Perceptions of Drinking Water Quality in Southwestern Bangladesh

By

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

INTRODUCTION

Research Objectives:

1. To understand the current social and economic factors that surround the villages in Southwestern Bangladesh;
2. To ascertain average levels of water quality found within water sources most common to the villages in Southwestern Bangladesh;
3. To determine if there is any relationship between the socio-economic factors of daily life for respondents and their perceptions of water quality;
4. To explore further how and why perceptions of water quality may change based on socio-economic factors, as well as explore challenges currently faced by rural Bangladeshis and how climate change may exacerbate those struggles.

There is growing global demand for fresh water for drinking and increasing agricultural needs as our global population continues to grow. In fact, the UNDP estimates we will have a global population of eight billion by 2025 (UNDP- United Nations Development Programme, 2006). With strenuous demands being placed on our natural resources, particularly fresh water, much research has been done on water quality and availability. More often we use the term water security, which according to the UN is "*The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socioeconomic development, for ensuring protection against water-borne pollution and waterrelated disasters, and for preserving ecosystems in a climate of peace and political stability.* (UN Water, 2013)*."* Global water security is an object of much debate, especially in light of anthropogenic climate change, which will likely further decrease water security in LDC's (least developed countries).

One of the most populous and more susceptible LDC's is Bangladesh, a low-lying deltaic country in Southeastern Asia. As most of the country is rural and agricultural, the main source of income for most families is most often paddy farming, or shrimp/fish aquaculture (Ravenscroft, 2003). For both of these agricultural operations, water is needed in vast quantities. While water is crucial to survival for all people and animals, Bangladeshis are particularly linked to their water due to the many rivers that flow through the country. Water is an integral part of the economy and health, and is also linked to the culture of the Bangladeshi people. If it weren't for the rivers that flow through down from the Himalayas, Bangladesh wouldn't exist as we know it today. Silt deposited from the Ganges, Brahmaputra and Meghna rivers has and will continue to shape the landscape (Schendel, 2009). Along with these major rivers, Bangladesh is comprised of an intricate network of rivers, tidal channels, ponds, all contributing to the labyrinth of water channels that define the nation. Bangladesh also experiences a tropical monsoonal climate, with most of the annual rainfall coming from June-September. During these months, rainfall is plentiful for both agricultural and domestic needs. However, during the dry season, clean drinking water can become scarce as there are only a handful of water sources, particularly for those living in more rural areas where municipal or piped water is nonexistent. Primary water sources for agricultural and household use are river water, harvested rain water, pond water, and tube wells.

Tube wells, once considered the safest source of drinking water, were designed to be a healthier alternative to surface water sources which often led to gastrointestinal diseases (Flanagan, 2012). Millions of wells have been created across the nation, both deep (> 150 M), and shallow (< 150 M). However, between 2000-2003, 4.94 million tube wells were tested for arsenic contamination and marked as either safe or unsafe for drinking. Since then well switching has substantially lessened the number of exposed to chronic arsenic poisoning. Still, according to a survey from 2000-2010, *"an estimated 35 to 77 million people in the country have been chronically exposed to arsenic in their drinking water in what has been described as the largest mass poisoning in history* (Flanagan, 2012)*."* Chronic arsenic exposure has been linked to a myriad of health issues including cancer, skin lesions, hypertension, and many other illnesses (Flanagan, 2012). Not only this, but local medical facilities do not or are not able to treat arsenic related illnesses. However, arsenic levels are not easily predicted, as one tube well's arsenic levels may be well above the Government of Bangladesh's acceptable limit of 50 µg/L, but a well twenty meters away may contain little to no arsenic, as the reducing environments that allow arsenic into the water are found in a random patchwork type of pattern (Abedin, 2014). In fact, results from a study on sources of Arsenic and Salinity in Southwestern Bangladesh reports two distinctive types of stratigraphy. One is a coarse sand dominated lithology up to 60m in depth with scattered mud layers, while the upper unit comprises 30-40 m of sand and mud deposits. *"Many tube wells in this area are screened in the upper part of this early Holocene aquifer,"* this intermittent mud and sand deposits causes the groundwater to change direction and results in a slow rate of flow and inhibit mixing, which allows the spatial variability in groundwater composition (Ayers, 2016).

Global consumption of water is doubling every 20 years, or at twice the rate of population growth (Abedin, 2014). In fact, it is estimated that that by 2025 at least 3 billion people will be living in water insecure areas, and currently, millions of people are using unsafe drinking water (Abedin, 2014).In the 1990's almost 97% of the rural population of Bangladesh had no access to improved drinking water sources, but currently 73% of the rural population are using tube well water as their primary drinking water source. However, due to the naturally occurring arsenic and frequency of high salinity in shallow depth aquifers, millions are still drinking unsafe water. Although government agencies and development partners are working towards improved water security in rural Bangladesh, it is the communities who are ultimately responsible for the success of any program implemented, as they are also the ones who are most reliant on it success. This is why we believe any successful water management program will be led by member of the community, since they are often the most knowledgeable about water issues.

Perceptions of water security and scarcity are pivotal to the success or failure of a water management plan, and since communities are the first to respond to a hazard, their perception of their current water security situation is quite important. This will become even more important in the coming decades as most of the coastal areas will be impacted by the seas level rise associated with climate change. In regards to how human impacts are changing their current landscape, many Bangladeshis believe their main problem limiting access to safe potable water is salinity intrusion. In fact, a study conducted in Southwestern Bangladesh reported that > 66% of respondents stated extensive shrimp farming was compromising their drinking water security (Abedin, 2014). In terms of socio-economic relationships, those that are not profiting from the lucrative shrimp farming trade, may be more inclined to blame those who are profiting from shrimp farming, since they have the perception that it is the main culprit in the reduction of available fresh water. This would only increase social tensions between rice farmers and shrimp farmers.

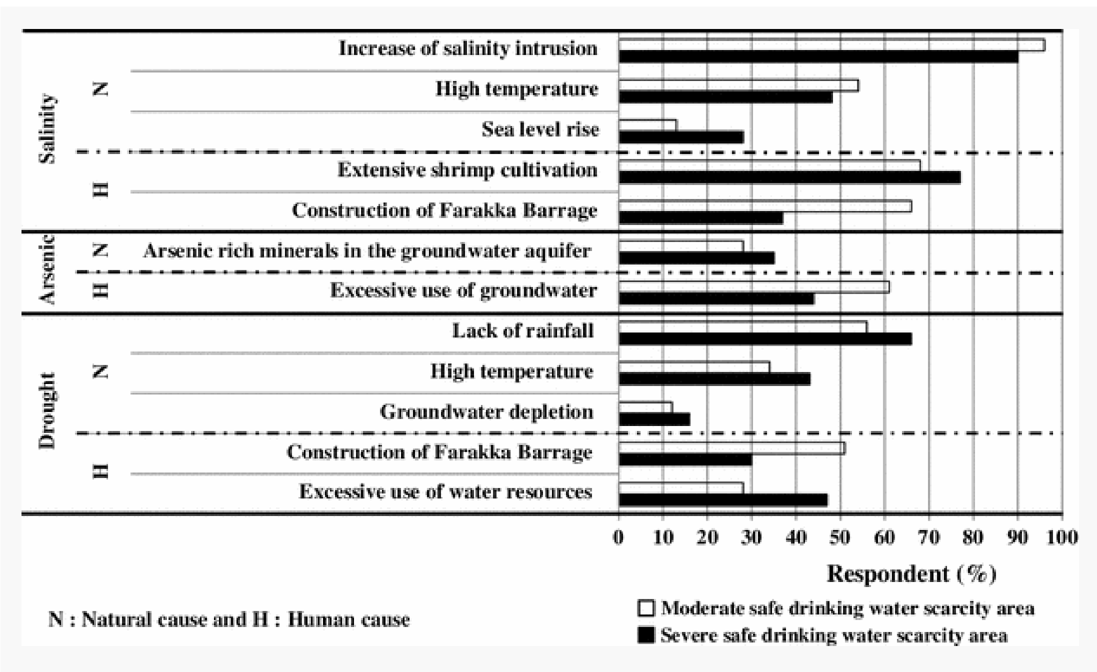

Figure 1: From a 2014 study on community perceptions and adaptations to water security (Md. Anwarul Abedin, 2014)

The figure above is from a 2014 study on community perceptions and adaptions to safe drinking water (Abedin, 2014). They surveyed their respondents on natural and human causes for increasing drinking water security in Khulna and Sutkhira districts. Respondents were grouped into two separate groups, those that lived in a moderate safe water scarcity area, and those which live in a severe area. You can see from the figure, the largest percentage of people perceive the increase in salinity in their drinking water is due to salinity intrusion, most from shrimp cultivation. However, research is finding that there is minimal exchange between surface waters and ground water aquifers in this region, and that most of the brackish water in shallow aquifers are from the Holocene (Worland, 2015). So, the perception that shrimp farming is increasing groundwater salinity is a misconception. However, the tensions between shrimp farmers and others will continue to be problematic because of the perceptions of how shrimp farming is affecting the water quality in the region.

This demonstrates the importance of perceptions of water quality, particularly in water scarce countries such as Bangladesh. How local people perceive the security of their current and future water sources will dictate their day to day actions regarding water usage. Misconceptions about the quality and security of water also has important implications for social and economic aspects. In fact, the rising tensions between shrimp farming and rice farming could potentially be lessened if the local knowledge was that shrimp farming does not directly impact drinking water security via salinity intrusion. However, shrimp farming does affect the salinity of surface water sources, increasing the dependence on tube wells. There is speculation that the increasing dependence on tube wells will lead to the drilling of more deep tube wells, because even though they are more expensive, they are often less contaminated with arsenic. In fact, only 5% of deep tube wells (>150m depth) exceed the WHO guideline of 10μg/L, compared with the 46% of shallow tube wells (Survey, 2001).

Since Bangladesh's most important economic activity is rice production, as well as being one of the largest users of water, ground water irrigation is a significant source of study and concern, particularly during the dry season (Chowdhury, 2012) (Ravenscroft, 2003) (FAO, 2013). Much of Bangladesh is cultivated land, with > 50% of the total area being cultivated land (FAO, 2013). In fact, the rural population of Bangladesh comprises 66% of the total population, with 41% of the total population being economically active in agriculture (FAO, 2013). It is abundantly clear Bangladesh relies heavily on agricultural production for its GDP and livelihood of its people, especially rural populations. It is then crucial to understand the specific water needs and water security and quality on a local scale, as the dynamic nature of this landscape creates a myriad of difficulties that vary from season to season, and are best addressed on a local scale. Each village and each farm has its own way of rotating crops, how they vary types of paddy, and if they employ aquaculture in their farms. A large scale national assessment of these activities will not reflect local variability, as each village will be unique in regards to water use and availability.

The recent increase in shrimp farming (~30 years) has proven ecologically detrimental. From destruction of mangroves to create new cleared land to use for agricultural purposes, the harvest of natural shrimps that devastate wild shrimp populations, capture fishery (Deb, 1998; Paul, 2011), to the contamination of groundwater aquifers and alteration of the chemical makeup of the soil and pond water (Paul, 2011), current fish farm practices in Bangladesh require further regulation. Since agricultural production of rice in Southwestern Bangladesh is one of the most significant both economically and in terms of water resources, the issue of water security becomes increasingly important to sustaining livelihoods. This is true particularly in the rural areas of the country, since agricultural production is almost exclusively the only income source for miles around. Shrimp aquaculture is in competition with paddy farmers land, mangroves, and coastal land, and recently construction of ponds/gher and the associated dykes and polders have caused flooding and waterlogging for several months every year in some coastal areas of Bangladesh (Paul, 2011). Making the regulation of new shrimp farms even more challenging, shrimp farming is quite profitable, in some cases, nine times more profitable than rice farming alone (Ali, 2006). This makes it quite difficult to persuade farmers to take a profit cut and not convert their land to shrimp aquaculture. Many of the negative impacts of shrimp farming are due to poor planning and management (Paul, 2011). As a result, efforts have been made to develop and enforce good aquaculture practices (GAP) and better management practices (BMP), which work towards reduction of ecological losses and social disruption, better site selection, farm management, fish health management, and better record keeping (Paul, 2011). The impacts of land conversion from paddy field or mangrove forest to aquaculture practices should not be ignored in terms of water security. In addition to the changes in soil salinity and acidity and the continued degradation in soil nutrients, the increasing unemployment rate associated with shrimp farming increases social violence (Ali, 2006), decreasing water security for many people.

The geographic location of Bangladesh is both a blessing and a curse. Its monsoonal climate and abundance of water causes much destruction through flooding and erosion, yet without the abundant water and fertile soil, Bangladesh would be as dry as the Sahara Desert, with whom it shares a latitude on the tropic of cancer (Lewis, 2011). The silt deposited from the rivers flowing from the Himalayan mountains provide Bangladesh with its incredibly fertile delta, but the ever-changing nature of the delta makes it difficult to develop lasting infrastructure. Not only this, but its location on the coastline allows access to shipping lanes that bode well for Bangladesh's future in trade (Lewis, 2011). The proximity to the coastline provides abundant resources in fisheries, as well as its access to the Sundarbans area. The Sundarbans are a source of abundant wildlife and other resources, as well as a source of protection from the cyclones, storm surges, and tsunamis that hit the coast of Bangladesh. This source of protection has become threatened in recent decades with the increasing number of shrimp farms in the Southwestern coastal region of Bangladesh.

The second obstacle to providing water security to Southwestern Bangladesh is the high salinity often found in this region. In this coastal region, where deep freshwater aquifers are available, the expense of digging deep tube wells are not feasible for the people living here. Often, people in this region are using harvested rain water, or ponds that collect rainwater and are filtered using a pond sand filter (PSF), although it is worth noting that the water is often not filtered before it is used. The use of PSF's has been implemented to remove biological contamination with some success, such as the removal of coliform bacteria (98-100% removal) (M. A. Y. A. Harun, 2012). However, the practicality of using PSF's as a primary water source is questionable. There is often a queue to collect water as it takes time for the water to be pumped through the filter, creating an even larger burden on those responsible for water collection, primarily women. In fact, worldwide 7 out of every 10 water collectors are either girls or women (Bos, 2010). Not only this, but other issues arise due to the monsoonal climate. If there are periods of drought, use of PSF's are limited as ponds will dry up (Abedin, 2014). The problem of salinity is further exacerbated from the presence of shrimp agriculture, where saline river water is brought in to the village in ponds (Abedin, 2014).

Areas of high salinity intrusion can severely impact not only daily life, but can also severely hamper livelihood and environments. High soil salinity can cause browning of paddy fields, reduction in germination rates, stunted growth (Tho, 2008), and decreased overall production

(Ali, 2006). The damage is not limited to paddy fields either, high salinity in water and soil affect productivity of fisheries, as well as decrease in livestock health and lower milk production (Ali, 2006). These are major sources of income for families, either directly through land ownership, or indirectly through labor and transportation of goods.

Water is not only the source of life and livelihood for people in this region, but intrinsically linked to the people in a way that guides their day to day actions and lives. The factors described above such as high salinity and arsenic concentrations, a monsoonal climate, coupled with a population very dependent on rural agriculture to sustain livelihoods makes this region highly susceptible to the seasonal fluctuations in water security. As such, we hope to illustrate the importance of assessing Bangladesh on a more regional scale rather than on a national scale, as the dynamic nature of this country creates an environment which cannot be examined on a national scale without taking into account all the variability within each region. This paper will analyze data collected during the course of an interdisciplinary study done in Southwestern Bangladesh on water security and issues that affect access to safe drinking water sources. Drinking water is compared using locally collected water data compared to nationally set criteria for safe drinking water, as well as using respondent's perceptions of taste and saltiness to assess water quality. Bangladesh has a current population of 169,996 million people, making it one of the most densely populated countries in the world. This paper hopes to examine in greater detail the coastal Southwestern region of Bangladesh and examine water security for the people living in this region. In doing so, we also examine how people's perceptions of their social, economic, or religious status effects their perceptions of water quality and water security. While measuring the quality of water both nationally and locally is important, it is also important to understand the social and economic aspects behind water consumption. Since water is used for both domestic and agricultural uses, it is crucial to study not only the physical properties of water, but the aspects of water use that effect how people gather water, and what factors may affect access to water.

CHAPTER 1

STUDY AREA AND DATA

1.1.1 Study area

Bangladesh is one of the most populous of the "least developed countries", as well as one of the world's most densely populated countries [Ravenscroft, 2003]. As Bangladesh is considered a low-lying delta, this area is susceptible to frequent flooding, cyclones and accompanying storm surges (Schendel, 2009). This is particularly true for the southwestern coastal region, as its proximity to the ocean means the rivers are dominated by tidal flow, creating a larger problem with salinity in this region, along with greater susceptibly to weather events such as cyclones and storm surges. To counter this low elevation, people began building crude embankments, which has evolved to what is now a much more intricate and sophisticated polder system. The land in southwest Bangladesh was cleared long ago with the start of agriculture in the region, and embanked in the 1960s and 1970s in order to create more arable land for paddy production, but the elevation of those embankments has since fallen due to *"interruption of sedimentation inside the embankments, combined with accelerated compaction, removal of forest biomass, and a regionally increased tidal range*" (Auerbach, 2014). This leaves the area susceptible to flooding and possible contamination of surface water drinking sources. Not only this, the southwestern region of Bangladesh is home to the Sundarban mangrove forest, a 10,000 km² UNESCO World Heritage site which stands in stark contrast to the human changes landscape surrounding its land borders (Auerbach, 2014).

Figure 2: Map of Bangladesh and surrounding borders: image from Google Imagery 2017

The tropical monsoonal climate of this region, along with a lack of sufficient storage capacity, means there is a shortage of clean water during the dry season, and a surplus of water during the rainy season. Throughout this Southwestern region of Bangladesh, the main sources used in our study area were harvested rain water, pond water, and tube wells. Harvested rain water is often collected in concrete containers which collect runoff from household roofs throughout the rainy season, which will often be shared among communities or several households. This storage tank will get the household through the rainy season with fresh water, as well as through the first couple months of the dry season. Pond water is the other major way of storing rain water, although this comes with its own challenges as well. There is a greater risk for bacterial contamination from waste material, as well as the possibility of water loss through evaporation, or contamination from flooding. The last major source of freshwater is from tube wells, which were dug by the millions over the last few decades to try and prevent gastrointestinal afflictions commonly associated with pond water storage. However, due to the natural geochemical makeup of the stratigraphy in Bangladesh, Arsenic contamination ad higher levels of Salinity in groundwater sources has long been recognized as a threat to human health and water security, potentially threatening millions of people.

The study area for this research encompasses much of Southwestern Bangladesh, mostly rural villages who rely primarily on rice paddy agriculture, or shrimp or fish aquaculture for a main source of income. There are eleven different upazillas (sub districts) represented in this study, all located in southern Bangladesh near the Sundarbans, or the mangrove forest. This combination of coastal and rural farmland coupled with its proximity to the largest mangrove forest in Asia, makes this research site an ideal place for water research, especially in light of predictions of seas level rise due to anthropogenic climate change. Over 170 million people live in the Ganges-Brahmaputra river delta, and sea level rise associated with climate change could put them at a great risk of flooding and submergence (Auerbach, 2014).

1.2.1 Data

Two separate data sets from Southwestern Bangladesh were used for analysis in this study. One is a physical water quality data set comprises approximately 34 sample sites. At each site, the water sample was taken from either a tube well or a surface water source. Field parameters were collected by the physical science research team using a Hydrolab field instrument and each sample site was marked with a latitude and longitude measurement using a handheld GPS. The samples were further analyzed in a laboratory setting. These measurements were collected throughout the year from January of 2014 to January of 2015. Samples were only taken only once during the year so our water quality data does not include seasonal patterns, as the research collection team was very small, and it took them this length of time to travel to each site and collect samples.

The second data set used in this study comes from a collaboration from s survey taken by the Vanderbilt Social Sciences team. During this survey, 1204 households from Southwestern Bangladesh were surveyed by the social science field research team on various aspects of their day to day lives. The data set included 29 separate site locations. At several site locations, the area was being surveyed for a potential new water source, a MAR (managed aquifer recharge) would be installed to improve drinking water in the area. The second type of site location was a return visit from a survey conducted in 2009 to survey the damage from the destruction of Cyclone Alia in 2009. Out of all those site locations, a random selection ranging from 20-80 households were selected from each site. This data set provided us with information about economic status, religious beliefs, gender, marital status, water sources, and taste perceptions of water sources. This survey was constructed after a 2013 pilot survey of a smaller in area in

Southwestern Bangladesh. This smaller pilot survey was completed on Polder 32, specifically Kamarkhola and Kaliboga/Sutarkhali mauzas, which included 200 randomly selected households, to test survey practices for the larger 2014 study. The survey includes several other variables, but for this analysis we chose to examine only these parameters.

The two data sets include overlapping study locations as indicated on the map above (Figure 2), both in Southwestern Bangladesh, which allowed us to study both the water quality, and water perceptions based on several socio-economic factors in this region. By using both data sets, we are able to gain a unique perspective on water security in this region. We used the water quality data to quantitatively measure a select sample of water sources to visualize what the physical properties of the water are, and we used the survey data to understand how and why people used which sources they did. We also had access to religious, economic, and other social aspects of their lives, which were useful in determining which factors might determine better or worse water security, as well as perceptions of social and economic status and how that may affect perceptions of water quality.

CHAPTER 2

MATERIALS AND METHODS

2.1.1 Religion & Gender

During our preliminary analysis, we were able to narrow applicable parameters through exploratory data analysis. By examining relationships between the survey questions asked during the household survey study, we were able determine if and where relationships existed. 1204 people were surveyed, 573 females and 631 males.

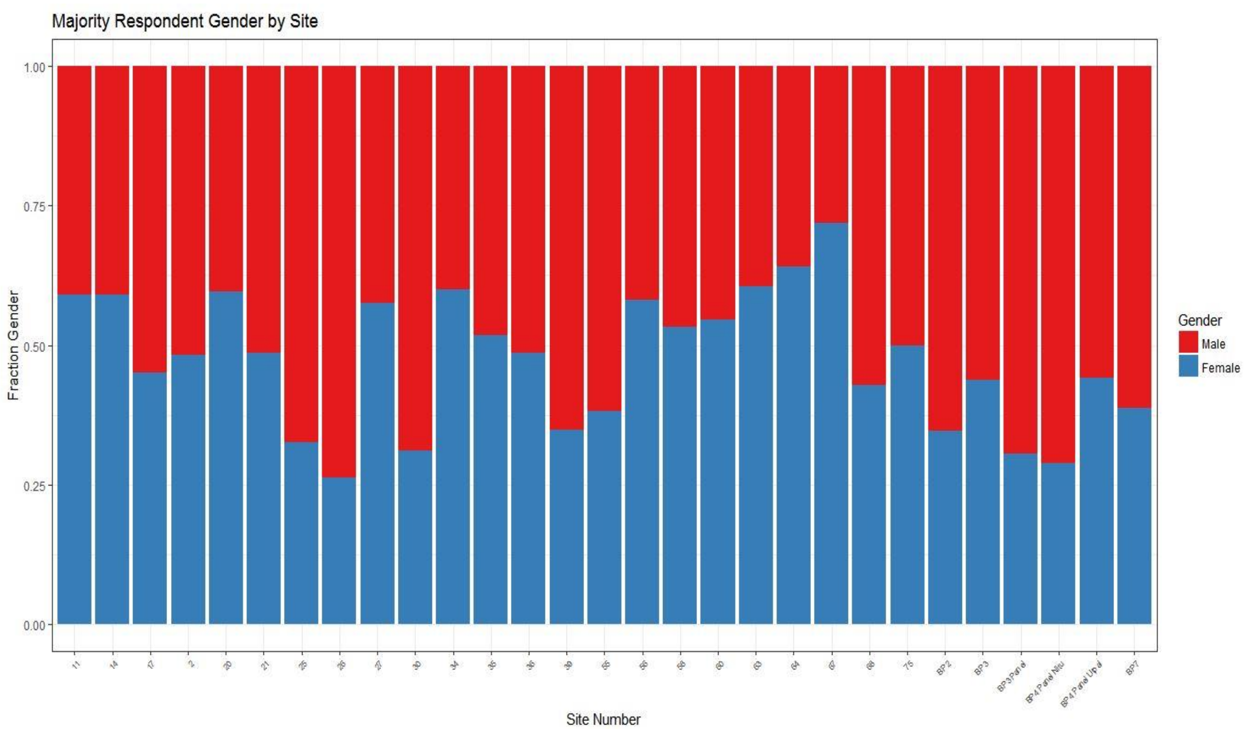

Figure 3: Fraction of males to females in our study area.

Figure 3 above demonstrates the fraction of males to females in our study area. In this dataset, 48% of respondents were female and 52% were male.

66% of the people surveyed were Muslim, 34% were Hindu, with the remaining .4% people identifying as Christian or other. However, it is important to note this proportion is not representative of the national averages in religious status, as 90% of people in Bangladesh identify as Muslim, 9.3% identifying themselves as Hindu, and the remaining .7% identifying as Buddhist or Christian (UN Data, 2009). Indeed, the Hindu religion is more prominent in the southwestern coastal region of Bangladesh than it is throughout the country as a whole.

2.1.2 Water seasonality & usage

We were also able to determine which of the available water sources were most often used, and gather an understanding of how frequently they were used. Out of all sources used in Southwestern Bangladesh (bottled water/purchased, fresh pond water, harvested rain water, municipal/piped water, river water, shrimp/fish pond water, tube well, desalinated water, and other), the most used were tube well (400 households), harvested rain water (565 households), and fresh pond water (760 households). For our analysis, we focused mainly on these most frequently used sources. However, households use more than one source throughout the year, which is why there are more than 1204 responses to the seasonal water usage.

Respondents were also asked about seasonal usage of the water sources, the following were the options from which they had to select: six months, all year, Boishak & Joistha(April-June), Asar & Sraban(june-August), Vadra & Ashwin(August-October), Kartik & Agrahan(October-December), Poush & Magh(December-February), and Falgun & Choitra (February- April). Since respondents were only able to select from one of these options, our answers are mostly skewed toward the six months and all year categories. This gave us good data indicating which sources are available year-round, and those which are only available for half the year, however, we were not able to discern for which six months of the year those sources were available.

When working with this survey data, the importance of understanding which questions and answers are relevant to the questions we are trying to answer quickly became apparent. Much time was devoted to understanding the details of how interviewers posed questions, and how the respondents were asked to answer the question. This initial exploratory analysis of the survey data allowed us to filter out any questions that were irrelevant to either our research question, or returned data that was not useable for our research purposes. Our exploratory analysis also gave us details on gender, religion, social and economic status, which help put our social data into the correct context.

Figure 4: Seasonal water source usage in Southwestern Bangladesh

Figure 4 demonstrates the sources used during the six months and all year time frames. We can see from this image that the most used sources are once again the ones we chose to focus our analysis on: tube wells, fresh pond water, and harvested rain water. However, it is also important to note that there are many other sources available, such as shrimp/fish pond water, river water, some bottled water, and a few sites even have access to water from a desalinization plant.

In Bangladesh, harvested rain water is used primarily during the rainy season, as women can simply place buckets, pots, or plastic containers outside of their home to collect the rain for daily use. Although, during the dry season, harvested rain water is not a viable option for everyday water use, even with the availability of large storage containers that collect rainwater from rooftops. Women will often walk to their preferred option for a tube well to pump water, or travel to a pond, sometimes using a PSF to filter the surface water source for contaminants. We can also see form Figure 4 above, there is no village that only uses a single source of water the way we in the United States are used to using our tap water.

Figure 5: Map of MAR survey sites in Southwestern Bangladesh. Red points indicate location of a surveyed household.

You can see from Figure 5 above, many of our site locations are in close proximity with the Sundarbans mangrove forest. Much of the Sundarbans has been cleared throughout the centuries to make room for more farmland, leaving many villages in the area more vulnerable to weather related disasters.

2.1.3 Taste perceptions and Socioeconomic status

The survey asked respondents how they would rank their economic and social status on a scale of one to ten. One would be the lowest economic or social status in the village, while ten would be the highest. We chose to use this parameter as a measure of wealth or status rather than expenditures or income because we felt some of the respondents may have not answered accurately or may not have understood what the interviewer was asking. Since respondents were asked to rate their own status compared to those living around them, we also gained some insight into how people feel they measure up against what they believe is the average economic or social status of their village.

Figure 6: Respondents perception of their perceived economic status compared to the perceived economic status of their neighbors. Red bar indicated the highest achievable income status, green indicates lowest income status, and blue indicates perceived level of income status of the individual being surveyed.

Figure 6 above demonstrates respondent's perception of their economic status. At each site, people were asked to rate their level of income, as well as the community's minimum and maximum level of income, on a scale of 1 to 10. In Figure 6 it is important to note, we are using respondent's perceptions of income status based on their village. We can see from this figure most sites determined the highest level of income status they could achieve in their village was about an 9, while the minimum is around one or two. Interestingly, most people believe their current level of income is around a level 5 or less, with a few exceptions. So, what we are seeing is that most people perceive themselves to have average income, or below average income status, while a few people perceive themselves to be above average. This is an important observation to make, because it gives a lot of insight into how people in Southwestern Bangladesh perceive themselves in terms of their ranking within their community.

A water security index was developed by Lautze and Mathrithilake for 46 Asian countries to create a better understanding of the concept of water security (Luatze, 2012). Here we can see Bangladesh falls 25 on the list of 33 here in Figure 7.

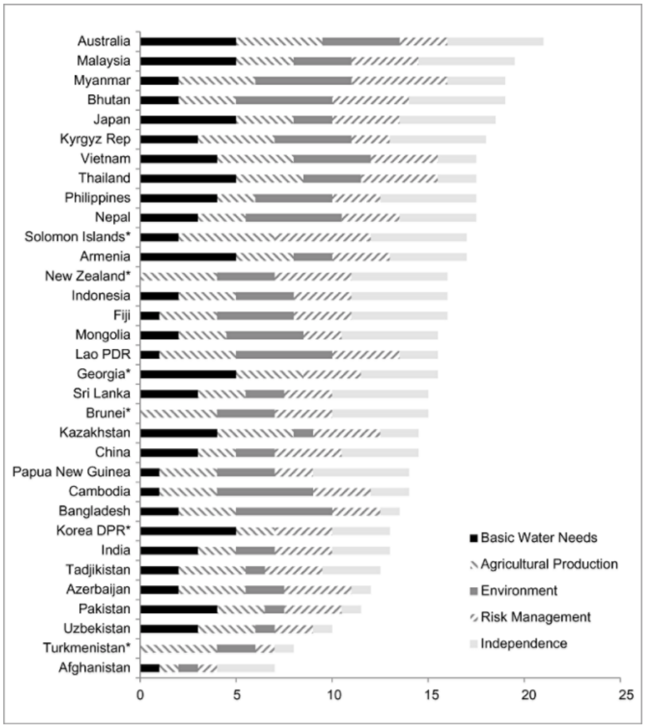

Figure 7: From Lautze & Mathrithilake's Country Water Security Index.

Only 33 appear here on this list because enough data was not available to include the remaining 13 countries included in the study. This index includes five components: basic household needs, food production, environmental flows, risk management, and water independence. However, this water security does not account for water related shocks along with many other factors, which is one of the reasons using water indices can be uninformative. For example, we can see in Figure 7 that New Zealand has a lower water security ranking than Nepal, which we know is not true from using our common sense. There are many terms used to describe lack of water resources, and many encompass more than simply the amount of water available to a person. For example, the Falkenmark indicator identifies regions based solely upon water resources per capita (Falkenmark, 1989), social water scarcity index (Appelgren, 1999), the water poverty index (Lawrence, 2002), the water resources vulnerability index (Raskin, 1997). Studying water indices and parameters becomes particularly complex in countries such as Bangladesh, due to the many complexities of the climate and seasonality. In a case study comparing Sri Lanka and Bangladesh in terms of water indices and parameters, these complexities and parameters are utilized to determine if they are effective tools for water managers. They found that there is “no single index can capture all of the complex interactions implicit in human-water systems, the omission or inclusion of key parameters can alter the conclusions drawn from an index (Grey, 2007) (Gunda, 2015).”

Index	Bangladesh[a]	Sri Lanka[a]	Source
Falkenmark Indicator	8,153 m^3/person/year (No water stress)	2,509 m^3/person/year (No water stress)	Falkenmark, 1989; Data: FAO, 2013
Social Water Scarcity Index	2.4 (relative sufficiency)	5.6 (relative sufficiency)	Appelgren & Klohn, 1999; Data: FAO, 2013; UNDP, 2013a
Water Poverty Index	58.1 out of 100	58.5 out of 100	Lawrence, Meigh, & Sullivan, 2002
Rural Water Livelihoods Index	65.44 out of 100	68.62 out of 100	Sullivan et al., 2009
Index of Drinking Water Adequacy-2	24 out of 100	37 out of 100	Kallidaikurichi & Rao, 2009
Water Resources Vulnerability Index	3 (Stress)	4 (High stress)	Raskin et al., 1997
Composite Water Vulnerability Index	0.11 (Low resilience)	0.22 (Upper-low resilience)	Paladini, 2012
National Water Security Index	1 out of 5	2 out of 5	ADB, 2013a
Water Security Index	13.5 (Poor)	15 (Satisfactory)	Lautze & Manthrithilake, 2012

[a]*Shaded indices indicate country with a more favorable ranking.*

Table 1: From "Exploring water indices and associated parameters: a case study approach." (Thushara Gunda, 2015) comparing Sri Lanka and Bangladesh using several different types of water indices. This demonstrates the complexities of measuring water security.

Our second data set (water quality data) contains 34 site locations, with 358 sample locations. Sample locations were chosen close to populated areas, mostly around where tube wells were located. For the purposes of this water quality analysis, we focused primarily on tube wells, as we did not have data on the type of surface water source was being sampled. The data set consisted of 160 tube wells, with the remaining samples as surface water. Out of all the 160 tube wells sampled, 132 were shallow (< 100m) with the remaining 28 wells having a depth greater than 100m. This data was collected during 2014, and each site was only visited once. This data set does not have data on the seasonality of sources, only physical water quality measurements taken at the site and those analyzed in the laboratory. Parameters analyzed in this study are pH, TDS (total dissolved solids), ORP (oxidation reduction potential), DO (dissolved oxygen), SPC (specific conductivity), Salinity, As (arsenic), and several other measurements not relevant to this thesis. Using these major indicators of water quality, we set out to determine the relative safety of available drinking water in this region (Southwestern Bangladesh).

CHAPTER 3

RESULTS AND DISCUSSION

3.1.1 Water Quality Results

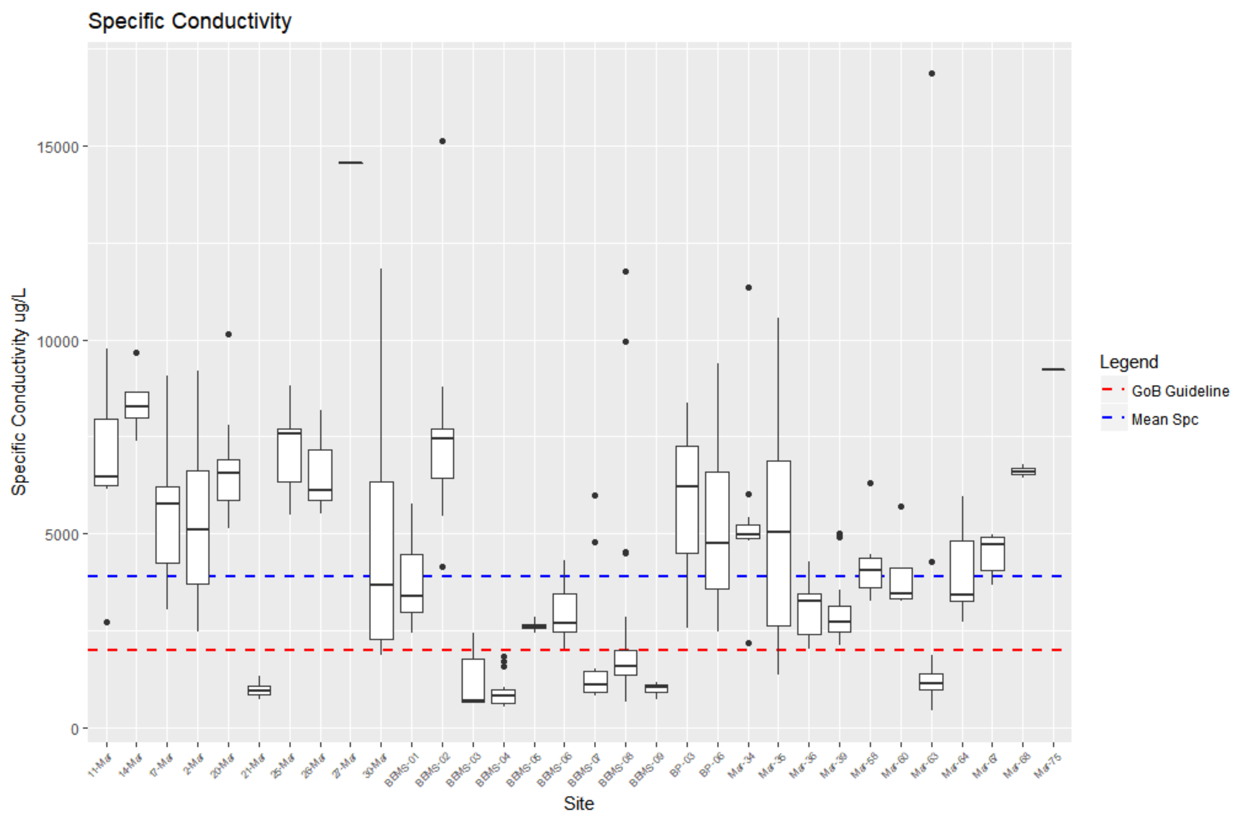

Figure 8: Demonstrating Specific Conductivity levels across 34 sites in Southwestern Bangladesh.

As you can see in the Figure 8 above, tube wells available in Southwestern Bangladesh do not meet irrigation and drinking water standards. In both arsenic and Specific Conductivity (SpC) criteria, drinking water levels in this area are well above the recommended thresholds indicated on the figures both above and below. The top horizontal line (green) in the figure above shows us the mean SpC across all sample sites, approximately 1000 µg/L, while the second and lower horizontal line (red) demonstrates the GOB guideline for these sites from our dataset. Almost all of these sites have water above the GOB guideline for safe drinking water. In southwest Bangaldesh groundwater SpC typically ranges from 1-10 mS/cm or 0.5-5.2 ppt (seawater is 35 ppt) (Ayers, 2016). Due to the close proximity to the tidal channels which mix freshwater with seawater from the Bay of Bengal, the channels are a perceived potential source of the high salinity commonly found in this area, but evidence suggests there is little to no recharge from modern tidal channels (Ayers, 2016). Another perceived potential source of saline water in the shallow aquifers is from shrimp ponds during the dry season, although only freshwater from the wet season would have sufficient volume of water to recharge the aquifer in any significant capacity (Ayers, 2016). Isotopic groundwater samples suggest the aquifers were formed in the Holocene era, and modern (~50 years) infiltration is not a major component of the groundwater compostion in the shallow aquifers (Worland, 2015).

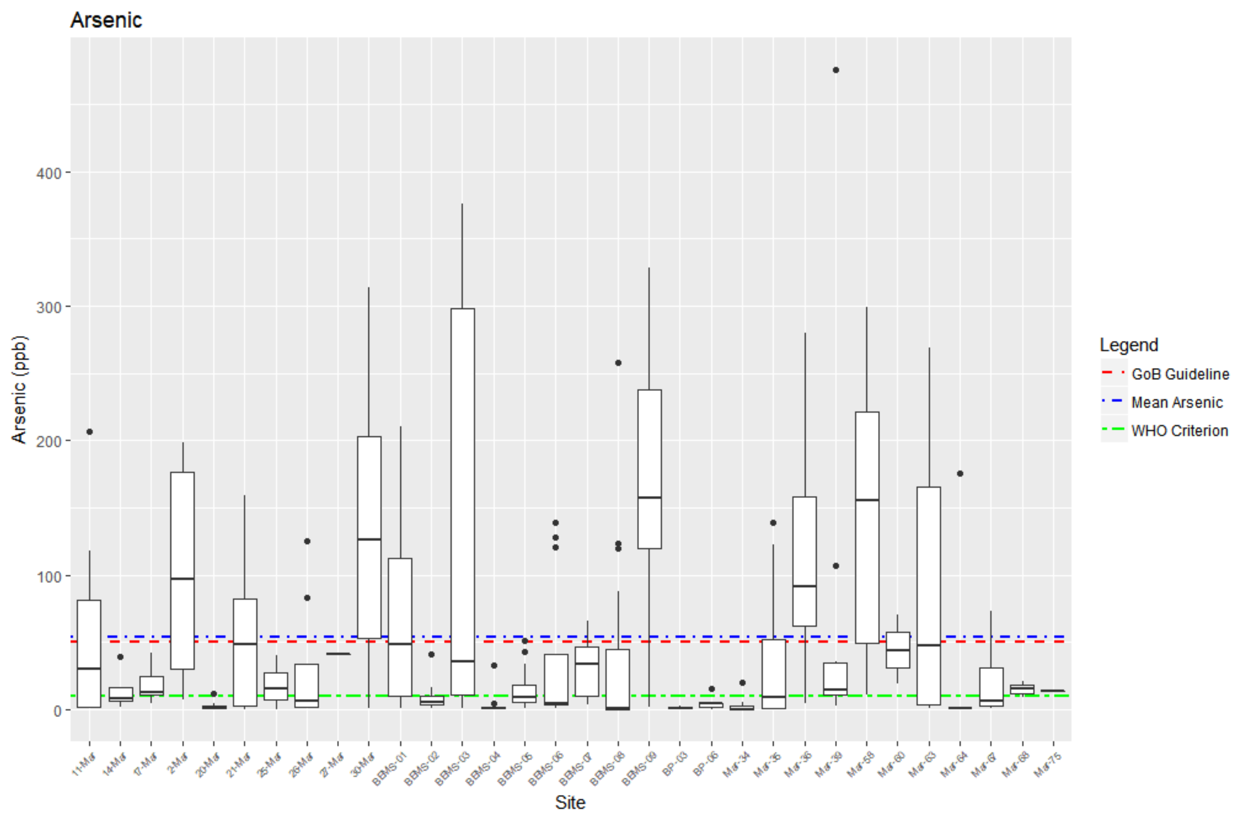

Figure 9: Demonstrating Arsenic levels across 34 sites in Southwestern Bangladesh.

Arsenic levels in this area are similar to the findings in a WHO bulletin from 2011 reporting that millions of people are drinking water with concentrations > 200 µg/L (Flanagan, 2012). The top line (blue) is the mean Arsenic concentration across all sites. The second line (red) in this figure represents the Government of Bangladesh (GoB) criteria for safe levels of arsenic in drinking water, and as such, tube wells that have been tested for arsenic and painted green (as in safe to drink), will be at or below this level. However, the bottom line on this figure (green), represents more current research on safe levels of arsenic in drinking water. The 2011 report on drinking water guidelines from the World Health Organization reports the safe level of Arsenic in drinking water is <10 ppb. (WHO- World Health Organization, 2011). A lower arsenic criterion in Bangladesh matching global standards means even more people will be drinking water with arsenic concentrations over the recommended limit. A local Southwestern Bangladesh NGO reported that 79% of tested tube wells of shallow aquifers are contaminated with arsenic beyond the acceptable limit (Abedin, 2014).

3.1.2 Water Quality Discussion

In 2009, it was estimated that 22 million Bangladeshis were still drinking water that does not meet the Bangladesh drinking water standard in regards to arsenic. Of those, 5 million were at greater risk because they were drinking water with > 200µg/L arsenic (WaterAid & BGS, 2001). There are ongoing efforts to reduce the number of people drinking contaminated water, including the well painting program, which tested and identified many wells, and painted the wells to signify red or green whether or not the water was safe to drink. Wells with As concentrations > 50µg/L were painted red, while wells with < 50µg/L were painted green to signify they were safe to drink (Van Geen, 2005). While this experiment proved to be quite beneficial in raising awareness of arsenic contamination to the local people, some suggest the information is fading from memory quickly as water grows scarcer.

3.2.1 Drinking Water Sources Results

We examined the survey data to determine what sources are available to the people of Southwestern Bangladesh and how frequently they are used. Throughout the region there are 9 sources most commonly used.

Source	**Number of Respondents**	**Percent**
River Water	19	1.0
Fresh Pond Water	760	41.6
Harvested Rain Water	565	30.9
Municipal/Piped Water	22	1.2
Tube Well	400	21.9
Shrimp/Fish Pond Water	35	1.9
Desalinization Plant Water	8	0.4
Other	19	1.0

Table 2: Demonstrating the number and percentage of people who use each water source. Respondents could answer multiple times, so there are more than 1204 responses to this survey question.

We can see the 3 major sources are Fresh Pond Water, Harvested Rain Water, and Tube wells. For our analysis, we chose to focus primarily on these sources as they are most likely to produce statistically significant results. We did not have water quality data on each individual source, but we were able to understand how respondents felt the water source tasted, both in saltiness and in general taste. Respondents were asked "Is this water salty?", and "Do you like the taste of the water?", to which they answered either yes, no, or no answer. The figure below shows us the fraction of people who thought the water source tasted salty.

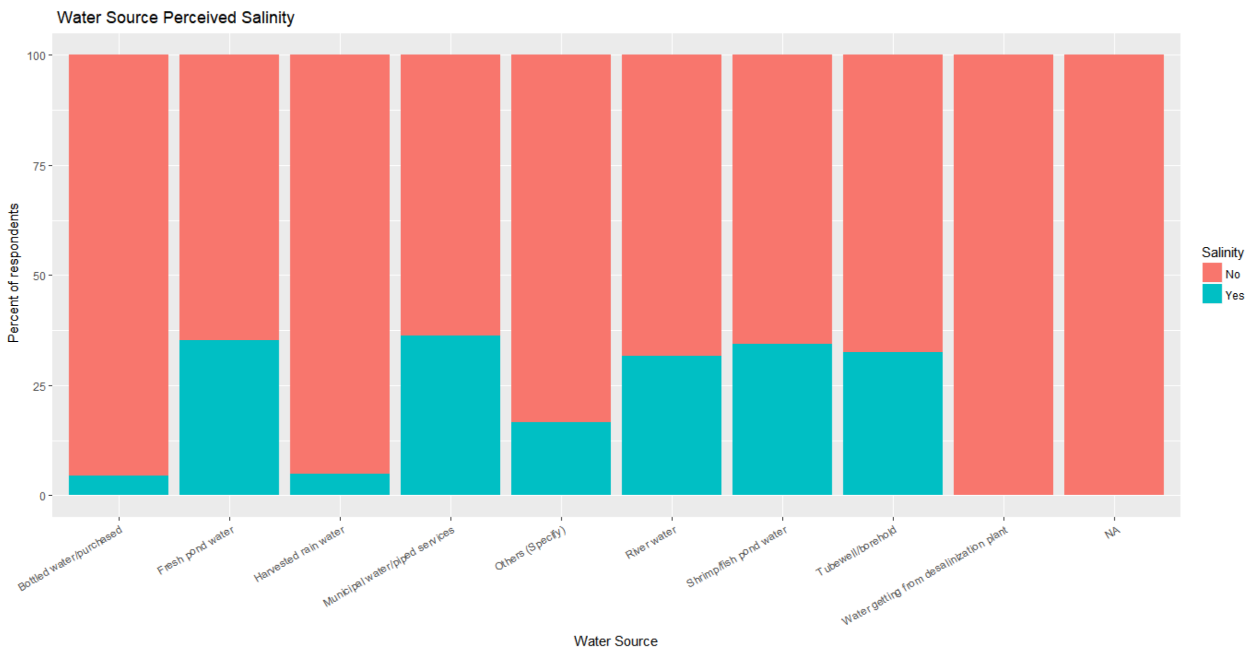

Figure 10: Perceived salinity of each available water source. No (red bar) indicates the respondents felt the water source did not taste salty, while Yes (blue bar) indicates respondents felt the water source tasted salty.

Figure 10 shows the majority of people felt that their water source was not salty, with > 50% of respondents at each site answering their water was not salty. This is a rather alarming statistic, due to the fact that the majority of available drinking water in this region was well above national drinking water standards.

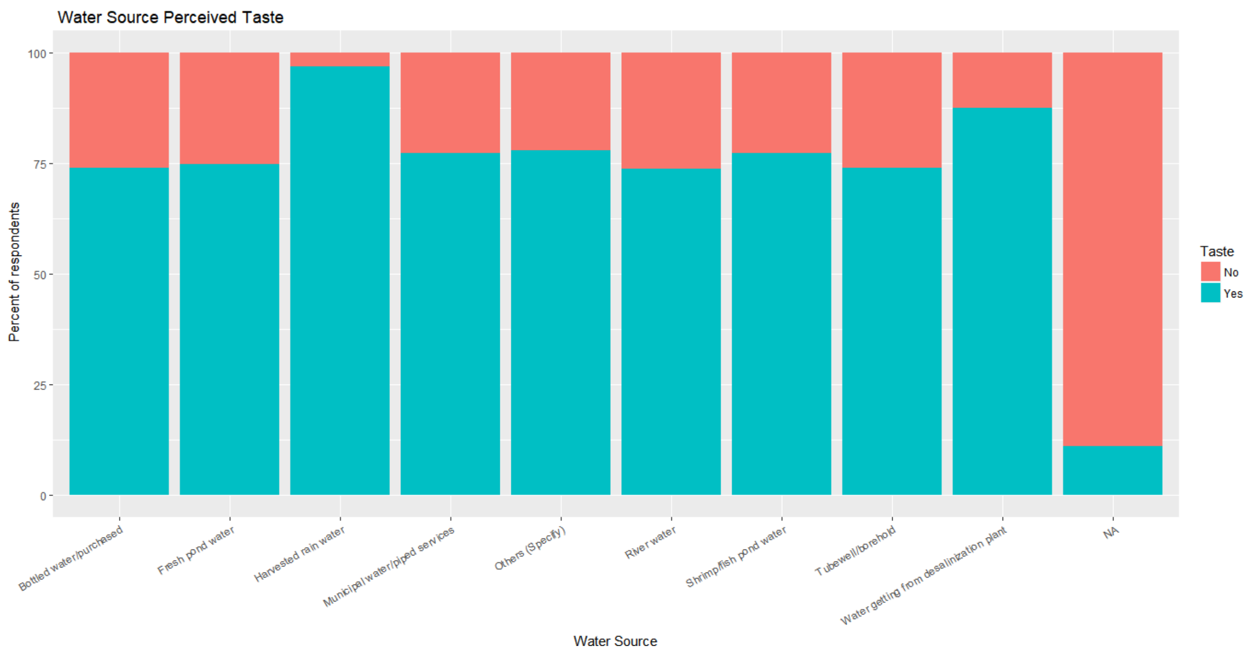

Figure 11: Perceived taste perception of each water source

Figure 11 above demonstrates that the majority of people like the taste of their drinking water. Once again, taste perceptions to not seem to correlate with our data on water quality in this region.

The Government of Bangladesh (Bangladesh, 1997) has set standards for drinking water, which are stricter than the WHO guidelines (2011) with the exception of arsenic (there are a few others, but those standards were not evaluated in this paper). Arsenic guidelines form WHO are set at 10µg/L, while GOB standards are currently at 50µg/L. There is no GOB standard for SpC, but there is a guideline of 2,000µg/L. This guideline has appeared in the literature and reports for a while, but the basis is unclear. Sone indicate the value is estimated from regression equations and the upper range of the GOB Cl limit (600mg/L) (Ravenscroft, 2003), while others say it came from and irrigation water limit for reduced rice yield (Kaudstaa, 2003) (Bennyworth, 2016).

3.2.2 Drinking Water Sources Discussion

When we examined our data on taste perceptions, we often saw that people did not mind the taste of their drinking water, even though we know much of the water they are drinking is quite unhealthy. It became rather puzzling to determine which factors went into their answer. There are several possible explanations as to why a person in this region may say they like the taste of water, even though someone from a different region may not like the taste. People living in villages with saline water may have become acclimated to the taste of water containing more salt, particularly if they have lived in the area for longer periods of time. Over time, drinking slightly saline water could result in a desensitization of the taste buds. However, acclimation in taste does not remove the health hazards posed form drinking saline water. Another explanation of taste approval in poor water quality regions is simply acceptance of their lack of better drinking water sources. Once it becomes normal for the water to taste this way, and since there is no water of better quality to compare it against, it becomes acceptable. In fact, when presented with fresh bottled water, local people will often refer to it as sweet water, since without the presence of the salt, it tastes quite sweet. The lack of available water options in this region of Bangladesh is quite similar to the lack of options for electrical energy. Without the option to access such things, people will adjust and adapt in order to continue on with their day to day lives.

Our analysis also found that economic or social status did not affect access to improved drinking water sources. People with higher perceptions of income and social status did not necessarily have access to better drinking water sources than villagers with lower income and status. If the people in Bangladesh cannot improve their quality of life through economic success, what other options do they have to gain year-round access to safe and clean drinking water, something most people consider a basic human right? This effects not only drinking water, but indeed the increasing salinity of surface and ground water in Southwestern Bangladesh creates an economic problem as well. Rice farming, the region's major occupation, might become nearly impossible without access to fresh water. Although the coastal regions only contribute about 16% of total rice production within the country (Ahmed, 2011), the ever-growing fish production farms constitute about 4% of Bangladesh's GDP as of 2012 (FAO, 2016). In fact, one of the many adaptations to increasing levels of salinity on the Southwestern coast is the conversion of paddy fields to fish farms.

3.3.1 Water Security and Seasonality Results

In a similar study done in 2014 by Laura Bennyworth from Vanderbilt University, water quality and access were examined in a small area in Southwestern Bangladesh, Polder 32 (Bennyworth, 2016). She found that reports of water security and access from larger studies across Bangladesh did not reflect the local variability found in the Southwestern region. We wanted to determine if this were true on a larger scale than what Bennyworth's study examined. Her study also concluded that "*both groundwater and surface water drinking sources in the southwest coastal area of Bangladesh have levels of arsenic, salinity, and a multitude of other contaminants above Bangladesh's drinking water criteria*. (Bennyworth, 2016)."

Respondents were asked to select one of the following seasons, which also show their corresponding Western months: six months, all year, Boishak & Joistha(April-June), Asar & Sraban(june-August), Vadra & Ashwin(August-October), Kartik & Agrahan(October-December), Poush & Magh(December-February), and Falgun & Choitra (February- April). We found a flaw in the study design, since each person was only asked to select only one of the answers, they were not able to specify which sources were accessible in each season. This allowed us to see which sources were most frequently used for a 6 month or year-round time frame, however, it was not season specific.

Still, we were still able to see patterns in which sources were used all year, and which were only used part of the year. It is reasonable to assume that those sources used year-round are the least variable, while those more often used for only 6 months of the year are either not available year-round, or have poor water quality during certain times of the year. Unfortunately, we had to focus specifically on the two answer options which had the most responses, 6 months with 562 respondents and all year which had 916 responses. Ashar-Srahon (June/July/August) had 256 responses, while the remaining options had < 35 responses each. The 6 months option had the Harvested rain water (235 respondents), Fresh pond water (217 respondents), Tube well/borehole (67 respondents), with the remaining options having less than or equal to 12 respondents per source. The major sources for the All Year option were Fresh pond water (503 respondents), Tube well/borehole (311 respondents), Harvested rain water (39 respondents), and shrimp/fish pond water (28 respondents) with the remaining options having less than 8 respondents each.

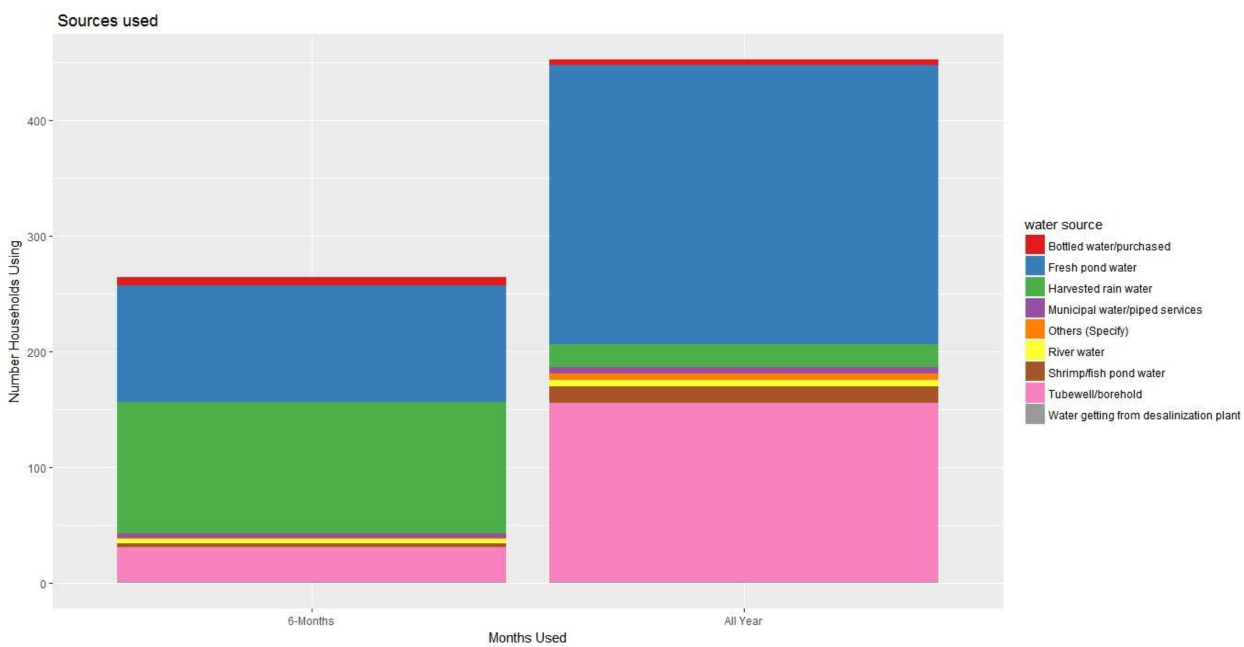

Figure 12: Seasonal usage of water sources.

3.4.1 Water Source Maintenance Results

In this region, primary water sources are either privately owned, or shared by the community. We wanted to investigate who was responsible for the ongoing maintenance of water sources. We found that most frequently, the community and household are responsible for maintenance of water sources, rather than the government or an NGO. This brings about the question of the feasibility of the burden of water source maintenance falling to a certain household or to a community as a whole rather than water source maintenance being a government responsibility. The community's maintenance affects the viability of the water supply, so while people living in the coastal community need access to safe drinking water, their low income suppresses their willingness to pay (M. A. Y. A. Harun, 2012). Often, tube wells or pond sand filters will break or become otherwise unusable due to the source not being maintained. This is often due to lack of funds provided to purchase replacement parts, or perhaps the people who are trained to maintain the equipment are not willing to do so for one reason or another.

When asked about taste perception of each source, respondents answered either yes, they liked the taste, or no they did not. In table 3 each source has approximately 75% or more respondents saying yes, they do enjoy the taste of the water from that particular source. However, that means in some cases, one fourth of the people using that source for drinking water do not like the taste of water from that particular source.

Source	**Number of respondents**	**Percent of each category that like the taste of the water source**
Bottled water/purchased	24	74
Fresh pond water	760	75
Harvested rain water	565	97
Municipal water/piped services	22	77
Others (Specify)	19	78
River water	19	74
Shrimp/fish pond water	35	77
Tube well/ bore hole	400	74
Water from desalinization plant	8	88

Table 3:Perceptions of taste of each available water source, number of respondents, as well as percentages of respondents who liked the taste of their water. Respondents could answer for multiple sources, so numbers are based on total responses.

However, when asked who currently maintains the source (for both tube wells and pond sand filters, henceforth PSF's), villagers said mostly the households were responsible for maintaining the source, but they felt the community should be doing more of the maintenance. For both tube wells and PSF's, the respondents trusted themselves and their community to be responsible for continued maintenance. Contrast that to here in North America, where we are primarily dependent on government workers to fix our water sources when they break, especially if we are connected to municipal water. In most of the industrialized world, access to clean drinking water is readily available an affordable cost to all but the poorest households. We may forget that for some people, accessing clean drinking water is a chore, a job that is quite laborious, and even then, safe drinking water is not a guarantee.

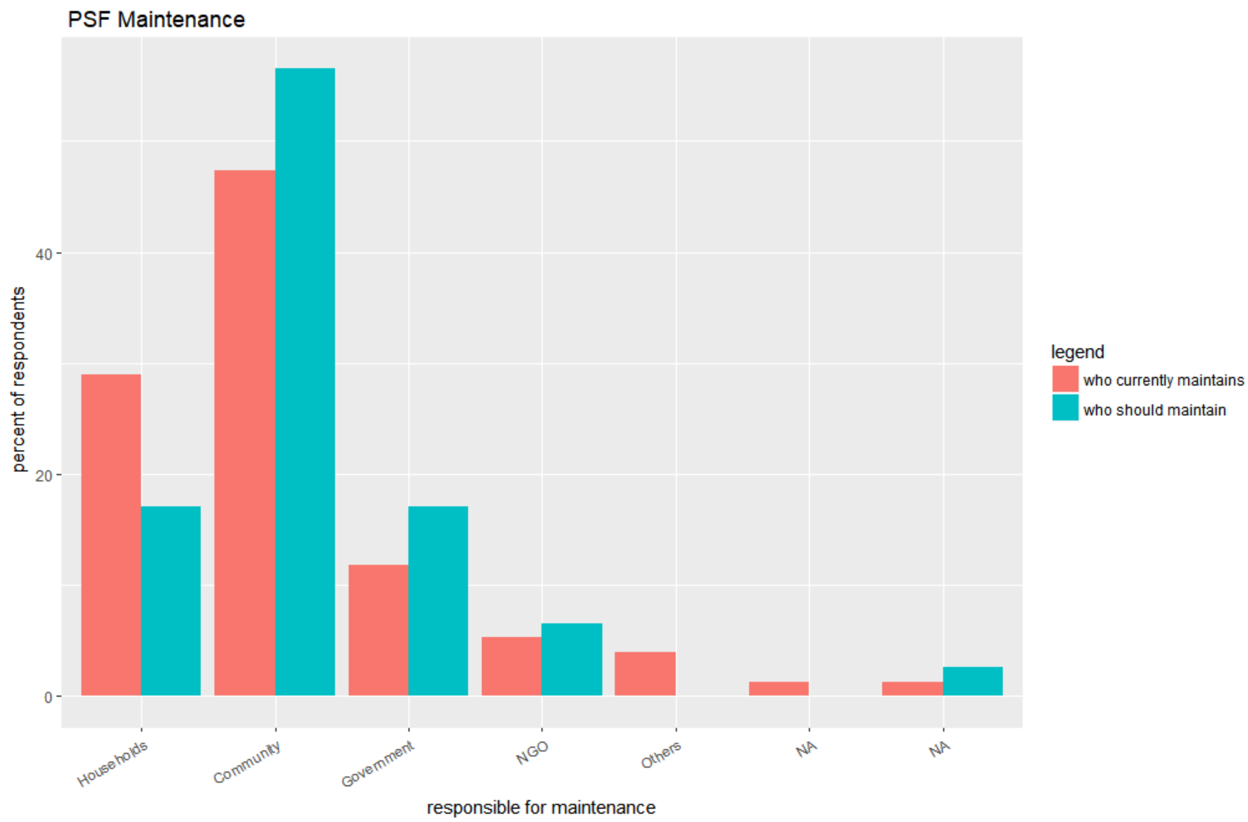

Figure 13: Pond Sand Filter (PSF) maintenance. Current party responsible for maintenance (red), as well as responses to which party should be responsible for PSF maintenance.

Figure 13 above demonstrates the current and future maintenance of PSF's across all sites. The red bar indicated who is currently maintaining the source, while the blue bar indicates who the respondents feel should be responsible for maintenance. The three major contributors to maintenance are households, communities, and government. We can see communities are largely responsible for the current and future maintenance of PSF's, followed by households and then government.

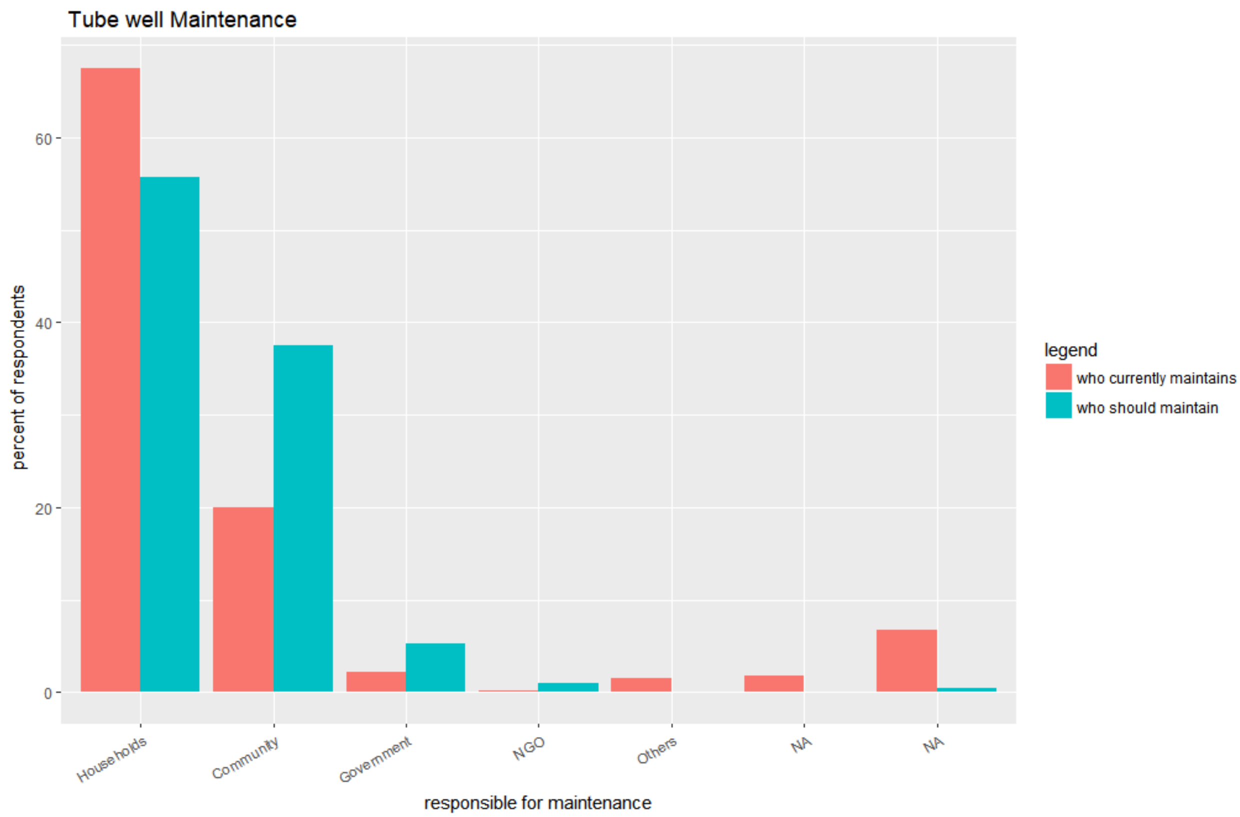

Figure 14: Tube well (TW) maintenance. Current party responsible for maintenance (red), as well as responses to which party should be responsible for TW maintenance.

Figure 14 above demonstrates the current maintenance of tube wells represented by the red bar, while respondents answered who they though should be responsible for maintenance of tube wells, represented by the blue bar. We see similar results to our respondent's answers to PSF maintenance as communities and households are still the two parties primarily responsible for maintenance. Although, it seems respondents felt that households are more responsible for tube well maintenance, where PSF maintenance should be shared more with other community members.

3.4.2 Water Source Maintenance Discussion

The problem of having household and community members being primarily responsible for water source maintenance is not only due to the financial burden. The time it takes to walk to these water sources, even when the sources are functional, creates a great burden on the person responsible for the water collection. Usually, the burden of water collection falls to women, and with financial strains already on a family, they are more likely to use their money buying food rather than fixing a water source that is broken.

3.5.1 Gender & Religion Results

Using all of the parameters listed previously, we began our analysis of water perceptions and access in Southwestern Bangladesh. Our initial exploratory analysis of the social survey data into gender and religious distributions allowed us to ensure the results were being interpreted correctly in the correct cultural context.

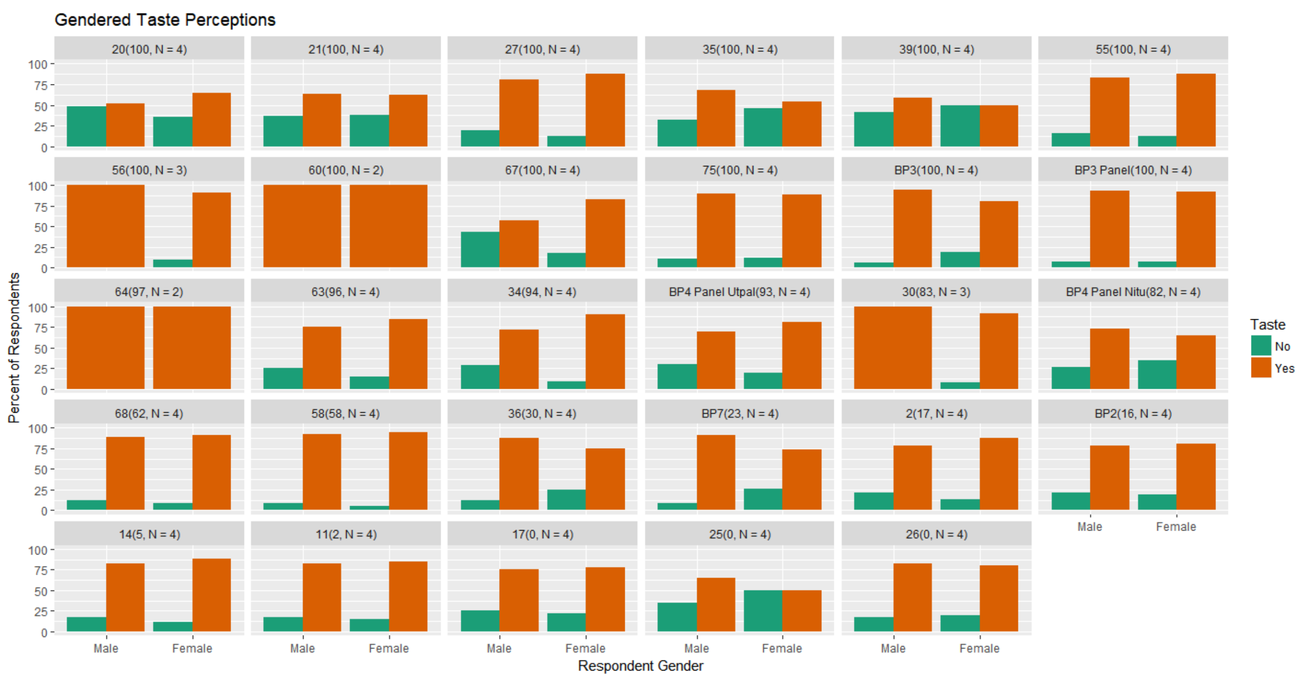

Figure 15: Taste perceptions of all available water sources based on gender

Figure 15 above shows respondents perceptions of water quality and taste based on their gender. As you can see, there is no significant difference in the responses of men and women in regards to taste perception. It is important to note that this is looking at taste perceptions of water based on gender, not their access to drinking water. It seems that gender does not play a significant role in determining taste perceptions in our study area, but the majority of women and men like the taste of the water. This is another alarming figure, because this means the people living in this area that are most likely drinking water of poor quality, do not taste the high salinity in the water which is evident from Figure 15.

We also examined the role of religion in relationship to taste perception. Similar to most of Bangladesh, a majority Muslim country, 795 respondents were Muslim, 404 were Hindu, and 5 identified as Christian. We first wanted to examine if gender or religious beliefs played a part in determining access to better or more reliable water sources. However, it is important to note that elsewhere in Bangladesh, there is a far greater ratio of Bengali Muslims than Hindu and Christian. According to the 2011 census, Sunni Muslims constitute 90 percent of the population and Hindus make up 9.5 percent of the total population. The rest are mostly Roman Catholic and Theravada-Hinayana Buddhist (United States Department of State, 2012).

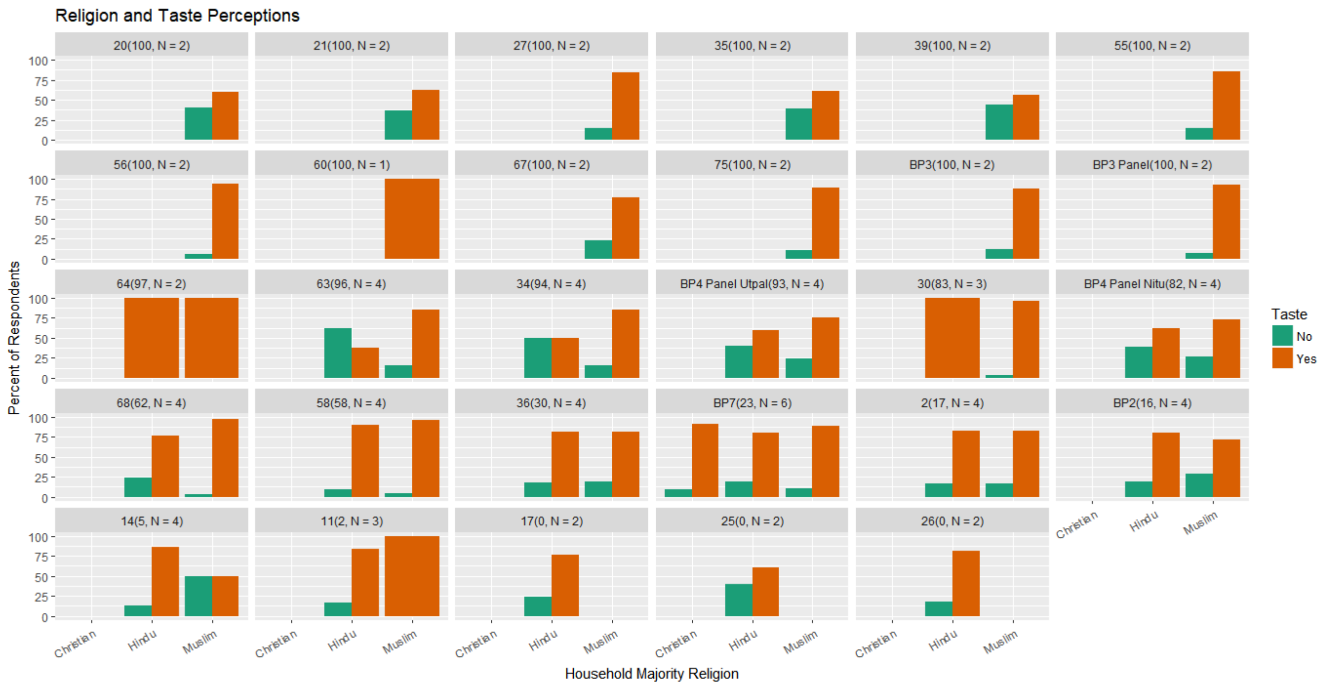

Figure 16: Taste perception of water sources based on Religion.

Figure 16 above demonstrates each sites Muslim, Hindu or Christian population and their perceptions of taste from all water sources. There is no significant difference in in religion and taste perception, although it is interesting to note there are seldom equal Hindus or Muslims at each site. It seems the villages are separated by their respective religions, with few sites having both a significant number of Muslims and Hindus.

3.5.2 Gender & Religion Discussion

In a study in Kathmandu, Nepal, researchers found a cost to water collection, a coping cost as well as WTP (willingness to pay). Coping costs, the cost associated with collecting, pumping, treating, and storing their own water due to the lack of government infrastructure (piped water). "*We find that these coping costs are almost twice as much as the current monthly bills paid to the water utility but are significantly lower than estimates of WTP for improved services. We find that coping costs are statistically correlated with WTP and several household characteristics* (Katuwal, 2007)." I suspect that similar results would be found in Bangladesh. Women and girls are often responsible for collecting the water for household purposes. In some cases, women are having to walk to several villages to gain access to drinking water, some walking as far as 6-12 km per day (Abedin, 2014). This potentially poses many problems including opportunity cost incurred during the day when so much time must be allocated to collect drinking water for the whole family. This makes it even harder for girls and women to receive an education, because water is the more immediate need for the family, and so they must spend hours getting water for their family rather than doing things like homework. In some cases, the impacts of drinking water scarcity on daily life causes school dropouts to occur (Abedin, 2014). Without better access to water, the problems for women will continue to grow, especially in coastal towns where climate change is already making fresh water harder to come by. As the commutes to get water get longer, so does the que at the pump, and so the wells with fresh water will be pushed to their limits. The burden of water collection is not a mere inconvenience for women and girls. A longer commute means they have more potential to encounter dangerous situations along the roads, particularly if they are walking alone in the evening, often without their husbands, who are frequently gone working in another city (Bagri, 2017).

The effects on themselves and their families are severe if they do not shoulder this burden of water collection. The continued use of saline, pathogenic, or arsenic water is quite detrimental to their health. Diseases from pond or river water lead to gastrointestinal distress, prolonged consumption of saline water causes heart disease, high blood pressure, gestational hypertension and pre-eclampsia, while the arsenic exposure in Bangladesh has been called one of the largest mass poisonings in history. In 2002 over one half of the total population of Bangladesh was being poisoned from drinking water contaminated with arsenic (WHO, 2002). Along with the arsenic positioning, women in coastal areas of Bangladesh are often drinking saline water, increasing complication in their pregnancies, particularly in the latter months of their gestation. They report swollen arms and legs, dysentery, and frequently sick. Aniere Khan, a researcher at the International Centre of Diarrheal Disease Research in Bangladesh, surveyed around 1500 women living on the southwest coast of Bangladesh. She found women in this area had much higher rates of preeclampsia and hypertension during pregnancy, compared with non-coastal districts (Bagri, 2017). Lack of fresh water creates many struggles for families, especially when the salinity intrusion is causing the paddy fields to become shrimp farms. Less labor is required on shrimp farms than for a rice production, so more men are finding themselves unemployed and looking for work outside of their own villages.

This outmigration is sometimes a temporary solution to unemployment, or a seasonal, or permanent migration in order to provide income to families back home. This migration is caused by an environmental hazard, often the intrusion of seawater onto land, causing loss of crop s and employment. This is a typical response to the types of environmental disasters we see frequently in Southwestern Bangladesh, and one that will likely become more frequent as sea levels continue to rise. However, it is important to note that it is usually the most socio-economically poor households that are most severely affected by environmental related disasters such as salinity intrusion, cyclones, storm surges, and the like (Mallick, 2012). The movement of people both as a family or only partially with the male head of household leaving to find work, creates a myriad of social problems. Not only is the man now separated from him family, but women are left to run the household alone, without the societal freedom to do so. Often, women are spoken about for going to the grocery store alone, or taking their children to the doctor without their husband being there, however the husband is forced to be away in order to make money for his family (Bagri, 2017). Problems such as these will become even more frequent with the continued water insecurity present in Southwestern Bangladesh.

3.6.1 Economic and Social Status and taste perceptions: Results

We wanted to examine the relationship between perceived socio-economic status and perceptions of water quality. If people who are of lower social or economic status feel their water tastes poorly, this may indicate a lower water quality. We examined all sites in the survey data set, correlating either social (Fig. 17) or income (Fig. 18) status against perceptions of water quality. Many of the site locations in the physical water quality study are also locations of some of the social science survey study sites. This allowed us to compare the region's physical water quality with the responses from the survey data regarding taste perception, economic status, and social status. Through examination of the survey data, we were able to ascertain respondent's perceptions of their economic status and social status. Using people perceptions of their status gave us a unique perspective on how people living in these rural areas saw their well-being in regards to others in the same geographic location. During the interview process, each respondent was asked to rate their economic and social status on a scale of one to ten, with one being the lowest ranking a person could have in the village with a ten being the highest status a person could achieve in the village. It is important to note that this method only examines a person's perception of their socio-economic status, and does not quantitatively measure their income, expenditures, or overall wealth. We chose to use this measure of wealth because we could not be sure people were not including their savings or overall wealth when they reported things like income.

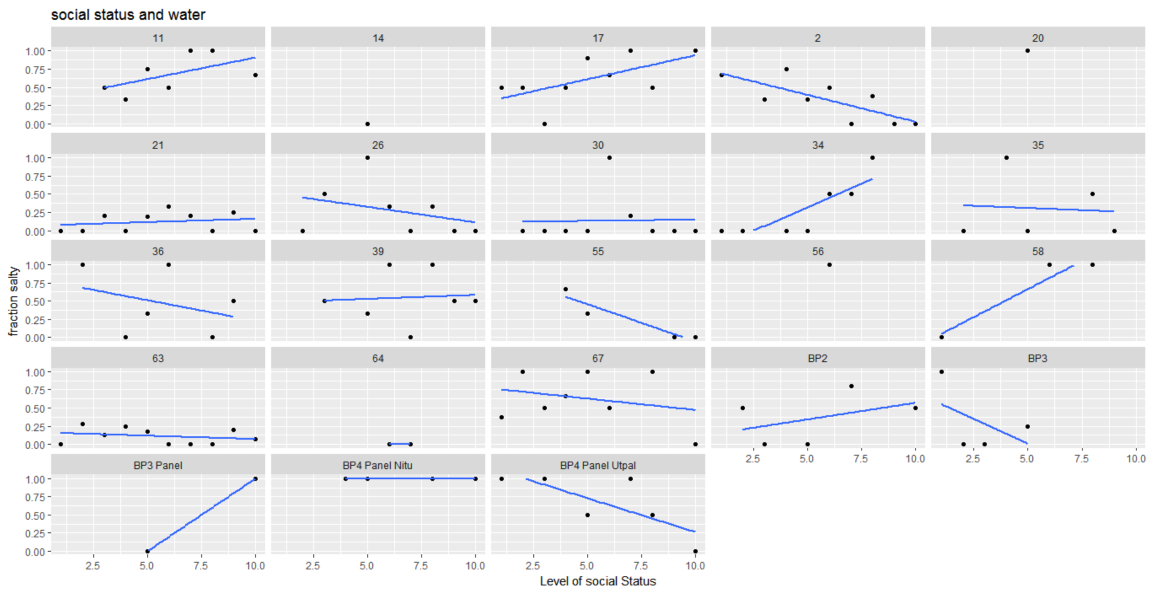

Figure 17: Correlation of taste perceptions and social status

Figure 17 demonstrates no relationship across all sites that indicates we can predict water quality perception based upon social status. In individual sites, we do see trends, some positive, some negative, that may indicate a relationship at that specific site. However, it seems just as likely for a person of higher social status to dislike the taste of their water as it does for a person of lower social status to dislike the taste.

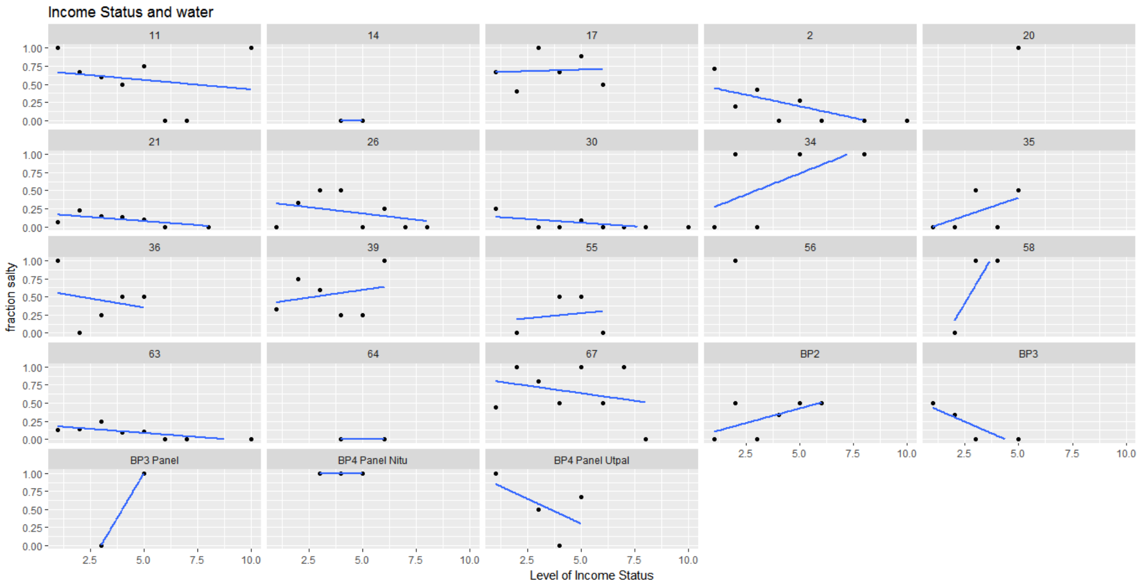

Figure 18: Correlation of taste perception and income status

Again, we can see from the figure above, there is no trend, either positive or negative across all sites. However, we do have some trends in specific sites. For example, several sites demonstrate a negative correlation between status and water quality perception. This seems to indicate a possible relationship between status and water quality or taste perception on an individual or site-specific level, but not a regional pattern.

3.7.1 Socio-economic status and water source access: Results

Next, we wanted to determine if people with higher income or social status were granted access to better water sources.

Figure 19: Access to drinking water sources and income status

Figure 19 above demonstrates each households water source usage along with their income status (ranked on a scale from 1-10).

We also wanted to analyze if better water security could be gained by an elevated social status. Particularly in Bangladeshi culture, social status can be a significant gateway to better resources. We wanted to see if this were true for fresh water as well.

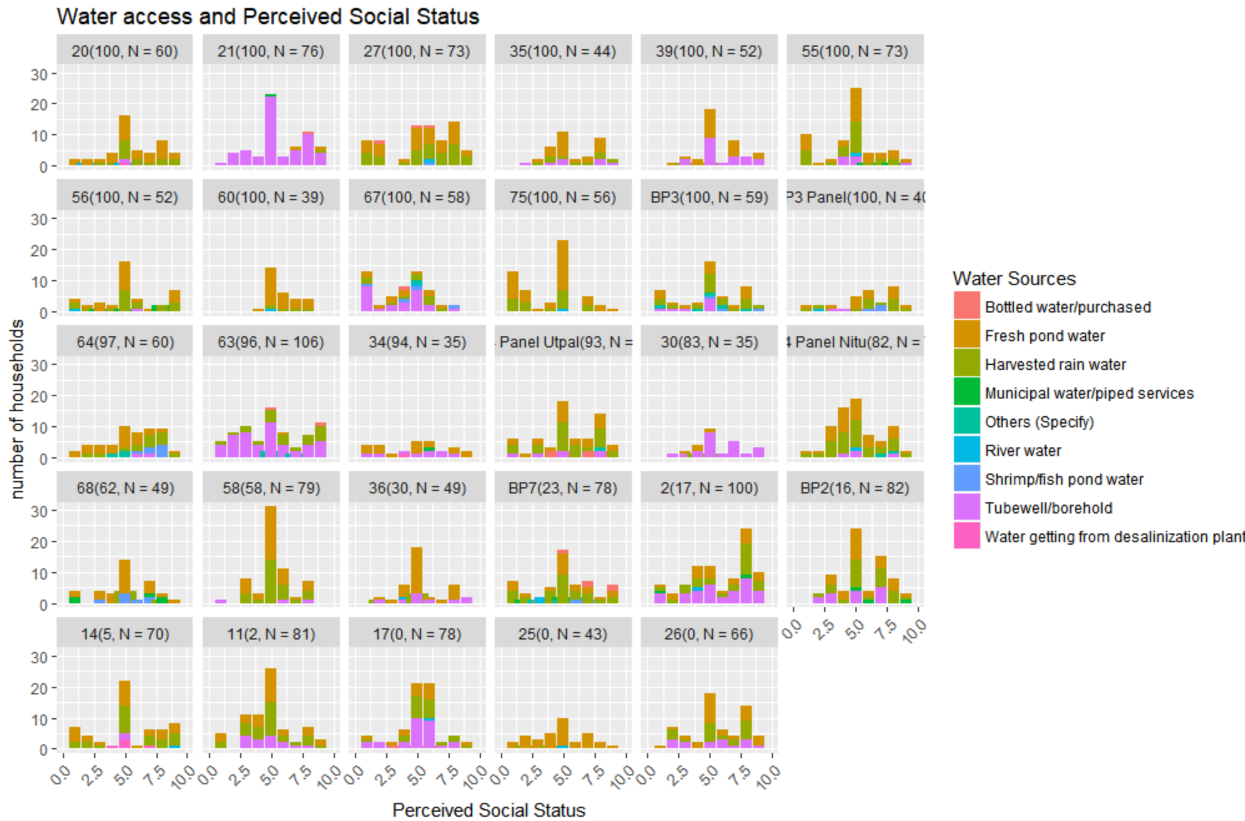

Figure 20: Access to drinking water sources and perceived social status

Figure 20 above is demonstrated access to water source based on perceived social status (ranked on a scale from 1-10). Again, we note that at most site locations, people all have access to the same water sources regardless of status. For example, site 63 demonstrates most people in that village are getting their water from tube wells, even those with very low social status, and those with high social status are using the same source, if not the same well.

3.7.2 Socio-economic status and water source access: Discussion

It seems that people are not given different access to water sources based on their income. We can see that at each site location, people are using roughly the same sources, regardless of income status. This would indicate that access to more money is not granting households better access to improved water sources. A paper written in 2010, “Energy Poverty in rural Bangladesh”, discusses how the alleviation of energy poverty is necessary to reduce income poverty (Barnes, 2010). If people have access to a certain threshold of energy, they have more time throughout the day for educational and economic pursuits. For example, if a household has the capability to keep their home illuminated after the sun goes down, that allows children more hours to study. Women most often bear the burden of firewood collection and meal preparation

(Saghir, 2005). If the home has enough energy to cook food without the use of firewood or other sources of fuel which require collection, more time is freed for education and therefore, development. “It [energy] can also encourage the development of higher literacy rates, gender equality, and women’s empowerment” (Cabraal, 2005). Research is showing there is a direct relationship between energy access and growth and development of rural economies (Khandker, 2009). Immediate effects of electrification include creating more time for studies, which in turn enhances educational achievements. Not only does electricity improve household achievements, it can improve agricultural production as well through a variety of pumps, irrigation techniques, harvesting equipment, and so forth (Khandker, 2009). We would argue that improved drinking water sources would do the same thing for rural households. With less time travelling to and from long lines for fresh water, more time is “created”. With the created time, more studying can be done, more harvesting can be accomplished, and perhaps, even yield could improve as fresh water is used for irrigation rather than saline water.

3.8.1 Bayesian analysis

We applied a Bayesian hierarchical logistic regression to the probability of a respondent saying that the water tastes good or that it tastes salty. The hierarchical structure of our analysis demonstrates that taste perceptions are influenced by a variety of factors ranging from socio-economic conditions to physical water quality properties. Our regression models each site locations probability that the respondent will think the water tastes poorly or tastes good. The probability is modeled using a hierarchical varying intercept logistic regression, where $_i$ is the index of the community, allowing α and β to vary from one site to the next.

P_taste = inverse-logit ($\alpha_i + \beta_i$* SS + €)

where

α_i ~ Normal (α_0, σ_β)

β_i ~ Normal (β_0, σ_α)

α_0 ~ Normal (0,1)

β_0 ~ Normal (0,1)

σα ~ Cauchy (0,2)

σβ ~ Cauchy (0,2)

The € represents the random variation that happens in the real world not explained by our variables here. SS represents either social status or income status of each household at the site location. P_taste represents the probability the taste perception of the water will be good.

We implemented the statistical model in the Stan probabilistic programming language [Carpenteretal.,2017], which generates a Hamiltonian Monte Carlo sampler. We used R to prepare the data and call the sampler [RCoreTeam,2016]. We ran 4 chains for 2000 iterations, 1000 for the warmup, for a total post warmup samples of 4000. Figures 21 and 22 demonstrate the regression of each site based on either the social status or the income status of each household and the probability they will think their water tastes poorly.

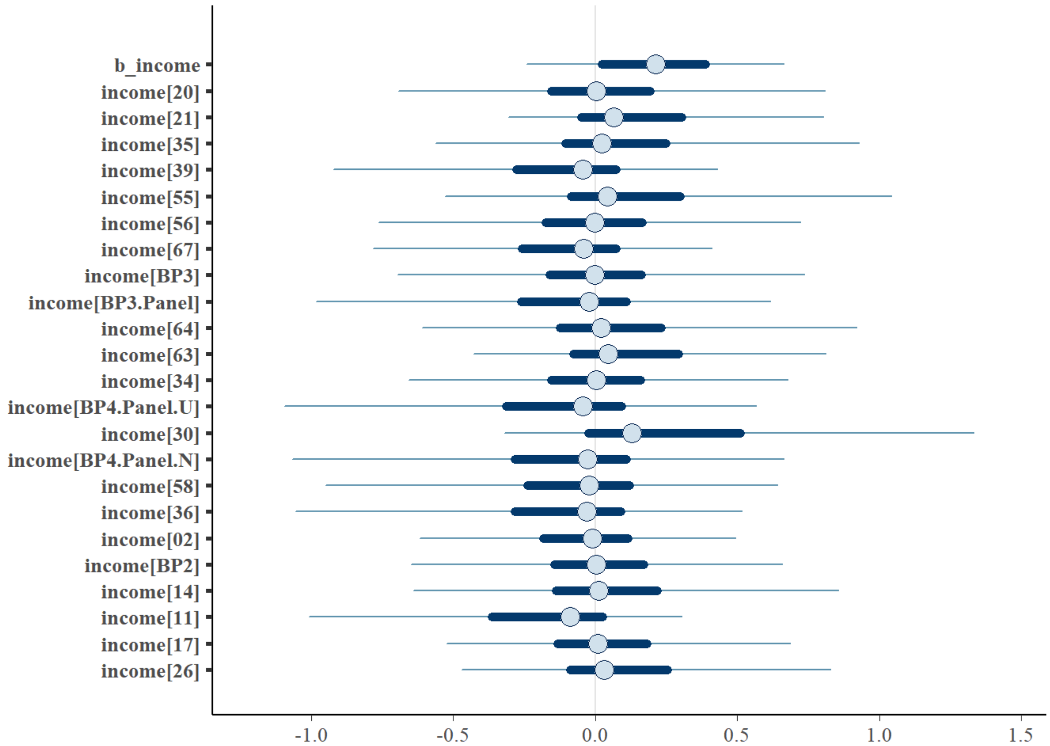

Figure 21 Taste perceptions and income status regression results. The thick bars are the 50% credibility interval and the thin bars are the 90% credibility interval for the posterior probability distribution and the labels refer to the slope associated with each variable. The first model uses the taste perception of water as the dependent variable (yes/no dichotomous variable), and level of income status as the independent variable.

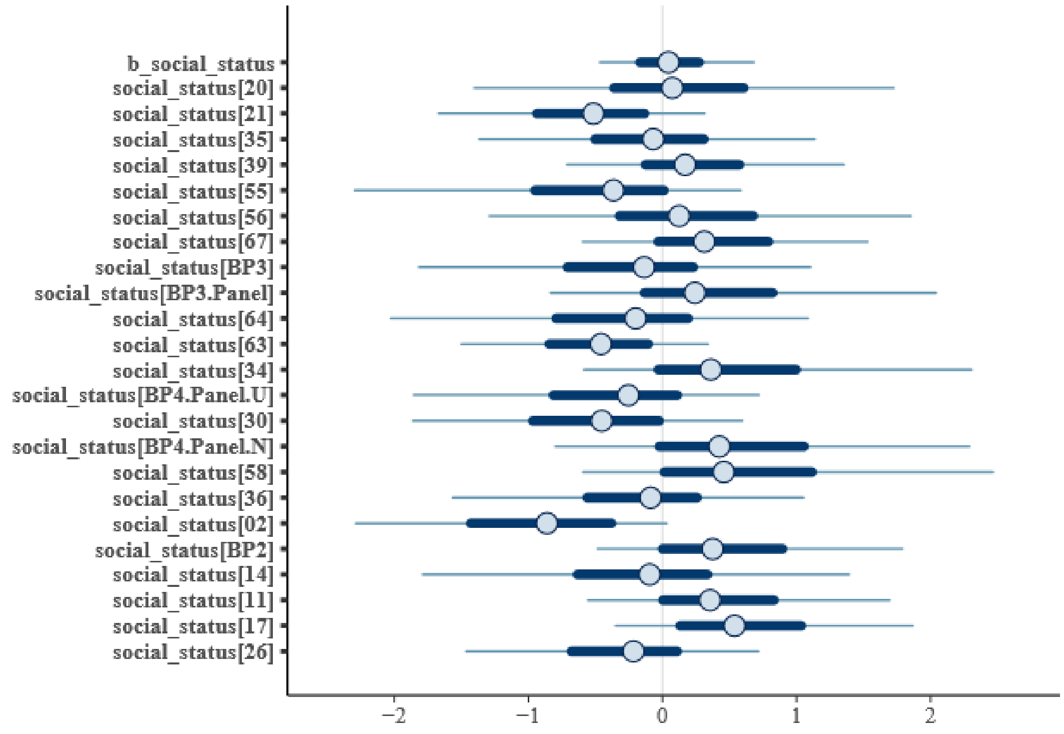

Figure 22 Taste perception and social status regression analysis results. The thick bars are the 50% credibility interval and the thin bars are the 90% credibility interval for the posterior probability distribution and the labels refer to the slope associated with each variable

Our second model uses as the dependent variable as taste perception of water, and income status as the independent variable with the population level effects of fraction of Muslim households in the community, household Muslim majority status, and relative economic situation (poverty). Our hierarchical analysis shows that for all sites, the perception of water having a good taste is not dependent on social status, nor is the model effected by gender and household majority religion, or social status and household religion (Figures 23 and 24).

$P\_taste = inverse\_logit\ (\alpha_i + \beta i_{,SS} * SS + \beta i_{Muslim} * I_{Muslim} + \beta_{i,interaction} * SS * I_{Muslim} + €)$

where

α_i ~ Normal (α_0, σ_β)

β_i ~ Normal (β_0, σ_α)

α_0 ~ Normal (0,1)

β_0 ~ Normal (0,1)

σα ~ Cauchy (0,2)

σβ ~ Cauchy (0,2)

I_muslim = indicator whether the household is Muslim (1 for Muslim, 0 for other).

SS = either social status or income status of each household at the site location.

P_taste = the probability the taste perception of the water will be good.

€ = the random variation from real world note explained by our variables.

Both Figures 23 and 24 examine the relationship between the income or social status of households at each site location and the group level effects of the majority religion of both the household and the community, as well as the possible effects from gender.

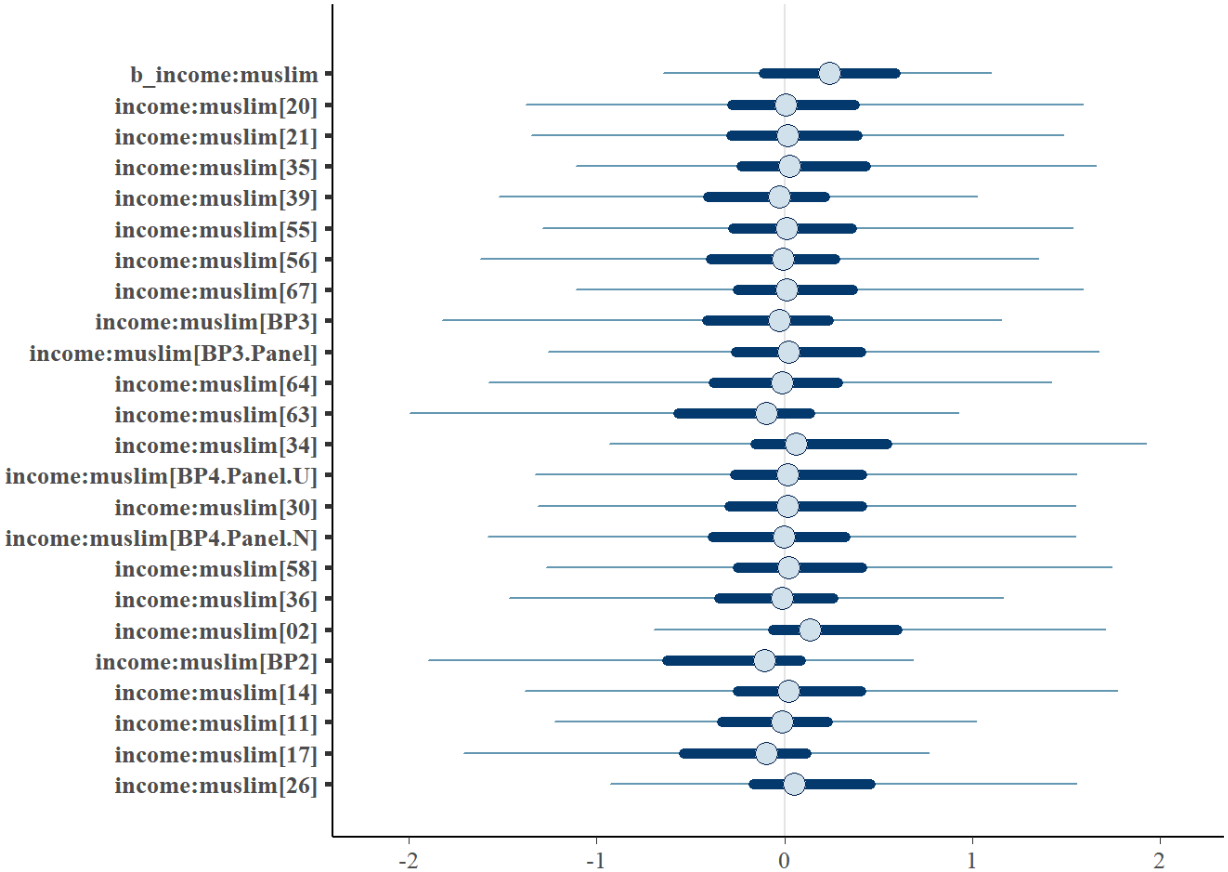

Figure 23Taste perception and income status regression results, with group level effects. The thick bars are the 50% credibility interval, the thin bars are the 90% credibility interval for the posterior probability distribution and the labels refer to the slope

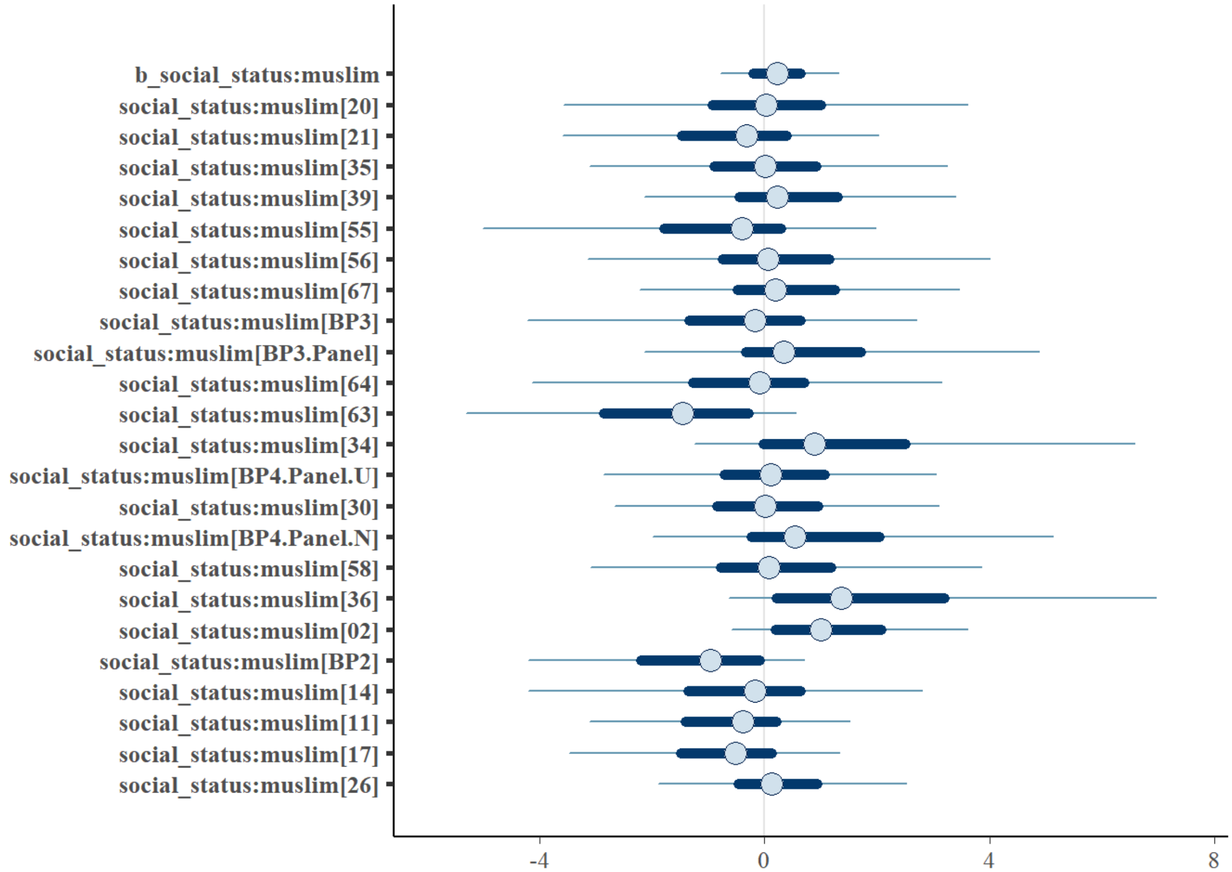

Figure 24 Taste perception and social status regression analysis with group level effects religion. The thick bars are the 50% credibility interval and the thin bars are the 90% credibility interval for the posterior probability distribution and the labels refer to the slope associated with each variable

3.8.2 Bayesian Analysis Discussion:

Before we began our Bayesian analysis, our analysis showed there may be several sites where either social status or income status were effecting taste perceptions. However, there was no statistically significant relationship between taste perceptions and income or social status. Most people surveyed did not think their water tasted salty, or that it tasted good, and there was no strong correlation between taste perceptions and socio-economic status.

When we ran the model with the group level variables such as religion and gender, there were no strong effects that would improve the fit of our model, indicating there was no relationship between those factors. From our examination of the results, we concluded that although most people have poor water quality, there was no impact on taste perception from social status, income status, gender, household religion, or community majority religion. Examination of our RHat (Gelman, 1992), the potential scale reduction factor on split chains at convergence is at 1, which indicates Monte Carlo sampling converged very nicely.

Examination of the cross plots between the different variables demonstrated no strong correlation between the different variables. The pairs plots are symmetrically distributed, demonstrating no strong correlation, indicating signs of no strong interactions between the different terms. So, no significant collinearity between the different variables. Our posteriors demonstrated distributions without strong collinearity.

These results indicate that if you live in Southwestern Bangladesh, increasing your socio-economic status will not provide people with better quality of water. Indeed, even purchasing water is not a convenient option for people in these rural areas, whereas people who would be considered middle class living in urban areas are able to purchase clean, filtered water. Higher status or income doesn’t grant access to better water when there is no clean drinking water to purchase. This problem becomes quite apparent as you look at the lack of reliable, clean drinking water sources in this area, demonstrating the real water poverty in this region. Just as the problem of energy poverty describes the lack of available energy resources to rural people, water poverty describes the lack of clean drinking water available, even to those who are considered well off for their region. When people are energy poor, more time and resources must be committed to daily activities such as cooking. When people are water poor, their time and energy is devoted to water collection, including travel time to and from the available water source. These water collection chores are often completed by women and children. These chores use up time that could be otherwise devoted to activities that increase their quality of life such as educational or economic pursuits.

CONCLUSIONS

During the examination of our data, we found that people often weren't even aware they were drinking unhealthy water, as they reported the water tasted good to them, but our water quality tests indicated the water contained salinity and arsenic content well above the national average. In light of forthcoming research on the potential impacts of anthropogenic climate change on coastal Bangladesh, high salinity in drinking water will only become more frequent. In fact, since about 78% of annual rainfall in Southwestern districts of Bangladesh falls during the monsoon months, that leaves only 22% of the annual rainfall to suffice for the rest of the year (Abedin, 2014). This is obviously problematic as water is needed every day. The seasonality of water is markedly one of the greatest problems when it comes to providing access to fresh drinking water year-round. The scarcity of rainfall during the dry months, coupled with the lack of infrastructure creates a situation in which families are being forced to take more extreme measures in order to supply themselves with enough water to live off of.

It is clear from our analysis of water quality and water sources that despite the resiliency of the people of Bangladesh, there is a real scarcity of water for the people living in Southwestern Bangladesh. Sampling from a selection of water sources within the area reveal an overview of groundwater contamination both from salinity intrusion and from arsenic contamination. Both of these present major health issues to people who have no options but to drink poor quality water every day. Chronic exposure will continue to worsen as the effects of climate change persist. Sea level rise will create more salinity intrusion, not just into the drinking water sources, but into irrigation ponds, fields, and rivers. Farmers will be forced to convert paddy fields into shrimp farms, displacing more people from their jobs and land, and causing more ecological damage to the Sundarbans. The continued destruction of the mangrove forest will leave the densely populated region even more vulnerable to increasing flooding, cyclones, and storm surges, exacerbating destruction even farther. As people are forced to move farther inland, population density will increase, and water will become even more scarce. The need for improved drinking water sources will only increase as the effect from climate change continue. These changes must be suitable for this dynamic landscape, as well as useable for the people and their culture.

However, it is important to note that Bangladeshis have been living with this monsoonal climate, flooding, cyclones, and the like for centuries. Adaption and flexibility, along with a miraculous resilience sets the people in this land apart from the rest. Often, the language used to describe Bangladeshis becomes rather problematic, as using terms to describe adaptations to climate change such as "climate refugees" may in fact overshadow the more pressing issues (Lewis, 2011). Migration is simply one method people are using to adapt to the problems associated with climate change such as rising sea levels resulting in salinity intrusion. It is also important to keep the dynamic nature of Bangladesh in mind when searching for solutions to environmental and social problems. The wetland nature of Bangladesh is one of the things that makes it such a fertile and rich agricultural land, yet thinking of changing it to a "dry land" is what led to the riverbed siltation problems the local people are now facing from poldering in the 1960's (Lewis, 2011). This type of thinking can often cause unintended consequences, even when the intentions are honorable, such as what happened with the poldering in coastal areas. Not only in environmental areas, but in social arenas as well, we try to understand the people in terms of their own culture and habits, rather than imposing our ideology upon our data.

APPENDIX

Site Number	Longitude	Latitude	Upazila	District
67	89.63853	22.54123	Rampal	Bagerhat
2	89.44556	22.64622	Batiaghata	Khulna
11	89.4668	22.59776	Dacope	Khulna
14	89.51763	22.50143	Dacope	Khulna
17	89.47195	22.57838	Dacope	Khulna
20	89.29697	22.45661	Koyra	Khulna
21	89.27823	22.61697	Paikgacha	Khulna
25	89.3501	22.48683	Paikgacha	Khulna
26	89.44046	22.63334	Paikgacha	Khulna
27	89.64051	22.48711	Mongla	Bagerhat
30	89.146	22.472	Assasuni	Satkhira
34	89.19971	22.50924	Assasuni	Satkhira
35	89.21259	22.46066	Assasuni	Satkhira
36	89.12938	22.57718	Assasuni	Satkhira
39	89.05666	22.43916	Kaliganj	Satkhira
55	89.82979	22.21517	Sarankhola	Bagerhat
48	89.14528	22.33209	Shyamnagar	Satkhira
47	89.13739	22.3117	Shyamnagar	Satkhira
52	89.05113	22.31387	Shyamnagar	Satkhira
45	89.06893	22.37567	Shyamnagar	Satkhira
56	89.78298	22.2928	Sarankhola	Bagerhat
58	89.83478	22.45786	Morelganj	Bagerhat
60	89.86145	22.50271	Morrelganj	Bagerhat
63	89.89086	22.72432	Kachua	Bagerhat
64	89.83602	22.62168	Kachua	Bagerhat
68	89.65361	22.52363	Rampal	Bagerhat
75	89.68082	22.40724	Mongla	Bagerhat
BP-1	89.61953	22.470681	Mongla	Bagerhat
BP-2	89.481542	22.539912	Dacope	Khulna
BP-3	89.875124	22.384301	Morelgonj	Bagerhat
BP-4	89.454032	22.43677	Dacope	Khulna
BP-5	89.286635	22.353224	Koyra	Khulna
BP-6	89.282778	22.243216	Shamnaghar	Satkhira
BP-7	89.613543	22.444812	Mongla	Bagerhat

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