Liu et al., 2012; Parashar et al., 2003; Prüss et al., 2002). In an attempt to understand and control the transmission of diarrhoeal diseases, recent intervention studies have employed an integrated approach of improved sanitation, personal and domestic hygiene, water supply and water quality. An influential meta-analysis revealed the importance of improved sanitation and source water protection for the reduction of diarrhoeal prevalence (Esrey et al., 1991). Additional evidence stresses the importance of excreta disposal and handwashing practice to prevent the transmission of pathogens (Curtis and Cairncross, 2003; Garrett et al., 2008; Mara, 2006). So numerous are the routes of transmission that improvements to water quality alone may be insufficient to preclude the spread of faecal-oral bacteria (Briscoe, 1984).
Improvements to personal and domestic hygiene have made significant changes in public health. Handwashing practice and awareness present a considerable barrier to the transmission of bacterial pathogens since hands often serve as vectors of conveyance. Curtis and Cairncross (2003), estimated the relative risk ratio (RR) of contracting diarrhoea due to not washing ones’ hands to be 1.88 (CI: 1.31 – 2.68) — equivalent to a 47% reduction in risk. A meta-analysis of handwashing and hygiene studies published between 1981 and 2001 revealed that only 13% (range: 0 – 20%) of respondents washed their hands after changing an infant’s diaper, while only 14% (range: 1 – 20%) reported washing their hands after defecating (Curtis and Cairncross, 2003). Integrated intervention strategies incorporate multiple transmission barriers in an effort to control the prevalence of diarrhoeal disease. Recent evidence suggests the importance of adequate sanitation, hygiene, water quantity and quality in the protection of public health (Curtis and Cairncross, 2003; Esrey et al., 1991; Fewtrell et al., 2005). However, improvements to any one of these conditions alone may not be enough; a multiple barrier approach may be necessary to interrupt pathogen transmission.

Early intervention studies for diarrhoeal prevention misrepresented the efficacy of water quality improvement. In light of reviews by Esrey et al. (1991) and Gundry et al. (2004), water supply and sanitation received significant notoriety, overshadowing the effectiveness of improved water quality. Together these reviews forged the dominant paradigm, suggesting proper excreta disposal and improved personal hygiene to be foremost in the improvement of public health (Esrey et al., 1991; Gundry et al., 2004). Water quality interventions alone were believed to have little effect on reducing the transmission of bacterial pathogens (Curtis and Cairncross, 2003). As part of his meta-analysis, Esrey et al. (1991), found a
median reduction of 16% in diarrhoeal disease resulting from improved to water
quality; independent findings varied greatly from 0 to 90%. Improvements to
sanitation however were identified as having the greatest health impact with a
median diarrhoeal reduction of 36% (Esrey et al., 1991). In a later study, Esrey
(1996), observed that incremental improvements to sanitation were associated with
incremental increases in child height-to-age ratios; a known indicator of child
health. The reported effects of improved water quality were less than those reported
for improved sanitation. Children with access to improved water were also found to
have healthier weight-to-age ratios, but only when improved sanitation was already
present.

Findings cited by early reviews were likely obscured by the heterogeneity of
reported results. The majority of studies examined by Esrey et al. (1991) and
Gundry et al. (2004), contained methodological flaws typical of early intervention
studies (Blum and Feachem, 1983) (Blum & Feachem, 1983). Furthermore, none of
the intervention studies examined by Esrey et al. (1991), included PoU technology;
recent findings suggest PoU water treatment to be one of the most effective health
interventions available (Clasen et al., 2007; Fewtrell et al., 2005; Garrett et al.,
2008). Esrey et al. (1991), relied primarily on studies using observational data
which are more likely to contain bias (Rosenbaum and Rubin, 1984). Similarly, the
review by Gundry et al. (2004), included many observational studies while omitting
other relevant studies meeting their inclusion criteria (Clasen et al., 2004). A
complete understanding of water quality interventions and their ability to interrupt
the transmission of waterborne pathogens may only be obtained upon the analysis
of recent studies.

Growing evidence suggests that water quality interventions may be more ef-
fective at reducing the diarrhoeal disease burden than previously thought, calling into question the validity of the dominant paradigm. A review by Clasen et al. (2007), suggests that such heterogeneity is reduced upon analysis by treatment type subgroup, citing significant differences between treatment type categories. Pooled odds ratios for water quality alone were found to be 0.76 (CI: 0.52 – 1.02), which did not differ when combined with instruction on basic hygiene, 0.51 (CI: 0.60 – 0.73) or sanitation, 0.60 (CI: 0.43 – 0.84). Application of a household water treatment intervention in rural Kenya was shown to have a significant impact on the prevention of diarrhoea (Garrett et al., 2008). Relative risk estimates revealed water quality to have the greatest effect (RR = 0.44, CI: 0.28 – 0.69) followed by water supply (RR = 0.70, CI: 0.52 – 0.95) and sanitation (RR = 0.71, CI: 0.54 – 0.92). Similar results were reported by Brown et al. (2008), with the application of ceramic filters in rural Cambodia. Intervention households reported significantly less diarrhoea than control households as demonstrated by longitudinal prevalence ratios (0.51, CI: 0.41 – 0.63). This recent evidence suggests that water quality interventions are effective barriers to the transmission of waterborne pathogens both in the presence and absence of sanitation and hygiene.

Recent literature suggests that modern point-of-use (PoU) technology may be more effective than the treatment of water at-source. A systematic review and meta-analysis by Fewtrell et al. (2005), investigated by treatment type subgroup the results of 38 intervention studies. Findings revealed water treatment immediately prior to consumption was of principle importance for the reduction of diarrhoea. PoU interventions (RR = 0.61, CI: 0.46 – 0.81) were found to be more effective than those targeting source water (RR = 0.89, 0.42 – 1.90). Post-collection contamination is highly variable and dependent on environmental hygiene. However,
water treated at-source is susceptible to recontamination during collection, storage and use in the home. Furthermore, the risk of recontamination is proportionately greater where water quality is good and the degree of environmental contamination is high (Wright et al., 2004). Water treated at-source is therefore more susceptible to later recontamination. For this reason, treatment of drinking water prior to consumption may be necessary to ensure appropriate water quality.

A discrepancy exists between the dogma of the dominant paradigm and the recent findings of intervention studies emphasizing the importance of water quality in diarrhoeal prevention. Such incongruity is attributable to several key factors. Firstly, contemporary intervention studies utilize a modern framework for study design in an attempt to control the influence of confounding factors. Lack of controls, inadequate recall periods and failure to operationally define health outcomes are some of the major problems hindering pioneer studies (Blum and Feachem, 1983). Fewtrell et al. (2005), suggest that 32% of the studies investigated in their meta-analysis were either poorly performed or poorly reported. Fewtrell et al. performed a comprehensive analysis of handwashing intervention studies and found that all contained methodological flaws including lack of randomization and failure to report compliance. Recent investigations apply a more stringent study design in an attempt to reduce variability and the influence of confounding factors (Clasen et al., 2007; Fewtrell et al., 2005; Garrett et al., 2008; Quick et al., 2002). A second explanation for the heterogeneity of reported results is the variability in underlying environmental risk. Environments with higher levels of fecal contamination pose a greater degree of risk to public health. Location, culture and pre-intervention conditions each contribute to the nature of a water quality improvement program. As such, differences between the environments of independent studies will ult-
mately contribute to the variability of results. Lastly, improvements made to sanitation have achieved significant reductions in diarrhoeal mortality; however this is not also true of diarrhoeal morbidity rates which have remained relatively constant for the last ten years (Huttly et al., 1997). This finding suggests that improvements to sanitation have little effect on the frequency of transmission. Where water contamination levels are high, drinking water becomes the primary route of transmission and water treatment is of principle concern (Moe et al., 1991). Recent evidence suggests that improvements made to drinking water quality are equally if not more substantial than those made by improvements to sanitation and hygiene. In light of this understanding, it has been acknowledged that the dominant paradigm is incomplete and requires further development (Clasen et al., 2004).

2.6 Alternative Water Treatment Technologies

Much of the developing world is decades away from having treated water delivered to the home via conventionally piped systems. Of the 750 million people worldwide without access to improved drinking water, nearly 100 million of those live in India (UN, 2012; World Health Organization, 2002). The majority of urban poor collect water from outside the home and treat it themselves at the household level (Brown et al., 2008). Even people with access to boreholes and standpipes are unlikely to have access to microbiologically safe drinking water. Point-of-use (PoU) treatment technologies are designed to empower people without access to safe drinking water by providing them with the means to treat it themselves and store it safely in the home (Sobsey et al., 2008).
Household water treatment and safe storage (HWTS) technologies are designed to meet the needs of a single family. To this purpose, a variety of treatment options exist, applying both physical and chemical methods of purification. Physical treatment processes include heating, filtering, boiling and disinfection by exposure to ultra-violet radiation (Sobsey, 2002). Chemical methods such as coagulation-flocculation, adsorption, ion exchange and chemical disinfection with germicidal agents are often applied in addition to physical methods and systems with more than one treatment technology are said to employ a multiple barrier approach. Preston et al, discovered that pretreatment of water with Aluminium salts (or Alum) reduced water turbidity and thus the demand for chlorine disinfectant (Preston et al., 2010). In certain cases however, the simplest solution is often the best one. Colwell et al. discovered that the transmission of vibrio Cholera could be significantly reduced in rural Bangladesh by simple water filtration using a folded Sari cloth (local garment) (Colwell et al., 2003). Sari cloth filtration provides a simple, cost effective method for improving the turbidity and microbiological quality of contaminated surface waters with locally available materials. For similar reasons, boiling is currently the gold standard by which all other treatment options are measured and compared.

When practiced correctly boiling is extremely effective, either killing or rendering inactive hazardous waterborne pathogens (Moe et al., 1991; Sobsey, 2002). Its application in semi-urban India has noted a 99% reduction of thermotolerant bacteria (Clasen et al., 2008). In Kenya, the incidence of coliform free drinking water rose from 10.7% to 43.1% by process of boiling; accompanied by a significant reduction in diarrhoeal illness within the study community (Lijima et al., 2001). Boiling has become widespread within the developing world because of its simplicity.
and the general availability of combustible materials. Despite its effectiveness, boiling does have its disadvantages. The unavailability or high cost of fuel may render households of low socio-economic status unable to boil their water. Furthermore, fires used to boil drinking water are often set indoors, diminishing air quality and posing a health risk to inhabitants (Rehfuess et al., 2006). A chief disadvantage to boiling is the relative inefficiency of energy consumption in relation to cost and sustainability of available fuels (Sobsey, 2002). It is estimated that one kilogram of wood is required to boil a single litre of water. Where wood is unavailable, supplementary fuels such as charcoal or kerosene must be purchased. Thus the cost of boiling water becomes prohibitive.

The remainder of this section highlights four alternative water treatment techniques typically practiced in the home, in developing countries. The section addresses the advantages and disadvantages of each method, their treatment effect on microbiological water quality and disease prevention (where available), and potential limitations.

### 2.6.1 Chemical Disinfection

Chemical disinfection is commonly employed in drinking water treatment due to its efficacy in microbial reduction. Strong oxidants, such as free chlorine, ozone, chlorine dioxide, and chloramines, are the most preferred and widely employed chemical disinfectants. In developing countries, free chlorine, in the form of either sodium hypochlorite (NaOCl) or calcium hypochlorite (Ca(OCl)2), is used because of its wide availability and low cost. According to standards set by the WHO and UNICEF, chlorine concentrations in drinking water are not to exceed 2.0 mg/l at
the time of consumption; nor should they fall below 0.2 mg/l for residual protection
against waterborne pathogens (WHO, 2008). Because chlorine is an oxidizing
agent, it reacts with organics in the water. Therefore, the chlorine dose must be
sufficient to react with the organics as well as disinfect any microbial pathogens; the
remaining unreacted chlorine is called the free residual. WHO guidelines suggest a
dose that produces a minimum free residual of 0.5 mg/L, with a minimum contact
time of 30 minutes. Chemical disinfection is also influenced by water turbidity,
with greater efficacy in less turbid waters. Microbes commonly adhere to colloidal
particle, which protect them against inactivation by reacting with and consuming
the chemical disinfectant, along with other dissolved constituents. Therefore, it
is recommended that disinfection should follow a pre-treatment which reduces
turbidity to <5 NTU (Sobsey, 2002).

Sodium dichloroisocyanurate (NaDCC) is an alternative source of chlorine, with
potential advantages over the more conventional NaOCL for point-of-use water
treatment. It’s an EPA, WHO and UNICEF approved water treatment material
with a time-release formula that contains chlorine stabilizers which improve treat-
ment efficiency in waters high in organic content. Upon application of NaDCC
to the raw water, it releases 50% of its chlorine as free available chlorine, which
reacts rapidly with organics present in the water. Unlike NaOCl, the remaining
chlorine does not react immediately, but remains as a reservoir for disinfection
in the form of chlorinated isocyanurates (Bloomfield and Miles, 1979). Chlorine
in the form of NaDCC is also more stable, with a 5 year shelf-life, considerably
longer than the recommended shelf-life of NaOCl of 6 months (Clasen et al., 2006).
Disadvantage of NaDCC include its availability and its cost. Unlike NaOCl, it may
not be procured locally, creating challenges for distribution and adding to the cost
of imported materials. However, with growing awareness and popularity, NaDCC could become more widely available, which could promote it as the most preferred method of chemical disinfection for water treatment in the developing world.

Chemical disinfection is often considered an essential element of water treatment, in part because of its proven rapid health gains. Developed by the Centre for Disease Control and the Pan-American Health Organization, the Safe Water System (SWS) employs three barriers to the transmission pathogens. Sodium hypochlorite is used to disinfect source water while the provided safe storage container prevents recontamination. Lastly, the system is delivered with instructions on proper water hygiene practices. SWS was found to be very effective, reducing the risk of diarrheal disease by 44% in low-income Bolivian households (Quick et al., 1999). Similar findings were reported for a different chlorine treatment option employed in both Bolivia and Bangladesh, for which Authors cited a 43% and 24% reduction of diarrhoeal illnesses respectively (Sobsey et al., 2003). Luby et al. (2006), while studying the health effect of a point-of-use flocculent disinfectant in Karachi, Pakistan, found a 55% (CI: 17% – 80%) reduction in diarrhoeal prevalence. Furthermore, a recent systematic review and meta-analysis of 21 intervention studies on the point-of-use effect of chlorine disinfection found significant reductions in the risk of childhood diarrhoea (pooled relative risk: 0.71, 0.58 - 0.87) (Arnold and Colford, 2007). The ease of use, affordability, and effective performance of chlorine disinfection makes it one of the most preferred methods for water treatment.

The use of chemical disinfection for drinking water treatment does however present some disadvantages. Despite the widespread effectiveness of hypochlorite there are high costs and difficulties associated with its transportation and distribution (Makutsa et al., 2001). Furthermore, effective uptake of hypochlorite is
generally greater in urban communities of higher socio-economic standing (Olembo et al., 2004). Vulnerable populations in marginalized communities demonstrate greater resistance to chemical disinfection due to ensuing changes in water taste and odor. Freeman et al, conducting a study in Western Kenya cited a 30% dislike for water treated with sodium hypochlorite as a result of an objectionable taste. Furthermore, only 50% of participants were found to continue treatment with hypochlorite following their first try (Firth et al., 2010). Aside from objectionable taste, there remains concern over the production of toxic chlorination by-products (CBPs), formed by chemical reaction with natural organic matter. Side effects include decreased birth weights, prematurity, intrauterine growth retardation, and neural tube defects (Krasner et al., 1989). Additionally, some CBPs such as Trihalomethanes (THMs) are potentially carcinogenic. Despite the production of CBPs, chlorination is admittedly one of the best front line defenses against diarrhoeal disease a known killer targeting young children in the developing world. The health risks associated with CBPs are less significant than those affiliated with bacterial contamination of untreated drinking water (Kalibbala, 2007). The application of chemical disinfection thus presents a problem of considerable complexity, whereby a balance must be achieved between microbiological and chemical risk.

2.6.2 Coagulation

The precipitation of colloidal particles in water treatment for later removal using sedimentation or filtration significantly reduces turbidity and microbial concentrations. The formation of precipitates, or flocs, is mediated by the addition of a chemical coagulant in the form of various salts of aluminum (alum), iron,
and lime. Coagulants act by destabilizing negatively charged colloidal particles that are attracted to the coagulant’s negatively charged hydroxide group, causing large flocs to form and settle with gravity (Sobsey, 2002). Under optimum conditions, coagulation-flocculation can achieve significant reductions in the number of bacteria, viruses, and protozoa; however, microbial reductions are generally low (<90%) when performed in the field, under sub-optimal conditions (Ongerth, 1990; Payment and Armon, 1989). Fraust and Aly (1998), reported that coagulation can effectively remove over 99% of turbidity and bacterial contaminant. However, the coagulation-flocculation of microbes is more effective in less turbid waters, where the coagulant can act more efficiently on the finer suspended particles. One of the greatest challenges to using a coagulant is determining the size of the dose needed to sufficiently treat the raw water. To do this, jar tests should be performed regularly, along with routine surveillance of turbidity and pH (WHO, 1997).

Coagulation-flocculation is also possible using indigenous plants such as Moringa oleifera, a flowering tree found widely in tropical and sub-tropical climates from South Asia to West Africa (Babu and Chaudhuri, 2005). Laboratory studies show that moringa coagulation can remove up to 90 to 99% of bacterial contamination and up to 96% of influent E. coli (Madsen et al., 1987; Nkurunziza et al., 2009). Oluduro and Aderkiye (2007), noted a 97.5% reduction of coliform bacteria upon treatment with M. oleifera, however the same study also found secondary bacterial growth of E. coli, Salmonella typhi and Shigella dysenteriae at 185%, 189% and 198% of their influent concentrations respectively, 24 hours post-treatment. The debate over the efficacy of M. oleifera in water treatment is on-going. Growing naturally in many rural areas, M. oleifera could be an inexpensive and widely-available coagulant for PoU water treatment purposes. Morgan MacDonald, and
colleague, Syed Imran Ali, conducted a study to investigate the efficacy of a PoU water treatment system featuring Moringa oleifera coagulation and/or sari-cloth filtration as turbidity control pre-treatments for solar UV disinfection (SODIS) (see Appendix B). The addition of moringa was found to increase COD in the treated water, with greater doses of moringa resulting in higher COD levels. This increased organic content may have encouraged the observed re-growth of coliform bacteria in those jars receiving moringa coagulant. The authors recommended sari-cloth filtration as a pre-treatment for SODIS, but suggested further investigation on the relationship between COD and bacterial re-growth before moringa coagulation can be recommended (Ali et al., 2011).

Water treatment using a multiple barrier approach relies on a series of unit processes, reducing the amount of chlorine required for effective disinfection. Coagulation is one such barrier which alters the chemical properties of water, by removing colloidal particles (Ghebremichael, 2004). Preston et al., cited a reduction in chlorine demand upon pretreatment with Alum. Additionally, water treated with Alum prior to disinfection was capable of retaining more free chlorine residuals than was water treated with chlorine alone. However, some natural coagulants such as Moringa Oleifera have been found to increase chlorine demand resulting in higher THM levels (Preston et al., 2010). The Moringa seed extract contributes a profusion of natural organic matter which reacts with chlorine to produce CBPs. Consequently, each procession of an HWTS must be collectively designed if the system is to perform optimally. Generally, chemical disinfection is most effective when preceded by the removal of sediment via coagulation and/or granular media filtration.


2.6.3 Filtration

Filtration is an attractive option for drinking water treatment at the household level. Filters are typically constructed using locally available materials, minimizing production costs while decreasing the community’s reliance on external assistance. It is in the absence of a conventionally piped water supply network, that alternative water treatment options yield immediate health gains for marginalized peoples. Where borewells are polluted by the ingress of contaminated groundwater and bottled water is purchased from unreliable merchants, water supply in slums is likely to be of poor quality irrespective of source. In order to be effective, interventions must be context specific that is different PoU options are differently suited for specific application. Where water is highly contaminated with parasites and cysts, a physical removal strategy such as filtration is a viable solution.

2.6.3.1 Porous Ceramic Filters

Ceramic filters are a highly effective, reproducible, low cost technologies designed for household-level water treatment. Cylindrical "candle" filters are designed so that water passes from the candles exterior to the inside through pores in the ceramic, before being conveyed to a safe storage container below the treatment compartment. A second design, ceramic pot filters, first distributed by Potters for Peace, have the appearance of a gardening pot, which filters raw water through pores in the ceramic, before it is captured in a storage vessel below. Ceramic filters are constructed of different types of clays, glass, diatomaceous earth, and other fine locally available particles. The media are mixed, then molded by hand or machine, before being dried and fired in a kiln. Slight alterations in the construction process,
such as changes in media composition and changes in kiln temperature, have been found to change the treatment characteristics of filters. Lantagne et al. (2010), found that while shape did not impact filter effectiveness, flow rates >1.7 l/hr decreased filter effectiveness. Similarly, too much sawdust in the media mixture resulted in an excessively porous filter, which decreased the treatment effectiveness (Lantagne et al., 2010). The majority of commercially produced ceramic filters are impregnated with colloidal silver, to act as a bacteriostatic agent, ensuring the complete removal of waterborne bacteria (Lantagne et al., 2010; Sobsey, 2002). There is evidence that at high bacterial concentrations, filters impregnated with silver consistently outperform those without (Oyanedel-Craver and Smith, 2007). The use of readily available materials, capacity for local production, and the high performance standards of porous ceramic filters makes the technology extremely suitable for water treatment in poor and underserviced communities. However, the technology is not without its limitations.

The filtration efficacy of ceramic filters is susceptible to changes in raw water characteristics, and technical variability caused by sub-optimal production. Large microorganisms, such as ova, cysts, and some bacteria, are trapped in the filters pores or rendered inactive by a bacteriostatic agent; however, smaller pathogens, such as viruses may not be removed. It has also been reported that adsorption sites for viruses can become occupied by competing colloids, reducing virus adsorption efficiency over time (Sobsey, 2002). The filters are also highly susceptible to breakage. Cracks and chips in the ceramic hinder pathogen removal, and make the filter unsuitable for water treatment. A study in rural Bolivia, employing ceramic pot filters for the reduction of diarrhoea, reported that 8 out of 25 filters were broken during the course of the six month trial (Clasen et al., 2004). Once the
filters are damaged, they cannot be repaired, so another filter must be purchased by
the household at full cost. Consequently, the decision to implement ceramic filters
must consider the significant turbidity and bacteriological removal efficiencies and
weigh them against high breakage rates and production costs.

Ceramic water filters have received extensive use in developing countries because
of their proven ability to remove microbiological contaminants and reduce the
burden of the diarrhoeal diseases. A study in Cambodia, found that households
using ceramic filters to treat their drinking water demonstrated a 75.3% reduction
in total coliform bacteria, which was associated with a 60% reduction in diarrhoea
(OR: 0.40, CI: 0.25 – 0.63) (Clasen et al., 2005). In a similar study, Clasen et al.
(2004), found the risk of diarrhoeal disease reduced by 70% (CI: 53% – 80%)
in Bolivian households having received ceramic filters. The reduction noted in
children under 5 years of age was more pronounced at 83% (CI: 51% – 94%) (Clasen
et al., 2004). Similar filters distributed by Potters for Peace, have demonstrated
bacterial removal efficiencies between 97 and 100% (Oyanedel-Craver and Smith,
2007). A study by Sobsey et al. (2008), suggests that baseline and maximum
removal efficiencies achieved by ceramic filters are greater than those reported for
biosand filtrations, and comparable to those reported for chemical disinfection with
free chlorine. Similar findings were reported for diarrhoeal disease reduction.

2.6.3.2 Slow Sand Filters

Slow sand filters (SSF), also known as biosand filters, have been in use since the
early 19th century for drinking water treatment at the community and sometimes
household level (Cairncross and Feachem, 1986). They are typically designed as
either basins or galleries, with a bed depth of 1–1.25 meters of sand (0.2 – 0.5 mm),
with a constant head of overlying water with a depth of 0.6–1.5 meters (Sobsey, 2002; WHO, 1997). Slow flow rates in the range of 0.1 – 0.3 m3/m2 per hour, are characteristic of SSF, which improve treatment efficacy by extending the bed retention time. The most significant feature of SSF is the formation of a biofilm layer, known as the *schmutzdecke*, the principle site of microbial treatment. It is here that microbes, organic matter, and colloidal particles are trapped and digested by other predatory microorganisms (Sobsey, 2002). The metabolism of waterborne bacteria, viruses and protozoa greatly improves the quality of filtered water, which is then collected by an underdrain, below a supportive gravel layer, and conveyed to an outlet valve (Figure 2.1).

**Figure 2.1:** Cross-section of a slow sand filter. From WHO (1997)

SSF are often implemented at the community level, but technical and logistical challenges make household level implementation difficult. Due to slow filtration
rates, SSF are often large to accommodate greater quantities of water, making them too expensive and inefficient for single household use. Also, the turbidity of influent water should be <60 NTU to prevent filter clogging, which reduces filter efficiency, and requires frequent maintenance. For water bodies with high turbidity, it is recommended that water be pre-treated using sedimentation or roughing filters (WHO, 2011). Even with less turbid influent water, the top layer (5–10 cm) of sand must be manually removed, cleaned, and replaced on a regular basis. During this time, the filter is not fit to provide safe drinking water, and must be allowed the time to ripen, or reestablish a schmutzdecke before it can achieve optimum performance. The greatest challenge to SSF as an option for household treatment is the need for a constant inflow of water. In order to maintain the schmutzdecke, the filter bed must be kept wet; otherwise the microbial community dries up and dies, significantly decreasing the effectiveness of the filter. As most households in poor and marginalized communities do not have access to uninterrupted source water flow, traditional SSF is not a viable option. However, the Manz filter, an intermittent SSF was designed to fit inside the home for point-of-use water treatment (Palmateer et al., 1997). The reported treatment efficacy of the Manz filter and other SSFs are discussed below.

A laboratory assessment of the Manz intermittent SSF, under controlled conditions, was found to remove up to 97% of fecal coliforms and over 99% of Cryptosporidium and Giardia Cysts (Palmateer et al., 1997). Stauber et al. (2006), reported similar findings of SSF performance under laboratory conditions with an average E. coli reduction of 94%, with a maximum log reduction value of 3 (or 99.9%). The same study reported an average E. coli reduction in the field of 93%, based on water samples collected from 55 households in the Dominican
Republic (Stauber et al., 2006). Filtration is the preferred method of removal for chlorine resistant Cryptosporidium and Giardia both of which are cyst forming parasites implicated in the aetiology of particular diarrhoeal disease (Bellamy, 1997; Palmateer et al., 1997). There are obvious knowledge gaps for the application of PoU filtration systems. While the removal rates are well understood there are discrepancies as to their effectiveness in the field (Clasen et al., 2007). Unlike treatment with chemical disinfectant, filtration alone offers no residual protection of water stored in the home. However, filtration remains one of the most effective front line defenses against a broad spectrum of waterborne pathogens. Its low cost construction and high rate of user acceptability make it ideal for application in South Asian communities without access to safe drinking water.

### 2.7 Transition to Chapter 3

The proceeding chapter discusses the participatory design of the Safe Water System (SWS) during phase one of the project. It explores the concepts of appropriate technology, participatory action research, iterative design, and sustainability. Furthermore, it demonstrates that complex development problems are more effectively solved by utilizing collective knowledge and problem-focused dialogue than by top-down reductionist and prescriptive methods. Finally, the paper reflects on lessons learned from this experience and suggests possible improvements to the current methodology. This paper has been published in The International Journal of Technology, Knowledge, and Society:

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opment of contextually appropriate water treatment technology in a marginalized, low-income South Asian community. *The International Journal of Technology, Knowledge, and Society, 8*: 105-120.

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Chapter 3

Collaborative innovation for the development of contextually appropriate water treatment technology in a marginalized, low-income, South Asian community

3.1 Introduction

The inclusion of lay persons in research and development has demonstrated improved problem identification and prioritization, solution generation, and public awareness (Anyawu, 1988; French and Bayley, 2011). The past thirty years
have seen the evolution of participatory development frameworks in various fields including information technology (Doll and Deng, 2001), community resource management (Anyanwu, 1988; Penning de Vries, 2007), environmental health sciences (Fallon and Dearry, 2002), small business enterprise (Nory and Thomas, 2004), and community based research (Bailey, 1992; Sanchez and Almeida, 1992). Lewin, the father of action research, was first to explore the use of intergroup relations, bringing together different groups of people under a common goal, to accelerate information sharing and effective social change. He emphasized the need for ‘bas-

ic social research’ using both field and laboratory studies as part of a holistic approach to understanding complex social phenomena (Lewin, 1947). Building on Lewin’s foundation of social research, Whyte stressed the importance of participant involvement in all phases of the research process, from its design to implementation and follow-up (Whyte, 1991, 1995). Abandoning conventional research methods, Whyte’s pragmatic model of participatory action research (PAR) bridges the gap between researchers and participants to achieve meaningful and practical results. In such cases, the subject is no longer viewed as an object to be studied but as valued associate, rich in personal experience and local knowledge. PAR is a process encouraging a two-way exchange of information and promoting collaborative learning toward a common goal. It increases the likelihood of sustainable development by promoting community control, encouraging local participation and pursuing a more ground-up approach to technological design than more conventional models.

This paper provides a case study of PAR in the development of a household water treatment and storage (HWTS) system in the peri-urban community of Mylai Balaji Nagar, Chennai, India.

The use of HWTS to improve drinking water quality and reduce the burden of
diarrhoeal diseases in poor and marginalized communities in the developing world has received considerable attention (Clasen et al., 2006, 2004; Colwell et al., 2003; Stauber et al., 2006). However, the technologies proposed by foreign researchers and engineers are often designed without the involvement of local people. Despite the considerable success of household water treatment technologies in removing waterborne pathogens (Clasen et al., 2007; Garrett et al., 2008; Palmateer et al., 1997) and reducing the incidence of disease (Clasen et al., 2006; Colwell et al., 2003; Fewtrell et al., 2005), the authors of this study were unable to locate reported cases of co-development for intervention technologies. Studies involving HWTS are primarily interested in the technology’s effectiveness, asking participants for self-reported frequency of illness (Altherr et al., 2008; Quick et al., 1999, 2002) and controlling for the influence of covariates by inquiring after household practice of sanitation and hygiene (Brown et al., 2008; Clasen et al., 2004). More recent studies have demonstrated a greater concern for intervention sustainability by investigating factors predicting their use (Altherr et al., 2008; Brown et al., 2008; Firth et al., 2010), production variables altering their effectiveness (Lantagne et al., 2010), and longitudinal follow-up studies determining the rates of their continued application (Luby et al., 2001; Rose et al., 2006). Given the cultural heterogeneity of low income communities throughout the developing world and the considerable difficulties of their contexts, effective implementation of any HWTS faces a myriad of obstacles. This paper describes a user-centered approach to HWTS design, exploring the concept of appropriate technology and placing greater emphasis on the social determinants of user satisfaction and technology adoption.

Mylai Balaji Nagar (MBN) is a peri-urban resettlement colony located on the border of Chennai’s city limits which relies on a highly polluted surface water
source for drinking water. Both the municipal and panchayat (village) governments fail to provide its residents with proper sanitation, waste removal services and safe drinking water. The water received by MBN is drawn from a nearby lake which, during storm events, receives surface runoff from the streets of neighbouring communities, accumulating garbage as well as human and animal excreta. The water is then pumped, often untreated, from an adjoining infiltration well to standpipes (lane water) where it is collected and used for bathing, food preparation, and consumption.

In 2009, researchers from the University of Guelph (Ontario, Canada), Queen’s University (Ontario, Canada), and the Indian Institute of Technology (IIT) Madras (Chennai, India), began working with residents from the community on the design of an alternative water treatment system. The technology was intended to improve drinking water quality and reduce the transmission of waterborne diseases. Worldwide, diarrhoeal diseases are responsible for 1.7 million annual deaths, 88% of which are attributable to improper water, sanitation and hygiene (World Health Organization, 2002). In an effort to improve community health and interrupt the transmission of bacterial pathogens, local leaders and community members were invited to join project researchers in forming a safe water system co-design team; interest was the only pre-requisite for participation. In accordance with PAR, the co-design team encouraged active participation and collaboration at every stage in the development process (Fallon and Dearry, 2002; Sanchez and Almeida, 1992), meeting on six separate occasions to address the issue of poor water quality and to design an alternative treatment system. Workshops, typically composed of eight to ten community residents and three to four researchers, were held in each one of the community’s four sectors to encourage equal participation and representation.
This paper outlines the five stage approach used for the participatory design of an appropriate HWTS system in MBN. As highlighted by Bailey (1992), PAR must be envisioned and implemented by members of a co-design team composed of both community participants and project researchers. Most investigations into the effectiveness of water treatment systems focus almost exclusively on contaminant removal effectiveness, with little attention paid to user satisfaction and acceptability (Chaudhuri et al., 1994; Clasen et al., 2004; Stauber et al., 2006). The following paper is organized under the five headings of participatory design: Conceptualization, Design, Pilot Testing, Implementation, and Adaptation; with each section discussing the relevant ideas and contributions of the co-design team. We demonstrate that complex development problems are more effectively solved by utilizing collective knowledge and problem-focused dialogue than by top-down reductionist and prescriptive methods. Finally, the paper reflects on lessons learned from this experience and suggests possible improvements to the current methodology.

### 3.2 Stage 1: Conceptualization

The first stage in the participatory design of an alternative water treatment technology requires a two-way exchange of information between researchers and the community (Brown, 2009; Bruns, 2003). The role of the researcher is to employ their knowledge of water treatment processes and give shape to the ideas and opinions expressed by community participants.

Since type and concentration of water contaminants dictate the need for specific treatment mechanisms, eleven water quality parameters were assessed to guide the selection of an appropriate treatment type. Findings of this investigation are pre-
presented in Table 3.1. Lake water samples were found to contain high concentrations of organic matter by proxy measures of chemical and biological oxygen demands (COD and BOD, respectively), as well as high turbidity and microbiological contaminants. Lane water samples, retrieved from individual households who collect the water from communal standpipes, corroborated the need for microbiological treatment and the reduction of organic matter. Of principle concern were the elevated levels of total and thermotolerant (faecal) coliform bacteria. The presence of thermotolerant coliforms in the water suggests probable contamination with human or animal faeces, making it unfit for human consumption (APHA, 2005).

These findings were presented at an all-stakeholder forum attended by researchers, community participant, NGOs and local government officials. In light of these findings, the community asked for a system capable of removing potentially hazardous waterborne pathogens while concurrently improving the taste and aesthetics of their water.
Table 3.1: Baseline Water Quality and Parameters of Interest

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lake Samples (mg/L)</th>
<th>Lane Samples (mg/L)</th>
<th>Bureau of Indian Standards (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>137.6 (126.4-148.8)</td>
<td>89.1 (84.3-93.8)</td>
<td>300 600</td>
</tr>
<tr>
<td>Chloride</td>
<td>119.9 (104.6-135.3)</td>
<td>137.6 (129.2-146.0)</td>
<td>250 1000</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>150.9 (138.8-163.0)</td>
<td>214.2 (196.5-231.8)</td>
<td>200 600</td>
</tr>
<tr>
<td>Turbidity</td>
<td>14.94 (10.96-18.93)</td>
<td>0.93 (0.88-0.99)</td>
<td>5 10</td>
</tr>
<tr>
<td>Organic COD*</td>
<td>58.7 (53.8-63.6)</td>
<td>14.8 (11.9-17.7)</td>
<td>5 20</td>
</tr>
<tr>
<td>Organic BOD**</td>
<td>12.6 (11.8-13.5)</td>
<td>3.1 (2.7-3.5)</td>
<td>2 5</td>
</tr>
<tr>
<td>Iron</td>
<td>2.18 (1.39-2.97)</td>
<td>0.60 (0.46-0.75)</td>
<td>0.3 1</td>
</tr>
<tr>
<td>Nitrate</td>
<td>5.99 (5.60-6.38)</td>
<td>5.0 (4.80-5.25)</td>
<td>45 100</td>
</tr>
<tr>
<td>Fluoride</td>
<td>0.32 (0.28-0.35)</td>
<td>0.45 (0.42-0.49)</td>
<td>1 1.5</td>
</tr>
<tr>
<td>Total coliforms</td>
<td>45.3 (33.7-53.9)</td>
<td>16.98 (14.25-19.73)</td>
<td>0 0</td>
</tr>
<tr>
<td>Faecal coliforms</td>
<td>20.1 (16.2-23.9)</td>
<td>8.42 (6.99-9.85)</td>
<td>0 0</td>
</tr>
</tbody>
</table>

*Organic content via COD (Chemical oxygen demand)
**Organic content via BOD (Biological oxygen demand)

Several household water treatment systems (HWTS) were considered for application within MBN. The first, a multi-barrier treatment approach used coagulation with aluminum salts (alum) and chemical disinfection with chlorine tablets. Initially, this method was well received by community representatives who showed great appreciation for the immediate and visually observable improvements in water
clarity. However, this method was later excluded from further consideration by the co-design team since the process had little to no effect on water odour. Typically, water received by the community contained high concentrations of organic matter which exuded an unpleasant odour when left untreated. The inability of alum to remove the dissolved fraction of organic matter or improve the unpalatable effect of its presence was the foremost reason for this method’s rejection. The second treatment method employed dual media filtration using sand and charcoal followed by chemical disinfection with chlorine. Filtration was accepted as the method of choice because of its ease of application, rapid treatment time, effective removal of waterborne pathogens, and marked improvements to water appearance, taste and odour. Researchers agreed with the community’s selection of a dual-media filter which is well suited for application in communities relying on surface water for drinking purposes (Bellamy, 1997; Palmateer et al., 1997; Stauber et al., 2006). Following the selection of a media filter, the co-design team initiated the construction of multiple prototypes which were subsequently assessed for their effectiveness and contextual appropriateness.

3.3 Stage 2: Design

Successful implementation and uptake of HWTS in marginalized communities of the developing world depend on the utilization of inexpensive, locally available materials, as well as the system’s ease-of-use and cultural acceptability (Murphy et al., 2009). Encouraging local participation in technology development promotes greater user acceptability while developing a sense of ownership and user responsibility. Complex problems, such as those encountered in the diverse
communities of South Asia are most effectively addressed by coalescing technical skills and local knowledge, guided by human values and focused on practical problems (Doll and Deng, 2001). The following section presents findings from community development workshops held in MBN where local representatives were asked to provide critical feedback on prototype filters constructed by technical staff at IIT Madras. Each prototype filter was designed as the initial stage of treatment in a multi-barrier approach, followed by chemical disinfection with chlorine tablets (dose concentration 2 mg/L).

3.3.1 Earthen Pot

The first design in a series of prototypes employed a dual media water filter, contained within two clay pots, situated one on top of the other. Since both pots had rounded bottoms, they were most stable when posed over a rounded base of support, such as the opening to a length of pipe or the rounded opening of a like container. The first pot housed the filter media, a top layer of sand separated from a bottom layer of charcoal using a nylon cloth, each with a bed depth of 13 cm. Untreated water was emptied into the upper pot, which percolated through the filter before passing through a small hole (0.2 cm diameter) in the bottom of the pot and entering the storage pot below. Filtered water would remain in the storage pot until released by the user operating a metal tap on the pot’s side.

When presented at the design workshop, participants approved of the filters effectiveness and ease of operation. They appreciated the filter’s uncomplicated design, near effortless application, and the use of locally available materials in its fabrication. However, there was significant concern expressed over the filter’s
vulnerability to breakage. The earthen pots were delicate, susceptible to breaks and fractures with repeated use. Members of the co-design team remarked that children of the household were apt to knock the filter over, leading to an even higher incidence of broken and damaged filters. One female participant who expressed concern over the fragility of the pots suggested the need for future prototypes to be constructed of either metal or plastic. Researchers recognized the community’s need for a more durable design and responded by ensuring all subsequent prototypes were constructed of more resilient materials.

3.3.2 Vertical Tower Filter

The second concept filter involved a series of four vertically aligned pots, housed within a six feet high steel shelving structure. The gravity fed filter drew untreated water from the first pot, on the top shelf through a small hole in the pot’s base (0.2 cm diameter), its effluent passing through a second pot containing sand (particle size 0.2 – 0.4 mm), and a third pot containing charcoal before coming to rest in the fourth pot designed to capture the treated water. Two filters of this design were constructed; the first using plastic pots and the second using steel pots.

The filter was highly criticized when brought before the co-design team. Issues of practicality, which had eluded project researchers, became immediately apparent to the people for whom the technology was intended. They explained that that filter’s height made it unstable and posed a falling hazard to small children who might attempt to climb the stand. Indeed, the stand was made of solid steel and could cause serious injury to an adventurous child. Local participants further declared the design was too expensive. The amount of steel required to build the
stand cost 2000 Indian National Rupees (1 INR = 49 USD), making the design unaffordable to most MBN households. Lastly, the most criticized feature of the Tower Filter design was its size. Residents proclaimed the six foot structure occupied too much space and couldn’t be accommodated within their homes of 15 ft. by 18 ft. One woman’s reaction to the filter was, “Do we have to keep four pots or can we even keep one pot? We do not have enough space to keep everything.” Consequently, the design team was tasked with developing a new filter incorporating the ideas recently expressed by community participants at the design workshop. The new filter would have to be smaller, more cost-effective and safer to store in the presence of small children.

### 3.3.3 PVC Pipe Filter

The new design again featured a dual media filter, this time housed within a single container reducing the amount of storage space required. A 40 cm long section of PVC pipe with a diameter of 18.3 cm was positioned vertically, the bottom opening sealed with an end-cap, and mounted to a metal tripod. A gravel bed depth of 5 cm gave support to 13 cm of charcoal on top of which was 13 cm of sand (particle size 0.2 – 0.4 mm). Two nylon cloths separated gravel from sand and sand from charcoal to prevent the mixing of media. An ‘on-off’ tap at the bottom of the filter prevented the emersion of unclean hands or cups during water retrieval, preventing recontamination of the treated water.

Presentation of the PVC Pipe Filter to the co-design team informed researchers that they had appropriately re-sized the filter but had not adequately addressed the issue of child safety. Community participants were pleased to learn that the
single length of PVC pipe contained both sand and charcoal, the same constituents contained within multiple vessels by both the Earthen Pot and Tower Filters. However, they expressed their dissatisfaction with the tripod design giving support to the new filter, which they affirmed still posed a falling hazard to small children. Lastly, community participants wished the filter to have a greater capacity for treating water. They expressed the need for 20 L of drinking water each day in order to provide for their families; the PVC Pipe Filter was only capable of producing 5 L in a single application. The four applications needed to achieve 20 L of drinking water would require approximately 2 hours of intermittent filter operation. Participants explained this was more time than they were able to spare on a daily basis. The critical factor disqualifying the PVC Pipe design was time.

3.3.4 Bucket Filter

In a fourth attempt to meet the needs of the local people, researchers designed a simple bucket filter, utilizing both sand and charcoal in water purification. The system was designed for water to enter the top of the filter and pass through 15 cm of sand (size 0.2 – 0.4 mm) and 15 cm of charcoal, both supported by a 7 cm bed of gravel. Each layer of media was separated by a nylon cloth to prevent mixing. In accordance with design criteria identified in previous community workshops, the filter was housed within a single container and capable of producing 20 L of purified water in a single application. The 50 L plastic bucket, with a flat bottom was extremely stable and posed no falling hazard to the user or small children. A tap, originally mounted 5 cm from the base of the bucket, was later raise to a height of 37 cm in order to accommodate an internally housed manifold of PVC
pipe buried beneath the filter media, designed to improve filtration efficacy. Water was collected by the manifold from within the gravel bed and conveyed by PVC pipe to the tap on the filter’s side by hydraulic pressure, where it emptied into a safe water storage vessel with a lid to protect against recontamination.

Despite adhering to the design specifications previously stated by community participants, the filter was not accepted before undergoing close scrutiny by the co-design team. They were impressed by the filter’s appearance, size, treatment capacity and efficacy; however, they expressed concern over the amount of maintenance the system required. One female participant shared, “They (community members) will not spend much time on this (water filtration). They want everything to be easier. That’s why they are using bottled water.” Her statement illuminates the community’s reliance on bottled water. Research staff responded by explaining the filter’s ability to provide 20 L of safe drinking water for a daily expense of only 0.70 INR compared to the high cost of bottled water which retails for 25 INR for 25 L. The benefits of filter use were further emphasized by researchers who explained that by treating the water themselves, individual households could ensure improved drinking water quality, a luxury inconsistent with the method of purchasing bottled water from unreliable merchants (Jeena et al., 2006) (Jeena, Deepa, Rahiman, Shanthi, and Hatha 2006). In response to this new information, one of the workshop participants offered, “Even if it is difficult, we will use the bucket filter since it is better one compared to alum method.” Support for the Bucket Filter was fostered by its ability to remove bad odours and organics from the water. The co-design team found the taste of treated water to be comparable to that of bottled water, which was unanimously accepted by the group. Table 7.1 2 presents a summary of the design criteria identified by researchers and community
members for the selection of an appropriate water treatment system.

**Table 3.2:** Design Criteria for the Selection of an Appropriate Water Treatment System

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
<th>Designs Meeting the Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>Compact and suitable for storage in households with limited space.</td>
<td>• Earthen Pot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• PVC Pipe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Bucket Filter</td>
</tr>
<tr>
<td>Safety</td>
<td>Stable with a wide base of support to avoid falling hazards, which pose a threat to small children.</td>
<td>• Bucket Filter</td>
</tr>
<tr>
<td>Treatment effectiveness</td>
<td>Capable of removing biological contaminants and improving overall aesthetics of the water.</td>
<td>• All designs met this criterion.</td>
</tr>
<tr>
<td>Capacity</td>
<td>Capable of treating &gt; 20 litres of water in a single application.</td>
<td>• Bucket Filter</td>
</tr>
<tr>
<td>Affordability</td>
<td>Using inexpensive, locally available materials to produce a low cost system, relative to the per capita income.</td>
<td>• Earthen Pot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• PVC Pipe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Bucket Filter</td>
</tr>
<tr>
<td>Ease of use</td>
<td>Uncomplicated designs suitable for use by all household members.</td>
<td>• All designs met this criterion.</td>
</tr>
<tr>
<td>Durability</td>
<td>Utilizing resilient materials to prevent breakage and the need for frequent repairs.</td>
<td>• PVC Pipe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Vertical Tower</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Adapted Bucket Filter (see Stage 5: Adaptation)</td>
</tr>
</tbody>
</table>

Community workshop participants selected the Bucket Filter for implementation within MBN because they found it suitable to their needs, circumstances, and
capacities. Researchers approved of the design because it was effective at removing waterborne pathogens and improving overall water quality. However, a formal laboratory investigation of the filter’s effectiveness was required before household implementation.

3.4 Stage 3: Pilot Testing

The Bucket Filter was assessed on its ability to remove principle contaminants of concern, identified during water quality testing at MBN, as part of the Conceptualization stage. The filter was dosed with 20 L of water per day for 27 days over a two month period with water drawn from Narayanapuram Lake, the surface water body from which residents of MBN receive their drinking water. Samples were tested for three parameters: turbidity, measured in nephelometric turbidity units (NTU); organic content via the proxy measure of chemical oxygen demand (COD); and microbiological quality via the proxy measure of total coliforms estimation using the most probable number (MPN) method. In order to contextualize the influent water quality, which was highly variable, average values and their corresponding standard deviations are provided in Table 3.3. All readings were done in triplicate to ensure accuracy, and their mean values reported. Average reduction values for each parameter, at each stage of treatment, aggregated across all available replicate trials are presented in Figure 3.1.
Table 3.3: Average Values of Key Influent Water Quality Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPN (Total coliforms/100 mL)</td>
<td>184.9</td>
<td>48.4</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>13.6</td>
<td>5.1</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>24.0</td>
<td>15.5</td>
</tr>
</tbody>
</table>

The number of replicate experiments aggregated in the summary measures is given by the \( n \) value indicated above each bar and the error bars represent the 95% confidence interval of the mean. It can be seen that with each subsequent stage in the treatment process there was a relative reduction in each of the three parameters of interest, with the exception of a reduction in turbidity following chlorination. Significant reductions were determined by performing paired t-tests (one-tailed) and are indicated in Figure 3.1 by an asterix (*) over the corresponding \( n \) value. Filtration alone significantly improved turbidity \((p < 6 \times 10^{-12}, n = 25)\), and MPN \((p < 2 \times 10^{-9}, n = 23)\) with apparent improvements to COD that were not found to be significant \((p = 0.059, n = 2)\). Following chlorination, MPN was significantly reduced relative to those concentrations observed in filtered water \((p = 0.006, n = 23)\).

In accordance with PAR, community participants were involved in data collection and analysis, by assessing the treatment technology’s microbial removal efficiency under real world conditions. Five participant households were provided with Bucket Filters, safe water storage containers and chlorine tablets and asked to collect daily samples of treated water with which to perform a presence-absence test for faecal bacteria. Participants were trained by research staff on how to perform...
H$_2$S (hydrogen sulfide) strip tests, an easy to perform, low cost, rapid test that looks for H$_2$S-producing bacteria associated with faecal contamination, suitable for application in rural or underserviced urban areas (Manja et al., 1982; Pillai et al., 1999). Members of the five households were tasked with reporting on the filter’s ease-of-use, their degree of satisfaction with the system, and the quality of water produced.

Community investigators were pleased with the performance of the filter, describing the taste of the water to be similar to that of bottled water. They reported the system was easily operated; however, they suggested more in-depth training for households upon their initial receipt of the filter. A total of 24 treated water samples were analyzed using the H$_2$S strip method, of which 60.2% were found to be free of H$_2$S producing bacteria (95% CI: 47.6 – 72.8). Previous investigations into household water treatment describe similar discrepancies in water quality when comparing treatment in the field to treatment in the laboratory, under controlled
conditions (Sobsey et al., 2008; Stauber et al., 2006) (Sobsey, Stauber, Casanova, Brown, and Elliott 2008; Stauber et al. 2006).

The co-design team approved the filter for more widespread dissemination and preparations were made for its implementation.

3.5 Stage 4: Implementation

A community census identified 180 households in MBN that consumed the contaminated tap water. Of this population, 65 households were randomly selected using a random number generator and enrolled in the study after giving their informed consent. Selected households were provided with a dual-media Bucket Filter, a sachet of chlorine tablets and a safe water storage container. A workshop was held at a central location within the community, on the same day as filter distribution, at which participants received a demonstration on how to properly operate, clean and maintain the filter. Trained project staff and community workers later made door-to-door visits, reviewing application and maintenance of the filter with each household and answering all questions. This training promoted autonomy by enabling households to care for and maintain their filters without researcher assistance. Community participants acquired the knowledge and skills necessary to provide their families with safe drinking water in a setting where centrally treated municipal drinking water is unavailable. Community members participated in filter distribution while recipient households were encouraged to assist in off-loading their filter from the truck and moving it inside their home. A local truck driver was employed to transport filters via community roads capable of accommodating his vehicle. Tricycle (‘fish-cart’) owners were hired to transport filters through narrow
streets where the truck could not go.

3.6 Stage 5: Adaptation

Similar to PAR, the adaptive methodology for ecosystem sustainability and health (AMESH) is rooted in complex systems theory, which recognizes the need for ongoing collaborative learning and action based on social and ecological feedback (Waltner-Toews et al., 2001). Complex socio-ecological systems, such as the present setting of marginalized South Asian communities, are vulnerable to unpredictable change. In order for intervention technologies to be sustainable, they must be capable of adapting to these dramatic structural reorganizations (Waltner-Toews et al., 2001). To this purpose, both PAR and AMESH promote iteration to adapt and improve their development strategies. Active adaptation is a management strategy used to modify interventions in response to new information or contextual change while explicitly incorporating learning as one of the objectives (Holling, 1978). In MBN, the first two months of filter implementation were followed by a period of active-adaptation, culminated by critical participant feedback and the need for incremental change. Ongoing field assessment of the Bucket Filter during the initial two months of its use demonstrated an average bacterial removal efficiency of 83.1% (95% CI: 75.4 – 90.9). Filter performance was deemed successful and was anticipated to improve over time, congruent with growing end-user familiarity with the technology. However, dialogue between research staff and the community revealed two weaknesses commonly encountered by participant households. First, the plastic bucket containers housing the filter media were susceptible to breakage, quite often developing small fractures from which water would leak. Second,
given the intermittency of water provision to the community via standpipe, water remaining in the filter following the last treatment application would stagnate and develop an odour. The aforementioned difficulties were frequently reported and would commonly result in households abandoning their filter. The situation necessitated technological adaptation if the filters were going to receive continued use.

The first modification involved a simple upgrade from the plastic bucket housing the filter to a more durable bin made of high density polyethylene (HDPE). The new bin was 25 INR cheaper than the older bucket, significantly more resilient to physical stress, and was capable of treating 55% more water in a single application. The community’s response to the upgrade was extremely positive. Participants felt free to move the filter about their homes without fear of damaging it. The new bin was more appropriate for application in small households with cement floors, where users found it essential to relocate the filter and thereby optimize their living space. Cross-sectional diagrams of the original plastic bucket filter and the adapted HDPE bin filter are depicted in Figure 3.2.

The second modification involved a change to the filter’s design which improved user satisfaction at the expense of filter performance. The new design incorporates a drainage spout (1.3 cm diameter) positioned 3.5 cm from the base of the bin and allows users to drain residual water from the bin in times of water scarcity to prevent stagnation. In effect, the filter bed retains less moisture preventing the development of a biofilm, reducing the filters effectiveness (Weber-Shirk, 2002). A compromise between technological efficiency and user satisfaction resulted in greater adoption of the filter amongst participant households and increased the potential for long-term sustainability.


Figure 3.2: Cross-Sectional View of both the Original Plastic Bucket Filter and the Adapted HDPE bin Filter

3.7 Conclusion

PAR methodological framework lends itself to collaborative innovation. The five stages of collaborative design documented here, parallel those practiced in traditional PAR studies (Bailey, 1992). As with the current study, the framework described by Bailey (1992), requires active community or non-specialist involvement in each of the five stages, in order for the research to be considered participatory. This pragmatic model also possesses elements of a learning alliance, an expert-led initiative to accelerate knowledge transfer and improve collaboration with non-experts in a dynamic multi-stakeholder environment (Kelly and Farahbakhsh, 2008). Such forums encourage problem-focused dialogue and collective learning, which in turn provide an ideal situation for technological development.
However, the advantage of PAR for the collaborative development of appropriate safe water systems in the developing world has largely gone unnoticed.

This paper exemplifies the suitability of PAR for designing an appropriate safe water technology in a marginalized, low-income community in South Asia. Additionally, it demonstrates the utility of adaptive management and research methodologies such as PAR and AMESH for understanding complex ecological systems, using a plurality of stakeholder perspectives, and designing sustainable interventions capable of evolving to incorporate changes in local conditions (Holling, 1978; Waltner-Toews et al., 2001). The paper also details an effective framework for undertaking collaborative innovation and modifying the technology in order to more effectively meet the needs and capacities of the local people. The principle findings of this paper include:

- the adaptive nature of PAR framework for poverty alleviation in South Asian communities through the development of safe water technologies;

- the effectiveness of PAR as a novel approach for improving user acceptability and technology adoption with its capacity to develop technologies that embody the concepts and preferences of the participants; and

- the importance of adaptable technology, accomplished by an iterative process of evaluation and design, encouraging sustainable innovation and solution diversity.

There are, however, limitations to the current study which require attention. First, the roles and responsibilities of all stakeholders were not openly discussed or defined upon conception of the study. A timely discussion of each stakeholder’s
needs and expectations, during the conceptualization stage, would have given more direction to the co-design effort and made each party formally accountable to the other. Second, a narrow range of treatment technologies were considered for application in MBN, excluding other potential technologies. Further research should consider a broader spectrum of treatment alternatives in order to more effectively match technical mechanisms with local conditions (Murphy et al., 2009).

3.8 Acknowledgments

The authors would like to thank project staffs Mr. S. Srinivasan, Ms. J. Jincy and Mr. Arun K. Sambath for their respective roles in the implementation of research activities and Mr. Ivo Romauld Sagayaraj for his creation of graphic images. This work was carried out with the aid of a grant from the International Development Research Centre, Ottawa, Canada.

3.9 Transition to Chapter 4

Chapter four presents water quality results from phase two of the research project, following the design and implementation of the SWS. Phase two involved a longitudinal water quality monitoring program, as part of a randomized controlled trial of 124 households in Mylai Balaji Nagar. Households were visited once every two weeks over a twelve month data collection period; survey data was collected once every two weeks, while water samples were collected once per month. This chapter compares the water quality findings of intervention-treated, intervention-untreated, and control water samples. The chapter also investigates the influence
of seasonal weather variability on treatment performance, and the resulting water quality. This paper has been prepared for submission to the journal of Water Science and Technology, to be considered for publication. The authors are delaying the submission of this paper until a second complementary paper can be written, and the two can be submitted together.
Chapter 4

The impact of rainfall and
seasonal variability on the
bacteriological removal
effectiveness of a point-of-use
drinking water treatment
intervention in Chennai, India

4.1 Introduction

An estimated 1.8 million children die each year in developing countries as a result of diarrhoeal disease, an illness that is largely preventable with access to proper sanitation and safe drinking water (Boschi-Pinto et al., 2008; Kosek et al., 2003).
Of the UN Millennium Development Goals (MDGs), goal four aims to reduce the under-five child mortality rate by two-thirds by 2015 (UN, 2002; WHO, 2002). For over 780 million people who lack access to improved water sources and the millions more drinking microbiologically unsafe water from improved water sources, the World Health Organization (WHO) declared point-of-use (PoU) household water treatment and safe storage (HWTS) to be an effective approach for achieving the Millennium goal (UN, 2012; WHO, 2002, 2011).

Epidemiological evidence suggests that diarrhegenic microbes are seasonally dependent and influenced by changes in the ambient environment (Haley et al., 2009; Hatha et al., 2004; Jones et al., 2013; Sood et al., 2008). While studying risk factors for childhood diarrhoea in northeastern Brazil, Guerrant et al. (1983) found that 84% of stool samples testing positive for enterotoxigenic E. coli were isolated during the rainy season. Similarly, Sahoo et al. (2010) in India, reported that diarrhoea was more prevalent during the rainy season. The study participants implicated seasonal changes in temperature, precipitation, and humidity in the recurrent emergence of disease, such as diarrhoea. The occurrence and persistence of waterborne pathogens in surface waters is closely linked to environmental factors such as temperature and water chemistry, that can trigger shifts in microbiological flora (Haley et al., 2009). Effective PoU water treatment technologies must therefore be robust in their ability to treat water of varying microbiological and physio-chemical properties through the seasons.

Very few studies examine the effect of seasonal change on PoU water treatment. While studying the health impacts of biosand water filtration in the Dominican Republic, Stauber et al. (2009), found less reduction in intervention household diarrhoeal incidence during the rainy season than during the dry season, relative
to controls. Albert et al. (2010), discovered that the selection of household water source in rural Kenya is a complex process that is largely dependent on seasonal rainfall. In times of water abundance due to rainfall, households were found to rely primarily on surface water sources that were discovered to contain the highest concentrations of *E. coli*. However, the impact of seasonal variability on the three different types of PoU water treatment examined in this study was not discussed. The majority of intervention studies are too short to accurately capture the impact of seasonal variability on treatment effectiveness, and failure to report on at least 12 months of data collection may constrain or bias the reported effect (Blum and Feachem, 1983; Clasen et al., 2007; Crump et al., 2004; Hunter et al., 2009).

With the widespread application of PoU water treatment in developing countries, more research is needed to examine the impact of seasonal variability on treatment effectiveness. Greater understanding of the potential treatment variability of PoU technologies could be used to guide the selection of treatment type according to region and climate, as well as advise on the potential vulnerabilities of treatment effectiveness caused by climate change. The objectives of the current study were to measure the bacteriological removal effectiveness of a PoU water treatment system in an underserviced community of Chennai, India. The Safe Water System (SWS), consisting of a dual-media bucket filter, a safe water storage vessel, and sodium dichloroisocyanurate (NaDCC) tablets used in disinfection, was examined for its ability to remove *E. coli* and total coliform bacteria in participants’ homes. Temperature and rainfall were examined for their effect on the bacterial densities of both treated and untreated water samples, and the overall bacteriological treatment effectiveness of the SWS.
4.2 Methods

4.2.1 The Safe Water System

The SWS was developed using a participatory framework, recruiting local knowledge to guide the development process (MacDonald et al., 2013). Twelve months of baseline water quality data was used to select an appropriate treatment type; a multi-barrier point-of-use technology, employing filtration and chemical disinfection was found to be most appropriate for reducing problematic contaminants, including turbidity, organic matter, and microbiological contamination. The dual-media, gravity-fed, bucket filter contained 15 cm of charcoal, on top of which was 15 cm of sand (size 0.2-0.4 mm), both supported by a 7 cm bed of gravel. The 65 litre high-density polyethylene bucket was also designed with a PVC pipe manifold that collected water from within the gravel bed, and conveyed it to a tap on the filter’s side by hydraulic pressure. It was experimentally determined that one tablet (35 mg) of NaDCC was appropriate for disinfecting 20 litres of filtered water, which was then stored within the safe water storage vessel, constructed with a narrow opening and a lid to prevent recontamination. In an effort to improve community health and interrupt the transmission of waterborne pathogens, local leaders and community members worked alongside researchers during the development of the SWS (MacDonald et al., 2013).

4.2.2 Study Population and Recruitment of Households

Mylai Balaji Nagar (MBN) is a peri-urban resettlement colony located on the border of Chennai’s city limits which relies on a highly polluted surface water
source for drinking water. The water received by MBN is drawn from Narayana-
puram Lake that, during storm events, receives surface runoff from the streets of
neighbouring communities, accumulating garbage as well as human and animal
excreta. The water is then pumped, often untreated, from an adjoining infiltration
well to standpipes where it is collected and used for bathing, food preparation, and
consumption.

Following 12 months of baseline data collection, a community-wide census
revealed 180 households that used tap water as their primary drinking water
source, and therefore met the study inclusion criteria. Of these, 124 households
agreed to participate, and were randomly assigned to one of two groups: an
intervention group receiving the newly designed safe water system, and a control
group receiving no intervention. All households were followed for 12 months post-
baseline, providing monthly water samples and responding to surveys on water
treatment practices.

4.2.3 Sample Collection and Analysis

Both treated and untreated water samples were collected from intervention house-
holds in sterile autoclaved 250 ml sample collection bottles and stored on ice
between 2° and 8° Celsius according to Standard Methods (APHA, 2005). Control
households were asked to provide a 250 ml sample of household drinking water. All
samples reached the Water Quality Laboratory at IIT Madras within eight hours
of collection, and were immediately analyzed for total coliforms and *E. coli*.

The standard membrane filtration method was used to enumerate total coliform
and *E. coli* bacteria, as described in *Standard Methods for the Examination of Wa-
Using a vacuum respirator, samples were filtered through a sterile 0.45 μm cellulose nitrate membrane, which was then transferred, using sterile forceps, onto pre-dried differential HiCrome Coliform agar medium with SLS (used for simultaneous detection of coliforms and E. coli). Samples were incubated upside down for 18-24 hours at 37°C, after which time pink and blue colonies were counted as coliforms, and blue colonies were counted as E. coli. Three serial dilutions of 100 ml, 2 ml, and 1 ml were performed for treated water samples, while untreated water samples were processed using two dilutions of 0.2 ml, and 0.133 ml. Slight modifications would be made to dilution assays in order to compensate for seasonal variations in the concentration of microbiological contaminants. Average counts of colony forming units (CFU) per 100 ml of sample water were generated for both total coliform and E. coli bacteria using standard methods (APHA, 2005). Log reduction values (LRVs) of total coliforms and E. coli bacteria were calculated as log_{10} influent water concentration minus log_{10} filtered water concentration.

The effect of seasonal rainfall and temperature on bacterial concentrations and removal effectiveness was examined using stratified analysis. Rainfall (average mm/mo) was compared with average bacterial concentrations for each month. The effect of the SWS during the monsoon and dry (or non-monsoon) seasons was calculated by classifying August, September, October, and November as monsoon months (> 200 mm/mo), and December, January, February, March, April, May, June, and July as non-monsoon months (< 200 mm/mo). Independent sample t-tests were used to compare the bacterial concentrations of treated and untreated water samples between monsoon and non-monsoon months. Regression modeling was employed to determine the predictive capacity of rainfall and temperature on...
the bacterial concentrations of treated and untreated water samples, as well as the overall bacteriological removal effectiveness of the SWS.

4.3 Results and Discussion

4.3.1 Bacteriological Treatment Effectiveness

All of the households enrolled in the study used tap water as their primary drinking water source; however, the proportion of households using tap water fluctuated according to its seasonal availability. Intervention households relied on tap water 95% (95% CI: 93 – 97%) of the time, with the lowest percentage of tap water use (60%) reported during the month of May; one of the hottest and driest months of the year, when the surface water source is mostly dried away. Similarly, households in the control group were found to rely on tap water 93% (95% CI: 90 – 96%) of the time, with the lowest percentage (56%) reported in May.

The mean annual concentrations of total coliform bacteria in control, intervention untreated, and intervention treated water samples were 17,553 cfu/100 ml (95% CI: 15,125 – 19,980 cfu/100 ml), 19,045 cfu/100 ml (95% CI: 15,849 – 22,242 cfu/100 ml), and 890 cfu/100 ml (95% CI: 700 – 1,081 cfu/100 ml), respectively. Independent sample t-tests confirmed significant differences in total coliform concentrations between control and intervention treated water samples (t = -13.46, p < .0001); distributions are presented in Figure 4.1. Similarly, dependent sample t-tests confirmed a significant difference between intervention untreated and intervention treated water samples (t = 10.82, p <.0001); the distribution of difference between these groups is presented in Figure 4.2. The results for E. coli
were analogous with those for total coliforms, just at lower concentrations, with significant differences between control and intervention treated water samples (t = -6.29, p < .0001), and also between intervention untreated and intervention treated water samples (t = 6.18, p < .0001). Distribution graphs comparing the *E. coli* concentrations of control to intervention treated water samples, and intervention untreated to intervention treated water samples, are presented in Figure 4.3 and Figure 4.4, respectively. Figure 4.5 presents average concentrations of total coliform and *E. coli* bacteria for each of the 12 months of data collection.

In order to analyze in-field treatment effectiveness, log reduction values (LRV) were calculated by subtracting the log concentrations of bacteria in treated water samples from the log concentrations of bacteria in untreated water samples (Figure 4.7). Average LRVs across all months of study were 1.92 (95% CI: 1.76 – 2.08) for total coliforms, and 1.54 (95% CI: 1.35 – 1.73) for *E. coli*. Despite variation in treated water quality, the safe water system greatly reduced the concentrations of microbiological contaminants, making the water safer to drink.

### 4.3.2 Impact of Seasonal Variability

The Chennai climate fluctuates between 17°C and 43°C, with humidity between 70% and 90%. With two monsoon seasons, the smaller southwest monsoon arriving in Chennai in late June, and the northeast monsoon arriving in late October, the city receives an average annual rainfall of 1,425 mm (Kea, 2012). Variations in seasonal rainfall greatly impacted the state of the community water source; however, temperature was not found to be correlated with the bacterial concentrations of either treated or untreated household water samples, or treatment effectiveness with
Figure 4.1: The distribution of total coliform bacteria in control and intervention treated water samples.

Figure 4.2: The distribution of total coliform bacteria in intervention untreated and intervention treated water samples.
**Figure 4.3:** The distribution of *E*. coli bacteria in control and intervention treated water samples.

**Figure 4.4:** The distribution of *E*. coli bacteria in intervention untreated and intervention treated water samples.
Figure 4.5: Average concentrations of *E. coli* (upper) and total coliform (lower) bacteria for intervention treated, intervention untreated, and control household water samples.
the SWS. In Figure 4.6 A, monthly rainfall is plotted according to concentrations of total coliform and *E.* coli bacteria identified in untreated household water samples, and no significant relationship was identified between bacterial concentration and seasonal rainfall. Furthermore, there was no statistically significant difference in untreated total coliform or *E.* coli concentrations between monsoon and non-monsoon months. However, Figure 4.6 reveals a visually observable trend, that with greater rainfall, bacterial concentrations in untreated water samples appear to be reduced. These findings are contrary to those reported by Sood et al. (2008), who found elevated levels faecal and total coliform concentrations in the Ganga River with increases in rainfall. Hatha et al. (2004) reported increases in the fecal coliform concentrations of the Cochin estuary during the monsoon months, when heavy rains increased levels of waste discharge into the system. That is, rainfall had the effect of increasing the total volume of Narayananapuram Lake, and thereby diluting bacterial concentrations in untreated household water.

Bacterial densities appear to be increased in treated household water samples during the monsoon months (Figure 4.6B). Statistically significant differences in total coliform densities are apparent between monsoon and non-monsoon months ($p < .0001$). Higher concentrations of total coliforms are observed in treated water samples during the monsoon season. *E.* coli concentrations in treated household water samples were also significantly different during the monsoon season ($p = .0023$). The greatest concentrations of *E.* coli were observed during the monsoon months. These findings were corroborated with regression modelling which demonstrated an increase in total coliform concentration of treated water by 3.03 cfu/100 ml ($p < .0001$) for every millimeter of rainfall. Similarly, *E.* coli concentrations in treated household water samples were demonstrated to increase by 0.52 cfu/100 ml.
Figure 4.6: Bacterial concentrations in both untreated (A) and treated (B) intervention household water samples with seasonal rainfall. An asterix (*) is used to identify each of the four monsoon months.
(p = .002) for every millimeter of rainfall. The results of these models are presented in Table 4.1.

Table 4.1: Summary of univariate modelling for the impact of seasonal rainfall on water quality and treatment effectiveness

<table>
<thead>
<tr>
<th>Response Variable</th>
<th>Estimate</th>
<th>SE (Estimate)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated TC</td>
<td>-1.021</td>
<td>6.6108</td>
<td>0.8773</td>
</tr>
<tr>
<td>Untreated E. Coli</td>
<td>-3.2448</td>
<td>2.2657</td>
<td>0.1521</td>
</tr>
<tr>
<td>Treated TC</td>
<td>3.0273</td>
<td>0.7293</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Treated E. Coli</td>
<td>0.5212</td>
<td>0.1713</td>
<td>0.0023</td>
</tr>
<tr>
<td>LRV for TC</td>
<td>-0.0032</td>
<td>0.0006</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>LRV for E. Coli</td>
<td>-0.0019</td>
<td>0.0005</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

Unexpectedly, treatment effectiveness of the SWS decreased under the conditions presented by heavy rainfall. Log reduction values for both total coliforms and E. coli were lowest during the monsoon season. It’s possible that a gross concentration change in bacteria accompanies the change in seasons. Monthly averages of total coliform LRVs were inversely related to seasonal rainfall (R = -0.79, p = .002). E. coli LRVs were also dependent on seasonal rainfall (R = -0.678, p = .015). This finding is somewhat counter-intuitive: with an increase in rainfall, and lower bacterial densities, water treatment with the SWS was adversely affected. It may be that that with lower concentrations of bacteria entering the SWS, small agglomerations of bacteria were able to be transported through the filter media. Only perfectly compliant households, those that consistently dosed the filtered water with NaDCC tablets and allowed sufficient time for disinfection, would have been unaffected by this apparent reduction in filter effectiveness. Only 29.3% of treated water samples were found to have a chlorine residual, suggesting
that the vast majority of households relied exclusively on filtration to treat their drinking water. Perhaps reluctance to disinfect the filtered water with NaDCC tablets may have arisen from an accompanied change in water taste and odour, as has been found in previous studies that used chlorine products to disinfect drinking water (Crump et al., 2004; Reller et al., 2003).

In summary, log reduction values for both total coliform and \textit{E. coli} bacteria were inversely related to rainfall (Figure 4.7). Rainfall is a significant predictor of total coliform LRV, so that with every millimeter of rainfall received in the study community, the total coliform LRV was reduced by 0.003 (95%CI: -0.004 – -0.002, p < .0001). The predictive effect of rainfall on \textit{E. coli} LRV was comparable to that for total coliforms; with every millimeter of rainfall received in the study community, the \textit{E. coli} LRV was reduced by 0.002 (95%CI: -0.003 – -0.001, p = .0002).

\section*{4.4 Conclusions}

This study provides evidence of the strong influence seasonal rainfall has on water quality and point-of-use water treatment. During the monsoon months, from late August to November, heavy rainfall appears to have diluted the surface water source, resulting in the lowest concentrations of bacteria observed in untreated household water samples during the course of this study. This change in the physical and microbiological nature of the source water appears to have affected the ability of the filter to remove bacteria, resulting in lower LRVs for both total coliforms and \textit{E. coli}. It’s possible that the transport and attachment of bacteria through the filter media was altered by the change in influent water characteristics, with smaller agglomerations of bacteria capable passing through the porous media.
Figure 4.7: Changes in log reduction values with seasonal rainfall
unrestricted.

4.5 Transition to Chapter 5

The next chapter also presents data from Phase two of the research project, conducted in India to determine the appropriateness of the SWS for application in poor and marginalized communities of South India. This chapter examines the technical, social, and institutional factors affecting participant compliance, by examining longitudinal survey data on water treatment and provisional practices in 69 intervention households over the 12 month data collection period. Lastly, the paper concludes by emphasizing the importance of certain design considerations for developing HWTS, to optimize compliance and increase the potential of achieving the desired public health outcomes. This paper has been submitted to the American Journal of Tropical Medicine and Hygiene, to be considered for publication (Submitted on May 22, 2013).
Chapter 5

Predicting Participant Compliance with Point-of-Use Water Treatment: The Implications of Improving Water Aesthetics

5.1 Introduction

Diarrhoeal disease remains a leading cause of mortality and morbidity in the developing world, killing an estimated 1.8 million children each year (Boschi-Pinto et al., 2008; Kosek et al., 2003). At a United Nations Summit in 2000, the international community established the Millennium Development Goals (MDGs), of which goal four aims to reduce the under-five child mortality rate by two-thirds
by 2015. Since the transmission of diarrhoeal disease is primarily attributable to contaminated water and inadequate sanitation, goal 7 means to “halve by 2015 the proportion of people without sustainable access to safe drinking water and sanitation” (UN, 2002; WHO, 2002). For the estimated 900 million people who lack access to improved water sources and the millions more drinking microbiologically unsafe water from improved water sources, the World Health Organization (WHO) declared point-of-use household water treatment and safe storage (HWTS) to be the most cost-effective approach for achieving the MDGs (WHO, 2002, 2011).

Despite the general success of HWTS in preventing diarrhoea by reducing population exposure to waterborne pathogens, recent reviews find the effectiveness of such technologies and their subsequent health impacts to be highly variable (Clasen et al., 2007; Waddington and Snilstveit, 2009). Heterogeneity amongst trials suggests that the actual level of effectiveness is affected by variable technology, environmental conditions, community capacity, participant compliance, as well as a variety of other factors researchers are not yet able to explain. DeWilde et al. (2008), propose a causal pathway through which safe water programs can prevent the transmission of enteric pathogens and reduce the burden of diarrhoeal disease by: 1) identifying drinking water as the principle route of transmission, 2) properly maintaining the safe water intervention, 3) ensuring that the population drinks the safe water consistently, and 4) protecting treated water from the threat of recontamination. The authors stress that any disruption to the causal pathway diminishes health benefits by increasing population exposure to unsafe water (DeWilde et al., 2008). Hunter (2011), furthers this argument by stressing the importance of frequent and consistent use of HWTS for there to be a resulting health impact, despite the level of treatment effectiveness. Therefore, the
importance of technological effectiveness of water quality interventions is secondary to consistent compliance amongst beneficiaries in order for safe water programs to deliver a beneficial health impact.

Compliance, the degree to which beneficiaries use a HWTS intervention, is positively correlated with the value of project outputs, such as a reduction in diarrhoea prevalence (Clasen et al., 2007; DeWilde et al., 2008; Doocy and Burnham, 2006; Enger et al., 2012). For example, a point-of-use flocculent-disinfectant intervention reduced diarrhoea incidence by 90% and prevalence by 83% in two camps for displaced persons in Monrovia, Liberia. Doocy et al. attribute the overwhelming success of the intervention to a 95% participant compliance rate, verified by routine chlorine residual testing (Doocy and Burnham, 2006). Similarly, flood-affected families in Bangladesh were provided with PUR sachets and Aquatabs following massive flooding in 2006 (Lantagne and Clasen, 2012). Unannounced water testing visits confirmed that 100% treated water samples had free chlorine residuals and were free of faecal coliforms. A recent study by Enger et al. (2012), suggests that communities with more ‘perfectly compliant’ individuals have greater reductions in diarrhoea incidence. Moreover, quantitative microbial risk assessment models predict little benefit of log reduction values (LRVs) of E. coli greater than 2 when 80% of community children are perfectly compliant; with diminishing returns for higher LRVs (Enger et al., 2012). Although the implication of these findings suggests the need for greater compliance, creating a culture of consistent and reliable household water treatment in developing countries is a precarious process laden with challenge.

The dogma of conventional efficacy studies overstates the importance of short term health impacts used to indicate program performance, while neglecting the
underlying social determinants driving program success or failure. A 2011 report on drinking water and the status of MDGs suggests that on average, 36% of hand-pumps across Sub-Saharan Africa are non-operational (WHO, 2011). A similar report by the World Bank states that the majority of rural water development projects fail within their first three to five years of operation (Davis and Iyer, 2002). Discontinuance, the decision to reject a technology after having previously adopted it, has been linked to limited demand, user inconvenience, a lack of affordability and community capacity, low perceived benefit, and inadequate operation and maintenance causing frequent system dysfunction (DeWilde et al., 2008; Rogers, 2003; Waddington and Snilstveit, 2009; WHO, 2011). Additionally, the preventative practice of drinking water treatment has difficulty being accepted by society since the benefit gained (e.g. cases of diarrhoea avoided) is a ‘non-event’ and is not easily perceived by the user (Enger et al., 2012; Rogers, 2003). Such findings indicate that perceived benefit, contextual appropriateness, and user convenience play a more significant role in technology diffusion and user compliance than previously believed.

In order to improve user compliance, many researchers have adopted a participatory approach to program implementation meant to educate beneficiaries on the importance of safe water and include them in the research process (Bailey, 1992; Bewket, 2007; Isham and Kahkonen, 2002; Narayan, 1995; Sanchez and Almeida, 1992) (Bailey, 1992; Bewket, 2007; Isham & Kahkonen, 2002; Narayan, 1995; Sanchez & Almeida, 1992). Using local participation and indigenous knowledge to guide the innovation process improves user satisfaction by developing relevant and contextually appropriate technologies that take into account user preferences (Bewket, 2007; Bruns, 2003; Isham and Kahkonen, 2002; Murphy et al., 2009)
However, researchers who overlook community input because they are unprepared to share in decision making process risk placating their participants, generating resentment, and hindering compliance (Arnstein, 1969; Bewket, 2007; Bruns, 2003) (Arnstein, 1969; Bewket, 2007; Bruns, 2003).

Clear limitations exist in our understanding of compliance and the underlying complexities of user preference and adoption. This paper presents an investigation of the social and institutional factors that drive compliance and lasting behavioural change in a marginalized community of South India. We investigate the effects of perceived benefit, inherent demand, community capacity, technological efficacy, and gender on participant compliance in the case of an HWTS technology developed by a coalition of community representatives and project researchers using a participatory development framework. Such an investigation has implications for the use of participatory research in mediating high compliance rates. Also, this investigation contributes to the continuing discourse on program evaluation and on overcoming challenges to achieving the MGDs by examining user priority, capacity, and preference, elements essential to program sustainability.

5.2 Materials and Methods

5.2.1 Setting

Mylai Balaji Nagar (MBN) is a peri-urban resettlement colony located on the border of Chennai’s city limits which relies on highly polluted surface water as its drinking water source. In 1995, the people of MBN were evicted from their homes
along the banks of the Buckingham Canal in Chennai’s district of Mylapore; the Tamil Nadu government required the area for the construction of a new light-rail station. Nearly twenty years later, the 10,000 residents of MBN are without proper sanitation, solid waste management and safe drinking water. The water received by MBN is drawn from a nearby lake which receives surface runoff from the neighbouring communities, accumulating garbage as well as human and animal excreta. The highly polluted water is then pumped, from an infiltration well to standpipes where it is collected and used for bathing, food preparation, and consumption. The exceptionally high concentrations of biological contaminants found in the community’s water supply, such as *E. coli* which commonly exceeded 4037 cfu/100 ml (UCL: 5275 cfu/100 ml) in untreated household water supplies, pose a serious threat to the health of the community, particularly in children under 5 years. Informed consent was obtained from an adult member of each participant household, and all research activities were pre-approved by the research ethics board of the University of Guelph.

### 5.2.2 Study design

Following a 12-month baseline data collection period, 124 households using tap water as their primary drinking water source were randomly assigned to one of two groups: an intervention group receiving a safe water system), and a control group receiving no intervention. Following one month of post-baseline data collection, the intervention group was enriched with the addition of seven households that relied primarily on tap water, increasing the number of intervention households from 62 to 69. All households were followed for 12 months, providing monthly water samples
and responding to surveys on water treatment practices and diarrhoeal disease. The study was intended to compare the diarrhoea rates of intervention households to those of controls; however, baseline findings indicated a remarkably low prevalence ratio of 1.06% in children under the age of five. Therefore, in addition to disease monitoring, the study was modified to include water quality assessment to indicate the effectiveness of the safe water system.

A learning alliance between community residents and project researchers formed the basis for collaboration on the research, design and implementation of an appropriate water treatment system. It has been documented that increasing user participation directly improves project outcomes which can enhance user acceptance of new technology and improve the likelihood of adoption (Bewket, 2007; Isham et al., 1995). Community residents in collaboration with the research team developed a dual media bucket filter that employed sand and charcoal in the reduction of turbidity, organic matter, and bacterial pathogens. A 35 mg tablet of sodium dichloroisocyanurate (NaDCC), selected for its wide availability, was then added to the safe water storage pot in order to disinfect the 20 L of filtered water.

Each household assigned to the intervention group (n = 69) received a safe water system (SWS), consisting of a bucket filter, a safe water storage vessel, and a sachet of NaDCC tablets for household water treatment. Participants in the intervention group were provided with the safe water system at no charge; the approximate cost of which is $25 USD. The annual cost of operating the system on a daily basis is estimated at $5.50 USD per household. Upon receipt of the safe water system, households in the intervention group were given detailed verbal and written instructions on filter operation, maintenance, and care, with demonstrations from project staff. Households assigned to the control group did not receive the safe
water system until the end of the study; however, both groups were exposed to the same awareness campaign conducted by the project staff to educate the community on the importance of good water, sanitation and hygiene.

5.2.3 Weekly visits

5.2.3.1 Diarrhoea monitoring

All households enrolled in the study were visited by research staff twice per month during the 12 month study period to monitor for diarrhoea. Using the World Health Organization (WHO) standard definition of a diarrhoeal disease episode as three or more loose, liquid, or watery stools or at least one bloody stool in a 24 hour period, project staff recorded the presence of diarrhoea in each household member using a standardized questionnaire. Prevalence ratios were calculated for each household by dividing the number of days of diarrhoea by the total number of person-days of observation. Prevalence ratios have been demonstrated as strong predictors of long-term health outcomes and are commonly used to measure diarrhoea in children under 5 years (Brown et al., 2008; Clasen et al., 2004; Morris et al., 1998; Stauber et al., 2009).

5.2.3.2 NaDCC tablet distribution

Intervention households were resupplied with NaDCC tablets every two weeks by project staff. Records were kept of the number of tablets distributed to each household.
5.2.4 Questionnaires

On-going survey data collection, conducted once every two weeks in conjunction with the diarrhoea monitoring programme, informed researchers of variations in household water practices, sanitation, and hygiene. It was also designed to investigate levels of household satisfaction and compliance amongst intervention households, related to the appropriateness of the safe water system within the context of a marginalized, peri-urban, South Indian community. Household compliance was assessed using reported and observed use of the safe water system, reported and observed maintenance of the safe water system, consistent consumption of treated water within the household, and reported consumption of NaDCC tablets for water disinfection. Following the conclusion of the regular data collection schedule, an exit survey was administered to investigate household preferences for available water sources based on aesthetic criteria. The same survey was used to investigate household perceptions of the capability of the safe water system to deliver a positive health impact.

5.2.5 Water quality testing

All participant households received unscheduled and unannounced water testing visits during which a member of the household was handed a 250 ml wide-mouth sample collection bottle and asked to retrieve a sample of drinking water as if they were retrieving a cup of water for personal consumption. Intervention households were asked for samples of both treated and untreated water, while control households were asked for one sample of the household drinking water. Samples were stored between 2° and 8° C according to Standard Methods (APHA, 2005), while
on-route to the Environmental and Water Resources Engineering lab at the Indian Institute of Technology Madras. Total residual chlorine was tested for using the neutral ortho-toluidine method, Indian Standard method for the determination of residual chlorine for water and waste water (IS, 1986). Microbiological quality was assessed using the membrane filtration method, providing a definitive count of colony forming units (cfu) for total coliform and \( E. \) coli bacteria, per 100 ml of sample water, according to standard laboratory method (APHA, 2005). Samples were incubated at 37\(^\circ\)C on HiCrome Coliform agar, selective for total coliform and \( E. \) coli, for 24 hours before cultural characteristics were observed.

### 5.2.6 Index creation

A six point rating scale was used to index household compliance based on repeated measures of frequency of use, consumption of untreated water, system maintenance and location, NaDCC tablet usage, and water retrieval practices. Household specific responses were averaged for each repeated measure. Depending on the range and variability of these averages, the data were binned by quartile or quintile, and each household was assigned a score from one to four, or one to five, respectively. Each repeated measures score was assigned a weight, according to the parameter’s affinity to indicate compliance; the results were summed and used to assign each household a score from one to six. Households which did not comply with intervener instructions on proper use of the SWS were assigned an index score of 1, indicating non-compliance. The remaining scores were binned by quintile and used to assign each household an index score from two to six, indicating household compliance from Very low through a neutral point, to Very high. Table 5.1 provides an example
of how the Compliance index was generated; however, the example only utilizes three of the six repeated measures.

**Table 5.1:** An example of index creation for Compliance, using the responses of three repeated measures

<table>
<thead>
<tr>
<th>HH*</th>
<th>NaDCC Tablet Usage</th>
<th>Freq. Use</th>
<th>Maintenance</th>
<th>Sum**</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td># Tab</td>
<td>Bin</td>
<td>Scr. (a)</td>
<td>Wt. (e)</td>
<td>Scr. (b)</td>
<td>Wt. (f)</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>Zeros</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>29</td>
<td>0&lt;x≤31</td>
<td>3</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>31&lt;x≤59</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>67</td>
<td>x&gt;59</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

*Note: HH = household; Scr. = survey score; Wt. = weight assigned to survey score; Tab = number of NaDCC tablets used by the household.  
**Sum \((a \times e) + (b \times f) + (c \times g)\)

Similar indices were generated for: Inherent Demand, based on household diarrhoea prevalence rates; Technological Efficacy, based on log reduction values for total coliform and E. coli bacteria; Perceived Benefit, based on household valuation of treated water aesthetics and perceived changes in household health; Community Capacity, based on preferred management structure, awareness of local water group, willingness to share the safe water system with family and neighbours, and willingness to advocate the safe water system within the community; and finally Gender, based on the degree to which the primary female caregivers for each household were responsible for the operation and management of the safe water system within the home. All categorical indexing was performed at the household level since participant selection and assignment was conducted at the household level.
5.2.7 Statistical analysis

Given the ordinal nature of the data, comparisons between Compliance and other indices were performed using a Spearman ranked correlation. Multivariate and univariate logistic regression models were performed with Compliance as the outcome variable. Predictor variables included: Inherent Demand, Perceived Benefit, Technological Efficacy, Community Capacity, and Gender. All statistics were performed using SAS version 9.3 for Windows (SAS Institute Inc, Cary, NC).

5.3 Results

5.3.1 Inherent demand

Innovation-development is stimulated by the recognition of a need or problem for which a solution is required (Rogers, 2003). The research process lends itself to innovation-development through a framework of problem identification, solution generation, implementation and assessment. In some cases scientists may anticipate an impending problem and employ the research process to derive a solution. The majority of cases, however, are in response to an existing problem such as poor drinking water quality and its role in the transmission of waterborne pathogens. The current project used participatory action research to develop the safe water system to reduce the burden of diarrhoeal diseases within the study community. The project was predicated on the understanding that the community relied on a highly polluted drinking water source that was believed to be a cause of diarrhoeal infection within the community. By developing a point-of-use treatment technology, researchers hoped to empower local residents with the means to improve their own
drinking quality water and reduce the burden of diarrhoeal diseases.

Based on recent findings, our initial estimates of diarrhoeal prevalence in MBN were greatly overstated (Marimuthu et al., 2009; Shah et al., 2003). Given the high concentrations of bacteriological contaminants in the water source, prevalence rates were expected to be 15% - 25% for children under five years of age. In 1996, the WHO found diarrhoea to be the leading cause of mortality in Indian children under five, accounting for 28% of some three million annual child deaths (WHO, 2001). Marimuthu et al. (2009), in a study of Delhi slums, found an overall prevalence of 15.4%, while Mishra et al. (1990), found seasonal variation of diarrhoeal prevalence between 8.7% and 33.0% in urban Mirzapur, India. Baseline evaluations of community health, conducted between January 10, 2010 and February 26, 2011 indicate an overall diarrhoeal prevalence rate of 1.06% in children under 5 years of age. The greatest proportion of illness was found in children between the ages of 1 and 2 years, followed by infants under the age of 1 year; in accordance with the current literature which finds children under 5 to be at greater risk (Brown et al., 2008). Health surveys administered following the implementation of the safe water system are consistent with the baseline findings. Figure 5.1 presents the results of 19 field visits that indicate an overall intervention household diarrhoeal prevalence rate of 2.02% in children aged 5 years and under; following data stratification, no difference was observed in children between the ages of 1 and 2 years or infants under the age of 1 year. A marginally lower rate of 0.98% was identified in adults and children over 5 years. Therefore, the prevalence rates reported in this study were an order of magnitude short of initial estimates drawn from previous experiences in the literature. The unusually low prevalence may have resulted from a courtesy bias, where study participants reported low illness rates because they believed it’s what
the researchers wanted to hear. It’s also possible that participants failed to provide honest reports of household illness due to the embarrassment it may have caused, or because the longitudinal nature of this study could have incited participant fatigue.

**Figure 5.1:** Diarrhoeal disease prevalence stratified by age cohort.

If the reported diarrhoeal prevalence rates are indeed accurate, they indicate good community health. With truly low reported prevalence, participants may be less inclined to treat their drinking water, thereby affecting compliance rates. Significant reductions in prevalence as a result of water quality improvement are only possible in communities where drinking water is the principle source of disease transmission (Arnold and Colford, 2007; DeWilde et al., 2008; Moe et al., 1991; Schmidt et al., 2007). Similarly, low acceptance of safe drinking water alternatives has been associated with low preference in populations which fail to recognize
the connection between diarrhoea and water quality (DeWilde et al., 2008; Gadgil, 1998; Jalan and Ravallion, 2003). However, simply because a community recognizes the importance of water quality does not assure the acceptance of the treatment technology. For this reason point of use water treatment is most effective when the perceived value of clean water outweighs the disadvantages associated with system compliance such as cost, time and effort (Enger et al., 2012). Doocy and Burnham (2006), found that point of use water treatment with a flocculant-disinfectant reduced diarrhoeal incidence by 90% and prevalence by 83% in two Liberian refugee camps. The authors attribute the magnitude of disease reduction to an extremely high compliance rate (95%), likely driven by epidemic levels of disease prevalence in the camps. During focus group discussions, participants identified ‘observed reduction in diarrhoea among family members’ as a principle factor in compliance (Doocy and Burnham, 2006). Prevalence rates both at baseline and throughout the current study were significantly less than those reported in the current literature for communities of similar contexts. Univariate logistic regression models found no significant effect of Inherent Demand on the outcome variable, Compliance. Summary statistics of this model are presented in Table 5.2. The unprecedented low levels of diarrhoea in MBN very likely impacted household opinion on the importance of safe drinking water and water treatment by:

1. Eliminating the perceived need for improved quality water — households with high illness rates possess an inherent need for clean drinking water, generating a demand for appropriate water treatment that influences behavioural change;

2. Making it nearly impossible for participants to detect a change in the health of their household following adoption of the safe water system; and
3. Failing to create a primary leverage point to counter-balance the trade-offs of compliance such as cost, time, and effort.

Table 5.2: Univariate logistic regression model summary statistics for Compliance, the outcome variable.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Level</th>
<th>IRR</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inherent Demand</td>
<td>High</td>
<td>1.34</td>
<td>0.0959</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>1.31</td>
<td>0.0249</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>0.08</td>
<td>0.1444</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Perceived Benefit</td>
<td>Very High</td>
<td>3.77</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>3.36</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>3</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>2.16</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>*Very Low</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Technological Effectiveness</td>
<td>Very High</td>
<td>1.44</td>
<td>0.0178</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>1.26</td>
<td>0.1823</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>1.09</td>
<td>0.5697</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>1.41</td>
<td>0.0271</td>
</tr>
<tr>
<td></td>
<td>*Very Low</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Community Capacity</td>
<td>High</td>
<td>1.04</td>
<td>0.6806</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>0.99</td>
<td>0.9704</td>
</tr>
<tr>
<td></td>
<td>Very Low</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

5.3.2 Perceived benefit

The degree to which we can expect any given household to adopt a new technology is almost directly proportional to the benefit associated with its use. In order for families to consciously alter their household water practices, they must recognize the safe water system as a valuable tool in water treatment, for which the benefits greatly outweigh the burden of regular maintenance and routine operation. The
system is therefore more likely to be adopted by households with a greater appreciation for the quality of the treated water and by those households who perceive a resulting reduction in the frequency of household illness.

The safe water system stood a better chance of being adopted by households who recognized their water to be of poor quality, and who were aware of the potential benefits of water treatment. Due to the infrequency of tap water availability, it was common for study households to exchange one drinking water source for another. Tap water was the least expensive, but of the poorest quality, and only intermittently available. Lorry water, assumed to be of marginally higher quality than tap water was delivered to the community via tanker truck and sold for five rupees per 25 liters. Bottled water was the highest quality water available to the community; however, at a cost of 20 rupees per 25 litre container, it was inaccessible to the community’s poorest residents. Both baseline survey and the exit survey findings indicated that bottle and lorry water users believed their water to be of good quality and therefore, unlikely to recognize the advantages of the safe water system. Tap water users were less satisfied, with 67.9% and 100% of respondents reporting that their water was of poor quality, in baseline and exit surveys, respectively. Of the self-reported tap water users, 69.6% were forced to seek an alternative drinking water source due to the infrequency of tap water availability. Only 30.8% of households supplementing their drinking water with lorry water, were satisfied with its quality. Consequently, households relying on some form of tap water were more inclined to benefit from using the safe water system than those households relying solely on bottle water or lorry water. Exit survey findings revealed that irrespective of water source, 89.7% of participant households employed the safe water system to treat their water before consumption.
This finding differs from the baseline data which indicates that only 10.4% bottle water users and 69.0% of tap water users treated their drinking water within the home. As expected, the proportion of tap water users at baseline who reported dissatisfaction with their drinking water quality equivalent to the proportion of households who reported treating their water in the home; data from the exit survey corroborates this finding.

Table 5.3: Indicators of household need for water treatment technology

<table>
<thead>
<tr>
<th></th>
<th>Bottle</th>
<th>Lorry</th>
<th>Tap</th>
<th>Tap &amp; Lorry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Do you think your drinking water is of good quality?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline Survey</td>
<td>Yes</td>
<td>100</td>
<td>87.5</td>
<td>32.2</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0</td>
<td>12.5</td>
<td>67.9</td>
</tr>
<tr>
<td>Exit Survey</td>
<td>Yes</td>
<td>100</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td><strong>B. Do you treat your drinking water in the home?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline Survey</td>
<td>Yes</td>
<td>10.4</td>
<td>82.4</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>89.7</td>
<td>17.7</td>
<td>31</td>
</tr>
<tr>
<td>Exit Survey</td>
<td>Yes</td>
<td>100</td>
<td>91</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td><strong>C. When do you treat your drinking water?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline Survey</td>
<td>Never</td>
<td>82</td>
<td>21.4</td>
<td>33.9</td>
</tr>
<tr>
<td></td>
<td>Always</td>
<td>10</td>
<td>57.2</td>
<td>55.4</td>
</tr>
<tr>
<td></td>
<td>When children are sick</td>
<td>0</td>
<td>21.4</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>Sometimes</td>
<td>4</td>
<td>0</td>
<td>7.1</td>
</tr>
<tr>
<td>Exit Survey</td>
<td>Never</td>
<td>0</td>
<td>9.1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Always</td>
<td>90.9</td>
<td>81.8</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>When children are sick</td>
<td>0</td>
<td>9.1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sometimes</td>
<td>9.1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

In addition to perceived need for water treatment, user satisfaction is a principle motivator of compliance and lasting behavioural change. During 19 household visits, participants were asked about changes to the aesthetics of their drinking
water when using the safe water system; 96% reported improved water taste, 98% improved colour, and 97% improved turbidity. Ambiguous findings were cited for water odour, with 61% of participants reporting an improvement and 24% reporting a deterioration. Foul odours were periodically reported by intervention households throughout the study. Field investigations revealed that water remaining in the system between treatment applications would stagnate and develop an odour. The solution was to change the system’s design, by adding a spout to its base, permitting the user to drain the filter completely between applications. Unfortunately, ongoing surveys reported no change in the perceptions of beneficiaries following this adaptation. Conversely, exit survey findings indicate that the majority of intervention households preferred the smell of water treated using the safe water system (62%) over the smell of bottled water (18%), and lorry water (21%). In Figure 5.2, it can be seen that intervention households found aesthetic benefit in the quality of water produced by the safe water system; 67% of households preferred its taste, 62% preferred its odour, and 69% preferred its colour. The majority of intervention households reported the safe water system capable of producing water of an aesthetic value superior to that of any other available source. Although aesthetic preference does not provide a direct measure of participant compliance, it indicates the degree of participant satisfaction, as well as provides an assessment of attitudes and aspirations for the continued use and long-term adoption of the safe water system.

It is widely acknowledged that preventative practices, such as water treatment, have difficulty disseminating within society because the benefit is a ‘non-event’, and is not always apparent to the user (Rogers, 2003) Therefore, long-term adoption of the safe water system was in-part, contingent on its ability to reduce the incidence
of disease in compliant households, as well as the capacity of those households to recognize this change. In Figure 5.3, it can be seen that intervention households perceived nominal reductions in both skin disease (Mean: 7%) and diarrhoea (Mean: 5%), with the majority of households reporting no change. The same households perceived much greater reductions in the number of fevers (Mean: 52%), and colds (Mean: 63%) throughout the course of the study. As previously stated, compliance is contingent on whether the advantages of a new technology, real or perceived, outweigh its inherent challenges. In this case, participants credited the safe water system as having reduced the burden of disease within
their households. Despite contradicting epidemiological data which suggested no change in the diarrhoeal diseases, it is the perception of a health benefit which perpetuated the use of the safe water system and facilitated lasting behavioural change in the community.

Figure 5.3: Perceived illness reduction in intervention households

Multivariate and univariate logistic regression models with and without interaction terms, were used to estimate the incident rate ratio of compliance, as a function of perceived benefit. A full generalized model was fitted to the data with generalized estimation equation (GEE) extensions, and random intercepts. Our small sample size limited the use of multivariate statistics to predict compliance; therefore we relied primarily on univariate modeling. The univariate model of
perceived benefit suggests that households with low, moderate, high, and very high levels of perceived benefit are 2.16, 3.00, 3.36, and 3.77 times more likely to be compliant than are households with very low levels of perceived benefit, respectively (Table 5.2). Perceived benefit was the only index variable found to be a significant predictor of household compliance. To further our understanding of perceived benefit, the variable was deconstructed to permit the multivariate analysis of perceived reduction in household illness (Illness), and drinking water taste and aesthetic preferences (Aesthetics), as predictors of compliance. Aesthetics were found to be highly significant at all levels, with IRRs suggesting consistently positive predictions of compliance. Similar results were revealed for both moderate and high levels Illness. However, both parameters were significant at all levels when analyzed with a univariate model. Summary statistics for both models are presented in Table 5.4.

**Table 5.4:** Univariate logistic regression results for illness, aesthetics, and perceived benefit as predictors of compliance.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>Level</th>
<th>Univariate</th>
<th>Multivariate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IRR</td>
<td>p-value</td>
<td>IRR</td>
</tr>
<tr>
<td>Illness</td>
<td>High</td>
<td>1.85</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>1.65</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>1.6</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>*Very Low</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Very High</td>
<td>3.17</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>3.18</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>2.95</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>1.13</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>*Very Low</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 5.4 presents IRRs of compliance for various levels of Illness and Aesthet-
ics, estimated using a multivariate model, and Perceived Benefit, estimated using a univariate model, as Perceived Benefit exists as a combination of the other two variables.

![Graph showing predictions of compliance by elements of perceived benefit](image)

**Figure 5.4:** Compliance estimates for different levels of perceived benefit, as generated by univariate logistic regressions

### 5.3.3 Technological effectiveness

The success of water treatment technology depends on its efficacy to remove waterborne pathogens and improve overall aesthetics of water quality while meeting local needs and capacities. For compliance to be high, beneficiaries must recognize the value of its output, which can only happen when the technology satisfies or exceeds local expectations. Therefore, technology effectiveness can be divided into:
1) Removal efficacy, the ability of the safe water system to remove or render inactive microbiological contaminants; and 2) Appropriateness, the suitability of the safe water system to meet the needs, circumstances and capacities of the local people while employing locally available materials in an environmentally and socially sustainable fashion (Murphy et al., 2009). As this paper will discuss, behavioural change will not take place nor will the adoption of new technology if that technology is regarded as unfit in either of the aforementioned ways.

Removal Efficacy was assessed based on the safe water system’s ability to improve household drinking water quality as indicated by log reduction values (LRVs) of total coliform and *E. coli* bacteria. Preliminary laboratory testing of the safe water system, produced LRVs of 2.78 (UCL: 3.35) for total coliforms and 2.56 (UCL: 3.50) for *E. coli*, when dosing the system with raw surface water from Narayanapuram Lake, the community water source. In order to analyze system efficacy in the field, treated and untreated water samples were collected from intervention households once a month for one year. Average LRVs across all months of study were 1.89 (UCL: 2.21) for total coliforms, and 1.53 (UCL: 1.82) for *E. coli* (Figure 5.5). The discrepancy in filter effectiveness between the laboratory and in-field settings is likely attributable to variations in social and behavioural factors such as poor system maintenance (Parker and Skytta, 2000), and the recontamination of treated water prior to use (Wright et al., 2004). Despite variation in treated water quality, the safe water system greatly reduced microbiological contamination, making the water safer to drink.

*Appropriateness* of the safe water system was assessed based on the degree to which it satisfied the water needs of each household, and addressed their preferences while working within the confines of a resource limited community. This study
employed a participatory research strategy in which participants were encouraged to take part in all levels of the research process, including innovation development. Focus groups, interviews and community meetings provided forums for the two-way exchange of information which allowed researchers to employ their knowledge of water treatment processes and give shape to the ideas and opinions expressed by community participants. In this way, we hoped to avoid many of the social complexities inherent in the application of new intervention technologies for poor and marginalized communities by including them in the decision making process. This strategy led to the development of a low-cost, simple to use, water treatment technology that community members were capable of reproducing on their own using inexpensive and locally available materials. It was believed that a
participant-guided innovation process would create relevant technology well suited to community needs, improve user satisfaction, and increase compliance.

Survey data, collected once every two weeks for one year, indicate the contextual appropriateness of the safe water system by assessing the level of satisfaction amongst beneficiaries as well as behavioural change in water practices within the home. Of the 65 intervention households, 99.1% reported treating their water with the safe water system at least once per day. Of these households, 64% (UCL: 71%), said they ‘always’ treated their drinking water, while 20%, 15%, 1% said they treated their drinking water ‘never’, ‘when children are sick’, and ‘sometimes’, respectively. The average number of households satisfied with the quantity of water produced by the system in a single application was 71% (UCL: 79%), however this value varied according to seasonal variations in water availability. The majority of households reported taking less than one hour to perform routine system maintenance (61%, UCL: 74%), but it was commonly reported that the time required was too long and inconvenient. Of the 78% of households that reported cleaning their safe water systems, it was found that 1.8 months was the duration of the average cleaning cycle (UCL: 2.4 mo.), and that this number increased over time. Exit surveys administered during the final month of the study found that 55% of households described the system as ‘easy to use’, while another 42% described it’s operation as ‘not difficult’. Satisfaction with the safe water system within the intervention group appeared to be high.

*Technological Effectiveness* was not found to be significantly correlated with Compliance ($p = 0.106$). However a simple logistic regression revealed “low” and “very high” levels of Technological Effectiveness to be predictive of household Compliance (Table 5.2). The model indicates that households with low and very
high levels of technological effectiveness were 1.44 (p = 0.0178), and 1.41 (p = 0.0271) times more likely to be compliant than households with very low levels of technological effectiveness. The marginal difference in magnitude between these two predictions would suggest that compliance remains largely unaffected by improvements to bacterial removal effectiveness. Technical effectiveness and general user satisfaction are strong motivators in the adoption of new technology; however, technologies may still be rejected if socioeconomic and institutional barriers outweigh the benefits of its outputs.

5.3.4 Gender

In this project, women were identified as effective cultural agents for enabling the prevention of water-borne diseases by using and propagating the safe water system. While the male-female difference is a biological reality, gender is a social construct. In MBN, as in much of South India, women are expected to remain at home with the children, and perform domestic chores, which include water collection, and in some cases, water treatment; gender based roles pitch women as both regulators and beneficiaries of water and its usage in the home. Unfortunately, the same social construct absolves local men of any and all responsibility in water preparation, segregating society and creating an imbalance of health awareness within the community. Consequently, household patriarchs are less educated on the dangers associated with untreated drinking water, yet in this patriarchal society they maintain ultimate decision making power over nearly all household affairs, including whether or not to treat household drinking water. The study conducted in MBN very clearly indicated that in order to yield a positive response, enlisting
the support of local women was most crucial. The power structure (patriarchy) at times delayed the active participation of women, and the potential health impact of the safe water system at a high cost to the community, both economically (medical costs) and culturally (women forced to stay at home to tend sick children). Attempts were made to enrich project participation among local men and boys through project activities and health awareness programming. Unfortunately, a lack of interest amongst community men, likely as a result of social prejudice, challenged the diffusion of the safe water system in MBN, impacting adoption rates and participant compliance.

During the dissemination of project materials and instructions, researchers discovered the necessity of tailoring project messaging to actively engage local women. Project staff continually found evidence for the importance of involving local women in project decision making. Groups of women from the community provided meaningful and insightful feedback during the development of water treatment alternatives, as well as suggesting design modifications to make the system more cost effective and user friendly; giving shape to the safe water system in its final form. The same women openly endorsed the safe water system, promoting it within the community, and thus increasing the likelihood for successful adoption and community diffusion.

However, gender-role stereotyping can have a polarizing effect on community participation rates when the intervention being developed is culturally linked to gender roles. The results of 19 field visits indicated that water treatment was the sole responsibility of the household primary female caregiver in 86.2% of households. Only in 2.3% of households did children assist their mothers with this task, while only in 2.7% of households was water treatment a shared responsibility.
between a man and a woman. Similar trends were revealed in an investigation of system maintenance, where 85.3% of households delegated the responsibility to the matriarch, 3.8% of household matriarchs were assisted by their children, and only 3.1% of household patriarchs shared the responsibility with their families. Households in which the patriarch was solely responsible for water treatment and system maintenance was reported only twice throughout the course of the study, and only during one of the twelve months of study. Since household water treatment was found to be almost exclusively the responsibility of the primary female caregiver, the data were invariable, and not suitable for inclusion in regression analyses. Due to the extreme bias of gender roles in MBN, we were unable to conclude that gender was a significant predictor of compliance.

5.3.5 Community capacity

Safe water treatment technologies have the potential to create lasting health benefits, but only if people continue to use them after the project has ended. Effective technology adoption requires a significant investment from the user in the form of skill acquisition, operational capital, and certain behavioural modifications before they are likely to perceive the value of its output. Sustainability and long-term compliance is largely dependent on the community’s physical, financial, and organizational capacity to support current users of the technology, and promote uptake amongst new users (DeWilde et al., 2008). Researchers commonly promote sustainability by employing community management frameworks to mobilize residents and available resources in support of people willing to adopt safe water treatment technologies, and help to entrench the new practice in everyday life (Bruns, 2003;
MacDonald et al., 2013; Opare, 2011; Roma and Jeffrey, 2011). Therefore, the willingness of the community to form a management group and their ability to operate effectively while overcoming inherent challenges has significant implications on the long-term compliance rates of safe water system users.

Community Capacity was not find it to be a significant predictor of participant compliance. Nor were the two variables found to be correlated (R = 0.04, p = 0.817). Logistic regression models indicate that Community Capacity had no predictive effect on household Compliance rates. Model statistics are presented in Table 5.2.

Mylai Balaji Nagar is an urban slum plagued by inequality, social fragmentation, unsecure land tenure, without community support for local leadership which jeopardizes the sustainability of development initiatives. However, project design can be tailored to compensate for these constraints by enlisting the service of a local NGO, securing an equitable distribution of project generated funds, and adopting a participatory approach to project development and programme implementation (Khwaja, 2006). As previously discussed, this project used a participatory framework to elicit local skills and knowledge by using key informant interviews, directed discussions, and stakeholder forums for the selection and design of the safe water system. Each stage of the project encouraged local participation by calling on local residents to assist in the delivery of safe water systems to participant households, conduct microbiological tests of water quality, and assist in an iterative design process by making improvements to the safe water system in response to user feedback (MacDonald et al., 2013). Participatory frameworks can improve the likelihood of sustainable water treatment by building upon existing knowledge systems that will encourage autonomy, boost participant self-confidence,
and promote a sense of empowerment by identifying solutions to relevant community challenges and generating sustainable solutions (Bewket, 2007). Isham et al. (1995), identified a positive causal relationship between project performance and beneficiary participation by documenting the association in 121 rural water projects. Unfortunately, community specific limitations do affect adoption rates, as does non-rational human behaviour and subjective thinking that can dissuade potential users from adopting the technology even when they perceive an economic benefit (Kessler, 2006; Khwaja, 2006). However, community self-management has the potential to compensate for these challenges and stimulate compliance by encouraging the formation of local alliances, developing lasting support, and creating a social network of interdependence.

In the final eight months of the project, researchers assisted community members in the formation of a local water group that would assume the responsibility of managing the safe water system once the project ended. Members of the self-titled Five Star Water Quality Centre (FSWQC) were internally elected to executive positions identified by the group. The FSWQC met with researchers once a week for the first four months, and once every two weeks for the final four months to discuss issues of service delivery, tariff collection, record keeping, problem reporting, and small business management. During this time, all members received comprehensive training on the construction and maintenance of the safe water system, empowering the FSWQC with the tools required to sustain local O&M.

Social capital, the community norms and networks essential to collective success, was found to be lacking in Mylai Balaji Nagar, and attempts to compensate with improved project design fell short. Residents openly discussed their unfavorable history of accountability and community solidarity, following the recent failure
of a community-based waste removal service initiated by the international environmental NGO EXNORA. It was for this reason that researchers questioned the feasibility of a community-level system and opted for point of use water treatment. Ironically, it may have been the disjointed efforts of individual household treatment that precipitated the collapse of collective action by making households accountable to only themselves, handicapping cooperation, absolving individuals of their neighbourly responsibilities, and making community management a near impossibility. Exit Survey findings revealed the intentions of all households to continue to use the safe water system after the project had ended, and that 13.0% felt they would need assistance in order to do so. When asked whether they would promote the use of the safe water system within their community, 25.9% of households said they would tell their neighbours of its effectiveness, and 9.0% said they would share it with their neighbours and friends. Despite promotional programming, only 15.7% of participant households were aware of the FSWQC, and only 63.6% said they would approach the FSWQC for assistance after learning of their function. When asked who they would prefer to have overseeing the management of the safe water system, 54.5% of households said college students, while only 24.7% expressed interest in local community management. Fear of community management was commonplace, as many residents expressed concern over untimely and unbalanced service delivery, profiteering, and operational negligence. This mistrust of community management coupled with a hesitation amongst users to promote the safe water system eroded the ability of the FSWQC to operate in the community and discouraged sustainable collective action.

In addition to sociological constraints, the community’s capacity for sustainable management was thwarted by unreliable revenue streams and inconsistent institu-
tional support. Financial assistance has been identified as a principle determinant of the impact of community based water services (Isham and Kahkonen, 2002; Opare, 2011; Roma and Jeffrey, 2011) (Isham & Kahkonen, 2002; Opare, 2011; Roma & Jeffrey, 2011). In additional to the need for funding required to cover operational costs, the payment of allowances or financial incentives to the community management team is essential (Opare, 2011) (Opare, 2011). Members of the FSWQC openly expressed their unwillingness to assist the group or even attend group meetings without some form of reward. It was suggested that the formation of a small social enterprise would generate a modest income for group members through maintenance tariffs, part replacement fees, and unit sales; however, the idea of forthcoming payment for work performed ‘today’ was not acceptable to the FSWQC. It has been found that the recruitment of local governments or NGOs can further enhance community capacity by facilitating the formation and growth of a functioning water committee, such as the FSWQC (Isham and Kahkonen, 2002; Roma and Jeffrey, 2011) (Isham & Kahkonen, 2002; Roma & Jeffrey, 2011). Hand in Hand (HiH), a locally active NGO, was commissioned to provide technical, logistical, and administrative assistance to the FSWQC following project completion and the withdrawal of research programming. Regrettably, this effort to marry local management with external support failed due to a lack of inter-group communication, a general lack of interest, and a lack of unity in the pursuit of a common goal. Consequently, low social capital and weak institutional support will depreciate compliance rates in MBN because current users will have to become completely self-reliant if they intend to continue using the safe water system in the absence of a local management group.
5.4 Discussion

This study investigated the complex nature of user compliance with HWTS by means of ongoing surveys, exit interviews, routine water quality analysis, and epidemiological study. Baseline analyses of water quality in MBN indicated drinking water as an area in need of development, a finding supported by community residents who advocated project efforts to provide safe drinking water. The analyses of results indicated that compliance can be improved by enhancing the perceived benefit to the user, of which, improved health, taste, and aesthetics are principle factors. Participatory development of the safe water system predisposed the technology to comply with local needs and capabilities while maintaining a necessary degree of cultural appropriateness. Identification of perceived benefit as a decisive factor in participant compliance likely would not have been possible had a participatory framework not been used to guide the development of an appropriate technology. Otherwise, the impact of perceived benefit may have been masked by critical flaws in the structural design of the safe water system.

This research identified perceived benefit as the single greatest predictor of participant compliance. In the same vein that user convenience has been identified as the greatest leverage point for programme improvement (DeWilde et al., 2008), this study suggests that frequency of use, frequency of maintenance, consistency of use, and water retrieval practices can be improved by enhancing perceptions of water quality and its potential to improve family health. Behavioural economics would suggest that the perceived benefits of safe water must outweigh the cost, time, and effort of water treatment, relative to the status quo, in order for people to adopt new behavioural patterns and comply with the treatment technology.
Intuitively, compliance can be improved by increasing user awareness of the potential health benefits associated with safe water. Jalan and Ravallion (2003), while studying the effects of piped water on diarrhoea, found that child-health gains were higher for children in households in which women were better educated, and likely more knowledgeable on the subjects of water treatment and illness prevention. Thevos et al. (2000), found that health education, when paired with motivational interviewing resulted in higher purchase rates of disinfectants for water treatment in marginalized urban communities in Zambia. Conversely, water treatment requires a significant investment of time and effort that can discourage potential users (Bewket, 2007; DeWilde et al., 2008). Therefore, the decision making heuristics of compliance form a balance in which perceived benefit to the user must outweigh the costs and challenges of behavioural change.

This paper’s deconstruction of perceived benefit revealed the importance of water taste, colour and odour, as well as perceived reduction in household illness, as significant predictors of participant compliance. According to our regression model, households with high and very high perceptions of treated water quality and water aesthetics were between 3.17 and 3.18 times more likely to comply with treatment instructions, system maintenance, and safe water storage and retrieval practices. Our results are similar to those of Gadgil (1998), who found that water taste, colour and odour had the greatest impact on user compliance, even greater than perceived changes in health. Reller et al. (2003), while investigating the use of a flocculent-disinfectant for drinking water treatment in rural Guatemala, found that unpalatable levels of residual chlorine can adversely affect participant compliance. Crump et al. (2004), observed similar results while studying the application of a flocculent-disinfectant in Western Kenya, when adverse taste was cited as one of
the principle reasons for study attrition. A very few residents of MBN reported consuming untreated tap water simply because they preferred its taste, despite their awareness of its potential to transmit diarrhoea. Clearly, the concept of water aesthetics deserves greater priority when designing HWTS technologies. Our results suggest that greater compliance and disease prevention is possible if HWTSs are designed with greater attention paid to the aesthetic preferences of the intended users. In this way, the greatest health impact to be achieved by HWTS is contingent on its ability to produce aesthetically pleasing water.

The contributions of different technological, social, and behavioural factors in water treatment compliance are uncertain and require further examination. Although Inherent Demand for water treatment was not found to be a significant predictor of compliance, the authors of this paper maintain that community need plays a significant role in technology adoption. It’s possible that the Inherent Demand index, generated to differentiate between varying levels of household illness, was unable to capture the marginal intra-household variations in diarrhoeal prevalence believed to impact compliance, in a population with apparently low prevalence. Reassessment of this assumption should be conducted in a community with endemic rates of diarrhoea, however, avoiding emergency settings where diarrhoea rates are atypical of routine lifes. Other predictors of compliance not found to be significant, also deserve reassessment. The affect of community capacity may have been significant if the data had been more robust. Community capacity was assessed as part of the exit survey, which reflected the values and opinions of only 56.5% (n = 39) of intervention households. Similarly, the data for Gender were highly skewed toward female involvement, with only two households reporting assistance from the household patriarch with respect to water treatment and system maintenance.
It is believed that households and communities in which these tasks are shared will have higher rates of compliance, resulting from greater social awareness and understanding of the importance of water treatment amongst community males, and also by sharing the physical burden and time required for routine water treatment.

The proportion of the world’s population with access to improved drinking water increased from 77% to 87% between 1990 and 2008, indicating that the world is on-track to extending access to 89% of the global population by 2015, and thus achieving goal 7 of the MDGs (WHO, 2011). Household water treatment and safe storage technologies have played an integral role in extending this coverage; however, compliance with these technologies as well as their consistent and proper use remain on-going challenges (Boisson et al., 2010). Even in low doses, acute and chronic exposure to enteric pathogens from either occasional or routine consumption of untreated water can compromise the protective effects of water treatment. Compliance, and therefore disease prevention can be improved by enhancing the aesthetics of treated water. Principle findings of this research indicate that:

- compliance with HWT technologies can be improved by enhancing the perceived benefit to the user;
- the deconstruction of perceived benefit revealed the importance of water taste, colour and odour, as well as perceived reduction in household illness, as significant predictors of participant compliance; and
- the concept of water aesthetics deserves greater priority when designing HWT technologies.
5.5 Acknowledgements

We are grateful to our local project staff for their hard work and dedication: Manikandan, S. Srinivasan, Fhareeda Begum, J. Jincy, G. Vinothini, and K. Arun Sampath. We are also appreciative of Kristan Aronson and Ligy Philip for their valuable contributions to this project and their continued support. Additionally, we would like to thank all of the study participants from Mylai Balaji Nagar for all of their time and patience, without whom this study would not have been possible. Funding support for this research comes from the International Development Research Centre (IDRC), in Ottawa, Canada.

5.6 Transition to Chapter 6

Chapter six addresses the issue of program sustainability for research based development projects, following the withdrawal of the researchers (or project implementers). It describes the application of Bruns’ ‘Extended Ladder of Participation’ and how it was used to guide the transfer of decision-making power from project implementers to local communities via institutional reform and user participation. The chapter concludes by addressing the benefits of such a model for guiding program strategy and tailoring development activities to fit an appropriate level of community involvement.

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Lausanne, Switzerland, cole Polytechnique Fdrale de Lausanne.
Chapter 6

Applying an Extended Ladder of Participation for the Development of a Community-Managed Safe Water System in a Marginalized South Asian Community

6.1 Introduction

Mylai Balaji Nagar (MBN) is a peri-urban resettlement colony located on the border of Chennais city limits which relies on highly polluted surface water as its drinking water source. The municipal governments fail to provide its residents with proper sanitation, solid waste management and safe drinking water. The water received by MBN is drawn from a nearby lake which, during storm events,
receives surface runoff from the streets of neighbouring communities, accumulating garbage as well as human and animal excreta. The water is then pumped, often untreated, from an infiltration well to standpipes where it is collected and used for bathing, food preparation, and drinking. In 2009, researchers from the University of Guelph (Ontario, Canada) and the Indian Institute of Technology (IIT) Madras (Chennai, India), began working with residents of the community on the design of a point-of-use water treatment system to address the self-identified community development priority of improving water quality and controlling diarrhoeal diseases. This paper applies Bruns Water Tenure Reform: Developing an Extended Ladder of Participation, a nine stage model of citizen participation, to the participatory development of an appropriate safe water system in MBN and the emergence of a community water committee responsible for operations and management.

Participatory research transcends the mere inclusion of participants in the research process, asserting them as equal partners in development to accelerate knowledge transfer and improve collaboration in a dynamic multi-stakeholder environment (Bailey, 1992; Kelly and Farahbakhsh, 2008; Sanchez and Almeida, 1992).

This research defines participatory development as a mechanism for improving community health and productivity by meeting the basic needs and capabilities of the local people, with the redistribution of decision-making power to marginalized groups through a process of institutional reform, resource mobilization and collective problem solving. This paper attempts to demonstrate the utility of participatory development for guiding the co-creation of appropriate technology (AT) while concurrently developing a community-led operations and management framework. Learning alliances (LA) assist in the development process by creating dynamic networks of diverse stakeholders to improve collaboration and solution
diversity (Kelly and Farahbakhsh, 2008; Sanchez and Almeida, 1992). Similarly, AT aims to meet the basic needs of both men and women by increasing their capacity to independently improve their living conditions, while employing locally available resources in an environmentally sustainable manner (Murphy et al., 2009). However, AT and participatory development also entail non-technical aspects of development such as knowledge transfer mechanisms and the empowerment of local people through collaborative action. Despite recent trends in participatory development, often research projects neglect the transfer of management and decision-making authority to the community. Community management bodies dependent on external support will inevitably fail when researchers withdraw from the study community unless researchers develop and implement an effective transition strategy.

The first Ladder of Citizen Participation, developed by Arnstein (1969), framed the concept of community involvement as a struggle for power between government officials and community lobbyists. This framing is inappropriate for application in a mutually beneficial development context for the pursuit of a common goal such as safe water. Connor (1988), next developed a New Ladder of Citizen Participation for the prevention and resolution of community conflict. However, despite noticeable improvements, including the addition of a participant feedback loop, the model was configured for application in a legal setting and does not strive to increase the level of community participation. Common to the majority of shared decision-making models, power is progressively shifted from the authoritative body, such as the local government, to the community. Potapchuk (1991), stresses the importance of community consent and citizen engagement in his Levels of Shared Decision Making. Potapchuks model outlines five stages for the transition of
power to the community via mechanisms of co-management and mutual agreement. Choguill (1996), explores the concept of shared decision-making in international development contexts in his *Ladder of Community Participation for Underdeveloped Countries* which emphasizes the importance of government action in development projects in urban settings. However, this model is less concerned with enhancing the degree of community participation and citizen power as it is with maximizing government support, which makes it incongruent with the ambitions of the current study to encourage the autonomous community operation of an appropriate safe water system by utilizing LA and an incremental framework of co-management. Building on Arnstein (1969), Bruns Extended Ladder of Participation (2003) categorizes development efforts according to their ability to empower community participants, build the skills and capacities of local people, and develop a system of independent management (Bruns, 2003).

This paper discusses the research activities that were part of a three year development project on the participatory design and implementation of a decentralized safe water system. Each of Bruns nine stages are defined by varying degrees of community involvement and distinguished by measurable criteria based on legal authority, power, and influence over decision-making. This paper attempts to adapt Bruns model to more closely mirror the principle of participatory development and demonstrates its utility for guiding the co-creation of AT while concurrently developing an appropriate community-led operations and management framework. Furthermore, participatory models such as Bruns *Extended Ladder of Participation* prioritize people over technical ingenuity, encouraging user satisfaction and technology uptake. The next sections outline how the present project at MBN relates into the nine levels of participation in Bruns model.
6.2 Level 1: Consult

What was originally defined by Bruns as the second level in his ladder of citizen participation, *Consult*, is characterized by a two-way exchange of information between researchers and the community, establishing a foundation for future collaborative efforts. Here we propose a reversal of *Inform* and *Consult* because, in accordance with the precepts of participatory development, researchers are first required to consult members of the community and gain a better understanding of their needs in a highly complex local context before defining project objectives. Only by building on local knowledge and experience can outside investigators effectively address the concerns of local beneficiaries. Public hearings, interviews and focus groups are employed to promote co-learning and encourage local involvement. Preliminary investigations at MBN identified water quality as an area needing improvement, mobilizing researchers and the community behind a common goal.

Exploratory walks and informal interviews with community leaders began in December 2007. Researchers performed visual inspections of the physical environment and engaged community members in informal interviews with the aim of identifying local development priorities for future work. Narayanapuram Lake, the community's main water supply, was found to be highly polluted with garbage as well as human and animal excreta, washed from the streets of the surrounding neighbourhoods. The lake was also a site for informal solid waste disposal and a watering hole for cattle kept by the local population. Public consultation confirmed degraded water quality and its limited quantity, as well as associated illnesses amongst children, as major problems for residents. Researchers and community members would later perform a co-investigation of the physical environment for
sources of contamination and vectors of disease transmission. An epidemiological study was also used to investigate the state of public health in the community.

In addition to site assessments, public forums also helped to develop researcher understanding of the hardships residents faced with respect to water. The first such event, originally intended as an informal information session on water, sanitation and hygiene (WASH), quickly transformed into an open discussion on the difficulties encountered by households relying on tap water for drinking water provision. Apart from communicating WASH messaging, these sessions were found to draw people with an interest in community health and water management. This helped to identify individuals with an interest in actively improving their community, many of whom would become, and are still, involved in the project. The second opportunity for collaborative brainstorming and information exchange was an all-stakeholders forum, attended by twenty-five community representatives, researchers from both the University of Guelph and IIT Madras, Managing Directors of the Tamil Nadu Slum Clearance Board (TNSCB) and the Chennai Metro Water Sewage and Sanitation Board (CMWSSB), Panchayat government officials, and representatives from NGOs active in the community. The open exchange of information was a milestone in community development at MBN since, by bringing all of the stakeholders to the table it gave participants the opportunity to share their perspectives on some of the core problems. In accordance with the precepts of participatory research, this forum facilitated the involvement of community members in problem identification and issue prioritization (Bailey, 1992; French and Bayley, 2011; Sanchez and Almeida, 1992). Water quality was recognized by community members and the other stakeholders present as an area in urgent need of improvement.
The all-stakeholder forum was also used to inform the community of preliminary research findings as well as to consult with them on the appropriateness of research goals. Moreover, the forum involved the community and collaborated with them, linking to further levels of the *Extended Ladder of Participation*; these will be discussed in the following sections.

### 6.3 Level 2: Inform

Typically the first level in Bruns model, *Inform* is defined by a top-down dissemination of information from researchers to the community, pertaining to problem identification, solution generation and advanced notice of future action. Rather than being participatory, this expert-led level in Bruns model, is defined by limited community involvement, lack of collaboration, and uneven decision-making power. It is, in the present work, positioned as the second level of participation.

Two public hearings were organized upon inception of the project to share with the community information gathered during the *Consult* phase and to explain the purpose and timing of future tasks. An inaugural ceremony on August 15th, 2009, coinciding with Indias National Independence Day, marked the official commencement of a study investigating the design and use of decentralized water treatment alternatives in MBN. The ceremony, held in one of the local schools and open to the general public, presented researchers with an opportunity to explain the project objectives, the three year work plan at MBN, and their goal of forming a LA with community residents to more effectively address the issue of water quality. The second event, the all-stakeholder forum previously discussed in the *Consult* stage, took place in the community on December 1st, 2009. In addition to
further discussion on the challenges faced by community with respect to water, the forum also introduced the upcoming baseline water quality and epidemiological monitoring studies. In a general sense, the inauguration ceremony and the all-stakeholder forum were designed to make the community informed of project activities, encourage local participation, promote WASH awareness, and nurture the development of a trusting relationship between researchers and the community.

6.4 Level 3: Involve

Interactive discussions and co-planning are meant to involve community members in decision-making processes, in comparison to earlier stages of the model which entail a top-down approach. Bruns model ascends the rungs of participation, moving from a situation with limited community involvement and decision making power to one of autonomy and active participation, reducing the need for external support. This stage is marked by greater participant involvement and enhanced communication between partners to ensure community development goals do not become subordinated to other research goals. While community input is formally recognized and bears influence on decision-making, final authority lies with the researchers. For this reason, the level Involve possesses an inherent threat to the overarching goal of community mobilization and independent community management. If researchers fail to exercise caution and overlook community input when making decisions, they run the risk of placating their participants and evoking sentiments of anger and frustration (Arnstein, 1969; Bruns, 2003).

The nuances of this stage were exemplified in this project during the selection of an appropriate level of decentralized water treatment. Decentralized alternatives
function on the basis of shifting operational capacity from large-scale centralized plants to locations closer to the point of consumption, such as at the community- or household-level (Ali, 2010). In accordance with Bruns concept of involvement, the decision to adopt a household water treatment and safe storage (HWTS) system was made in large part by the research team, in consultation with representatives from the community. Focus groups and interviews were held in all parts of MBN to discuss the implications of each approach, explore peoples preferences, and the demands of the context. While some participants supported HWTS, many others preferred treatment at the community-level due to its cost effectiveness and ability to offer greater coverage and accessibility. However, following a recent failure of a community-based waste removal service initiated by the international environmental NGO EXNORA, researchers questioned the feasibility of a community-level system in area context with an unfavorable history of accountability and community solidarity. As one participant expressed during a focus group in MBN:

*If it [treatment system] is common and public there will be clash as to who will do it [maintenance] and everybody will try to shift and point to the other to do the task and if it [treatment system] is at the individual level everybody ought to do it [maintenance] and they will not like to shift from their responsibility.*

This sentiment was echoed throughout the community. In light of these concerns, researchers believed an HWTS would be more appropriate in MBN, where insecure land tenure, negative experiences with community action, and poor relationships with the local *Panchayat* and the TNSCB have fostered a sense of indifference toward collective action. Researchers made the decision to design and
implement an HWTS with the expectation that households would develop a sense of ownership of the system, and with it the responsibility to maintain the technology, thereby improving its potential for sustainability.

6.5 Level 4: Collaborate

Real collaboration between the community and researchers demands an even greater effort to promote participation. A joint problem solving effort requires that all parties have equal opportunity to openly express their ideas and concerns. Consensus is often sought but the final decision still lies with the researchers in this level. Aside from having a seat at the table, the community is expected to take part in information gathering, data analysis and collaborative troubleshooting as part of a co-inquiry team. At first glance, the difference between Involve and Collaborate may be difficult to distinguish, however the two are discernible by the greater influence afforded to local participants in the latter, something that is likely required for restructuring the management framework.

In the project at MBN, a coalition of researchers and community participants were tasked with developing an appropriate safe water treatment system capable of meeting the needs, circumstances and capacities of the local people. Community participation became an integral component of the decision-making process, complementing scientific rigour with rich personal experiences and the knowledge of local residents. The design of the safe water system was dependent on community input and feedback, altering the decision-making framework and shifting more power into the hands of the participants. A series of six participatory design workshops, typically composed of eight to ten community residents and
three to four researchers, were held in each one of the community’s four sectors. Researchers and technical staff at IIT Madras were responsible for the adaption of prototypes in accordance with the preferences expressed by participants during design workshops. The sixth and final prototype, a dual-media bucket filter, was selected for application at MBN on the basis of its ease-of-use, demonstrated bacterial reduction efficacy, and its use of locally available materials. Drawing on the knowledge and experiences of community participants enabled the design team to develop a contextually appropriate safe water system, capable of meeting the needs and capacities of local people.

In addition to being the locus of innovative collaboration, this stage in the project is also notable for community participation in data collection and analysis. Five participant households received a bucket filter, a safe water storage container and chlorine tablets and then asked to report on their degree of satisfaction with it as well as its ease-of-use. In addition, households were also tasked with performing presence-absence tests for fecal bacteria using H2S strip tests which are a simple, low cost, and rapid test for H2S producing bacteria associated with fecal contamination (Manja et al., 1982; Pillai et al., 1999). Findings demonstrated that 60.2% of water samples tested were free of H2S producing bacteria at the household level (95% CI: 47.6–72.8). Furthermore, participant assessments revealed a need for more comprehensive training when households received them. Ultimately, participatory data collection was more effective than conventional methods at solving complex problems, such as those encountered in marginalized communities of the developing world.
6.6  Level 5: Partner

Partnership is predicated on the basis of a mutual agreement in which decision-making control is more equally shared and no one party has the authority to assume a dominant role in decision-making. Effective co-management can be achieved when solutions are generated from a collaboration of all stakeholders and each stakeholder holds veto power, rendering the decision-making process one based on consensus. However, a power imbalance is inherent to any relationship where there are asymmetries in information, expertise or perceived authority. On this rung of Bruns ladder, the power of the local participants resides in their ability to disagree with the research partners and influence the process such that their concerns are accurately represented and addressed.

In anticipation of the end of the research project, researchers organized a community water committee at MBN. Four recruitment sessions, one in each sector of the community, informed residents about the need for a committee composed entirely of community members who would accept the full responsibility of maintaining the operation and management of the HWTS filter upon completion of the research project. Additionally, committee members would also potentially have to the role of being community emissaries to the local government when addressing water issues affecting the whole community. A group of ten women and one man who are local leaders and activists accepted these responsibilities and became formal partners with the research team. Forthcoming skills workshops and management training sessions will build the capacities of the individuals on the water committee while gradually phasing out the presence and transferring the responsibilities of the research team. Development projects that anticipate
the eventual transfer of control to a local managing body increase the potential for long-term effectiveness if this transfer occurs gradually. It was during the first group meeting that the committee autonomously selected its name, *The Five Star Water Quality Centre* (FSWQC), by which they will be referred to throughout the remainder of this document.

### 6.7 Level 6: Delegate Authority

Shifting to the community decision-making authority breaks with the traditional dichotomy between outside implementers and local participants in both international development and research projects. The research team relinquishes decision-making authority, delegating it to the community and choosing to accept whatever solutions they arrive at. True delegation is defined by the authoritative body’s inability to veto decisions made by the delegated party (Bruns, 2003).

The research team and the FSWQC started meeting on a regular basis to establish a framework for the transition of filter management into the hands of the community. During the second committee meeting, all participants were encouraged to share their personal reasons for participating in the group. Some of the reasons given included: the acquisition of knowledge for filter construction; the community health benefit of safe water; the maintenance of filter use within the community; and the potential for income generation. The FSWQC was assisted by researchers in the conceptualization of a mission statement:

> To improve the health of our community by using our knowledge and skills in water filtration to provide better quality drinking water.
The statement embodies the collective ideal of the FSWQC, uniting its members and mobilizing their efforts toward achieving the common goal of a self managed safe water system. Researchers encouraged the groups independence by creating identification cards for its members, each one individualized with the members picture, signature and address, while unifying them under the group name, reinforced by their mission statement proudly depicted at the bottom of the card.

In order for the research body to delegate authority, there must be a community management body with a sound operations and management framework, capable of being delegated to. Prompted by researchers during the third group meeting, the FSWQC identified eight executive positions required of an operations and management framework to oversee the maintenance, repair, reproduction and continuity of the safe water system in MBN. Apart from four sector representatives, the managing committee would incorporate a president, a secretary, a treasurer, and a field manager. Each position was clearly defined by all members of the FSWQC, highlighting their roles and responsibilities while emphasizing the importance of coordinated actions. Researchers had originally anticipated position assignment through a series of blinded elections; however, the FSWQC independently nominated their peers during the discussion of roles and responsibilities, unanimously assigning each member to a management position based on their known strengths and skill sets. In this exercise, researchers delegated the development of a management framework by promoting independent identification and allocation of group responsibilities, further preparing the FSWQC for subsequent decision making and greater responsibility.
6.8 Level 7: Establish Autonomy

In the seventh level of citizen participation and community self-management, the research body relinquishes certain management powers to the community, such as public service delivery and administrative tasks. The community is responsible for autonomous actions as permitted by a regulatory arrangement with the research body. Local decision-making is enacted by the ability of the community committee to act without the need for additional authorization from the research team; however, they must adhere to a set of general regulations mutually agreed upon with the research body. As Bruns suggests, this level might best be described as regulated autonomy.

Activities designed to establish community autonomy are currently underway, encouraging the FSWQC to assume managerial control and technical responsibility of the safe water system. Group members were invited to attend a half-day workshop at IIT Madras on the general principles of filter construction, the tools and materials involved, and their practical importance to the filters efficacy. A follow-up workshop in MBN reinforced the newly acquired skills, insisting that each group member independently construct a filter. In addition to a skills workshop, this exercise functioned as a non-monetary incentive for group participation since members were later able to take a filter home with them. In this second workshop, researchers assumed a passive role, setting the stage for group independence and diminishing the need for external support. This process of mobilizing knowledge and enhancing personal capacities has been extended to information transfer on small business management, record keeping, and service delivery. Door-to-door household visits, performed jointly with project researchers, have garnered support
for the FSWQC and raised community awareness of the forthcoming shift of filter management to community control.

It is anticipated that the FSWQC will eventually carry out filter operations and management independent of the research team under an umbrella of mutually-agreed principles. However, as of February 20th, 2012, the FSWQC is yet unqualified to undertake autonomous operation and management of the safe water system. Despite their knowledge of the technology and the appropriateness of their internally appointed management council, the FSWQC lacks motivation and places too much importance on monetary reward. Uncoordinated efforts, absenteeism at meetings, and the lack of an immediate financial return contribute to the vulnerability of the FSWQCs and threaten its capacity for independent management.

6.9 Level 8: Advise

This level of participation and community-self management assumes complete community independence but recognizes the community's potential need for technical assistance or professional guidance. An external advisory body assumes a supportive role, commonly in the form of an annual technical report or research study, providing the community group with helpful feedback. The report may suggest ways to improve efficiency or offer assistance in capacity building, but the community has no obligation to comply.

The implementation of development programmes with multiple objectives often requires support from third-party agencies. This is especially true of low-income settings, where the local population may have little education or professional training and lack both resources and coordination, such as MBN. Hand in Hand (HiH),
a coalition of independent NGOs with the aim of eliminating poverty through an integrated community development programme, were recruited to provide support to the FSWQC upon completion of the research project. A tripartite agreement was formed between HiH, the FSWQC and researchers from the University of Guelph and IIT Madras defining the needs and obligations of each stakeholder. Generally stated, HiH will function solely in a supportive role, reinforcing the existing community management structure while providing motivation and technical assistance where required. HiH will also liaise between the FSWQC and researchers from IIT Madras who will provide technical assistance and troubleshooting on issues which exceed the technical capacity of HiH. The benefits to HiH include the first-hand observation of filter efficacy and its potential for scalability in other like communities. The FSWQC will continue to build their repertoire of skills and solidify their operations and management framework toward the end of complete autonomy over the distribution, maintenance, and expansion of safe water systems in MBN. Until that autonomy is achieved, the FSWQC can look to its supporting institutions for guidance and assistance.

6.10 Level 9: Enable

This final stage of community participation is more appropriately applied to situations where the government has abdicated power to a local organization. In cases where the government (or authoritative body) no longer maintains a regulatory role, it may still play a significant role in legal administration and conflict resolution. As Bruns suggests, the government enables the community/organization through the application of a legal framework, contracts, liabilities and other matters.
Since the FSWQC is bound by no legal obligation to the research team, HiH or the local government, this stage in Bruns Extended Ladder of Participation is not applicable to this context.

6.11 Conclusion

Ultimately, program sustainability is up to the community. Local organizations and coalitions are capable of decentralized decision-making if they are first provided with the skills and resources necessary to oversee the task at hand. Development projects anticipating the eventual transfer of power to a local managing body increase their potential for long-term impacts if the shift in power occurs gradually. Applying a model of community participation assists this process by guiding program strategy and tailoring development activities to fit an appropriate level of community involvement.

Bruns Extended Ladder of Participation is an effective tool for addressing complex problems in the developing world, mobilizing available resources, and bridging the gap between participants and researchers. Imported technologies, commonly designed by engineers who prioritize technical ingenuity over context appropriateness, are less likely to achieve long-term sustainability than systems that are co-designed by an collaborative team of researchers and community participants (Bowen 2008; Murphy et al. 2009). Furthermore, application of a participatory framework encourages the formation of local alliances, developing lasting support and interdependence, eventually rendering the need for external assistance as unnecessary. Bruns model was found to be useful for the following reasons:

- it coordinates participatory research efforts and guides the transfer of power
to the community;

- it has the capacity to link technology and society, by guiding the development of AT and meeting the needs and capacities of the local people in a challenging environment;

- it has the capacity to guide the development and implementation of an appropriate research exit strategy, incorporating the smooth and gradual transfer of decision making power to a local managing body.

Bruns model presents an integrated approach to water resource management, engaging local organizations and the general public in participatory decision making. The model is effective in developing new AT, stimulating institutional reform, encouraging local involvement and promoting decentralized autonomy.
Chapter 7

Conclusions and Recommendations

7.1 Conclusions and Recommendations

Engineering can be described as the art of using science to mould and shape the resources of nature to meet the needs of human society. The last twenty-five years have seen a change in engineering practice to include critical reflection on public safety, health and welfare. Amadei et al. (2010), suggest that engineers have an ethical obligation to use their knowledge of science and technology in order to provide basic water, food, health and energy for all. This is especially true in regions of the underserviced and otherwise marginalized poor—more specifically in developing countries. The expansion of engineering into the global humanitarian field forces todas engineers to employ new methods for solving basic technological problems. Engineering practices typically employed in the developed world are often incongruous with the socio-cultural and physical environments encountered.
in developing communities (Cruickshank and Fenner, 2007). Therein lies the issue faced by humanitarian engineers today. How do we develop maintainable, socio-culturally appropriate, low cost, effective technology which promotes equity while leaving room for future development?

This section summarizes community health and sociological findings, as well as those from the water quality monitoring program, and finally findings and insights on program development and sustainability. The section concludes with recommendations for future research to improve our understanding of HWTS technology performance in the field, reduce performance variability, improve user satisfaction, and promote sustainability.

7.2 Community Health & Sociological Findings

- Gender based roles pitch women as both regulators and beneficiaries of water and its usage in the home. Unfortunately, the same social construct absolves local men of any and all responsibility in water preparation, segregating society and creating an imbalance of health awareness within the community. Consequently, household patriarchs are less educated on the dangers associated with untreated drinking water, yet in this patriarchal society they maintain ultimate decision making power over nearly all household affairs, including whether or not to treat household drinking water.

- Despite the high-risk environment presented by Mylai Balaji Nagar, a poor and marginalized community with inadequate water treatment, sanitation, and waste disposal services, overall intervention household diarrhoeal prevalence rates were an order of magnitude smaller than initial estimates drawn
from previous experiences in the literature. The unusually low prevalence may have resulted from a courtesy bias, where study participants reported low illness rates because they believed its what the researchers wanted to hear. Its also possible that participants failed to provide honest reports of household illness due to the embarrassment it may have caused, or because the longitudinal nature of this study could have incited participant fatigue.

- No difference in diarrhoeal disease prevalence was found between control and intervention households. Nor was there a significant difference in intervention household prevalence between pre- and post-baseline. For reasons unknown to the researchers, prevalence rates were too low to provide an accurate indication of water treatment effectiveness.

- Contrary to reported prevalence rates of diarrhoeal disease, households perceived significant reductions in the incidence of fevers, skin disease, diarrhoea, and colds throughout the course of the study. Participants with the intervention perceived a greater reduction in household illness than had actually been reported throughout the course of the study.

- The majority of intervention households preferred the smell of water treated using the safe water system over the smell of bottled water, and lorry water. Furthermore, intervention households found aesthetic benefit in the quality of water produced by the safe water system; 67%, 62% and 69% of households preferred its taste, odour, and colour, respectively. These perceived benefits helped to create a leverage point to counter-balance the trade-offs of compliance such as cost, time, and effort.
• Participant compliance with household water treatment technologies can be improved by enhancing the perceived benefit to the user, of which, improved health, taste, and aesthetics are principle factors.

• The deconstruction of perceived benefit revealed the importance of water taste, colour and odour, as well as perceived reduction in household illness, as significant predictors of participant compliance. Households with high and very high perceptions of treated water quality and water aesthetics were more than three times more likely to comply with treatment instructions, system maintenance, and safe water storage and retrieval practices.

• In light of the previous conclusion, greater disease prevention is possible if HWTSs are designed with more attention paid to the aesthetic preferences of the intended users.

• Participatory frameworks can improve the likelihood of sustainable water treatment by building upon existing knowledge systems that will encourage autonomy, boost participant self-confidence, and promote a sense of empowerment by identifying solutions to relevant community challenges and generating sustainable solutions.

### 7.2.1 Recommendations for Implementers

1. All efforts should be made to include local men, women, and children in the development and implementation of alternative water treatment. The advocacy of local men will encourage the diffusion of water treatment within the community and reinforce the importance of clean drinking water in com-
2. The unusually low diarrhoeal prevalence may have resulted from a courtesy bias, where study participants reported low illness rates because they believed it was what the researchers wanted to hear. It's also possible that participants failed to provide honest reports of household illness due to the embarrassment it may have caused, or because the longitudinal nature of this study could have incited participant fatigue. The recruitment of a local healthcare facility and their involvement in the project may cause participants to be more aware of changes in family health, evoking more accurate recall of recent illnesses. It would also provide researchers with an independent measurement of disease prevalence, with which to compare their own values.

3. The selection of target communities intended to receive HWTS should be guided by an in-depth baseline investigation of environmental, sociological, and community health measures. Only those communities expressing a clear demand for and sincere interest in water treatment should be chosen for implementation.

4. The research and development of an alternative water treatment system should involve the local community, be guided by a participatory framework, and give serious consideration to the aesthetic value of the water produced. All efforts should be made to produce treated water that the users find aesthetically pleasing in order to achieve the intended health impact.

5. Contextual appropriateness is equally as important as technical performance in the selection of a HWTS for application in poor and marginalized regions of
the developing world. Of particular relevance to the contextual appropriateness of HWTS are seven criteria that require the attention of implementers: size, safety, treatment effectiveness, capacity, affordability, ease of use, and durability.

7.3 Water Quality Findings

- Findings indicated significant improvement to the microbiological quality of drinking water treated with the SWS in a field-setting. However, the quality did not consistently meet WHO Water Quality Guidelines of >99.9% removal, or <1 cfu/100 ml of *E. coli* or thermotolerant coliform bacteria for small scale water treatment.

- The SWS was found to provide effective microbiological treatment of drinking water, with significant changes to the bacterial concentrations in intervention household samples. Total coliform and *E. coli* concentrations in intervention household water samples were significantly less than both control and intervention untreated water samples.

- Average LRVs across all months of study were 1.89 (UCL: 2.21) for total coliforms, and 1.53 (UCL: 1.82) for *E. coli*. These levels are consistent with the presumed effectiveness specified in WHO guidelines for granular media filtration (LRV 1 - 4+, for bacteria), but not for chemical disinfection (LRV 3 - 6, for bacteria). Few intervention households disinfected their water with NaDCC tablets, relying primarily on the treatment effect of filtration to purify their water.
The majority of treated water samples met the WHO Water Quality Guidelines for turbidity, with <1 NTU. However, the mean reduction in turbidity for intervention households samples was only 26.2% (SD: 44.9%), falling short of the WHO guideline of >90% removal for sand filtration.

Organic matter, reported by proxy measure of chemical oxygen demand (COD), was reduced by 53.0% (SD: 34.9%) in treated water samples. The mean COD in treated water samples was 9.6 mg/L (SD: 9.0 mg/L), below the permissible limit of 20 mg/L cited by the Bureaux of Indian Standards.

Intervention household treated water samples were significantly higher in total coliform and E. coli concentrations during the monsoon months, from August to November; a season with the lowest reported concentrations of bacteria in untreated water samples. It’s likely that transport and attachment of bacteria through the filter media was altered by the change in influent water characteristics, with smaller agglomerations of bacteria capable passing through the porous media unrestricted.

The combination of moringa coagulation and sari-cloth filtration significantly improved the turbidity of raw surface water. However, the same improvement to turbidity could have been accomplished by either sari-cloth filtration or moringa coagulation independently. The addition of moringa seed powder also appeared to increase organic levels in treated water, with greater doses of moringa resulting in higher COD levels.

The combined pre-treatment of moringa coagulation and sari-cloth filtration was most effective at reducing turbidity; nevertheless sari-cloth filtration
alone produced a significant reduction in turbidity with respect to controls. Since sari cloth filtration alone did not increase COD levels and associated bacterial re-growth—in addition to its low cost, ease of use, and availability—simple sari-cloth filtration is recommended as a pre-treatment for SODIS.

7.3.1 Recommendations for Implementers

1. Health education and community outreach should accompany the implementation of HWTS to promote consistent and effective water treatment. Only those households that are perfectly compliant in their water treatment and prevention of recontamination are capable of consistently meeting the WHO guidelines.

2. Disinfection with sodium dichloroisocyanurate is required in addition to filtration with the SWS in order to achieve bacterial concentrations of <1 cfu/100 ml. Additionally, residual chlorine levels will protect households drinking water from recontamination and the regrowth of bacteria. Challenges to the adoption of chemical disinfection may be overcome by comprehensive community-wide education, or the selection of an alternative secondary treatment such as solar disinfection.

3. For the treatment of influent waters with high concentrations of organic matter, bucket filter designs should incorporate a mechanism for filter drainage. Completely draining the filter between treatment applications prevents the pooling and stagnation of water within the filter, eliminating the development of odour causing algae and bacteria. Biosand filters are the exception to this rule, as they require that the filter bed be kept moist to maintain the
4. When considering the use of natural organics in the treatment process, such as *Moringa Oleifera* for coagulation-flocculation, implementers should conduct laboratory investigations prior to implementation in the field to assess for adverse effects. For example, water pre-treated with moringa coagulation did not outperform laboratory trials of sari-cloth filtration alone with respect to MPN levels of total coliforms. This may have been the result of coliform bacteria re-growth, following coagulation with moringa, which was observed in several replicate trials. The re-growth of total coliform bacteria may be associated with elevated levels of organics, as greater re-growth appeared to be associated with higher doses of moringa coagulant.

5. The performance of PoU water treatment is inconsistent, dependent on a long chain of causal factors. Seasonal variability has been demonstrated to affect the quality of water produced and the treatment effectiveness of the SWS. Implementers of this technology and other similar HWTS should be aware of such variability and prescribe the use of each HWTS within the confines of its capabilities. The SWS performs best with moderate to high concentrations of influent bacteria, observed during non-monsoon months. Lower concentrations of bacteria, resulting from excess rainfall were associated with significant reductions in performance.
7.4 Sustainability and Participatory Development

This project employed a participatory development framework in problem identification, technology development, technology implementation, programme assessment, and sustainable system management. Participatory research has been referred to as a post-normal science, designed to address complex interdisciplinary questions by bridging the gap between science and practice through community engagement (Wallerstein and Duran, 2010). Many scholars and practitioners argue that the standard or contemporary model of science and research is ill equipped to address the value-laden, multi-faceted health concerns of society (Bidwell, 2009; Martin and Sherington, 1997). It has been suggested that hypothesis driven normal science is too objective, focusing exclusively on individual risk factors, while failing to consider a broad combination of social and environmental conditions that impact overall health. Additionally, normal science is criticized for its dismissal of indigenous knowledge, its exclusion of local people from decision making, and for its top-down monopolistic control over the research process (Bennett, 2004; Bidwell, 2009; Brown et al., 2006). Conversely, participatory methods encourage partnership between researchers and local peoples in a unified effort to improve community health and eliminate social disparities. The following seven principles form the foundation of participatory research, as identified by Budd Hall, an early architect of this field (Hall, 1981; Bennett, 2004).

1. The community plays a central role in problem identification, investigation, and solution generation;

2. Project beneficiaries are members of the community in which the problem originates;
3. Members of the community play a full and active role in every aspect of the research project, from inception to completion;

4. Participatory research seeks out and attempts to include a wide range of marginalized groups of people, including the poor, the oppresses, and the exploited;

5. The goal of participatory research is to mobilize people and promote greater awareness through education, empowerment, and skills acquisition;

6. It is a scientific method which facilitates a more accurate and authentic analysis of social reality through community involvement;

7. The researcher is recognized as both an active participant and learner in the research process.

Participatory research is an effective tool for developing contextually appropriate intervention technologies that meet the needs and capabilities of local peoples in difficult settings such as the developing world. It has been used to guide resource management strategies and develop community cooperatives for long-term sustainable change (Bruns, 2003; Sanchez and Almeida, 1992). The sustainability of proposed interventions is thought to be enhanced by the inclusion of beneficiaries in the decision making process. Stakeholders are actively engaged at each level of the research process, contributing thoughts and ideas which ultimately shape the design and outcome of the study. Participatory research champions integrated knowledge translation; harmonizing technical scientific skills with indigenous knowledge and learned experience.
In recent decades, participatory research has received considerable attention. The inclusion of lay persons in the research process democratizes science by extending the peer community, but it should not be mistaken for a simple alternative to conventional methods. It is the exclusive purview of scientific experts that the research process is made more difficult by sharing decision making power with a diverse group of stakeholders, and by giving credence to their viewpoints and opinions (Bennett, 2004; Cornwall and Jewkes, 1995). Common challenges to community based participatory research include (Bennett, 2004; Wallerstein and Duran, 2010):

- Skepticism or disinterest amongst community members;
- Community unwillingness to invest the considerable amount of time and effort required in a participatory project;
- Task exhaustion amongst participants;
- Generating excitement and interest within the community without raising false hopes for highly successful research outcomes;
- Frustration amongst participants if the knowledge generated from the research does not translate into or guarantee access to benefits;
- The concept of research and its potential benefits may not be entirely understood by the community;
- Trust is essential between the community and the research team, but it takes time to establish and requires ongoing maintenance.
Other challenges are introduced by the researchers themselves, stemming from their own ambitions, preconceptions, and attitudes that can bias project outcomes. Some scholars suggest that participatory research can be used as a manipulative tool to sway community opinion (Hall, 1981; St. Denis, 1992). For example, the Canadian Department of Indian Affairs used participation as a coercive instrument in the development of the Indian Act of 1985, giving First Nation communities a false sense of inclusion in the decision making process (Bennett, 2004). In Arnstein’s Ladder of Citizen Participation, this phenomenon is termed Placation, since these instances of involvement are entirely superficial, giving the appearance of inclusion without being impactful (Arnstein, 1969). In such situations, feelings of frustration and resentment can manifest and have a detrimental effect on the participatory process.

Researcher bias, not often performed intentionally, can unwittingly affect study findings and participation. Some scholars have question the ability of researchers to maintain objective neutrality when working so closely with the community (Brown, 1993; Harding, 1998). Blurring the lines between empirical evidence and human emotion can lead researchers to confuse scientific solutions with ethical solutions. However, others argue that true participatory research should include researcher bias with an inclination toward the protection of human life (Bidwell, 2009).

Based on the works of Wallerstein and Duran (2003), Bidwell proposes a continuum between the pragmatic and emancipatory poles of community based research (Bidwell, 2009). The pragmatic model is more consultative in nature, commonly employing the service of advisory committees for problem focused development. It is often used as a supplemental measure to encourage greater participation rates and gain better access to guarded communities. In contrast, the emancipatory
approach aims to improve the lives of disenfranchised communities with social and institutional reform through the redistribution of power (Bidwell, 2009).

The current research, performed as part of the *Alternative Water Systems Project*, employed a combination of pragmatic and emancipatory measures to develop an appropriate HWTS system in MBN. We formed a co-design team composed of both community participants and project researchers. Together, we worked to understand and overcome complex development problems using our collective knowledge and problem-focused dialogue. Extensive community outreach was conducted in an effort to redress existing power imbalances and establish trusting relationships. The following section discusses elements of this participatory process and highlights aspects of the study design that enriched my own experience within the community and contributed to the wealth of our findings.

- The participatory development of the safe water system predisposed the technology to comply with local needs and capabilities while maintaining a necessary degree of cultural appropriateness. The pragmatic participatory action research (PAR) model employed in this project possessed elements of a learning alliance, an expert-led initiative to accelerate knowledge transfer and improve collaboration with non-experts in a dynamic multi-stakeholder environment that provide an ideal situation for technological development.

- This research revealed the importance and utility of adaptive methodologies such as PAR and AMESH for understanding complex ecological systems, using a plurality of stakeholder perspectives, and designing sustainable interventions capable of evolving to incorporate changes in local conditions. The evolution of the safe water system employed an iterative design process,
which adapted the technology to be more compatible with local lifestyles; encouraging user compliance and long-term adoption by promoting sustainable innovation and solution diversity.

- The transfer of project management and decision making power into the hands of local community leaders increases the potential for long-term impacts if the shift occurs gradually. Local organizations and coalitions are capable of assuming the responsibilities of decentralized decision-making if they are first provided with the skills and resources necessary to oversee the task at hand.

- In addition to the need for funding required to cover operational costs, the payment of allowances or financial incentives to the community management team is essential. Members of the FSWQC openly expressed their unwillingness to assist the group or even attend group meetings without some form of reward. The idea of forthcoming payment for work performed 'today' was not acceptable to the FSWQC. Future development projects should include in their budget a nominal start-up allowance for community based organizations that are anticipated to assume managerial control of the project.

- Bruns’ *Extended Ladder of Participation* is an effective tool for addressing complex problems in marginalized communities, mobilizing available resources, and bridging the gap between participants and researchers. It presents an integrated approach to water resource management, engaging local organizations and the general public in participatory decision making. The model is effective in developing new AT, stimulating institutional reform, encouraging local involvement and promoting decentralized autonomy.
7.4.1 Recommendations for Implementers

1. Implementers should encourage the participation of local stakeholders, not only in the implementation and assessment of HWTS, but also in their development. Contextual appropriateness is a highly complex social phenomenon most effectively addressed by coalescing technical skills and local knowledge, guided by human values. Encouraging user participation throughout the research and development process promotes the long term adoption and sustainability of HWTS.

2. Participatory development should be considered an iterative process that encourages solution diversity and endorses the evolution of technical innovation. Regular program evaluation and adaptation champions sustainable development in poor and marginalized communities of the developing world, areas characterized by regular social, political, and environmental change.

3. Implementers need to be accountable for the sustainability of their development projects. The gradual transfer of knowledge and expertise, skills development, and decision making authority to community based organizations disposes the community to lasting behavioural change and long-term adoption of newly implemented HWTS. This process is supported by the application of a participatory management framework, such as The Extended Ladder of Participation, by Brian Bruns, which has the capacity to guide the development and implementation of an appropriate research exit strategy, incorporating the smooth and gradual transfer of decision making power to a local managing body.
7.5 Study Limitations

This dissertation provides a pragmatic model for the participatory development of a sustainable household water treatment and safe storage technology in marginalized communities. It identifies challenges and provides strategies to mitigate technical, social, institutional, and geographical barriers to achieving the desired public health outcome. However, there are limitations to the research that are addressed below:

1. A narrow range of treatment technologies were considered for application in MBN, excluding other potential technologies. Further research should consider a broader spectrum of treatment alternatives in order to more effectively match technical mechanisms with local conditions (Murphy et al., 2009).

2. In MBN, as in much of South India, women are expected to remain at home with the children, and perform domestic chores, which include water collection, and in some cases, water treatment; gender based roles pitch women as both regulators and beneficiaries of water and its usage in the home. Unfortunately, the same social construct absolves local men of any and all responsibility in water preparation, segregating society and creating an imbalance of health awareness within the community. Attempts were made to enrich project participation among local men and boys through project activities and health awareness programming. Unfortunately, a lack of interest amongst community men, likely as a result of social prejudice, challenged the diffusion of the safe water system in MBN, impacting adoption rates and participant compliance.

3. Low diarrhoeal prevalence in the study community limited our ability to
perceive and record the effects of the SWS on disease transmission. Significant reductions in diarrhoeal prevalence as a result of water quality improvement are only possible in communities where drinking water is the principle source of disease transmission (DeWilde et al., 2008; Moe et al., 1991; Arnold and Colford, 2007; Schmidt et al., 2007).

4. The implementation of development programmes with multiple objectives often requires support from third-party agencies. This is especially true of low-income settings, where the local population may have little education or professional training and lack both resources and coordination, such as MBN. Hand in Hand (HiH) was commissioned to provide technical, logistical, and administrative assistance to the FSWQC following project completion and the withdrawal of research programming. Regrettably, this effort to marry local management with external support failed due to a lack of inter-group communication, a general lack of interest, and a lack of unity in the pursuit of a common goal. However, sustainable partnerships between community based organizations and third-party institutions are possible if allegiances are forged early, during the project outset, and provided the time to strengthen. The delayed introduction of the FSWQC to HiH, in the current project, did not allow enough time for the two groups to create an effective communication strategy or form a trusting relationship. Consequently, the partnership failed, and the FSWQC dissolved, causing current users of the SWS to become completely self-reliant.

5. Financial assistance has been identified as a principle determinant of the impact of community based water services (Isham and Kahkonen, 2002;
Opare, 2011; Roma and Jeffrey, 2011). In addition to the need for funding required to cover operational costs, the payment of allowances or financial incentives to the community management team is essential. Members of the FSWQC openly expressed their unwillingness to assist the group or even attend group meetings without some form of reward.

7.6 Recommendations for Future Research

Evidence suggests that HWTS technologies meet an urgent need for water treatment in the poor and marginalized communities of the developing world, reducing child mortality, and empowering the poor with access to safe drinking water. Conversely, water quality produced by HWTS has been reported as highly variable, often containing a significant concentration of waterborne pathogens, and potentially creating a false sense of safety. Further research is needed into the performance of these technologies in the field, reducing performance variability, improving user satisfaction, and promoting sustainability. The following is a list of recommendations for future research.

1. Give greater consideration to a wider range of household-level treatment options, such as ceramic pot filtration, biofiltration, solar disinfection, and pasteurization, and also community-level treatment options, such as slow sand filtration, coagulation-flocculation, and combined treatment. Greater recruitment of community participation and decision making in the selection of an appropriate treatment technology may encourage a greater sense of project ownership, community involvement, and technology adoption.
2. Investigation into the social and economic barriers to the formation of community based organizations. International development and humanitarian engineering require a greater understanding of the process required to form sustainable community management of newly implemented systems and technologies.

3. Determine maintenance cycles for the SWS given different influent water quality characteristics, treatment schedules, and volumes.

4. Creation of a user friendly indicator test for the presence of faecal coliform bacteria in drinking water following point-of-use treatment, which may help to ensure the quality of drinking water before its consumed. This research project considered the use of hydrogen sulfide (H\textsubscript{2}S) strips for the detection of faecal coliforms in drinking water to be administered by each participant household. However, in a preliminary trial of this design, some households abandoned the SWS when their treated water tested positive for the presence of hydrogen sulfide producing bacteria. Consequently, the idea of independent household surveillance of drinking water quality was omitted from the study, out of concern that positive test results would provoke widespread study attrition. However, presence-absence tests for faecal coliforms present a unique opportunity for quality assurance to be performed independently by the user, presenting greater potential to achieve the desired public health outcomes of HWTS.

5. Research into the social and health benefits of combining water treatment with water source protection and remediation. This approach is especially relevant in India where water bodies are considered appropriate sites for solid
waste disposal.
Appendices
Appendix A

Permission to include published journal articles in the dissertation
TO WHOM IT MAY CONCERN

The Cooperation & Development Center (CODEV) at EPFL hosted the 2012 International Conference of the UNESCO Chair in Technologies for Development from 29-31 May 2012.

We hereby confirm that the paper:

Applying an Extended Ladder of Participation for the Development of a Community-Managed Safe Water System in a Marginalized South Asian Community

which was presented at the conference by the lead author Mr. Morgan MacDonald, can also be included in Mr. MacDonald’s PhD dissertation.

With sincere best regards,

S. Hostettler
Deputy Director, Cooperation & Development Center
EPFL, Lausanne
18 June 2013

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21 June 2013

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Appendix B

Efficacy of an appropriate point-of-use water treatment intervention for low-income communities in India utilizing Moringa oleifera, sari-cloth filtration, and solar UV disinfection
A.2 Introduction

Throughout the global South, people living in rural areas and peri-urban slums are often forced to rely upon contaminated surface water as their primary drinking water source, resulting in significant burdens of water-related disease. Point-of-use (PoU) water treatment technologies have been shown to improve the quality of drinking water at the household level and can achieve rapid health gains amongst marginalized populations (Fewtrell et al., 2005). A range of water treatment options are available for applications at both the household and community level (Sobsey, 2002). Sustainable options are those that meet local capabilities in terms of materials and resources, encourage local participation, and are flexible, adaptable and socio-culturally appropriate (Murphy et al., 2009).

A.2.1 Opportunities and challenges with solar UV disinfection

Solar disinfection (SODIS) is one of the simplest and most cost-effective methods for improving the microbiological quality of drinking water currently available. It employs the synergistic effects of thermal and ultraviolet (UV) radiation treatment, killing up to 99.9% of waterborne pathogens (Hijnen et al., 2006; Wegelin et al., 1994). By mimicking the thermal effects of the Nairobi sun, Joyce et al. (1996) found that E. coli levels were reduced by six orders of magnitude following seven hours of exposure. Similarly, Wegelin et al. (1994) found that the synergistic effect of water temperature could enhance the efficiency of SODIS by approximately a factor of two, once a threshold of 50°C had been reached. Photocatalytic disinfection of waterborne pathogens by UV irradiation is also central to the SODIS method.
Gómez-couso et al. (2009) found the infectivity of Cryptosporidium parvum oocysts to be inversly proportional to radiation intensity. Furthermore, Lonnen et al. (2005) found that simulated solar exposure at 200 W/m² in the 300-400 nm UV range produced a 4-log reduction in protozoan, fungal and bacterial viability. Field studies have also demonstrated SODIS can significantly reduce the incidence of diarrhoeal disease in children under the age of five (Conroy et al., 1999; Rose et al., 2006). In addition, compliance with SODIS is generally high. In 75% of visits to the field, Rose et al. (2006) found that 78% of households in Vellore, India practiced appropriate SODIS application following a safe water intervention.

In comparison to household chlorination, another prevalent PoU technique for disinfecting drinking water, SODIS can circumvent the formation of potentially carcinogenic disinfection by-product (DBPs) associated with the chemical disinfection of natural waters containing organic compounds. Furthermore, reactions between chemical disinfectants and organics may also produce taste and orour compounds which render the water less palatable, limiting uptake (Freeman et al., 2005). For these reasons, SODIS is seen as an attractive option for improving the microbiological quality of water at the household level. It may be well applied amongst extremely impoverished households, as a first-line, gap-filling measure.

The penetration of ultraviolet radiation, and thus the effectiveness of the SODIS process, is negatively affected by the presence of colour and turbidity in the water to be treated (Gómez-couso et al., 2009). For this reason, treatment with SODIS is not recommended for water with turbidity greater than 30 NTU (SANDEC, 2008). Clarifying water prior to SODIS treatment can improve its effectiveness, and for some natural waters, clarification may in fact be a necessary pre-treatment step. For this reason, the present study seeks to investigate two potential pre-
treatment methods for SODIS – *Moringa oleifera* a natural plant-based coagulant, alone or in combination with used cotton sari-cloth filtration. These methods may be applied in conjunction with SODIS to form a simple, combined PoU treatment system for low-income rural and peri-urban households in the Indian subcontinent and elsewhere.

### A.2.2 *Moringa oleifera*: A potential natural coagulant pre-treatment for SODIS

*Moringa oleifera* is a flowering tree found widely in tropical and sub-tropical climates from South Asia to West Africa. In addition to an array of nutritional and traditional uses, the desiccated seed powder of *M. oleifera* has also been observed to have coagulant properties and can be used for water clarification purposes (Babu and Chaudhuri, 2005). Laboratory studies show that moringa coagulation can remove up to 90 to 99 % of bacterial contamination and up to 96 % of influent *E. coli* (Madsen et al., 1987; Nkurunziza et al., 2009). Olduru et al. (2007), noted a 97.5 % reduction of coliform bacteria upon treatment with *M. oleifera*, however the same study also found secondary bacterial growth of *E. coli*, *Salmonella typhi* and *Shigella dysenteriae* at 185 %, 189 % and 198 % of their influent concentrations respectively, 24 hours post-treatment. Re-growth of secondary bacteria in *M. oleifera* treated water has also been observed in other studies (Madsen et al., 1987; Wilson, 2010). Lea (2010), recommends the frequent treatment of smaller volumes of water in order to avoid bacterial re-growth prior to consumption. The debate over the efficacy of *M. oleifera* in water treatment is on-going. Growing naturally in many rural areas, *M. oleifera* could be an inexpensive and widely-
available coagulant for PoU water treatment purposes; however, further testing is required with natural surface waters to determine its bacterial removal efficacy and its potential as a pre-treatment for SODIS.

Moringa coagulation has previously been assessed as a pre-treatment for chemical disinfection, with recent studies indicating that moringa may not be a desirable option for use in conjunction with the common chlorination agent sodium hypochlorite (Preston et al., 2010). For one, moringa introduces natural organic matter to the treated water which itself exerts a chlorine demand, requiring larger doses of hypochlorite and reducing the likelihood that an adequate residual can be maintained. Furthermore, hypochlorite reacts with natural organic matter to form taste and odour compounds, and more troublingly, trihalomethanes (THMs) and other potentially harmful DBPs (Ghebremichael et al., 2006). Given this chemistry, moringa coagulation is not a suitable pre-treatment for chemical disinfection; however it may be an appropriate pre-treatment prior to UV disinfection, as irradiation does not induce DBP or taste and odour compound formation in the presence of organics.

A.2.3 Sari cloth filtration: A second potential pre-treatment for SODIS

The present study also examines simple filtration with used cotton sari-cloth as a pre-treatment for SODIS. Though sari-cloth is specific to the South Asia region, the filtration effect is likely observable for any previously used cotton fabric. Colwell et al. (2003), showed that simple cotton sari-cloth, folded several times, produced a filter of effective pore size of 20 μm that had the ability to remove copepod
zooplankton, upon which *Vibrio cholerae* are commensal. Though this pore size would be unable to remove free-floating bacteria which typically range in size from 1 to 5 m, it may be able to capture some of the solids that contribute to turbidity. In addition, sari cloth filtration may effectively remove flocs formed during moringa coagulation, in doing so possibly enhancing its effectiveness. Combining moringa coagulation and sari cloth filtration could be a simple, inexpensive, and widely available pre-treatment for SODIS applications.

This study aims to assess the efficacy of a multi-stage PoU water treatment system combining moringa coagulation and/or sari-cloth filtration with SODIS, using a contaminated surface water source taken from a peri-urban slum in Chennai, India. In doing so, it will investigate whether moringa coagulation and/or sari cloth filtration are suitable pre-treatments for SODIS. Turbidity, organic content, and microbiological quality of treated water will be assessed at various stages and configurations of the proposed treatment system.

### A.3 Methods

#### A.3.1 Setting

All research activities were conducted at the Environmental and Water Resources Engineering labs of the Indian Institute of Technology Madras (IITM) in Chennai, India. Water samples for this study were taken from a surface water body supplying a peri-urban slum (Mylai Balaji Nagar) in south Chennai, Tamil Nadu, India. The lake is a receiving body for runoff from surrounding neighbourhoods and on-going monitoring of the lake indicates that water quality is severely degraded.
with excessive levels of organics, turbidity, and microbiological contamination (Ali, 2010).

A.3.2 Study design

We obtained raw lake water and subjected it to three stages of treatment: moringa coagulation (at different dosages of coagulant), sari cloth filtration, and SODIS. We extracted samples for analysis prior to treatment and again after each treatment stage. We analyzed for three parameters: turbidity, measured in nephelometric turbidity units (NTU) with a Eutech Instruments TB1000 Cyberscan WL Turbidimeter (Thermo Fisher Scientific, Navi Mumbai, India); organic content through the proxy measure of chemical oxygen demand (COD), following the standard laboratory method (APHA, 2005); and microbiological quality through the proxy measure of total coliforms estimation using the most probable number (MPN) method (APHA, 2005). All readings were done in triplicate to ensure accuracy and the results were averaged for reporting purposes. A total of eight replicate experiments were conducted, three in May 2010 and five in October 2010. The experimental design is outlined in Figure A.1.

A.3.2.1 Preparation of moringa stock solution

Desiccated seeds of *Moringa oleifera* (var. PKM1) were obtained from the Regional Research Station in Paiyur, Krishnagiri District, Tamil Nadu, India (Figure 3.2). Following the procedure described by Lea (2010), the seeds were shelled and ground to a fine powder using a mortar and pestle, then sieved using a 0.4 mm mesh tea strainer. The seed powder was then mixed with an appropriate volume of distilled
Figure A.1: Schematic representation of experimental design
water in a clean, re-sealable PET soft drink bottle in order to produce a 10,000 mg/L stock solution (by dry weight). Fresh stock solution was prepared the day of each replicate experiment.

![Image of seeds]

**Figure A.2:** *M. oleifera*. L to R: desiccated seed, shelled kernels, and ground and sieved seed powder

### A.3.3 Influent water sample collection

For each replicate experiment, we collected 20 litres of raw lake water in 5 litre plastic containers. The water was drawn from four different locations in the lake and mixed together in the lab in order to account for known spatial variability of lake water quality. A sample of the raw lake water was extracted after mixing for
analysis to determine influent water quality.

A.3.3.1 Stage 1: Moringa coagulation

Preliminary jar tests indicated 100 mg/L to be the optimal dose of moringa coagulant, which is consistent with guidelines drawing on previous experience (Lea, 2010). Four plastic beakers were each filled with 2 litres of raw source water. Into each of the four jars a different volume of moringa stock solution was added. Jar 1 received no moringa stock solution and was thus a sari-filtration-only control jar. Jars 2, 3, and 4 received a sub-optimal dosage (50 mg/L), an optimal dosage (100 mg/L), and a supra-optimal dosage (150 mg/L) respectively. The jars were then placed on a Scientific Engineering Corporation Cat. No. SECOR 41 flocculator/jar test apparatus (Delhi, India) and subjected to rapid mixing for 2 minutes at 100 rpm, followed by slow mixing at 10 rpm for 20 minutes, and finally settling under quiescent conditions for 1 hour. Following settling, samples were decanted from each jar for analysis.

A.3.3.2 Stage II: Sari cloth filtration

Four sections of previously-used cotton sari-cloth measuring 1 m x 2 m were washed with laundry soap and air-dried in the sun. Sari cloths were folded 4 times to produce 16 layers of fabric and then secured with an elastic band over the opening of four clean beakers. Each jar from the previous stage was then decanted into the clean beakers through the sari-cloth filters. Following filtration, water samples were extracted for analysis.
A.3.3.3 Stage III: Solar UV disinfection

Following sari-cloth filtration, the waters from the four beakers were placed in four clean 2 litre PET bottles (i.e. common 2 litre plastic soft drink bottles) and positioned in direct sunlight for 4-5 hours on an inclined roof surface (Figure A.3).

![Figure A.3: Bottles placed on inclined roof surface for SODIS stage](image)

Though SODIS guidelines recommend a minimum exposure period of 6 hours for sunny conditions (EAWAG, 2010; Wegelin et al., 1994) (EAWAG, 2010; Wegelin et al., 1994), only 4-5 hours were possible during the present experiment because of the time required to complete the preceding experimental steps.

A SODIS-only control was prepared by filling a 1 litre bottle with raw source water and subjecting it to the SODIS stage only, without moringa coagulation or
sari-cloth filtration (Figure A.4). Additionally, a sample of raw source water was collected at the end of the day and analysed as a no-treatment control.

Figure A.4: Bottles ready to be subjected to SODIS

A.3.4 Data analysis

All data was compiled in Microsoft Excel and analyzed with the Analysis Toolpak for statistical difference between means using the one-tailed (unless otherwise indicated) paired t-test with $\alpha=0.05$. 
A.4 Results and Discussion

As several replicate experiments were conducted, the influent water quality was found to vary substantially from trial to trial. To account for this, all analytical results were normalized as a fraction of the influent concentration on the specific day of the replicate experiment. In the graphs in the following section, the labels along the abscissa MO, SF, and UV represent the water quality of the treated water after moringa coagulation (Stage I), after sari-cloth filtration (Stage II), and after UV disinfection (Stage III), respectively. The first set of bars on each graph, labelled as SW, represents the influent concentration of the source water and is thus normalized as 1. The two control samples described in the preceding section the no-treatment control and the SODIS-only control were sampled after the final stage of treatment, UV (Stage III), and thus appear with the final set of bars on each graph. Finally, the number of replicate experiments aggregated in the summary measures is given by the n value indicated above each bar, and the error bars represent the standard error of the mean.

A.4.1 Turbidity reduction

Average turbidity reductions for each test jar, aggregated across all available replicate trials, are presented in Figure A.5.

The final turbidity levels after the multi-stage treatment process, with associated 95% confidence intervals are given in Table A.1.
Figure A.5: Average turbidity removal efficacy of treatment

Table A.1: Relative turbidity levels after multi-stage treatment process with associated 95% CI intervals

<table>
<thead>
<tr>
<th>Moringa jars</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample/Jar</td>
<td>1</td>
</tr>
<tr>
<td>Relative Turbidity</td>
<td>0.47</td>
</tr>
<tr>
<td>95 % CI</td>
<td>0.10</td>
</tr>
</tbody>
</table>

At any given treatment stage in the graph above, it can be seen that with each progressive increase in moringa dosage there is a corresponding reduction in turbidity. As expected, when the moringa concentration exceeds its optimal dose there is a trend towards diminishing returns. There also appear to be progressive
reductions in turbidity after the moringa coagulation stage and then again after the sari cloth filtration stage, suggesting that both of these treatments are effective at improving the turbidity of treated water. As expected, there is no apparent change in turbidity following the UV stage as SODIS is not expected to effect the turbidity of the water. Although it appears in the graph above that moringa coagulation with the optimal dose alone (MO - Jar 3) engenders a greater reduction in turbidity than does sari-cloth filtration alone (SF - Jar 1), the apparent superiority of moringa coagulation over sari-cloth filtration was not found to be statistically significant (P=0.06, n=7). However, combining optimal moringa coagulation and sari-cloth filtration (SF - Jar 3) does outperform sari-cloth filtration alone (SF - Jar 1) at a statistically significant level (P=0.0001, n=7). Likewise, sari-cloth filtration following moringa coagulation (SF - Jar 3) significantly improved turbidity reduction compared to just moringa coagulation alone (MO - Jar 3) (P=0.016, n=7). Both of these observations show that the combination of moringa coagulation and sari-cloth filtration is an effective means to improve turbidity, and the combination of the two is more effective at improving turbidity than either method by itself. The combined treatment chain of optimal moringa coagulation, sari-cloth filtration, and SODIS (UV - Jar 3) significantly improved turbidity with respect to both the SODIS-only control (UV - Raw water UV treated) (P=0.0002, n=4) and the blank control (UV - No treatment) (P=0.006, n=3) as expected. Similarly, the jar receiving only sari-cloth filtration pre-treatment before SODIS (UV - Jar 1) significantly improved turbidity with respect to the control with no-pre-treatment before SODIS (UV - Raw water UV treated) (P<0.05, n=5).
A.4.2 Effect on organic content (COD)

The aggregated effect of the treatment process on the organics in the water, as measured by COD, is presented in Figure A.6.

![Figure A.6: Average effect of treatment process on COD, aggregated from several replicate trials (given by n)](image)

Final COD levels following the full treatment chain, with associated 95% confidence intervals, are given in Table A.2.
Table A.2: Relative COD levels following multi-stage treatment process with associated 95% CI intervals

<table>
<thead>
<tr>
<th></th>
<th>Moringa jars</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample/Jar</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Relative COD</td>
<td>1.10</td>
<td>1.14</td>
</tr>
<tr>
<td>95% CI</td>
<td>0.69</td>
<td>0.97</td>
</tr>
</tbody>
</table>

As seen in the graph above, COD levels appear to increase following the addition of moringa in the first stage of the treatment process. These levels remain relatively stable through the second sari-cloth filtration stage and then appear to decline following the final UV disinfection stage. The observed increase in COD levels was expected given the introduction of organic material with the moringa solution, as has been observed by other workers (Arnoldsson et al., 2008; Ghebremichael et al., 2006). The apparent decline in COD levels following the SODIS stage may be explained by UV-mediated degradation of organic compounds (Wetzel et al., 1995). Those samples receiving greater concentrations of moringa displayed higher COD levels. For instance, after the final UV treatment stage, the jar receiving a moringa dose of 100 mg/L (UV - Jar 3) displayed more COD than that jar receiving only 50 mg/L (UV - Jar 2) (P=0.04, n=7). Extracting the seed oil and using only the presscake (which is as effective a coagulant agent) is one possible means to control the enrichment of organics in treated water (Lea, 2010).
A.4.3 Effect on microbiological quality

The effect of the treatment process on the microbiological quality of the water was analysed with total coliform estimation using the MPN method. This method indicates the most probable number of total coliform bacteria per 100 mL of sample water. Aggregate results from several replicate trials are presented in Figure A.7.

![Figure A.7: Effect of treatment process on microbiological quality of water as represented by MPN](image)

The final MPN levels for each of the moringa jars and controls, after all three stages of the treatment chain, are presented in Table A.3.
Table A.3: Relative MPN levels following multi-stage treatment process with associated 95% CI intervals

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moringa jars</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Relative MPN</td>
<td>0.11</td>
<td>0.27</td>
</tr>
<tr>
<td>95% CI</td>
<td>0.16</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Figure A.7 above shows a progressive reduction in total coliforms with each stage of treatment. Following the moringa coagulation stage there is an apparent decrease in the level of MPN for all moringa dosages, a slight decrease for most jars after sari-cloth filtration, and then another substantial decrease following UV treatment for all jars. As indicated in Table A.3, the four treatment jars reduced MPN levels to between 10% and 27% of the influent level. Though these trends can be observed in Figure A.7, due to the strong variability present in the data, they cannot be corroborated statistically. The optimal moringa coagulation and sari-cloth filtration pre-treatment (UV - Jar 3) did not appear to outperform pre-treatment with sari-cloth filtration alone (UV - Jar 1) (Ptwo-tail=0.41, n=3). Likewise, we cannot statistically conclude that either of the pre-treatments or their combined application had any effect on the microbiological content of the water with respect to the controls. However, it has previously been reported that SODIS is less effective when applied to turbid waters (Sobsey et al., 2008). Given that moringa and sari-cloth filtration were found to significantly improve turbidity, one would expect greater efficacy of SODIS as well.

An interesting feature can be observed in Jar 4 in the SF stage in Figure A.7.
The MPN level increases from 0.34 to 0.52 of the influent level in the one hour of time elapsed between the moringa coagulation stage and the sari-cloth filtration stage. This apparent re-growth was observed several times in the individual replicate experiments for all jars receiving a dose of moringa; however, due to the variability in the data, it is not visible in the aggregated data with the exception being Jar 4. The re-growth phenomenon can be more clearly seen in the disaggregated data from the individual trials, for instance in the first replicate (Figure A.8).

![Graph showing Total Coliforms (MPN) reduction efficacy of treatment process]

**Figure A.8:** Total Coliforms (MPN) reduction efficacy of treatment process

As previously discussed, the application of moringa resulted in elevated COD levels (Figure A.6). The re-growth of total coliform bacteria was not observed in Jar 1 (Figure A.8), the one jar receiving no moringa, suggesting that the addition of moringa may encourage bacterial growth in treated waters. The natural organic material introduced with the moringa coagulant may acts as a nutrient source encouraging the growth of various bacteria species. This may also explain why Jar 4, having received the greatest dose of moringa, displayed the apparent re-growth
in Figure A.7. Furthermore, re-growth facilitated by nutrient enrichment with moringa addition may explain why optimal moringa coagulation with sari-cloth filtration (Jar 3) did not outperform sari-cloth filtration alone (Jar 1) with respect to microbiological quality. Although moringa coagulation reduces turbidity more effectively than simple filtration, it does so at the cost of increasing the organics content and very possibly, the total coliform levels. It should be noted however that the re-growth of total coliform bacteria does not necessarily indicate the re-growth of pathogenic bacteria (EAWAG, 2010) NO REF. Further research is needed to better characterize the relationship between COD and MPN during household-level moringa coagulation.

A.5 Conclusions

Solar UV disinfection (SODIS) has been advocated as a simple, low-cost, and effective means of improving the microbiological quality of water and has several benefits over household chlorination. However, like chlorination, its effectiveness is limited when waters are turbid, and as such, pre-treatments to control turbidity may be necessary. The present study sought to examine two low-cost, appropriate pre-treatment methods: coagulation with desiccated seed powder of M. oleifera and/or sari-cloth filtration. Pre-treatment combining optimal moringa coagulation and sari-cloth filtration significantly improved the turbidity of raw surface water compared to controls, as did either pre-treatment alone compared to controls. More importantly however, combining optimal moringa coagulation with sari-cloth filtration significantly improved the turbidity reduction that either sari-cloth filtration or optimal moringa coagulation could achieve independently.
The addition of moringa seed powder also appeared to increase organic levels (as measured by COD) in treated water, with greater doses of moringa resulting in higher COD levels. Similarly, reductions in microbiological contamination (as measured by MPN/100 mL) - between 10 and 27% of influent levels were observed for all jars subject to pre-treatment; however, due to considerable variability in the data, this apparent improvement was not found to be statistically significant when compared to controls. It was observed however that jars also undergoing moringa coagulation did not outperform those undergoing sari-cloth filtration alone with respect to MPN levels. This may have been the result of coliform bacteria re-growth, following coagulation with moringa, which was observed in several replicate trials. The re-growth of total coliform bacteria may be associated with elevated COD levels, as greater re-growth appeared to be associated with higher doses of moringa coagulant. Further investigation as to the relationship between organic content and microbiological contamination of treated water, is required before moringa coagulation can be recommended as a pre-treatment for SODIS in the field.

In general, the combined pre-treatment of moringa coagulation and sari cloth filtration was most effective at reducing turbidity, nevertheless sari-cloth filtration alone produced a significant reduction in turbidity with respect to controls. Since sari cloth filtration alone did not increase COD levels and associated bacterial re-growth—in addition to its low cost, ease of use, and availability—simple sari-cloth filtration is recommended as a pre-treatment for SODIS.
A.6 Acknowledgements

This work was carried out with the aid of a grant from the International Development Research Centre (IDRC), Ottawa, Canada.
Appendix C

Ethics Approval Documents
The members of the University of Guelph Research Ethics Board have examined the protocol which describes the participation of the human subjects in the above-named research project and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement.

The REB requires that you adhere to the protocol as last reviewed and approved by the REB. The REB must approve any modifications before they can be implemented. If you wish to modify your research project, please complete the Change Request Form. If there is a change in your source of funding, or a previously unfunded project receives funding, you must report this as a change to the protocol.

Adverse or unexpected events must be reported to the REB as soon as possible with an indication of how these events affect, in the view of the Responsible Faculty, the safety of the participants, and the continuation of the protocol.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and approvals of those facilities or institutions are obtained and filed with the REB prior to the initiation of any research protocols.

The Tri-council Policy Statement requires that ongoing research be monitored by, at a minimum, a final report and, if the approval period is longer than one year, annual reports. Continued approval is contingent on timely submission of reports.

Membership of the Research Ethics Board: M. Bowring, CME; F. Caldwell, Physician (alt); J. Clark, PoliSci (alt); J. Dwyer, FRAN; M. Dwyer, Legal; D. Dyck, CBS; D. Emslie, Physician; M. Fairburn, Ext.; J. Hacker-Wright, Ethics; G. Holloway; CBS (alt); V. Kanetkar, CME (alt); L. Kuczynski, FRAN (alt); S. Lachapelle, COA; L. Mann, Ext.; J. Minogue, EHS; P. Saunders, Alter. Health Care; S. Singer, COA (alt); L. Son Hing, Psychology; V. Shalla, SOAN (alt); L. Spriet, CBS; L Trick, Chair; T. Turner; SOAN; L. Vallis; CBS (alt).

Approved: ______________________ Date: ______________________
per
Chair, Research Ethics Board
The members of the University of Guelph Research Ethics Board have examined the protocol which describes the participation of the human subjects in the above-named research project and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement.

The REB requires that you adhere to the protocol as last reviewed and approved by the REB. The REB must approve any modifications before they can be implemented. If you wish to modify your research project, please complete the Change Request Form. If there is a change in your source of funding, or a previously unfunded project receives funding, you must report this as a change to the protocol.

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The Tri-council Policy Statement requires that ongoing research be monitored by, at a minimum, a final report and, if the approval period is longer than one year, annual reports. Continued approval is contingent on timely submission of reports.

Membership of the Research Ethics Board: B. Beresford, Ext.; F. Caldwell, Physician; K. Cooley, Alt. Health Care; J. Clark, PoliSci (alt); J. Devlin, OAC; J. Dwyer, FRAN; M. Dwyer, Legal; D. Dyck, CBS; D. Emslie, Physician (alt); H. Gilmour, Legal (alt); G. Holloway, CBS (alt); B. Ferguson, CME (alt); S. Henson, OAC (alt); L. Kuczynski, Chair; J. Minogue, EHS; I. Newby-Clark, Psychology (alt); L. Niel, OVC (alt); A. Papadopoulos, OVC; B. Power, Ext.; L. Robinson, CBS; V. Shalla, SOAN (alt); L. Son Hing, Psychology; J. Srbely, CBS (alt); T. Turner, SOAN; E. van Duren, CME.

Approved: ______________________
Chair, Research Ethics Board

Date: ______________________
Appendix D

Project Surveys
**Household Data**

Interviewer Name: ……………………………      Date (D/M/Y): ………………………………

Household Code: ……………………………

---

**Disease Status**

<table>
<thead>
<tr>
<th>Question</th>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1. Do you have soap in your house for washing hands?</td>
<td>☐ 1. Yes</td>
</tr>
<tr>
<td>Q2. Has anyone in your family had diarrhea in the last 7 days prior to</td>
<td>☐ 1. Yes</td>
</tr>
<tr>
<td>now?</td>
<td>☐ 2. No</td>
</tr>
</tbody>
</table>

*Explain the definition of diarrhea to the interviewee:* Diarrhea can be defined by relieving loose or watery motions 3 times or more in 24 hours.

<table>
<thead>
<tr>
<th>Nº</th>
<th>Age (Yr./Mo.)</th>
<th>Gender (M/F)</th>
<th>Is he/ she a child that is Breastfed (Yes/ No)</th>
<th>Feces with blood (Yes/No)</th>
<th>How did you cure this diarrhea? (Enter code as shown below)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

0=No treatment
1=Mix water with rehydration salts (packages)
2=Western medicine (doctor vist), **specify**
3=Western medicine (self medication), **specify**
4=Traditional medicine (herbs), **specify**
5=Home medicine, **specify**
6=Don’t know
Q4. Has anyone in the household been ill in the last 7 days with the following symptoms?

- □ 1. None
- □ 2. Worm, intestinal # of people ..........
- □ 3. Skin infection # of people ..........
- □ 4. Eye disease # of people ..........
- □ 5. Abdominal pain # of people ..........
- □ 6. Vomiting # of people ..........
- □ 7. Nausea # of people ..........
- □ 8. Other, specify ..........., # of people .......

**Drinking Water Management**

Q5. What source of water do you use for drinking right now?

- □ 1. Bottles (20L cans – bubble top)
- □ 2. Lorries (trucked-in water)
- □ 3. Well (personal well)
- □ 4. Public Taps (lake water)
- □ 5. Other, specify: ..........................

Q6. How often do you clean your drinking water?

- □ 1. No treatment
- □ 2. Never
- □ 3. Always
- □ 4. When children are sick
- □ 5. For baby milk powder
- □ 6. Sometimes, specify: ...................

**Application of the AWSP System**

Q7. How often do you use the AWSP system?

- □ 1. More than once per day
- □ 2. once per day
- □ 3. once per week
- □ 4. Never
- □ 5. Sometimes, specify: ..................
<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
</table>
| Q8. Do you use other forms of treatment to clean household drinking water? | 1. Yes  
2. No  
☐ 1. No treatment  
☐ 2. Boiling  
☐ 3. Alum  
☐ 4. Bleaching powder (chlorine)  
☐ 5. Filter (candle filter)  
☐ 6. Cloth (cotton fabric)  
☐ 7. Other, specify: ………………………. |
| Q8a. What form of treatment do you use?                                  | ☐ 1. No treatment  
☐ 2. Boiling  
☐ 3. Alum  
☐ 4. Bleaching powder (chlorine)  
☐ 5. Filter (candle filter)  
☐ 6. Cloth (cotton fabric)  
☐ 7. Other, specify: ………………………. |
| Q9. Have you noticed any differences between water treated with the AWSP system and your normal drinking water? | 1. Yes  
2. No  
Better OR Worse  
☐ 1. Taste  
☐ 2. Colour  
☐ 3. Cloudiness  
☐ 4. Odor  
☐ 5. Other, specify: ………………………. |
| If Yes…                                                                  | ☐ 1. Taste  
☐ 2. Colour  
☐ 3. Cloudiness  
☐ 4. Odor  
☐ 5. Other, specify: ………………………. |
| Q9a. What are some of these differences?                                 | ☐ 1. Taste  
☐ 2. Colour  
☐ 3. Cloudiness  
☐ 4. Odor  
☐ 5. Other, specify: ………………………. |
| Q10. How much water does your family clean using the AWSP system each day? | # of containers: ……………………….  
☐ 1. Yes  
☐ 2. No  
☐ 1. No reason  
☐ 2. No clean water prepared  
☐ 3. Being away from home (ie working, visiting, etc)  
☐ 4. Untreated water is preferred  
☐ 5. Other, specify: ………………………. |
| Q10a. What kind of container do they use:                                 | ☐ 1. Yes  
☐ 2. No  
☐ 1. No reason  
☐ 2. No clean water prepared  
☐ 3. Being away from home (ie working, visiting, etc)  
☐ 4. Untreated water is preferred  
☐ 5. Other, specify: ………………………. |
| Q10b. What is the volume of the container:                               | ☐ 1. Yes  
☐ 2. No  
☐ 1. No reason  
☐ 2. No clean water prepared  
☐ 3. Being away from home (ie working, visiting, etc)  
☐ 4. Untreated water is preferred  
☐ 5. Other, specify: ………………………. |
| Q10c. Are the containers covered?                                        | ☐ 1. Yes  
☐ 2. No  
☐ 1. No reason  
☐ 2. No clean water prepared  
☐ 3. Being away from home (ie working, visiting, etc)  
☐ 4. Untreated water is preferred  
☐ 5. Other, specify: ………………………. |
| Q11. Do members of the household ever drink untreated water?             | ☐ 1. Yes  
☐ 2. No  
☐ 1. No reason  
☐ 2. No clean water prepared  
☐ 3. Being away from home (ie working, visiting, etc)  
☐ 4. Untreated water is preferred  
☐ 5. Other, specify: ………………………. |
### Alternative Water Systems Project
Intervention Household Questionnaire (with Water Sample)

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
</table>
| Q12. Does the AWSP system produce enough drinking water for all members of the household? | □ 1. Always  
□ 2. Never  
□ 3. Most of the time  
□ 4. Sometimes, specify:………………………………….. |
| Q13. How much time is spent cleaning the water each day?                  | □ 1. Less than 15 minutes  
□ 2. Half an hour  
□ 3. One hour  
□ 4. 1-2 hours  
□ 5. Other, specify:………………………………….. |

### Management of the AWSP System

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
</table>
| Q14. Who in the household is responsible for cleaning the drinking water? | □ 1. Father  
□ 2. Mother  
□ 3. Grandparent  
□ 4. Children  
□ 5. All family members  
□ 6. Other, specify:………………………………….. |
| Q15. Who in the household is responsible for maintaining the AWSP system? | □ 1. Father  
□ 2. Mother  
□ 3. Grandparent  
□ 4. Children  
□ 5. All family members  
□ 6. Other, specify:………………………………….. |
| Q16. How often is the AWSP system cleaned?                                | □ 1. Never  
□ 2. Every 5-7 days  
□ 3. Every 7-14 days  
□ 4. Every month  
□ 5. Other, specify:………………………………….. |
| Q17. When was the AWSP system last cleaned?                               | □ Never  
□ ____ days ago  
□ ____ weeks ago  
□ ____ months ago  
□ Never |
**Alternative Water Systems Project**  
**Intervention Household Questionnaire (with Water Sample)**

| Q18. How much time is spent cleaning the sand and charcoal for the AWSP system? | □ 1. Less than 15 minutes  
□ 2. Half an hour  
□ 3. One hour  
□ 4. 1-2 hours  
□ 5. Other, specify: ................................................. |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q19. Where does the household keep the AWSP system? <em>(Make a visual check, and specify its location)</em></td>
<td>Location:</td>
</tr>
</tbody>
</table>
| Q19a. Does the system look well taken care of? | 1. □ Yes  
2. □ No  
Comments:........................................................................... |
| Q19b. Is the AWSP system covered? *(Make a visual check, and specify type of cover)* | 1. □ Yes  
2. □ No  
*Specify type of cover: .............................................* |

### Water Sample Collection

**Sample #1:** Hand the interviewee a 250 ml plastic collections bottle with the top off and ask them to *‘fill the bottle as if you were getting a drink of water for yourself or someone else in the household.’*

<table>
<thead>
<tr>
<th>Q20. Does the interviewee <em>(Check all that apply):</em></th>
<th></th>
</tr>
</thead>
</table>
| □ 1. Wash their hands before retrieving the water?  
□ 2. Pour the water from the vessel?  
□ 3. Dip the cup into the storage vessel? | |

Seal the bottle by applying the screw top before labeling it and storing it in the cooler.

| Q21. What is the source of this water? | □ 1. Lorries (trucked-in water)  
□ 2. Well (personal well)  
□ 3. Public Taps (lake water)  
□ 4. Other, specify: ................................................. |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q22. Was the water treated?</td>
<td>□ 1. Yes □ 2. No</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>If yes….</td>
<td></td>
</tr>
</tbody>
</table>

| Q23. How long ago was the water treated? | □ 1. 1 hour ago □ 2. Between 2 and 6 hours ago □ 3. Between 7 and 12 hours ago □ 4. Yesterday □ 5. Other, specify: ………………………. |

**Sample #2:** Hand the interviewee another 250 ml plastic collections bottle with the top off and ask them to *fill the bottle with untreated drinking water.*

Seal the bottle by applying the screw top before labeling it and storing it in the cooler.
**Household Data**

Interviewer Name: ..................................  Date (D/M/Y): ........................................

Household Code: .................................

**Disease Status**

Q1. Do you have soap in your house for washing hands?  □ 1. Yes  □ 2. No

Q2. Has anyone in your family had diarrhea in the last 7 days prior to now?  □ 1. Yes  □ 2. No

*Explain the definition of diarrhea to the interviewee:* Diarrhea can be defined by relieving loose or watery motions 3 times or more in 24 hours.

Q3. If YES, ask which family members (currently living in the household) had diarrhea and record all data into the next table.

<table>
<thead>
<tr>
<th>Nº</th>
<th>Age (Yr./Mo.)</th>
<th>Gender (M/F)</th>
<th>Is he/she a child that is Breastfed (Yes/No)</th>
<th>Feces with blood (Yes/No)</th>
<th>How did you cure this diarrhea? (Enter code as shown below)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1= Yes</td>
<td>1= Yes</td>
<td>0=No treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2= No</td>
<td>2= No</td>
<td>1=Mix water with rehydration salts (packages)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2=Western medicine (doctor visit), <strong>specify</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3=Western medicine (self medication), <strong>specify</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4=Traditional medicine (herbs), <strong>specify</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5=Home medicine, <strong>specify</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6=Don’t know</td>
</tr>
</tbody>
</table>
Q4. Has anyone in the household been ill in the last 7 days with the following symptoms?

- 1. None
- 2. Worm, intestinal  
- 3. Skin infection
- 4. Eye disease
- 5. Abdominal pain
- 6. Vomiting
- 7. Nausea
- 8. Other, specify ........................................

**Drinking Water Management**

| Q5. What source of water do you use for drinking right now? | □ 1. Bottles (20L cans – bubble top)  
| - □ 2. Lorries (trucked-in water)  
| - □ 3. Well (personal well)  
| - □ 4. Public Taps (lake water)  
| - □ 5. Other, specify: ……………………….

| Q6. Do you ever clean your drinking water in the home? | □ 1. Yes  □ 2. No  

**Q6a. How do you clean your drinking water?**

- □ 1. No treatment  
- □ 2. Boiling  
- □ 3. Alum  
- □ 4. Bleaching powder (chlorine)  
- □ 5. Filter (candle filter)  
- □ 6. Cloth (cotton fabric)  
- □ 7. Other, specify: ……………………….

| Q7. How often do you clean your drinking water? | □ 1. No treatment  

**Q7a. How often do you clean your drinking water?**

- □ 2. Never  
- □ 3. Always  
- □ 4. When children are sick  
- □ 5. For baby milk powder  
- □ 6. Sometimes, specify: ……………….
**Water Sample Collection**

Hand the interviewee a 250 ml plastic collections bottle with the top off and ask them to ‘fill the bottle as if you were getting a drink of water for yourself or someone else in the household.’

<table>
<thead>
<tr>
<th>Q8. Does the interviewee (Check all that apply):</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ 1. Wash their hands before retrieving the water?</td>
</tr>
<tr>
<td>□ 2. Pour the water from the vessel?</td>
</tr>
<tr>
<td>□ 3. Dip the cup into the storage vessel?</td>
</tr>
</tbody>
</table>

Seal the bottle by applying the screw top before labeling it and storing it in the cooler.

<table>
<thead>
<tr>
<th>Q9. What is the source of this water?</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ 1. Lorries (trucked-in water)</td>
</tr>
<tr>
<td>□ 2. Well (personal well)</td>
</tr>
<tr>
<td>□ 3. Public Taps (lake water)</td>
</tr>
<tr>
<td>□ 4. Other, specify: …………………………………</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q10. Was the water treated?</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ 1. Yes □ 2. No</td>
</tr>
</tbody>
</table>

If yes….

<table>
<thead>
<tr>
<th>Q10a. How was the water treated?</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ 1. No treatment</td>
</tr>
<tr>
<td>□ 2. Boiling</td>
</tr>
<tr>
<td>□ 3. Alum</td>
</tr>
<tr>
<td>□ 4. Bleaching powder (chlorine)</td>
</tr>
<tr>
<td>□ 5. Filter (candle filter)</td>
</tr>
<tr>
<td>□ 6. Cloth (cotton fabric)</td>
</tr>
<tr>
<td>□ 7. Other, specify: ………………………</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q11. How long ago was the water treated?</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ 1. 1 hour ago</td>
</tr>
<tr>
<td>□ 2. Between 2 and 6 hours ago</td>
</tr>
<tr>
<td>□ 3. Between 7 and 12 hours ago</td>
</tr>
<tr>
<td>□ 4. Yesterday</td>
</tr>
<tr>
<td>□ 5. Other, specify: ………………………</td>
</tr>
</tbody>
</table>
Alternative Water Systems Project
Exit Questionnaire

Interviewer Name: ……………………… Date (D/M/Y): ………………………………
Household Code: ………………………

Household Data

Household Code: ………………………
Sector: ………………… Interviewee’s name: ……………………… Gender: …………………
Age: …………………
Number of Household Members: …………………

Fill in table with information about all household members (start with the interviewee’s information):

<table>
<thead>
<tr>
<th>Nº</th>
<th>Age (year or months)</th>
<th>Gender (M/F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td></td>
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<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Drinking Water Management

Q4. What source of water do you use for drinking right now?
- □ 1. Bottles (20L cans - bubble top)
- □ 2. Lorries (trucked-in water)
- □ 3. Well (personal well)
- □ 4. Public Taps (lake water)
- □ 5. Other, specify: ………………………

Q5. Do you think your drinking water is of good quality?
- □ 1. Yes □ 2. No

Q5a. If yes, why?
Write down comments: ………………………
…………………………………………
…………………………………………

Q5b. If no, why?
…………………………………………
…………………………………………
…………………………………………

Q6. Do you ever clean your drinking water in the home?
- □ 1. Yes □ 2. No

Q7. How do you clean your drinking water in the home?
- □ 1. No treatment
- □ 2. Boiling
- □ 3. Alum
### Alternative Water Systems Project
#### Exit Questionnaire

| Q9a. Is it covered? (Make a visual check, and specify type of cover) | □ 1. Yes □ 2. No □ 3. Some |
| Specify type of cover: ……………………… |

#### Household Water Management

| Q16. How long do you have to wait in between times for the water to come on in the taps? | □ 1. 5-7 days □ 2. Between 8 – 14 days (1 – 2 weeks) □ 3. Between 2 – 4 weeks □ 4. More than 4 weeks |
| Q17. Are you ever required to purchase water when tap water is unavailable? | □ 1. Yes □ 2. No □ 3. Some |
| If yes….. Q17a. How often do you need to buy water? | □1. every day □2. every other day □3. every 3 days □4. Every 5 days |
| Q17b. How much money do you spend when you | □1. Rs 15 - 30 |
**Hygiene and Sanitation**

**Q18. Where do you place the solid wastes from your house?**
- □ 1. In the canal
- □ 2. By the roadside
- □ 3. In a bin
- □ 4. Take and dispose somewhere else
- □ 5. Other, specify: ……………………..

**Q19. Where do you and your family use the toilet?**
- □ 1. Toilet in the house
- □ 2. Public toilet blocks
- □ 3. Personal latrine outside the home
- □ 4. Open space
- □ 5. Other, specify: ……………………..

**Q20. Can you tell me when do you wash your hands with soap? (Do not prompt interviewee, allow them to answer freely and check all that apply)**
- □ 1. Never
- □ 2. Before cooking
- □ 3. Before eating
- □ 4. After eating
- □ 5. After using the toilet
- □ 6. Before sleeping
- □ 7. After cleaning baby’s bottom
- □ 8. Before feeding children/ baby
- □ 9. After helping my children use the toilet
- □ 10. When dirty
- □ 11. Other, specify: ……………………..

**Q21. When do your children under 5 years old wash their hands with soap? (Do not prompt interviewee, allow them to answer freely and check all that apply)**
- □ 1. Do not have children
- □ 2. Never
- □ 3. Before eating
- □ 4. After eating
- □ 5. After using the toilet
- □ 6. Before sleeping
- □ 7. When dirty
### Filter Sustainability

**Q1**: Which type of water has the best taste?  
Order them from best (1) to worst (5)

- Tap  
- Bottle  
- AWSP Filter  
- Metro  
- Other: __________________________

**Q2**: Which type of water has the best smell?  
Order them from best (1) to worst (5)

- Tap  
- Bottle  
- AWSP Filter  
- Metro  
- Other: __________________________

**Q3**: Which type of water has the best colour?  
Order them from best (1) to worst (5)

- Tap  
- Bottle  
- AWSP Filter  
- Metro  
- Other: ____________________________

**Q4**: Please indicate whether you and your family have noticed an “increase”, “decrease”, or “no change” in the frequency of
- a) skin infections:  
- b) eye infections  
- c) diarrhoea  
- d) fever  
- e) colds

- 1. Increase  
- 2. Decrease  
- 3. No Change

**Q5**: How difficult is it to use the filter?

- 1. Very Difficult  
- 2. Difficult  
- 3. Not Difficult  
- 4. Easy  
- 5. Very Easy

**Q6**: How much do you think this filter should cost?

- 1. Free  
- 2. Rs 100  
- 3. Rs 300  
- 4. Rs 500
<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q?. What is the <strong>maximum</strong> amount you would pay for this filter?</td>
<td>□ 5. Rs 700</td>
</tr>
<tr>
<td></td>
<td>□ 6. Rs 1000</td>
</tr>
<tr>
<td></td>
<td>□ 7. Rs 2000</td>
</tr>
<tr>
<td>Q?. When the research team withdraws from MBN on May 31st, will you:</td>
<td>□ 1. Yes</td>
</tr>
<tr>
<td>a) Continue to use the filter?</td>
<td>□ 2. No</td>
</tr>
<tr>
<td>b) Need someone to help you clean and maintain the filter?</td>
<td>□ 1. Yes</td>
</tr>
<tr>
<td></td>
<td>□ 2. No</td>
</tr>
<tr>
<td>Q?. Which of the groups below would prefer to manage the filter within MBN; rank them from 1 to 4:</td>
<td>( ) NGO</td>
</tr>
<tr>
<td></td>
<td>( ) College</td>
</tr>
<tr>
<td></td>
<td>( ) Self help group in MBN</td>
</tr>
<tr>
<td></td>
<td>( ) Government</td>
</tr>
<tr>
<td></td>
<td>( ) Private company</td>
</tr>
<tr>
<td>Q?. Are you aware of the Five Star Water Quality Centre?</td>
<td>□ 1. Yes</td>
</tr>
<tr>
<td></td>
<td>□ 2. No</td>
</tr>
<tr>
<td>Q?. What are you prepared to do in order to continue filter use within your household and your community? (check all that apply)</td>
<td>□ 1. Tell a neighbour about the benefits of filter use</td>
</tr>
<tr>
<td></td>
<td>□ 2. Share your filter with friends and neighbours</td>
</tr>
<tr>
<td></td>
<td>□ 3. Join the FSWQC</td>
</tr>
<tr>
<td></td>
<td>□ 4. Approach the FSWQC for assistance/services</td>
</tr>
<tr>
<td></td>
<td>□ 5. Other:____________________</td>
</tr>
<tr>
<td>Q?. What makes using the filter easy or difficult in your household?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Q?. Would you modify the filter? If yes, what would you modify?</td>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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