MIXED METHODS EVALUATION OF COMMUNITY-RUN WATER DESALINATION PLANT PROJECT IN COASTAL BANGLADESH

by

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Abstract

The effects of climate change on water security have become increasingly apparent with the increasing salt contamination of freshwater sources in coastal Bangladesh. In 2011, the Climate Change and Health Promotion Unit (CCHPU) of the Bangladesh Ministry of Health and Family Welfare began its response to this problem through the installation of small-scale reverse osmosis desalination plants in 10 villages of Satkhira district, using a Community Based Adaptation Private-Public Partnership model (CBA-PPP) with support from World Bank. The purpose of this paper is to evaluate the implementation of this model in terms of clean water accessibility, health impact and long-term sustainability of operations. Primary data was collected from focus group discussions with water collectors and project committee members at plants in Nalta Sharif and Nowapara villages. Secondary data on sub-district waterborne diarrhea admission rates were obtained from the Institute for Epidemiology, Disease Control and Research (IEDCR) and total diagnosis rates of waterborne illnesses in the sub-district of Debhata were acquired from Debhata Health Complex. In Nalta Sharif, participants found supply of water, long wait times and limited hours at which water could be retrieved to be the most significant barriers to accessibility. However, in Nowapara, it was found that financial constraints, largely due to electricity costs, were the main barrier to access. In both villages, participants observed a noticeable reduction in waterborne illness rates since the plants became operational. This was supported by the surveillance data from Debhata, which showed significant reductions in rates of all waterborne illness rates that were monitored. Thus, the intervention was found to be effective in reducing waterborne illness rates, but was inadequate in meeting the drinking water demand for the communities. Long-term sustainability was a major issue in both communities, emphasizing the importance of financial planning for the survival of such projects.

Keywords: Salinity; Climate Change Adaptation; Reverse Osmosis Desalination; Coastal Bangladesh; Water Security; Health

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BWRO	Brackish Water Reverse Osmosis
CBA-PPP	Community Based Adaptation Private-Public Partnership
CCHPU	Climate Change and Health Promotion Unit
FGD	Focus Group Discussion
IEDCR	Institute for Epidemiology, Disease Control and Research
MOFW	Ministry of Health and Family Welfare
SWRO	Seawater Reverse Osmosis
Tk	Bangladeshi Taka

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Background

Salinity intrusion from seawater is a growing problem in the 19 coastal districts of Bangladesh (see Figure 1), posing a serious threat to the water safety and security of 20 million people (Ministry of Water Resources, 2005; Basar 2012; Rasheed et al., 2014). Salinity has increased by approximately 26% in Bangladesh over the past 35 years through saltwater intrusion into soil and groundwater (Mahmuduzzaman et al., 2014). Salinity is particularly concerning in the context of anthropogenic climate change, which is predicted to worsen and spread this problem further and further inland (Mahmuduzzaman et al., 2014).

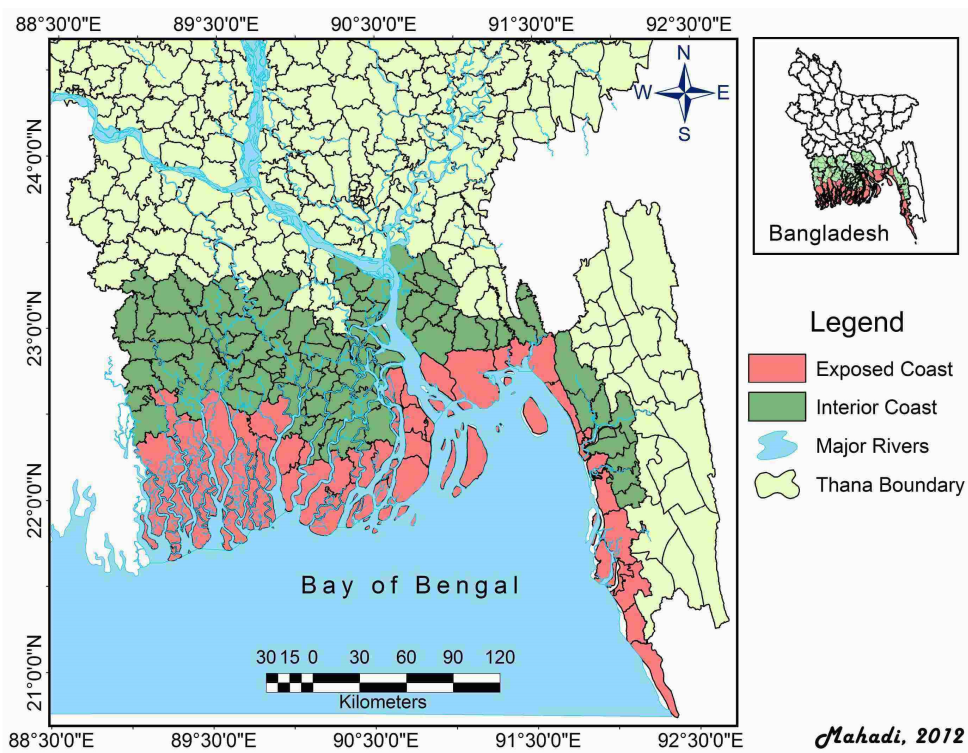

Figure 1. Coastal Sub-districts of Bangladesh. Note. From *Know the Wonderful Geology of the SW Coastal Belt of Bangladesh*, by M.M. Hasan, 2012. Retrieved July 28, 2016 from: https://geobangla.wordpress.com/2015/01/30/overall-geology-and-hydrogeology-of-the-southwestern-coastal-belt-of-bangladesh/

Climate change causes sea level rise through thermal expansion of the oceans and the melting of the polar ice caps, which contributes to backwater effects (slowing of river outflow by an increase in water level) as well as an increased frequency and intensity of cyclones, tidal floods, and storm surges. These impacts all contribute to the intrusion of saline seawater into freshwater sources in coastal Bangladesh. Climate change also reduces the availability of freshwater by reducing precipitation, which decreases the replacement of groundwater supply, and by raising average temperatures, increasing evaporation. In the long-term, climate change is predicted to decrease the amount of glacial ice from the Himalayas, reducing the volume of river discharge, which is an important freshwater source (Mahmuduzzaman et al., 2014).

However, it is important to recognize that salinity is a complex issue with many factors at play. In addition to climate change, the increased conversion of freshwater ponds to saline water for shrimp farming, poor polder management and decreased river flow due to Farakka Barrage are major contributors to salinity intrusion (Ali 1999; Basar 2012; Mirza, 1998). Other factors contributing to increased salinity in freshwater include sedimentation, weak and poorly maintained infrastructure, weak local water governance systems, increased groundwater extraction due to a growing population, and poor cross-boundary river policies (Mahmuduzzaman et al., 2014; Vineis Chan, & Khan, 2011).

Ideally, drinking water should come from groundwater, such as from wells supplied by aquifers, rather than surface water, such as river and pond water, as it is usually higher in quality (Ford, 2010). However, in coastal districts, such as Satkhira, that were affected by Cyclone Aila in May 2009, communal ponds consist of brackish water (salt contaminated freshwater) contaminated by seawater and tube wells often connect to groundwater aquifers contaminated with seawater and/or arsenic (Greenlee, Lawler, Freeman, Marrot, & Moulin, 2009; Mahmuduzzaman et al., 2014). Pond-sand filters and rainwater harvesting systems are also used, but have been found to be contaminated with bacteria and viruses at levels that pose a significant public health risk that may outweigh the risks posed by arsenic contamination (Islam, Sakakibara, Karim, Sekine, & Mahmud, 2011). Thus, often times clean drinking water in this region can only be accessed by those who can afford to purchase it (Ministry of Health and Family Welfare, 2013).

Consequently, communities are at increased risk of waterborne diseases, such as waterborne diarrhea, dysentery, hepatitis B infection and typhoid fever (Haque et al., 2013; Hoque et al., 2016). According to Constantin de Magny and Colwell, waterborne microorganisms, including *Vibrio cholerae*, proliferate more rapidly at higher salinity levels, however, the mechanism has yet to be elucidated (2009).

Furthermore, high salt intake increases the risk of acquiring hypertension, cardiovascular disease and pre-eclampsia (Haque et al., 2013; Hoque et al., 2016). A report by Caritas Development Institute and the government of Bangladesh also found that there was a correlation between high salinity and miscarriage, skin disease, acute respiratory infection, and hypertension in populations of coastal Bangladesh that were exposed through seawater contaminated freshwater sources used for drinking, cooking and bathing (Vineis, Chan, & Khan, 2011). Overall, however, there remains a paucity of statistical data on the human health impact of exposure to high salinity water (Vineis, Chan, & Khan, 2011).

In terms of exposure, one study using monthly measures of salinity from the Passur River of coastal Bangladesh found that there was 8.21g/L of salt during the dry season, which would lead to a daily intake of 5-16g of salt from drinking water alone for an individual consuming 2L of water per day (Khan et al., 2011). Thus, sodium intake in similarly affected populations is significantly higher than the tolerable upper intake level of 2.3g for adults, above which adverse health effects are observed in most people (Health Canada, 2005). These results were further supported by direct measurements of urinary sodium of adults in the southeastern coast who excreted an average 6.7g/day of sodium (115 mmol/day), significantly exceeding recommended level of 5g/day set by the World Health Organization (Khan et al., 2011; Rasheed et al., 2014). This is extremely concerning, as hypertension is already major problem for adults in Bangladesh (Rasheed et al., 2014).

One method that has been used to address the issue of salinity is desalination. This refers to the process of removing salt from water to convert it into freshwater. Freshwater is defined as water that is made up of less than 1000mg/L of total dissolved solids (TDS) including salt. As of 2012, membrane processes, such as reverse osmosis desalination, made up 63.7% of global desalinated water (Ghaffour, Missimer, & Amy, 2013). This is likely due to the higher economies of scale with membrane technologies compared to thermal distillation processes (Dore, 2005). It is also the most common type of desalination used at small scales, with costs estimated to range from \$0.78–\$1.33 US for every cubed meter of water for plants that treat 1000m^3/day of brackish water (Karagiannis & Soldatos, 2008). Reverse osmosis desalination is a process in which a membrane with a pore diameter between 0.1-1 nm not only filters out bacteria, viruses and proteins, but even the smallest contaminants, such as monovalent ions like sodium chloride from the water pushed through it. Before reaching the membrane, feed water is conventionally pretreated with acid, coagulant or flocculant, disinfectant, media filtration and cartridge filtration. Brackish water reverse osmosis (BWRO) is used to treat water between 1000 and 10 000mg/L TDS. Compared to seawater reverse osmosis (SWRO) membranes, BWRO membranes usually have a higher water flow rate through them, a lower rejection of salt and require less operating pressure since brackish water has a lower osmotic pressure than seawater. However, despite being more widespread than SWRO plants, BWRO plants tend to be smaller in capacity for filtration. BWRO usually go through two stages, both of which recovers 50-60% of the input water. In the first stage, water is concentrated and in the second stage this concentrate is used as the feed to produce the final filtered product, which recovers 75-80% of the input water. (Greenlee et al., 2009)

In 2011, the Climate Change and Health Promotion Unit (CCHPU) of the Bangladesh Ministry of Health and Family Welfare (MOHFW) initiated a small-scale reverse osmosis desalination pilot project in 10 villages of Satkhira district with technical and financial support provided by the World Bank. A Community Based Adaptation Private-Public Partnership model (CBA-PPP) was used in which the MOHFW provided the material resources for the establishment of the plants using brackish pond water as the water source. Locals were trained as caretakers to maintain the plants, while committees made up of local community members were formed to take responsibility for the management of the plants. This evaluation studied the short-term impact of the desalination intervention in the villages of Nalta Sharif, located in the sub-district of Kaliganj (population: 293,252), and Nowapara, with a population of approximately 3500 people, located in the sub-district of Debhata (population: 125,381) (MOHFW, 2013; MOHFW, 2014a; MOHFW, 2014b). The sub-districts of Kaliganj and Debhata in the Western part of Satkhira are shown in

Figure 2, which also shows that the sub-district of Debhata was found to have moderate safe drinking water scarcity (Abedin, Habiba & Shaw, 2014).

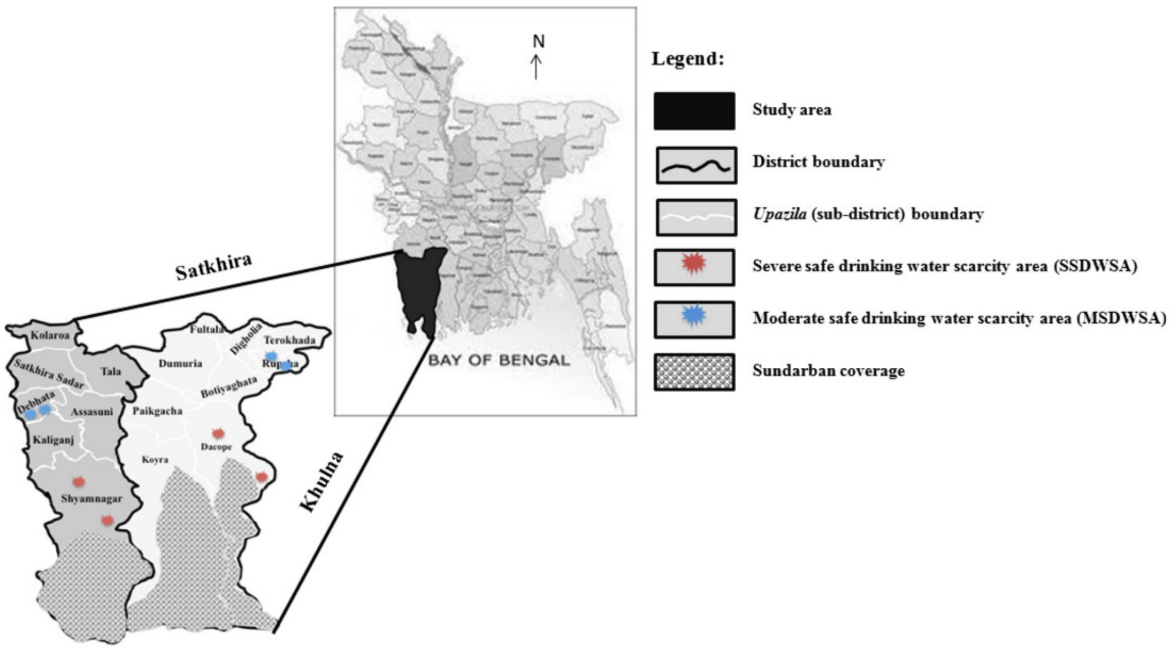

Figure 2. Location of severe and moderate drinking water scarcity areas in Khulna and Satkhira districts of Bangladesh. Adapted from "Community Perception and Adaptation to Safe Drinking Water Scarcity: Salinity, Arsenic, and Drought Risks in Coastal Bangladesh," by M. A. Abedin, U. Habiba and R. Shaw, 2014. *Int J Disaster Risk Sci,* 5, pp. 110–124. Copyright 2014 by the Authors.

Purpose

The purpose of this evaluation is to assess the accessibility, health impact and sustainability of the CCHPU desalination intervention in the coastal belt of Bangladesh in order to inform the design of a more in-depth future evaluation of the intervention. It also serves to contribute to evidence on the effectiveness of the CBA-PPP model for reverse osmosis desalination interventions in low resource areas affected by water insecurity due to high salinity from sea level rise, as well as other types of water contamination.

Methods

Study design

A mixed methods approach, incorporating qualitative and quantitative data, was chosen to evaluate the desalination project in the two case-study villages of Nalta Sharif, located in the sub-district of Kaliganj, and Nowapara, which is located in the sub-district of Debhata (Figure 3). These villages were chosen by the local project coordinator and key informant based on the contrast in the success of the projects, as Nowapara was struggling significantly in comparison with the Nalta Sharif plant, which was more financially stable. This was done in order to better identify and compare strengths and weaknesses in implementation. The qualitative component of the evaluation consisted of focus group discussions (FGDs), allowing detailed data to be collected on perceptions and experiences with the project. The quantitative component consisted of surveillance data on waterborne illness rates in each sub-district before and after project implementation for diarrhea, typhoid, dysentery and jaundice, providing a preliminary objective measure of health impact.

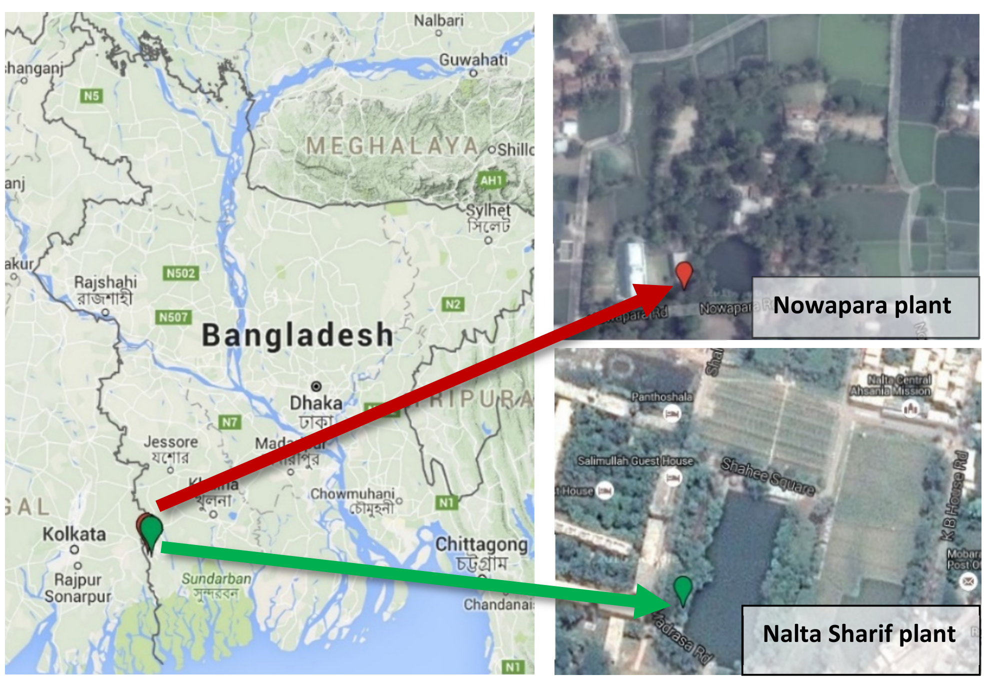

Figure 3. Map of Field Sites

Qualitative

Focus Group Discussion

Focus group questions were written by the student evaluator following the *W.K. Kellogg Foundation Evaluation Handbook* under the supervision of the IEDCR Outbreak Investigation Officer, Dr Farhana Haque. Women who regularly collected water from the plant and members of the committee managing the plant were recruited for focus group discussions by the local project coordinator in the week prior to the interview date using a convenience sample method due to restrictions of resources and time. Only female water collectors were recruited, as it is mostly women that collect the water in these communities. This also functioned to create a more comfortable space in consideration of the local gender norms in which women do not normally mix with men and in which men tend to take more dominant roles. In order to get the perspective from the management side and from men, committee members, who were all male, were recruited through purposive sampling. All FGD participants were provided a small amount of monetary compensation for their time.

FGDs were conducted from June 29 to June 30, 2015 in the villages of Nalta Sharif and Nowapara. In Nalta Sharif, one focus group was done with 10 local female water collectors, lasting 43 minutes. In Nowapara, a 31-minute focus group was done with 10 local female collectors, followed by a 31-minute focus group with 8 male committee members responsible for management of the plant. Due to unforeseen circumstances, the focus group planned with the committee members in Nalta Sharif ended prematurely.

Consent to participate, record audio and take photographs of participants was obtained verbally and in writing prior to the start of each FGD. The age, sex, village and sub-district were recorded for each participant. Independent ethical approval of the study was not obtained in accordance with the IEDCR's policy where ethics approval was not essential for quality improvement and evaluation studies. However, all research instruments used to gather information were shared among senior researchers of the local team to detect and alter any component that could negatively impact the participants' psychology in any way. All tools and materials were carefully tested to ensure their cultural sensitivity and appropriateness.

FGDs were supervised by the writer, who was partially fluent in Bengali and led by two Bangladeshi facilitator-notetakers from IEDCR. The FGDs were also audio recorded for transcription. Subsequently, the FGDs for the local collectors and committee members were transcribed from the audio recordings into Bengali and then translated into English with supplementation from notes taken during the FGDs. Words, phrases and sentences from the English translated transcriptions were coded using NVivo 10 software. Objectivist and descriptive codes were used for line by line coding. The main codes used were "barriers," "access," "expenses," "waterborne disease," "benefit," "response," "awareness," "supply," "travel," "solution," "religion," and "family life." From these codes, major themes were identified.

Quantitative

Waterborne diarrhea admission rates in Kaliganj Health Complex and Debhata Health Complex were obtained from the IEDCR web-based surveillance dataset for the periods from 2012 to 2015. However, waterborne diarrheal admission rates at Debhata Health Complex from this dataset were not available for the period between December, 2012 and July, 2014. Diagnosis rates for diarrhea, dysentery, jaundice and typhoid were obtained from Debhata Health Complex for the 2010-2014 period.

Results

Focus Group Discussions

The mean age of focus group participants was 32 years, 40 years and 45 years for Nalta Sharif users, Nowapara users and Nowapara committee members, respectively.

Table 1. Central Tendency and Dispersion Measures of Focus Group Participant Age

Village	Nalta Sharif Women Collectors (n=10)	Nowapara Women Collectors (n=10)	Nowapara Men from Committee (n=8)
Age (years)	Mean = 32 Median = 29	Mean= 40 Median = 33.5	Mean = 45 Median = 44.5

	Min = 12 Max = 60	Min= 30 Max = 70	Min = 35 Max = 52

Nowapara

Nowapara Male Committee Members

State of Drinking Water before Implementation: Before the plant was operating, most people used pond water. High salinity in drinking water sources was described as a longstanding issue:

Interviewer: …this water, for how many days has saltwater been here?
Participant: *We've seen it since our births.*
Interviewer: Ok since birth, it's a natural matter.
Participant: Yeah it's a natural matter.

Thus, by the interviewer's suggestion, he agreed that he thought salinity was a natural phenomenon. Before the plant was established, a 1200-foot-deep tube well was created, but the water was also high in salinity, as described by one committee member:

"Of course before this, to avoid saltwater a deep tube well was placed. They placed a deep tube 12 hundred feet. It didn't do us any good. It was the same situation."

Committee members also stated that the wells were also contaminated with iron and arsenic.

Implementation: The water desalination plant in Nowapara village of Debhata sub-district started operation in 2011. From the focus group discussion with the Nowapara committee members it was found that acquiring a location for the plant was not a problem, as the community had a number of potential spaces for the plant to choose from.

Committee members singled out the committee president, as playing the largest role in the establishment and maintenance of the plant through donating the most money. Committee members and politicians also played a role in supporting the plant financially.

Another strength of the plant is that the caretaker lives beside the plant, so if locals need water outside of regular hours, they are able to ask the caretaker provide it to them. Locals can also purchase the water to use for ceremonies and gatherings.

Challenges: Although space availability was not an issue, the community faced some challenges in deciding on which of the locations was best, as one committee member stated:

"But nobody said they wouldn't give. It wasn't like that. What happened was that there were people [disagreeing] whether this or that place would be better."

Reception: One of the committee members stated that locals responded very well to the plant water when it was introduced. There were no problems with the smell or taste of the water. Children did not refuse to take the water. The only problems the community faced was a number of days of indigestion after the pre-treatment chemical was added:

"After giving the chemical, for 2 or 3 days, we felt bad, the water gave us indigestion."

Capital and Finance: Three committee members and the Satkhira coordinator for all the plants explained that the government provided funding for the machine and the building for the plant, costing a total of 175,325 taka[1] (tk). For the electrical line installation, an additional 98,725tk had to be paid as well through government funding.

Local people donated between 10,000-20,000tk and committee members contributed more. However, the committee President was the main sponsor.

Desalination: Three members stated that before this plant was established they were unaware that saltwater could be made into freshwater. One stated that he thought this process was very good. Two members even suggested that the plant water was better than bottled water. They also mentioned that a representative of the Japanese International Cooperation Agency also said that the water from the plant was better than the water sold at the market.

"*this water is so good and helpful for protecting against our many stomach related diseases*"

Management

Funding sources: Previously, locals were being charged 2 tk per kolash (5L jug) of water. However, the committee later realized that this was not enough to pay for the cost for the

[1]Taka is the currency of Bangladesh. As of June 5, 2016, 1 Bangladeshi taka is equivalent to approximately 1.6 cents in Canadian dollars.

electricity. Thus, the price had to be increased to 5 tk per kolash, 10 tk per 30L barrel and 20 tk for more than 30L.

Barriers: The local project coordinator, who has been involved with all 10 pilot sites from the beginning, stated "Out of all the communities, this village is in the worst situation."

Infrastructure: Currently there are not enough funds to pay for a door to lock the water collection area outside and to fix the broken tap parts.

Expenses: Committee members stated that maintenance costs came from replacement of three filters, the honorarium for the caretaker, but mostly from the electricity bill:

"*We need help with the electricity bill*"

The treasurer explained that they were being charged for electricity at commercial rates of over 8tk per unit, which is more than double the cost of residential rate of 3.27tk per unit. This results in a monthly electricity bill of 12,000-14,000tk. The plant caretaker receives an honorarium of less than 1000tk.

However, only 5000tk per month is collected from the locals purchasing the water. The rest of the expenses are paid through donations by all the committee members, the committee president and through some government funds that political leaders have been able to reallocate. Currently, the debt is 15,000tk.

Health Impact: Two members showed awareness of waterborne diseases, stating that gas, jaundice, dysentery, diarrhea, cholera and stomach related diseases had gone down significantly since the community started using the plant's water. One member also noted improvements in sleep quality, and was able to sleep for longer with the treated plant water.

Members also noted that after the plant began operating, it is easier to access clean water. One member stated that before the plant opened it was difficult to bring water from outside. Another member added that the people used nearby pond water before the plant opened.

Nowapara All-Female Collectors

The main themes that were discussed in the local women's FGD were waterborne disease and challenges, especially with the cost of water.

Water Salinity: Two women stated that the water has been salty for a long time. Another woman stated that all the water in the area is saline and that it has been salty since she was born.

Awareness: Three women stated that they first heard about the plant through word of mouth from their neighbours.

Barriers and Challenges:

The cost of paying for the treated water was identified as the most serious challenge. One woman stated "The main problem is money." Another woman said, "They need to give the water for free," as the cost of the water for those in the lowest income bracket made the water less accessible.

After extensive prompting, women agreed that collecting water from the plant affected their family life. For most women in this group, the time required to collect the water was not a significant issue, as most lived close to the plant. Only one woman stated that she lived far away, but this was still less than 1 kilometer. She stated that the time she had to spend waiting in line for water took away time need for housework. Two women agreed that their children complain about them not being there due to going to collect water. One woman stated that sometimes the children miss lunch in the afternoon because of the time taken away to collect water. Two women also noted that those that came from far away had difficulties in transporting the water due to the road being muddy.

Health Impact: The women displayed a clear understanding of the connection between the saline water they used to drink and waterborne diseases. Three participants actively voiced their agreement that drinking saline water caused stomach problems and six of the participants stated or agreed that waterborne diseases had been almost completely eliminated after switching to the plant's water. No one disagreed.

Interviewer: You tell me, your area's waterborne diseases, diarrhea, cholera, dysentery, jaundice, typhoid. Before was there more? Now, is it like before or has it reduced compared to before?

Participant 1: No

Participant 2: Before there was much more.

Interviewer: There was more before.

Participant 2: After...no more… Now there's no more.

One woman stated that the saline water they used to drink caused stomach problems, gastric problems and dysentery and another woman agreed. Another woman stated "If we drink this water we get better" in reference to the water from the plant. Four women stated that they observed people in their family, whose waterborne diseases went away after switching to the plant water. None of the women knew of any children under 5 years who had waterborne illnesses, such as diarrhea or jaundice before or after the plant was installed. Also, no one knew of anyone that had gotten sick from drinking the plant water. Although, only four women were audible in the recording, there was an overall agreement that there had been a significant reduction in waterborne diseases.

Summary of findings: In the water collector FGD the most referenced issues were barriers, expenses and health benefit while in the committee FGD, the conversation was dominated by concerns about expenses, management and barriers (Tables 2 and 3). Tables 2 and 3 also illustrate that the same issues made up a significant portion of the percentage of the words transcribed (from here on referred to as coverage), with waterborne disease being the issue coded with the third highest coverage in the water collector FGD. Waterborne disease was referenced 13 separate times by committee members and 16 times by water collectors. It also made up 1.32% and 2.59 % coverage from the FGDs of the committee members and local water collectors, respectively, as measured with the Nvivo 10 software. The main barrier identified was the financial cost, particularly of the electricity bill, which limited how much water could be pumped and supplied. Expenses were referenced 64 times (7.91% coverage) by committee members and 25 times by the local collectors (2.85% coverage). Thus, the code reference frequency and coverage supports that the main issues discussed in both FGDs in Nowapara were that waterborne illness had decreased significantly after the water treatment plant began operating and that the main barrier to access was the cost of electricity.

Table 2: Codes from Nowapara Committee FGD Ranked by Reference Frequency

Code	References (times coded)	Coverage (%)
Expenses	**64**	**7.91**
Management	**35**	**6.60**
Barriers	**27**	**5.78**
Support	17	1.04
Location	15	1.64
Waterborne disease	13	1.32
Water source	13	0.85
Religious conflict	12	1.84
Strength	11	2.88
Electricity	9	1.31

Table 3: Codes from Nowapara Water Collector FGD Ranked by Reference Frequency

Code	References (times coded)	Coverage (%)
Barriers	**48**	**5.49**
Expenses	**25**	**2.85**
Benefit	17	2.13
Waterborne disease	16	**2.59**
Travel	14	1.70
Solution	12	1.73
Family Life	11	2.17
Saltwater	9	0.77
Cooperation	7	0.93

Nalta Sharif

Nalta Sharif Committee Members

Although, the meeting with committee members in Nalta Sharif ended prematurely, important information was obtained. In early 2014, the desalination plant in Nalta Sharif village of Kaliganj sub-district became operational. Before this, pond water filtered with a sand filter at Ahsania Mission and tube well water were the main sources of drinking water. The desalination project was an initiative of the former Minister of Health and Family Welfare, Dr Ruhal Haque, which was intended to supply water to community members living in a $1.5km^2$ area of the plant in his hometown of Nalta Sharif. There were no major barriers to implementation, as consensus was achieved in decision-making for the plant. For example, it was agreed on that the land on which the plant was built would be provided by Central Ahsania Mission at its headquarters.

In terms of expenses, installation of the plant cost 150,000 taka while the monthly maintenance for the plant costs between 15,000 and 20,000 taka. Electricity costs, chemicals costs and filter replacement costs were approximately 12,000-15,000 taka, 5,000 taka and 5,000 taka per month, respectively. The main barrier identified was the cost of electricity, as Ahsania Mission does not have funds reserved to cover the electricity cost and the money collected from the community is not enough to maintain the plant.

The plant typically produces 4L of water per minute. Committee members felt that the supply of water was inadequate to meet the community's needs, stating that additional plants or a bigger plant was needed.

Nalta Sharif Female Collectors

Barriers: Barriers were the most discussed topic of the FGD with female water collectors in Nalta Sharif. Barriers were referenced 18 times in total by respondents, making up 11.88% of the text transcribed. A significant portion of the barriers discussed were related to accessibility of the water. Issues related to access were referenced by the respondents 9 times (8.34% coverage).

When asked how much of the community was not able to access the water from the plant, one participant stated

"Many people. Around two thirds of people still drink water from outside this filter. Out of 100%, 75% people still drink water from another filter and 25% of us drink from this new filter."

Another issue identified was a lack of electricity supply for the plant. One participant stated "The current doesn't stay," referring to the lack of water supply due to electricity running out for the pump. In addition to lack of supply, long wait times were identified as major barriers. One participant stated

"If a woman has been waiting from 7 to 10 and then they don't get water. Then how bad does that feel? Then dragging around an empty pot is too much work."

Participants also felt that the time needed to collect water and lack of supply affected their ability to fulfill their caregiving responsibilities.

"We spend a lot of time just to collect water. We cannot spend enough time with our family members. Mostly we cannot help our children with their education. It could create bad effects in our family. We have to send our children to school by 9 am. But if we have to stand in line to get water, how will we give time to our kids? Sometimes they have to go to school without eating breakfast."

"We have to wake up early in the morning. It affects our sleep. We have problems to send kids to school early in the morning. It's time consuming sometimes. We can't get water from here if there's no electricity. Then, we have to walk 2 km more to get water from a tube well. But that water is not pure and clean. Sometimes we have to buy water bottle from stores outside."

The financial opportunity cost of purchasing the water was also recognized.

"We could save 60 taka per month if we didn't have to buy the water. That's worth the tiffin money of our kids in school. They could also buy their pens, notebooks etc with this money."

<u>Supply:</u> The lack of water supply from the plant was another major issue discussed. This problem was voiced numerous times as shown in the quotations below:

"Taking today's water doesn't last five days."

"If a larger supply of water was kept then a lot of the time people could get it"

"And if the machine is bigger, then we can get more water. We want to use it for cooking but we can't at this moment because there is not enough left after drinking."

"Yes, but it would have been better if the filter machine was bigger than it is now. Then we could get more water"

Thus, the supply of water did not meet the demands of the community, as the water lasted only a few days and there was not enough water even for cooking.

Expenses: According to respondents, each 5L kolash of water costs 2 taka. A 20L drum costs 5 taka and a 30L drum costs 10 taka.

Current and potential use for the water: Respondents were clear that the water from the plant was only being used for drinking. One respondent stated "No, we will only use it for drinking it. We won't misuse it at all. We won't misuse it by washing our dishes with this water," showing that water from the plant was used scrupulously. When asked what other ways they would use the plant water if more was available one woman stated:

"*For cooking. Currently we use lake water for cooking. But it has all the bacteria and viruses. So, if we had more clean water, we would use it for cooking*."

Health Impact: Overall, waterborne disease was referenced 23 times by participants (5.54% coverage). Participants noted a significant improvement in health since drinking water from the plant.

Interviewer: How was the condition of your health before drinking this water? When did diarrhea occur more? Did it occur before or after drinking water from the new filter?

Participant: Diarrhea occurred more before and it occurred frequently.

Interviewer: How often did it occur in one year approximately?

Participant: Once in every one-two months.

Participants also noticed a significant difference in their health when they drank water from untreated sources instead of the plant.

Participant: If we drink unpurified water, we have problems if we drink unpurified water

Interviewer: What problems sister?

Participant: Our stomachs get acidic

Interviewer: I see, and?

Participant: And we sweat

Furthermore, one participant stated "when we drink this water, the illnesses don't occur." Similarly, another stated "If we drink this water we don't have any problems."

Summary of findings: The quantitative data obtained from NVivo shows that the plant water has been well-received and has reduced waterborne illness in Nalta with the lack of water supply being the major issue of concern (Table 4). Barriers to accessing water were discussed extensively, making up 11.88% of the transcribed discussion and was referenced 18 times while issues of access made up 8.34% of the transcribed text and was referenced 9 times. Issues of water supply were referenced 9 times and made up 4.11% of the transcribed text. Additionally, the benefits of the plant were referenced 14 times (6.47% coverage) and waterborne disease was referenced 23 times (5.54% coverage) mostly in terms of the reduction in these diseases since the plant became operational.

Table 2. Codes from Nalta Sharif Water Collector FGD Ranked by Reference Frequency

Code	References (times coded)	Coverage (%)
Waterborne disease	23	5.54
Barriers	18	**11.88**
Benefit	14	**6.47**
Awareness	11	3.74
Access	9	**8.34**
Supply	9	4.11
Water source	9	4.09
Health	9	2.43

Expenses	7	2.37
Demand	6	2.77

Surveillance Data

Surveillance data from Kaliganj Health Complex and Debhata Health Complex were obtained to observe the rates of waterborne illness in the regions where the case studies were located and to observe whether there was a significant reduction in waterborne illness rates since the desalination pilot project was initiated in 2011.

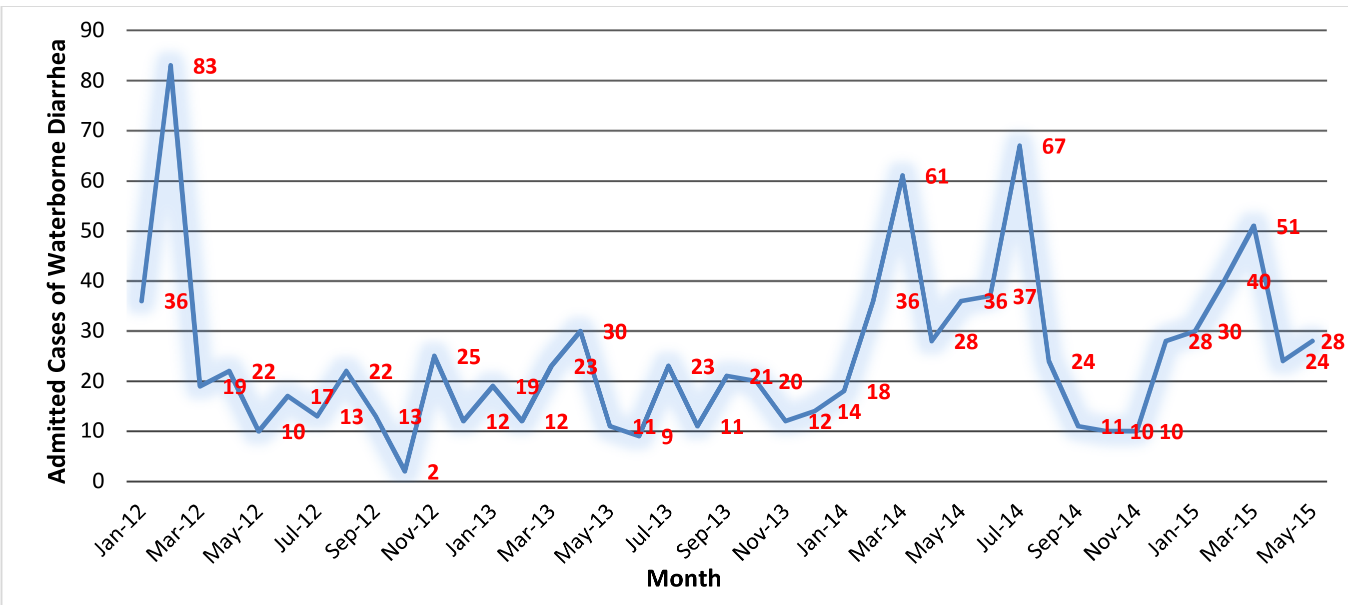

Figure 4. Monthly Waterborne Diarrhea Admission Rates at Kaliganj Health Complex from 2012-2015

Waterborne diarrheal admission rates from 2012-2015 in Kaliganj showed a consistent decline in waterborne diarrhea from March 2012 until January 2014 (Figure 4). This was followed by a resurgence of waterborne diarrhea in 2014 during both the dry season (November to April) when salinity is highest, and the monsoon season (June to October) with peaks in March and July (Minar, Hossan, & Samsuddin, 2013). After the opening of the desalination plant in July of 2014, cases of waterborne diarrhea declined from 67 to 24 in August 2014. After this, the peak number of cases in the dry season, declined from a peak of 61 in 2014 to a peak of 51 in 2015.

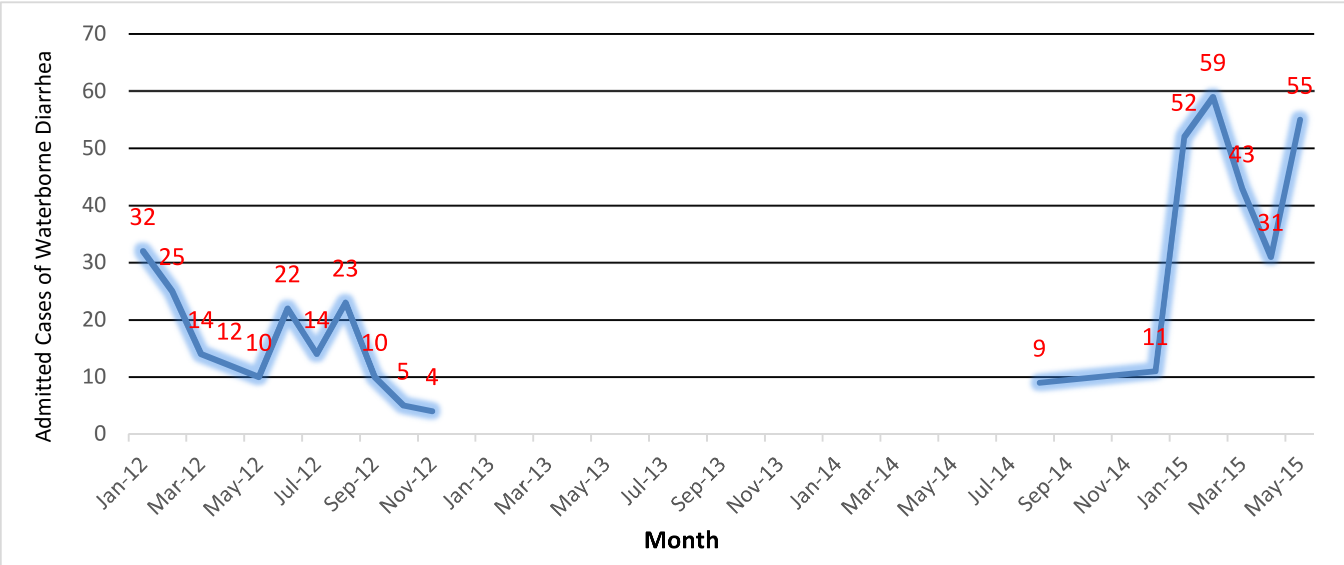

Figure 5. Monthly Waterborne Diarrhea Admission Rates at Debhata Health Complex from 2012-2015

Waterborne diarrhea admission rates at Debhata Health Complex have risen since January, 2015 (Figure 4). Most cases occurred during the dry season from January to March of 2015. Additionally, there is a second peak of cases that occurred during the hot season in May 2015. However, the overall trend is unclear due to the gap in data from November 2012 until August, 2014.

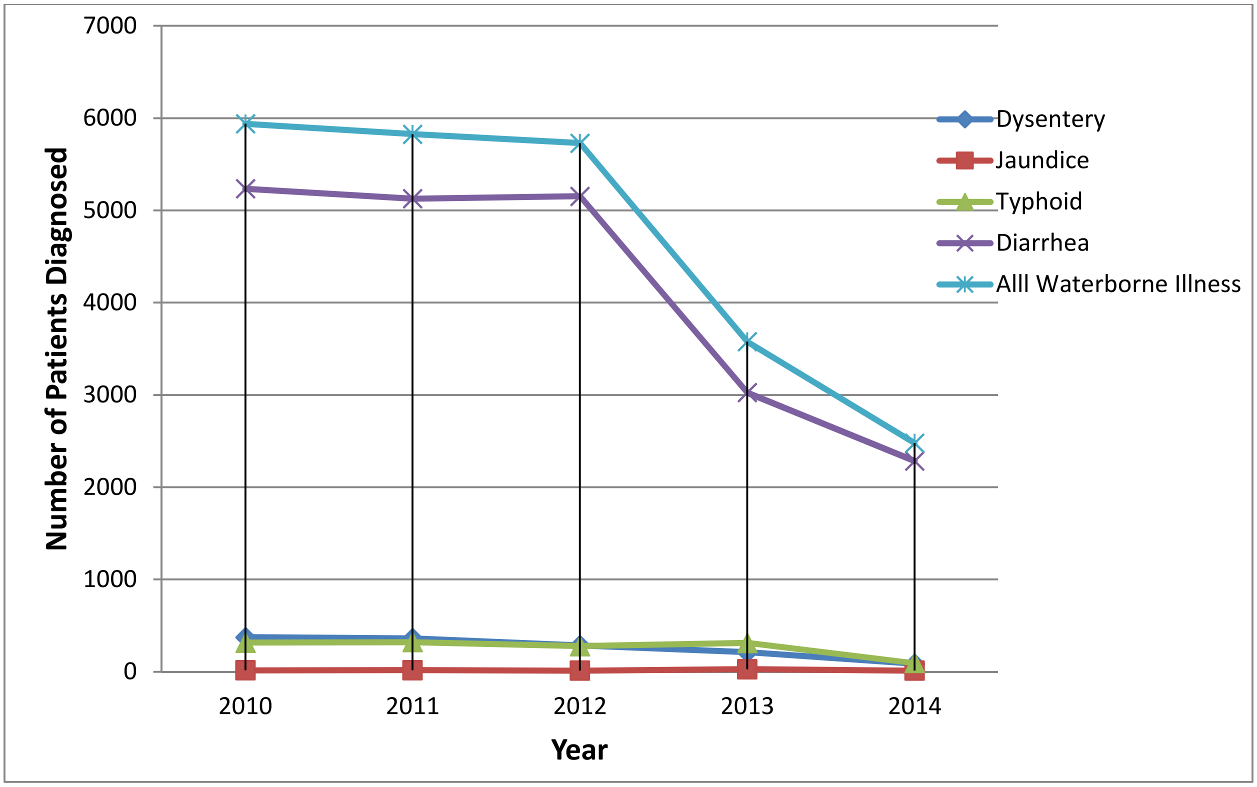

Figure 6. Rates of Waterborne Illness Diagnosed at Debhata Health Complex from 2010-2014

Rates of diagnosis of waterborne diarrhea, dysentery, jaundice and typhoid fever in Debhata sub-district have all decreased in the period between 2010 and 2014 (Figure 6). Diagnoses of waterborne diarrhea decreased most significantly from over 5000 patients from 2010-2012 to 2285 patients in 2014 (Figure 6). Thus, in terms of annual incidence of waterborne illness diagnoses, there has been a significant reduction since 2012 at Debhata Health Complex.

Discussion

Focus Group Discussions

It appears that salinity has been a decades long problem in the communities studied, as one middle aged Nowapara committee member stated that the water had been saline for as long as he could remember, believing it to be a natural phenomenon. According to both communities, groundwater from deep tube wells have been found to be contaminated with arsenic, iron and sodium chloride. Thus, surface pond water contaminated with seawater was relied upon for drinking water by those who could not afford bottled water before the plants were opened.

Overall, the common barrier to accessing water in both communities was the lack of water supply. In Nalta Sharif, the respondents attributed the lack of supply to a lack of electricity and the small capacity of the plant. In Nowapara, access was a greater problem due to the lack of funds the community had to pay the electric bill to run the plant's pump. Ultimately, this forced the committee to increase the cost of water for the end users from 2tk to 5tk for a 5 litre kolash, which made the water unaffordable for the community members in the lowest income bracket. However, the costs in both communities were similar, with electricity costing 12,000-15,000tk per month.

One potential reason that the Nalta Sharif project was more financially stable than the Nowapara project, was the leadership and political influence of former Health and Family Welfare Minister, Ruhal Haque in Nalta Sharif. As a result of this leadership and the greater investment in time and resources that resulted from it, the committee in Nalta Sharif was more organized than the Nowapara committee.

However, there were a number of limitations to the study. Another potential reason for the greater financial stability of the Nalta Sharif plant is that the it has only been operating since 2014. In contrast, the Nowapara plant began operating in 2011, so there has been more time for maintenance and funding issues to occur in Nowapara compared to Nalta Sharif. It remains to be seen how sustainable the plant in Nalta Sharif will be over time. Thus, a follow-up evaluation will be important for Nalta Sharif as well as Nowapara.

Another limitation was that the focus groups were held in the presence of other community members. Thus, there was no privacy for participants. This may have potentially influenced the responses given, as it may have reduced the comfort of participants to openly discuss more personal matters. However, due to the lack of privacy inherent to focus groups, it may not have been a significant limitation. Furthermore, the intention of the focus groups was to obtain information on perceptions and opinions that had community consensus consensus and the open format may help with this consensus or it may suppress diverse opinion. From what was observed, there was no indication that any of the participants were holding back an opposing opinion. However, this would need to be confirmed with further investigation.

Additionally, the seating arrangement for the Nalta Sharif focus group was not ideal. The participants sat in rows facing the interviewer, which resulted in those sitting closer to the interviewer tending to dominate the conversation and being heard more clearly in the audio recording during transcription. For all FGDs, there were major challenges in transcription, as often after the interviewer asked a question, many participants would speak at the same time, making it impossible to hear everyone's response. Thus, the reference and percent coverage calculations from NVivo are only rough estimations of the how much each theme was discussed in the FGDs, as some of the responses in the FGDs were not transcribed.

Another issue that affected the validity of some responses was the use of a number of leading questions by the interviewers. One example of this is when the interviewer asked "So, now that you spend money on buying this water and you don't have any diseases. Don't you think the cost for your medication has lowered due to drinking this water?" The lack of disagreement between respondents' answers, may have also been a consequence of social desirability bias. This bias may also have occurred when participants were prompted during the Nowapara collector FGD to express how the plant affected their family life.

Another potential limitation is the relatively high median age of the water collector participants of 29 and 33.5 years in Nalta Sharif and Nowapara, respectively. The average age of water collectors in these communities needs to be confirmed in order to determine what a representative sample would be in terms of participant age, as this may affect the type of responses obtained.

Although the barriers of time, travel and money were discussed for a significant portion of the interview with users from Nowapara, having been coded 48 times (5.49% coverage), it was difficult to obtain detailed information about how barriers affected the daily lives of the participants. The water collectors had difficulty answering questions about specifically what effects the collection of water had on their lives even with examples given by the interviewer. In the future, in-depth interviews may be a more appropriate method of eliciting feedback on social impacts, as these may include private concerns that participants may not be comfortable discussing among peers.

The three focus groups provided a significant amount of important contextual information about the impact of the intervention so far at two of the plants. Although the two plants were chosen based on the contrasts in their perceived success, they shared the same major problems. Despite water collectors in Nalta Sharif being charged less than in Nowapara, the cost of electricity was the main concern of both committees. The major difference was the greater affordability of the water in Nalta Sharif. However, this will not be sustainable if more funding is not found, as Ahsania Mission does not have reserve funds to maintain the plant in the future. Thus, the Nalta Sharif plant may face the same financial issues that Nowapara is currently facing in the future.

Wait times were another major problem that disrupted the lives of water collectors, taking time away from mothers to care for their children. However, it is important to note that time was also saved compared to before the plant opened in the cases of water collectors who had to travel further away than the plant to find cleaner sources of drinking water before it the plants were established. At Ahsania Mission, the pond sand filter was located a few meters away from the desalination plant. Further investigation is needed to determine the difference in time spent collecting water before and after the plants opened both in terms of travel time and wait time.

In addition, the issues of electricity cost, end-user cost, travel times and wait times are likely to be applicable to other low resource contexts where this intervention may be replicated. Thus, these factors should be considered when choosing appropriate communities and determining the support required if this intervention is to be scaled up to other communities affected by high salinity.

In terms of the health impact, both communities had a completely positive response to the impact that the treated water from the plants had on their health. All participants agreed that there had been a significant decrease in the rates of waterborne disease in their communities since they began drinking the treated water and only noted waterborne disease occurring when they used alternative water sources.

Surveillance data

The surveillance data on waterborne diseases showed mixed results. It is important to note that the dry season, in which salinity is the highest, occurs from November to April (Minar, Hossan, & Samsuddin, 2013). Furthermore, March and April are the peak months of the dry season

(Mahmuduzzaman et al., 2014). This may explain why all but one of the observed peaks in waterborne illness occurred near the end of the dry season around March in both sub-districts (Figure 4 and 5). In Kaliganj sub-district, where Nalta Sharif is located, it was found that admissions for waterborne diarrhea have increased since March 2014, which is close to the time that the Nalta Sharif plant began operating. External factors were likely significant contributors to this trend, as the population of Kaliganj, which consists of approximately 293,252 people, is much larger than just the village of Nalta Sharif, which likely has a population in the thousands. Other potential factors that may have contributed to the higher rates of waterborne illness include contamination due to climate related events, such as drought, flooding and cyclones, policies that may have improved detection of waterborne illness or access to the health complexes, and behavioural factors, such as water transport and storage practices.

The data on waterborne diarrhea at Debhata Health Complex, shown in Figure 6, suggests that the annual incidence of waterborne disease admissions has decreased significantly since 2012, which is the year after the desalination plant became operational in Nowapara. However, Figure 5 suggests that admitted cases of waterborne diarrhea have begun to rise again. There could be many reasons for these observations. One possibility is that the resurgent increase in cases in 2015 could be due to the higher cost of plant water decreasing access to the treated water. As this data is observational, factors other than high salinity may be increasing the risk of waterborne illness. Also, the number of constituents of Debhata who have access to the treated water are likely not significant enough to affect the overall rates of waterborne diarrhea in the region alone, as Nowapara only makes up between 2-3% of the Debhata population. Thus, further investigation into changes in waterborne illness rates before and after the plants opened in the pilot villages is required to clarify the health impacts of this intervention in quantitative terms.

Another important factor to keep in mind in Muslim majority countries like Bangladesh is the shifting time of Ramadan due to it following a lunar calendar. During the month of Ramadan, many Muslims do not eat or drink from sunrise to sunset, potentially reducing the demand for water.

Despite the limitations in the FGDs and surveillance data, it is significant that there was unanimous agreement of the positive health effects of the reverse osmosis pilot project in reducing rates of waterborne diseases and that the decline in waterborne illness diagnoses at Debhata Health

Complex strongly supports this observation. However, the cost-effectiveness of the project requires further elucidation. Thus, this project illustrates some of the advantages and disadvantages of the CBA-PPP model in addressing water security with sustainability the major issue of concern.

Like most existing adaptive responses, the intervention evaluated was mainly a technological adaptation, but was also part of the broader climate change adaptation plan of the Government of Bangladesh that includes institutional and social adaptation (Noble et al, 2014). The integration of these three types of options to each context will be key to effective climate change adaptation.

Currently, at the global scale, more efforts are being put into integrating climate change adaptation into private sector activities and broader government policy as opposed to focusing solely on climate change dimensions. Rather than designing interventions solely for the purposes of adaptation, actions are being undertaken with additional goals such as poverty reduction or profit. The advantage of this is that it has the potential to lead to a more practical, socially just and holistic systems approach that integrates diverse needs and stakeholders. Adaptation must be done through an iterative process, as the feasibility of interventions depends on the time window and climate scenario. (Noble et al, 2014)

Noble and colleagues have identified 15 considerations important to in adaptation planning. Ideally, adaptation initiatives should be effective in reducing vulnerability and increasing resilience; efficient; equitable; integrated with broader social goals; include stakeholder participation; be consistent with social norms and traditions; have legitimacy and social acceptability; be environmentally and institutionally sustainable; be flexible and responsive to learning and feedback; be designed for an appropriate scope and time frame; be likely to avoid maladaptive traps; be robust against a wide range of climate and social scenarios; ensure resources are available; consider the need for transformative changes and be coherent and synergistic with other objectives, such as climate change mitigation. Though it is rarely feasible to fully address all 15 considerations, these considerations should be reviewed and incorporated as much as possible during the planning process for future evaluations and initiatives to maximize effectiveness and equity. (Noble et al., 2014)

At the local level, the community based approach that was used in this project is key to ensuring that adaptation interventions reduce vulnerability and increase resilience by empowering communities to protect themselves from salinity related diseases, particularly waterborne disease. This model promoted equity, as community members were put in charge of their own water resources rather than a profit-driven company, which led to prioritizing the affordability of water. The project also appeared to be culturally appropriate, as in Nowapara, both Hindus and Muslims made up the committees and were able to overcome conflict. The plant was also socially acceptable, as the plant water was well-received by locals with news of the plant's water spreading quickly throughout the community. Thus, there are many strengths of the CBA-PPP model.

Moreover, as the price of renewable energy declines, it may also become possible to improve both the environmental and economic sustainability of this type of project by powering BWRO desalination plants with solar and/or wind power.

Recommendations

The treated water has been more affordable for water collectors at Nalta Sharif and Debhata Health Complex due to subsidization by the local non-governmental organization, Ahsania Mission, and by the Debhata Health Complex administration, respectively. However, at least in Nalta Sharif, Ahsania Mission does not have reserve funds to maintain the plant, so cost will likely become a greater concern in the future unless a source of funding is found. Currently, Nowapara is already facing the challenge of paying the electric cost. Therefore, for future projects, communities should be made aware from the beginning of the costs of managing the plant and efforts should be made to find stable funding to support communities that are unable to afford the full costs of maintenance. It is recommended that government officials help the communities to negotiate with the Rural Electrification Board to reduce the bills to the cost of residential bills or help them to find other avenues for financial support. This will ensure that the maximum number of locals have access to clean water and further help to improve health outcomes in these communities.

Efforts should also be made to supply enough water to meet at least the minimum needs of communities. In Nalta Sharif at the Central Ahsania Mission water plant, the demand for water is not being fully met with the reverse osmosis plant.

Strategies to reduce wait times should also be incorporated in the planning process for this intervention. For example, this could be done by assigning families specific times to collect water with exceptions made when there is urgent need for clean drinking water. However, it will be important to involve community members in the planning process, particularly those responsible for collecting water, to ensure these strategies are appropriate to each community's context.

The lack of health information was another issue identified. Due to the lack of detailed record keeping, rates of hypertension and pregnancy-induced hypertension could not be studied. Additionally, there was a major gap in the Debhata Health Complex monthly waterborne illness surveillance data obtained from the web-based surveillance system. Thus, there needs to be better coordination between different levels of government and more investment needs to be made in the monitoring and surveillance of salinity-related diseases.

In addition, water testing for minerals, pesticides, fertilizers, pharmaceuticals and other contaminants, if not already done, should be done to determine the quality and safety of the plant water. Water testing should also be done on pond water to elucidate the health risks of the pond water that is being used for cooking and bathing.

Additionally, technological adaptation solutions like desalination are just one option among many for climate change adaptation. Desalination should be part of a broader national climate change adaptation strategy to address water security in low lying nations like Bangladesh. Although the government of Bangladesh has developed a National Adaptation Programme of Action (NAPA) and the Bangladesh Climate Change Strategy and Action Plan that attempts to follow these recommendations, the amount of resources being invested into climate change adaptation is still inadequate to meet the urgent needs of the population (Ministry of Environment and Forests, 2015). Thus, the governments and corporations that are the largest contributors to climate change have the responsibility to provide more financial and technical support to vulnerable nations that are being disproportionately burdened by the impacts of climate change.

Finally, it is important that the issue of salinity be addressed as more than just an issue of climate change. An upstream approach that takes into consideration all contributing factors to increasing salinity is necessary to optimally mitigate salinity intrusion. At the local level, education about responsible water management is necessary. Communities should be made aware of whether or not the socioeconomic costs of shrimp aquaculture outweigh the benefits in their region, so they can make informed decisions. Capacity building of local government is also required, as there is currently a lack of capacity to regulate shrimp aquaculture, and protect and maintain coastal polders, embankments, roads and other infrastructure (Mahmuduzzaman et al., 2014). At the policy level, a joint strategy and policy between the governments of India and Bangladesh is needed to improve cross-border river management.

Reflection

This project was inspired by a recognition of the need for more literature on the current health impacts of climate change, particularly in the developing world, and on the potential climate change adaptation solutions to address the current impacts of climate change that have already affected many, as the problems of climate change have historically received more attention than the solutions. As a member of the Bangladeshi diaspora with maternal roots in coastal Bangladesh, I felt it would be more ethical to work here, as I had more cultural and linguistic understanding of Bangladesh than any other developing country. I was also privileged to be acquainted with a member of the CCHPU, who was eager to arrange this research for me despite being outside the country. Most importantly, however, I was driven to do this research out of a sense of social responsibility to my ancestral home, as it is one of the most vulnerable places in the world to climate change. I also express my deep gratitude to the Coast Salish people I have been privileged to have learned from during my time on unceded Coast Salish territories, who have taught me the importance of honoring our ancestors, being connected to ancestral lands and protecting the land for future generations.

Through the experience of performing a program evaluation, I have learned many important lessons about the factors that need to be considered and dealt with in planning an evaluation, supervising the collection of field data and analyzing focus group data. During the process of planning the evaluation and collecting the data, I faced a number of challenges. I learned to accept the things that were outside my control, such as obtaining background information about the project and baseline data when I needed it. I also learned to be flexible in working with what I was provided and became familiar with the types of limitations that exist in low resource settings. For example, since I was not very fluent in speaking Bengali, I had to rely on my co-investigator to communicate to the local project coordinator for me. As a result, I was not able to discuss how recruitment and planning of the field work was to be done and ensure it was done appropriately.

The biggest challenge I faced, however, was dealing with the ethics approval. I was covered for ethical approval by the university, as I was not the principal investigator, but I did not get ethics approval to do the evaluation from IEDCR. Although I began the process of applying for ethics approval at IEDCR, I was advised that if I wanted to be able to have the research done within the timeline planned I would have to do the evaluation without it. I was informed that it was not necessary for quality improvement and evaluation studies, but I still felt uncomfortable moving forward, as I was conducting a study with humans asking questions that could be personal. Ultimately, I decided to continue with the field work, as I felt that the potential benefit of the research to the communities as a tool that could be used for advocacy, outweighed the risk to participants.

It was also challenging to be taken seriously in my role as supervisor, partially due to my lack of fluency in Bengali. The combination of my lack of authority, youth and gender may have also played a role as well, as the facilitators, who were male, only had to be accountable to my female co-investigator who was unable to participate in the field work. For example, I told the two facilitator-notetakers that I wanted to review how I wanted the focus group discussions to be done, but they refused and instead tried to reassure me that they were experienced with conducting focus group discussions. Consequently, many of the directions I provided in the focus group guide I provided to them beforehand were overlooked, such as to avoid leading questions.

When we arrived to begin supervising the first focus group discussion in Nalta Sharif, I was overwhelmed and struggling with my lack of fluency in Bengali, which made me feel helpless. Although we were told that the focus group discussion was going to be held inside a clinic, it instead occurred at the water treatment plant where there was no privacy and many onlookers. If I were to face this type of situation again, I would assert myself in stopping the FGD to reflect on what is happening and ask whether a more appropriate location could be found. I also realized that I should have been more assertive in requesting the facilitators to show me how they were transcribing the interviews, as they summarized the results instead of transcribing the FGDs word for word. As a result, I had to transcribe and translate the results with the assistance of my friends and family. Thus, I learned the importance of assertiveness and not to be overly concerned with being too patronizing. This experience also gave me a better appreciation of the challenges of doing research in a second language and the additional time it requires.

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