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Well, Well, Well…:

A Secondary Data Analysis of Risk Factors for the Presence and Consumption of Arsenic-Contaminated Water in Hand-Pumped Tubewells in Narail District, Bangladesh

By

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Master of Public Health

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An abstract of

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in the Hubert Department of Global Health

2019

Abstract

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A Secondary Data Analysis of Risk Factors for the Presence and Consumption of Arsenic-Contaminated Water in Hand-Pumped Tubewells in Narail District, Bangladesh

By Mahnoor Mahmood

In one of the largest contemporary environmental crises in the world, an estimated 20-35 million Bangladeshis are chronically exposed to arsenic concentrations exceeding 0.05 mg/L through their groundwater-based drinking hand pumps. In low-resource settings like Narail, Bangladesh, it is important to identify tubewell attributes that increase the risk of their arsenic contamination as well as household attributes that increase the risk of consumption of arsenic-contaminated water, so that key characteristics may be targeted through exposure mitigation efforts. **Purpose:** The aims of this thesis are to: 1) To examine the association between tubewell attributes and the presence of arsenic contamination in household tubewells. 2) To examine the association between household attributes and the presence of arsenic contamination in household tubewells. 3) To examine the association between household attributes and the consumption of drinking water from an arsenic-unsafe alternative source, among those who have arsenic-contaminated household tubewells. **Results:** It was found that between two tubewells that differ in depth by 500 feet but have the same number of years since installation and ownership status, the shallow tubewell has 233 times the odds of containing unsafe levels of arsenic ($p < 0.0001$). Government-owned tubewells are less likely to be unsafe than privately-owned tubewells ($p = 0.0455$). Households whose primary source of income is the service industry are more likely to have unsafe tubewells ($p = 0.0053$). Furthermore, approximately 35% of respondents who switched from their unsafe tubewell did so to another unsafe tubewell. Among those who switched, older respondents were more likely to switch to unsafe tubewells than their younger counterparts ($p = 0.0133$). **Recommendations:** Public health professionals working in exposure mitigation efforts in this region should promote the equitable installation of sufficiently deep tubewells, and closely consider the role government can play in their installation, operation, and maintenance. Furthermore, arsenic risk communication strategies should be amended to reflect the dose-response nature of arsenic exposure to promote effective and feasible switching behaviors. Lastly, a targeted effort must be made to ensure access to safe water for high-risk subpopulations, such as those working in the service industry.

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بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

خودی کو کر بلند اتنا کہ ہر تقدیر سے پہلے
خدا بندے سے خود پوچھے بتا تیری رضا کیا ہے

Acknowledgements

I remember falling in love with poetry the very first time my Baba read this verse to me. Loosely, it translates to: Make yourself so capable that before every decree, God will ascertain from you: “What is your wish?” Today, I realize that the reason I loved this verse was because of the harsh realities of human existence that I saw around me. The world I was born into – the world in which I grew up, worked, formed friendships, laughed, studied, cried – in that world people did not get to dictate their own fate. Their fate was decided, predominantly, by the circumstances of their birth. The idea that one could break the cycles of poverty, violence, and inequality embedded in society to become the masters of their own fate, all the while under the guidance of God, was a beautiful one. It was also this idea that first inspired my love for public health.

When I began immersing myself in literature and sciences and medicine at my local library to begin the journey of becoming “capable” enough to decide the course of my own life, my parents often grounded me. Papa would often remind me that a person’s worth and capability was not determined by their level of education or the amount of money in their bank account, but by their character. Mama showed me that understanding people’s hearts, and not just books, was the best way to understand humanity. My accomplishments to date would have been impossible, or at the very least been empty, without their constant reminder that it is more important to be good than to be great, and for that I am eternally grateful.

They have not been alone in molding me into the person I am. Growing up in a joint family, I was blessed with a “village” of people who supported me, prayed for me, cried with me, fought with me, laughed with me, and ultimately loved me. The vastness of their love taught me to accept nothing less than deep and unrelenting support from others. Listed below, are just some of the people whose support and insight have been invaluable in the completion of this thesis.

- Dr. Joanne A. McGriff: for believing in and supporting me (at times, with a little tough love) and serving as an example of the kind of person I want to be- a strong, compassionate, and accomplished woman constantly pushing forward the boundaries of justice and health equity

- Dr. Bilqis A. Hoque & the EPRC staff: for entrusting me with their data and being a constant force for progress on the ground in communities who do not have enough people fighting for them
- Johnathan A. Edwards: for the balanced mix of encouragement and sarcasm, each of which was always perfectly timed
- Nana & Nani: for showing me that there is a strength in being open to learning from others, even if what they are saying contradicts everything you believe to be true and for always cheering me on
- Baba, Tai, Nana, & Nani: for allowing me to feel the love and belonging inherent in a large, hectic, crazy family
- Afshan Khala & Khalid Uncle: for opening your home to me and giving me the courage to embark on a journey of exploring myself, my roots, and my passion
- Hina Abid: for all the school projects, presentations, papers you stayed up all night to help me finish and for always reminding us that we live in your heart
- Ali Mahmood: for the years of "healthy debates" that prepared me for a lifetime of activism
- Maham Mahmood: for being the first person to call me out when I tried to compromise on what I want out of life and for perfectly timing your wedding to be at the most inopportune time possible
- Nayab & Duaa Abid: for always indulging my Bollywood/Punjabi karaoke needs
- Alam Mahmood: for the constant barrage of lame jokes and (occasional) hugs
- Ms. Dorothy, Ms. Pam, Mr. Woods, & the entire RSPH staff: for making Rollins a home away from home
- Marquetta Nelson: for nurturing my love of writing, reminding me that all stories deserve to be heard (including mine), and believing in me more than I could ever believe in myself
- Campus Crossings Crew: for the BIOS study sessions, late-night shenanigans, pool-side conversations, burrito dinners, and life updates over ice cream
- Naba Khan, Danish Shaikh, Asim Saeed, & Tanzeela Khan: for being wonderful companions on a journey of self-exploration, for encouraging me to be adventurous, reminding me to be unapologetic about my opinions and apologetic about my accent
- Jane Jacob & Nazow Tarakai: for the fierce friendship, painful fits of laughter, hours of google doc edits, and a lifetime of love
- Varnel Antoine, Shannon Lytle, & Taji Hutchins: for keeping me hip with pop culture updates and showing me that even though we *may* leave the Bottom Left, we will never leave each other
- Annam Ahmed, Alifiya Bukhari, & Terah Kalk: for being such loyal and wonderful companions on this journey, for the late nights and the (few) early mornings, the countless free "Uber" rides, the innumerable samosas, and for inspiring me to become a better person and friend
- Usama Lakhani: for giving me faith and love, for bringing me closer to God and loved ones, for being my companion in late-night study sessions and mid-day scooter outings, for being a source of strength, kindness, and perspective, and for letting me know that I will never face anything alone

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1. Introduction

In 2015, diarrheal diseases caused approximately 1.3 million deaths around the world, a significant reduction from years past (Troeger et al., 2017). Low- and middle- income countries such as Bangladesh often shoulder much of this burden of disease. In fact, in the 1970s the infant mortality rate (calculated for children less than one year of age) attributable to diarrhea was 36 per 1000 live births, accounting for over a quarter of all infant mortality in the country (Wu et al., 2011). Given these drastically high numbers, the national and international actors in Bangladesh hoped to identify the root cause of this problem. They found that deaths due to diarrhea were linked primarily to the consumption of microbiologically-contaminated surface water (Yunus et al., 2016).

Beginning in the 1970s, international actors such as UNICEF, along with the Department of Public Health Engineering (DPHE) of Bangladesh, launched a large-scale campaign to install and promote the use of hand-pumped tubewells as a simple and cost-effective means of increasing access to “safe” water that was not contaminated by diarrhea-causing microorganisms (Smith, Lingas, & Rahman, 2000). In the coming years, the installation of tubewells became largely a private sector activity as people began investing in safe water for themselves and their families (Smith et al., 2000). Since then, millions of tubewells, metal-reinforced cylindrical wells approximately five centimeters in diameter which are dug into the ground, have been installed in Bangladesh (Smith et al., 2000). In fact, it is estimated that by the year 2000, the total number of tubewells installed in Bangladesh was approximately 10 million (Kinniburgh & Smedley, 2001; Yunus et al., 2016).

Although the infant mortality rate due to diarrheal diseases has decreased in Bangladesh to approximately 13 per 1000 live births, the attribution of this trend to the large-scale installation of tubewells is contested by some who claim that the decrease is likely due to a confluence of improvements to water, sanitation, and hygiene (WASH), nutrition, and other public health interventions (Wu et al., 2011).

Given the scale of this intervention, it is important to consider the unintended negative consequences of the installation of these tubewells. Once praised as a revolutionary intervention, the Bangladeshi tubewells themselves have led to some grave consequences. Beginning in the 1980s, scientists and physicians identified an increase in the numbers of people presenting with arsenic-induced lesions in the Indian subcontinent (Yunus et al., 2016). However, it was not until 1993 that the DPHE of Bangladesh confirmed suspicions that the underground water in the Nawabganj District was contaminated with arsenic (As) (Yunus et al., 2016). Upon further examination, naturally-occurring arsenic was found to be widely dispersed throughout the underground water in this region; a study estimated that in 2005 fifty of the sixty-four districts of Bangladesh had groundwater arsenic contamination greater than 0.05 mg/L, the Bangladeshi standard for drinking water (Ahamed et al., 2006). It is also important to note here that the recommended guideline for arsenic concentration in drinking water set by the World Health Organization (WHO) is five times lower than the Bangladeshi standard at 0.01 mg/L (Smith et al., 2000). The WHO standard for arsenic concentration in drinking water is based on an average daily water intake of two liters (Chakraborti et al., 2015). However, the average daily water intake of adults in Bangladesh has been reported to be approximately four liters, and as high as six liters for those whose occupations demand heavy labor (Chakraborti et al., 2015). Considering the fact that the Bangladeshi population has, on average, a lower nutritional status than the international standard, higher levels of water intake, and more consumption of foods like rice, which accumulate inorganic arsenic, the standard for arsenic concentration in the drinking water of the Bangladeshi population should be considerably less than even the WHO standard (Chakraborti et al., 2015).

The cause of the naturally-occurring arsenic in the Bangladeshi water has yet to be definitively determined and many plausible mechanisms of arsenic leaching into the groundwater have been put forth (Ahmad, Khan, & Haque, 2018; Raessler, 2018). In the meantime, making safe water accessible to the Bangladeshi population is a key priority for many local, national, and international agents as it has been estimated that 20-35 million Bangladeshis are chronically exposed to arsenic levels exceeding 0.05 mg/L through their drinking water (*Bangladesh Multiple Indicator Cluster Survey 2012-2013*, *ProgotirPathey: Final Report*, 2015; Kinniburgh & Smedley, 2001).

In 1998, the government of Bangladesh launched the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) through which over five million tubewells were tested for arsenic and painted either green to indicate safe levels of less than 0.05 mg/L or red to indicate unsafe levels of over 0.05 mg/L (Ahmad et al., 2018). This process of testing tubewells and designating them as either green or red waterpoints continues to this day by both governmental and non-governmental entities and allows beneficiaries to ascertain whether a tubewell has been tested and if it is or is not safe. However, given the resource limitations that do not allow for continuous testing or replacement of every water point which is found to be contaminated, it is critical that this problem be approached from a strategic evidence-based perspective.

Therefore, this thesis aims to conduct a secondary data analysis examining three specific associations in regard to the presence and consumption of arsenic-contaminated water through hand-pumped tubewells. The analysis is conducted using data collected through the "Creating Arsenic-Safe Villages with User Women-Led Sustainable Improvement of Water, Sanitation and Hygiene in Narail District" project based in Bangladesh. Given the widespread and presumably random natural distribution of arsenic in groundwater, it was hypothesized that these associations would be null.

1. To examine the association between tubewell attributes and the presence of arsenic contamination in household tubewells.

2. To examine the association between household attributes and the presence of arsenic contamination in household tubewells.

3. To examine the association between household attributes and the consumption of drinking water from an arsenic-unsafe alternative source, among those who have arsenic-contaminated household tubewells.

Lastly, having completed the analyses required to examine these relationships, this thesis aims to make programmatic recommendations for the ways in which local NGOs and their partners in this area can effectively approach mitigation to arsenic exposure within the given population.

2. Literature Review

2.1. Adverse Effects of Arsenic Exposure

The adverse effects associated with chronic arsenic exposure are vast and span many domains; herein, we will focus our attention on the adverse effects of arsenic exposure on the physical, social, and economic well-being of Bangladeshis.

2.1.1. Adverse Effects on Physical Well-Being

Arsenic is a natural component of the Earth's crust and is, as such, disbursed throughout our environment; however, it can be highly toxic in low doses for humans in its inorganic form ("Arsenic," 2018). Inorganic arsenic is a known carcinogen and is the major chemical contaminant of drinking water of concern around the world ("Arsenic," 2018). The acute health effects of arsenic exposure include "vomiting, abdominal pain and diarrhea… [and] are followed by numbness and tingling of the extremities, muscle cramping and death, in extreme cases" ("Arsenic," 2018). However, exposure to arsenic is often chronic in many populations due to its widespread distribution in groundwater in various areas around the world ("Arsenic," 2018). Chronic exposure to arsenic can lead to arsenicosis.

Arsenicosis, or arsenic poisoning, has generally been defined in the literature to be the "chronic condition arising from a prolonged ingestion of arsenic above safe dose for at least 6 months, usually manifested by characteristic skin lesions of melanosis and/or keratosis with or without involvement of internal organs" (Ahmad et al., 2018). However, arsenicosis does not manifest the same way, or to the same degree, in all individuals drinking from contaminated water sources, thus making case identification, management, and treatment all the more complex (Ahmad et al., 2007). In a 2018 fact sheet, the WHO stated that the interindividual variability in the signs and symptoms of arsenicosis ensures that there will never be a universal definition of the disease ("Arsenic," 2018). For example, chronic exposure to arsenic has been linked to many dermatological pathologies, cancer, adverse pregnancy outcomes, decreased intelligence quotients among children, respiratory illnesses, peripheral neuropathy, along with a variety of other manifestations (Ahamed et al., 2006; Ahmad et al., 2018; Ahmad et al., 2007). The onset of arsenicosis is prolonged as it takes between 8-14 years to have an easily observable impact on health, dependent on factors such as the amount of arsenic ingested, the nutritional status of an individual, and the individual's specific immune response (Alam, Allinson, Stagnitti, Tanaka, & Westbrooke, 2002; Hanchett, Nahar, Van Agthoven, Geers, & Rezvi, 2002).

Given the variability of pathologies resulting from long-term arsenic exposure, there is no established standard for treatment or management of arsenicosis patients; therefore, even when caught at an early stage, arsenicosis treatment often requires long-term care (Ahmad et al., 2018). Treatment protocols are further complicated by the fact that most people do not seek care at the early stages of illness due to their lack of access, resources, or knowledge regarding arsenicosis (Ahmad et al., 2018; Ahmad et al., 2007). A lack of knowledge regarding treatment protocols on the part of the physician and the fact that there is often an irregular supply of medications used for treatment in many resource-limited settings contribute to poor outcomes among those affected by the disease (Hassan, Atkins, & Dunn, 2005). Together, these factors often make a curative treatment protocol nearly impossible (Ahmad et al., 2018). However, the minimum standard treatment protocol in all arsenicosis cases demands that the cessation of consumption of arsenic-contaminated water be a priority in mitigating the effects of arsenic exposure (Ahmad et al., 2018).

2.1.2. Adverse Effects on Social Well-Being

The effects of arsenicosis are not limited to the physical health of affected individuals. In a cross-sectional study by Ahmad et al. (2007) of 750 systematically sampled individuals from 25 villages, spanning five Upazilas, or sub-districts, it was found that 140 respondents had an arsenicosis patient in their home. Approximately 1 in 5 of those who had an arsenicosis patient in their home reported facing social barriers as a result of the disease (Ahmad et al., 2007). These barriers included feeling hated by others, being abandoned by their spouses, and being avoided by friends and peers (Ahmad et al., 2007). It has been reported that school-aged children that show the signs and symptoms of arsenicosis are often not sent to school by parents because hiding the illness is thought to be better than being avoided by classmates (Ahmad et al., 2007; Hassan et al., 2005). Such social barriers often result from a misconception among the surrounding population that arsenicosis is a communicable disease. For example, in a qualitative research study comprising 23 in-depth interviews and 40 participants in five focus groups, one arsenicosis patient shared that his closest friend now keeps a physical distance from him as he is afraid of being “infected” (Hassan et al., 2005). Other studies have confirmed a popular belief, especially among rural Bangladeshis, that arsenicosis is a contagious illness that can be avoided by socially isolating those afflicted with the disease (Ahamed et al., 2006).

A cross-sectional study by Kabir, Titus Muurlink, and Hossain (2015) aimed to further characterize the stigmatization of arsenicosis and the factors influencing it by randomly selecting 100 arsenicosis patients for face-to-face interviews from the 558 who were listed at facilities in 17 villages within two Upazilas. Kabir et al. (2015) identified four social impacts that served as markers of stigmatization for the purposes of the study: deterioration of relationships with family, neighbor avoidance, marriage problems, and divorce. It was found that women and those of low-income backgrounds had significantly higher odds of experiencing these adverse social impacts. Furthermore, it was found that those who resided in areas which had no NGO- or government-sponsored arsenicosis awareness-raising activities had 16 times the odds of experiencing the adverse social impacts of arsenicosis (Kabir et al., 2015).

2.1.3. Adverse Effects on Economic Well-Being

In the cross-sectional study of 750 systematically sampled individuals referenced in Section 2.1.2., Ahmad et al. (2007) also examined the economic impacts of arsenicosis. Of the 140 respondents who reported having at least one arsenicosis patient in their home, 58.6% stated that they had experienced economic problems as a result of the disease (Ahmad et al., 2007). The economic problems reported included reduced work efficiency, inability to buy medication or nutritious food, and an inability to get suitable work (Ahmad et al., 2007). Other studies have also reported that many employers in this region have been known to immediately dismiss workers that they see suffering from arsenicosis (Alam et al., 2002). Unsurprisingly, for those of low-income backgrounds who usually lack access to safe water options, the adverse economic impacts of arsenicosis only serve to provide further disadvantage. This, therefore, makes the costly and long-term care associated with arsenicosis treatment even further out of reach for the economically disadvantaged.

2.2. Tubewell Attributes and Arsenic Concentration

Many studies have explored associations between the various attributes of a tubewell and its arsenic concentration. Herein, we will discuss the literature surrounding three key attributes: depth, years since installation, and ownership.

2.2.1. Tubewell Depth and Arsenic Concentration

The literature suggests that tubewell depth is commonly thought to be associated with levels of arsenic concentration, with shallow tubewells being presumed to have higher levels of arsenic (Kinniburgh & Smedley, 2001). However, the classification of tubewells as “shallow” or “deep” can be misleading as it has been found that the actual depths of these tubewells can vary significantly. For example, one study by Chen et al. (2007), evaluating the reduction in urinary arsenic levels following an arsenic mitigation intervention in Araihazar, Bangladesh found that the sample of “deep” tubewells that were measured varied in depth anywhere from 118 feet to 590 feet. Another study by van Geen et al. (2016) referred to tubewells that were 300-500 feet deep as being of “intermediate depth” whereas only tubewells that measured approximately 500 feet or deeper were referred to as “deep.” It was also determined through the van Geen et al. (2016) study that reported depths may not be reliable as builders may reduce their costs by constructing tubewells that are shallower than reported. The standard definition for deep tubewells has been determined by Bangladesh’s DPHE to be ones with a depth of more than 150 meters, or approximately 500 feet (van Geen et al., 2016).

Addressing well depth as a means of mitigating arsenic exposure is commonplace; in fact, one of the largest interventions undertaken to minimize the exposure of the Bangladeshi population to contaminated wells that are mostly privately-owned and less than 300 feet deep, is the installation of deep community wells (Choudhury et al., 2016). However, although deep tubewells are generally considered safer than shallow tubewells in regard to their arsenic concentrations, there have been reported cases of deep tubewells that are contaminated with unsafe levels of arsenic, indicating that the deep aquifer feeding into these wells may also be contaminated (Choudhury et al., 2016). In order to further examine the likelihood of such an event, Choudhury et al. (2016) identified the wells within a specific 180 km^2 area that were greater than 300 feet deep and deemed unsafe by the Bangladeshi standard (n = 9) and closely analyzed them to find the source of arsenic contamination. It was found that in five out of the nine wells the reason for arsenic contamination was improper installation rather than contamination of the deep aquifer (Choudhury et al., 2016). Therefore, it is critical that deep tubewells be properly installed to ensure the safety of users who presume them to be arsenic-safe.

2.2.2. Tubewell Installation Year and Arsenic Concentration

The nationally representative DPHE/ British Geological Survey (BGS) National Hydrochemical Survey, conducted from 1998 to 1999 employed a stratified random methodology and found a distinct trend showing a positive correlation between years since installation of a well and its arsenic concentration (Kinniburgh & Smedley, 2001). Many years later, a case-control study of 1,489 cases by Mostafa and Cherry (2013) aiming to examine the link between health outcomes and arsenic exposure found that the risk of renal cancer increased monotonically with arsenic exposure in rural Bangladesh. Interestingly, it was also found that this risk was significantly modified by well installation year so that risk estimates for renal cancer were greater in areas that had earlier well installations (Mostafa & Cherry, 2013).

2.2.3. Tubewell Ownership and Arsenic Concentration

The literature surrounding the possible association between tubewell ownership and arsenic concentration is sparse. However, in a study by Khan and Yang (2014) comprising 25 face-to-face interviews with institutional stakeholders who play a role in arsenic mitigation efforts in Bangladesh, the idea of tubewell ownership was discussed at length. When the idea of community-based (presumably government or NGO-owned) or individual-level (presumably privately-owned) tubewells was explored, 68% of respondents were in favor of community-based safe water options and 63% were opposed to any individual-level water options (Khan & Yang, 2014). This was determined to be because stakeholders believed that "community-based systems allowed for better water management, provided wider safe water coverage and also reduced the risk of localized contamination of the aquifer" (Khan & Yang, 2014). Only 12% of respondents believed that ownership of a water source would promote responsibility and accountability for the operation and maintenance of water sources among end users (Khan & Yang, 2014).

2.3. Household Attributes and Arsenic Concentration

For the purposes of this thesis, six household attributes are closely analyzed: respondent's age and education level, household's primary source of income, land size, latrine placement within 30 feet of a tubewell, and previous WASH training. Herein, these attributes have been grouped under one of three categories: demographic characteristics (respondent's age and education level), socioeconomic characteristics (source of income and land size), and WASH characteristics (latrine placement within 30 feet of a tubewell and previous WASH training).

2.3.1. Demographic Characteristics

In a study by Hadi (2003), evaluating a community awareness-raising initiative, knowledge regarding arsenic exposure was assessed in 1,240 randomly selected individuals, of whom 636 hailed from villages receiving the intervention and 604 were from comparison villages. Within the villages receiving the mitigation intervention, approximately 42% of respondents were able to list at least two sources of arsenic-safe water, whereas only 10% of those in comparison villages could do the same. There were many sociodemographic factors that were found to be associated with levels of knowledge with a main finding that a respondents' age was inversely associated with knowledge, in that older individuals tended to have lower scores on the knowledge assessment. Furthermore, the relationship between formal education and arsenic knowledge was explored, revealing that although the inverse relationship with age exists, those with six or more years of formal education were consistently found to have significantly higher knowledge scores than those with less than six years of formal education (Hadi, 2003). Other studies have confirmed a link between respondents' age and odds of contracting arsenicosis (Hadi & Parveen, 2004) as well as the association of respondents' age and education level with arsenic knowledge (Paul, 2004).

2.3.2. Socioeconomic Characteristics

Socioeconomic status is widely thought to be associated with arsenic exposure (Hadi & Parveen, 2004); herein, two proxy measures of socioeconomic status were used: primary source of income and land size. These measures have been referenced, at length, in the literature (Argos et al., 2007; Hadi, 2003; Parvez et al., 2006).

For example, in the Hadi (2003) study evaluating a community awareness-raising initiative, referenced in Section 2.3.1., it was found that land ownership and source of income were significantly associated with arsenic-related knowledge. Those who did not own land were significantly less likely to demonstrate an adequate awareness of safe water options and the health effects of arsenic exposure (Hadi, 2003). Furthermore, those whose primary source of income was selling manual labor tended to demonstrate significantly less arsenic-related awareness (Hadi, 2003). An additional study by Parvez et al. (2006) confirmed that agricultural laborers, often considered the lowest socioeconomic group by occupation in this region, are less likely than those of other professions to be aware of the adverse health effects of arsenic exposure.

Argos et al. (2007) also conducted a study that aimed to examine the relationship between socioeconomic status and risk for arsenic-related skin lesions. Skin lesions are one of the earliest manifestations of arsenic poisoning and are thought by some to indicate an increased future risk for cancer. However, wide variability has been observed regarding the onset of skin lesions among individuals. Using the baseline data of 11,438 men and women from the Health Effects of Arsenic Longitudinal Study (HEALS), it was found that a strong dose-response existed between arsenic exposure and skin lesions. However, this relationship was found to be significantly modified by whether or not an individual owned land (Argos et al., 2007).

It has been suggested that not only does socioeconomic status influence the burden of disease on populations, but that it may also influence access to public health interventions aimed at reducing the burden of disease. For example, since community wells that tend to be deeper than most private wells have been shown to be critical for the mitigation of arsenic exposure, one study sought to examine the impact of 915 shallow and deep wells on safe water access over an area spanning 180 km^2 (van Geen et al., 2016). It was found that only 29% of shallow wells exceeding an arsenic concentration of 0.05 mg/L were within walking distance (100 m) of a deep community well. A hypothetical model showed however that, given proper planning, the deep community wells already in place in the region could be allocated such that 74% of shallow wells with arsenic concentrations exceeding 0.05 mg/L could have been within walking distance. Given that the locations of these community wells is often determined with the input of elected officials and the fact that a clustering of deep wells was found in areas where access to the well is limited only to the landowner, one can infer that this is a case of “elite capture,” wherein resources meant for the benefit of the public are unfairly distributed to the wealthy and/or otherwise privileged (van Geen et al., 2016). Although the government of Bangladesh aimed to adopt a “pro-poor” strategy in 2005 which would prioritize the socioeconomically disadvantaged when allocating new safe water options, there has been little improvement demonstrated in the situation faced by the poor (Raessler, 2018).

2.3.3. WASH-Related Characteristics

Knowledge of proper WASH behaviors is a key factor in determining decisions regarding water management, use, and consumption. The importance of training and education regarding WASH can be evidenced through a study which sought to evaluate the effectiveness of an arsenic education program. In the study, researchers randomly selected 1,000 participants from 20 villages in Singair, Bangladesh for a household-level arsenic education and well water testing intervention (George et al., 2013). At baseline, approximately 20% of respondents could not accurately define what the red and green labeling of wells indicated. Through the education intervention, this percentage was reduced to less than 2%. Additionally, 71% of respondents at baseline incorrectly believed that arsenic could be removed by boiling water, whereas this number was reduced to 33% at follow-up, thus decreasing the risk of people unknowingly consuming arsenic-contaminated water (George et al., 2013).

2.4. Arsenic Mitigation

2.4.1. Arsenic Mitigation Activities and Technologies

Arsenic mitigation activities are thought to fall within one or more of four main categories: distribution of safe water options, construction of safe water options, awareness-building, and patient management (Khan & Yang, 2014). There exist four principal arsenic mitigation technologies that are employed in Bangladesh as "safe" water options: dugwells, deep tubewells, pond-sand filters, and rainwater harvesting systems (Howard, Ahmed, Shamsuddin, Mahmud, & Deere, 2006).

"Dugwells are large diameter wells manually constructed, lined with concrete rings, and covered by a concrete slab or a metal sheet with ventilation… pond-sand filters are designed as a slow sand filtration system with water drawn from an adjacent pond…[and] rainwater harvesting systems are all individual household systems with foul-flush mechanisms and taps for removal of water" (Howard et al., 2006).

The relative safety, affordability, and convenience of these options have been debated and reliance on hand-pumped tubewells, investigated herein, is most common (Chen et al., 2007; Bilqis A Hoque et al., 2006).

2.4.2. Factors Influencing the Decision to Switch to a Safe Water Option

A prospective cohort study by Chen et al. (2007) of a multifaceted mitigation program involving individual interviews and urinary arsenic concentration measurements of 11,746 people, found that the interventions that were most effective at influencing well switching behaviors were well labeling in conjunction with community education and the installation of communal deep wells. Interestingly, the Chen et al. (2007) study included 506 participants who had unsafe wells at baseline and switched to unsafe wells by follow-up. Chen et al. (2007) suggest that this may be because these participants sought land ownership during this time which included access to a private tubewell that was also unsafe. Switching from an unsafe well to another unsafe well may also be the result of mislabeling of wells; after NGO workers hired by the BAMWSP tested and painted 799 wells in rural Bangladesh, 12% of a randomly selected subset were found to be mislabeled as being safe when they were actually unsafe (Chen et al., 2007). Another possible explanation for unsafe well switching is that the chosen well has a lower arsenic concentration than the well currently being used by individuals (Chen et al., 2007). Even though another unsafe well was chosen, the decision may still be beneficial given the dose-response nature of arsenic exposure (Chen et al., 2007).

In 2009, it was estimated that 692,488 different types of arsenic-safe water options were in place in arsenic-contaminated areas throughout Bangladesh; however, one-third of these arsenic-safe water options are not utilized by households who are at risk of exposure to arsenic-contaminated water and have access to them (Ahmad et al., 2018). It has been reported that land owners may be less likely to switch wells since they would likely use the tubewell located on their own property (Chen et al., 2007). Distance to safe water points and time needed for water collection continue to be a major barrier to the utilization of safe water options (Ahmad et al., 2007; B. A. Hoque et al., 2004; Johnston et al., 2014). Other reasons given for the continued use of water options that are known to be contaminated were: loss of arsenic knowledge over time, lack of cooperation from owners of safe water points, divine protection, lack of social acceptability, lack of community participation, taste preferences, the misconception drinking arsenic-contaminated tubewell water does not have adverse effects, and the misconception that boiling water removes arsenic (Ahmad et al., 2018; Ahmad et al., 2007; Balasubramanya et al., 2014; Hanchett et al., 2002).

Although many barriers to well switching exist, the benefits of well switching are well-documented (Aziz, Boyle, & Crocker, 2015; Chen et al., 2007; Majumdar, Ghose, Ghose, Biswas, & Mazumder, 2014). In fact, it has been found that the urinary arsenic concentrations of those who switched from unsafe wells to safe wells, tended to drop to approximately the average urinary arsenic levels of those consuming water that did meet the Bangladeshi safety guidelines (Chen et al., 2007).

Some have suggested that interventions that encourage well switching may not be effective in the long-term as people may revert back to using their prior wells, primarily for convenience (Hanchett et al., 2002). However, others suggest that the impact of arsenic knowledge on well-switching behaviors may grow over time (Balasubramanya et al., 2014). In one study which re-interviewed, in 2008, participants of a 2003-2005 study on well switching, it was found that the new incidence of switching since 2005 (17%) had doubled the total overall rate of switching among those using unsafe water options to approximately 33% (Balasubramanya et al., 2014).

2.4.3. Considerations for Water Safety in Arsenic Mitigation Activities

A link has been reported between arsenic mitigation activities and technologies and an increase in the incidence of diarrheal disease (Lokuge, Smith, Caldwell, Dear, & Milton, 2004; Wu et al., 2011). For example, in a study including approximately 60,000 episodes of childhood diarrhea between 2000 and 2006 in 142 villages throughout Matlab, Bangladesh, it was found that children drinking from intermediate-depth wells (140-300ft) had a significantly higher risk of diarrheal disease than those drinking from shallow wells (10-140ft) (Wu et al., 2011).

In a study conducting a risk assessment of arsenic mitigation options in Bangladesh, a modified cluster survey approach was used to select and test 36 dugwells, 36 deep tubewells, 42 pond-sand filters, and 42 rainwater harvesting systems in both the dry and monsoon seasons (Howard et al., 2006). Over 90% of dugwells and pond-sand filters showed microbial contamination even in the dry season, when contamination is expected to be lowest, exceeding Bangladesh's standard for thermotolerant coliforms (Howard et al., 2006). The deep tubewells and rainwater harvesting systems were determined to offer the best quality water and the lowest burden of disease (considering both microbial contamination and arsenic exposure); however, both did show some level of microbial contamination (Howard et al., 2006). Deep tubewells were microbially-contaminated especially in the monsoon season "almost certainly due to use of contaminated priming water" when water levels in the well are too low to create suction (Howard et al., 2006).

This suggests that more support is needed in training communities on ways to mitigate exposure to microbially-contaminated water.

It has been suggested that the use of arsenic filtering systems may also increase the risk of water-related infections due to the increased handling and storage of water at the point of use (Lokuge et al., 2004). The following explanation has also been put forth regarding the ways in which arsenic mitigation activities may be linked to an increased risk of diarrheal disease:

> "Assuming any individual household would prefer to use the most convenient well, usually the closest and often within the household compound, any change in the tube well would presumably involve a change to an uncontaminated but less convenient tube well, in terms of either distance or the number of individuals using the well for water. Aside from compliance issues, this also increases the risk of water- borne disease. Studies have found that in terms of protection against infectious disease, the quantity of water used is as important or even more important than the quality of water used (Esrey, Potash, Roberts, & Shiff, 1991), and that the quantity of water used is directly related to the distance to the water source and the number of users (B. A. Hoque, Huttly, Aziz, Patwary, & Feachem, 1989). Thus, even a change in the tube well used may increase the risk of diarrheal disease." (Lokuge et al., 2004, p. 1176)

In a study seeking to compare the likely impacts of arsenic mitigation efforts on arsenic-related diseases as well as water-borne infectious diseases, it was found that arsenic-related diseases result in approximately 174,174 disability-adjusted life years (DALYs) per year in those who are exposed beyond the Bangladeshi threshold, comprising 0.3% of Bangladesh's total disease burden in terms of DALYs (Lokuge et al., 2004). Researchers then assumed that arsenic mitigation interventions would result in a 20% increase in water-related infectious disease, based on risk difference data from a prior study (Pruss, Kay, Fewtrell, & Bartram, 2002). Under this assumption, it was determined that arsenic mitigation interventions must result in a minimum reduction of arsenic-related DALYs of 77% to achieve a net reduction in overall disease burden.

However, the association between arsenic mitigation technologies and increased incidence of diarrheal disease has been contested by some– in a survey of 543 randomly selected households in Bangladesh, it was found that the risk of childhood diarrhea was 46% lower for the households using deep tubewells than for the households using shallow tubewells (Escamilla et al., 2011). Additionally, it was found that socioeconomic status, latrine density, population density, and study year did not have a significant impact on risk of childhood diarrhea (Escamilla et al., 2011).

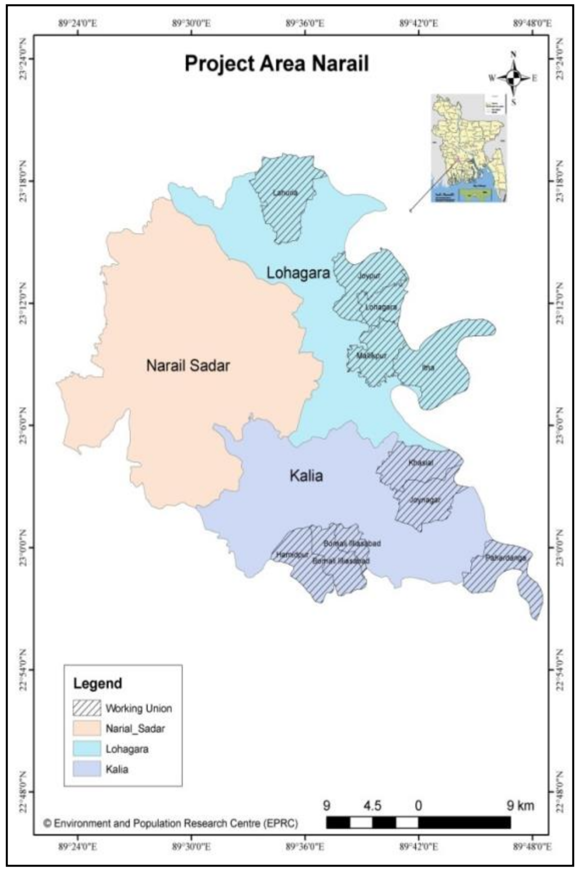
Furthermore, although the use of deep groundwater is thought to decrease the risk of arsenic contamination, other factors of water safety that must be considered when using deep water sources are: salinity, iron, and manganese (Johnston et al., 2014; Kinniburgh & Smedley, 2001). These topics fall outside of the scope of this thesis but should be kept in mind for those engaged in mitigation efforts.

3. Methods

3.1. Dataset Properties

The data used to conduct this analysis originates from a project entitled "Creating Arsenic-Safe Villages with User Women-Led Sustainable Improvement of Water, Sanitation and Hygiene in Narail District" conducted by the Environment and Population Research Centre (EPRC) in collaboration with UNICEF-Bangladesh and the Dutch Embassy in Bangladesh (B. Hoque, Khanam, Siddik, Huque, & Zahid, 2016). Narail district falls within the deltaic and coastal region of Bangladesh (Chakraborti et al., 2015). With the objective of creating arsenic-safe model villages which demonstrated sustainable improvements in water, sanitation and hygiene, the project chose ten Unions, local government units, which were most severely affected by arsenic contamination (B. Hoque et al., 2016). The ten Unions were located within two out of the three Upazilas of the Narail district: Kalia and Lohagara. The ten Unions also included representation from ninety Wards, subdivisions of cities. From November 2013 to January 2014, project staff visited every house with a known, functional tubewell installation within these ten Unions, tested their arsenic content using the Arsenic Econo-Quick Test Kit (n=19,705 tubewells), painted the tubewells red or green depending on the results, recorded the

Figure 1. Map of Project Area



GPS location of the tubewell, and provided the household owner with information regarding the negative health consequences of consuming arsenic-contaminated water (B. Hoque et al., 2016).

Following the water testing, a baseline survey was done in all ninety Wards from December 2013 to January 2014 (B. Hoque et al., 2016). A sampling frame was established in consultation with UNICEF-Bangladesh and a total of 510 households (approximately 5-6 per Ward) and approximately 30 female local government members were interviewed regarding sociodemographic characteristics, water access and use, sanitation, and familiarity with symptoms of arsenicosis. In order to select the households to be interviewed, each Ward was arbitrarily divided into five units of approximately equal size. Then, a pencil or pen was thrown in the middle of each part of the Ward and the house ten minutes to the right-hand side of the pen was selected. In total, 534 baseline surveys were conducted in the ten Unions selected from the Narail district. A woman from each household was asked to complete the survey on behalf of the household through a verbal administration process (B. Hoque et al., 2016). An English translation of the original code plan for the survey can be found in Appendix A.

Three hundred and twenty households with tubewells, matched using GPS locations, were assessed and analyzed in both components of the project and thus, constitute the final sample for analysis in this thesis. While not all ninety Wards are represented in the data, the dataset does include points from all ten Unions. Coding, data entry, and translation of all responses was completed by EPRC staff. Statistical analyses were conducted in SAS 9.4. All statistical tests were evaluated at an alpha level of 0.05.

All data was stored in a password-secure laptop. Institutional Review Board (IRB) consultation was sought for the secondary data analysis through the Emory University IRB and a determination of “No IRB Review Required” was received because the analysis does not meet the definition of “research” with “human subjects” or “clinical investigation” as set forth in Emory policies and procedures (Appendix B).

3.2. Data Cleaning

Data cleaning was done to recode variables that either had repetitive codes or needed to be made categorical for analytic purposes. For example, the continuous arsenic value data was converted to a Boolean variable which set the threshold for contamination at 0.05 mg/ L, the safety standard for arsenic presence in water as per the national laws of Bangladesh. It was found that 239 of the 320 tubewells in the dataset were contaminated with unsafe levels of arsenic, as determined by the Bangladeshi standards. Another Boolean variable was created which set the threshold for contamination at 0.01 mg/ L of arsenic in drinking water, the current value recommended by the WHO. When this threshold was set, 293 of the 320 tubewells were found to be contaminated.

3.3. Exploratory Analysis

Exploratory analysis was conducted across the variables of interest using frequency tables and univariate analyses. Through these, it was found that only two of the data points (n=320) referred to tubewells that were NGO-owned. An ANOVA was done to ensure that the mean arsenic values of tubewells did not differ significantly by ownership of tubewell. However, given the low power associated with them, the two data points detailing NGO-owned tubewells were set as missing from the data set. Frequency tables were also created to explore the distribution of the use of contaminated water for various activities in the households such as drinking, cooking, and bathing, using both thresholds to aid in the further characterization of the data. A frequency table was also used to determine how many of the respondents who have contaminated tubewells at home use alternative drinking water options that have been tested for arsenic and further, what the results of those tests have been (as denoted by paint color).

3.4. Exploring Associations through Regression Models

3.4.1. Association of Tubewell Attributes and Contamination of Household Tubewell

The researchers then aimed to determine whether specific attributes of the household tubewells themselves, such as depth, years since installation, ownership, and tubewell type (deep or shallow) were associated with arsenic contamination. Tubewell type was removed from the analysis as it was dependent on the tubewell depth variable. The remaining attributes (depth, years since installation, and ownership) served as the independent variables in the forthcoming analyses. A logistic regression model was run using the categorical Bangladeshi arsenic value threshold as the dependent variable and the three independent variables listed above to ascertain significant odds ratios relating the independent and dependent variables.

All of the aforementioned analyses were then repeated using the WHO standard of arsenic presence in drinking water of 0.01 mg/ L.

Lastly, the independent variables listed above were included in a multivariate regression model with the continuous value of arsenic as the dependent variable.

Stepwise model selection was then performed on all analyses wherein variables had to meet a criterion of $\alpha < 0.05$ to enter and remain in the model.

3.4.2. Association of Household Attributes and Contamination of Household Tubewell

Next, analyses were conducted to examine the associations between household attributes (source of income, land size, placement of a latrine within thirty feet of a tubewell, previous WASH trainings, respondent’s age, and respondent’s education level) and arsenic contamination of the household tubewell, by both the Bangladeshi and WHO standard. Home ownership was not included in the model due to the skewed distribution of respondents wherein approximately 98% of all respondents owned their homes. Data regarding highest education level in the family was excluded from the analyses as the presence of this variable alongside respondent’s education level did not allow regression models to converge. The Remittance and Pension categories of source of income were excluded from the analyses due to the low number of respondents within these categories.

An additional multivariate regression model was tested using the household attributes as the independent variables and the continuous arsenic value as the dependent variable.

Stepwise model selection was then performed on all analyses wherein variables had to meet a criterion of $\alpha < 0.05$ to enter and remain in the model.

3.4.3. Association of Household Attributes and Contamination of Drinking Water Source

Following these analyses, subsets of the data were created that constituted responses from those respondents who had unsafe levels of arsenic concentration in their household tubewells by both the Bangladeshi and WHO standards. Respondents from these households were asked about their source of drinking water as some may have opted to use alternative options available in the community. Those who did not know the test results of their alternative drinking water source (n=2) were excluded from the analyses. Having explored the distribution of responses through the frequency tables mentioned above, a logistic regression model was used to determine whether any household attributes were significantly related to the use of unsafe alternative drinking water options, among those whose household tubewells were unsafe. All analyses were conducted on both subsets of data that used either the Bangladeshi or the WHO threshold for determining whether drinking water is arsenic-safe or not.

Stepwise model selection was then performed on all analyses wherein variables had to meet a criterion of $\alpha < 0.05$ to enter and remain in the model.

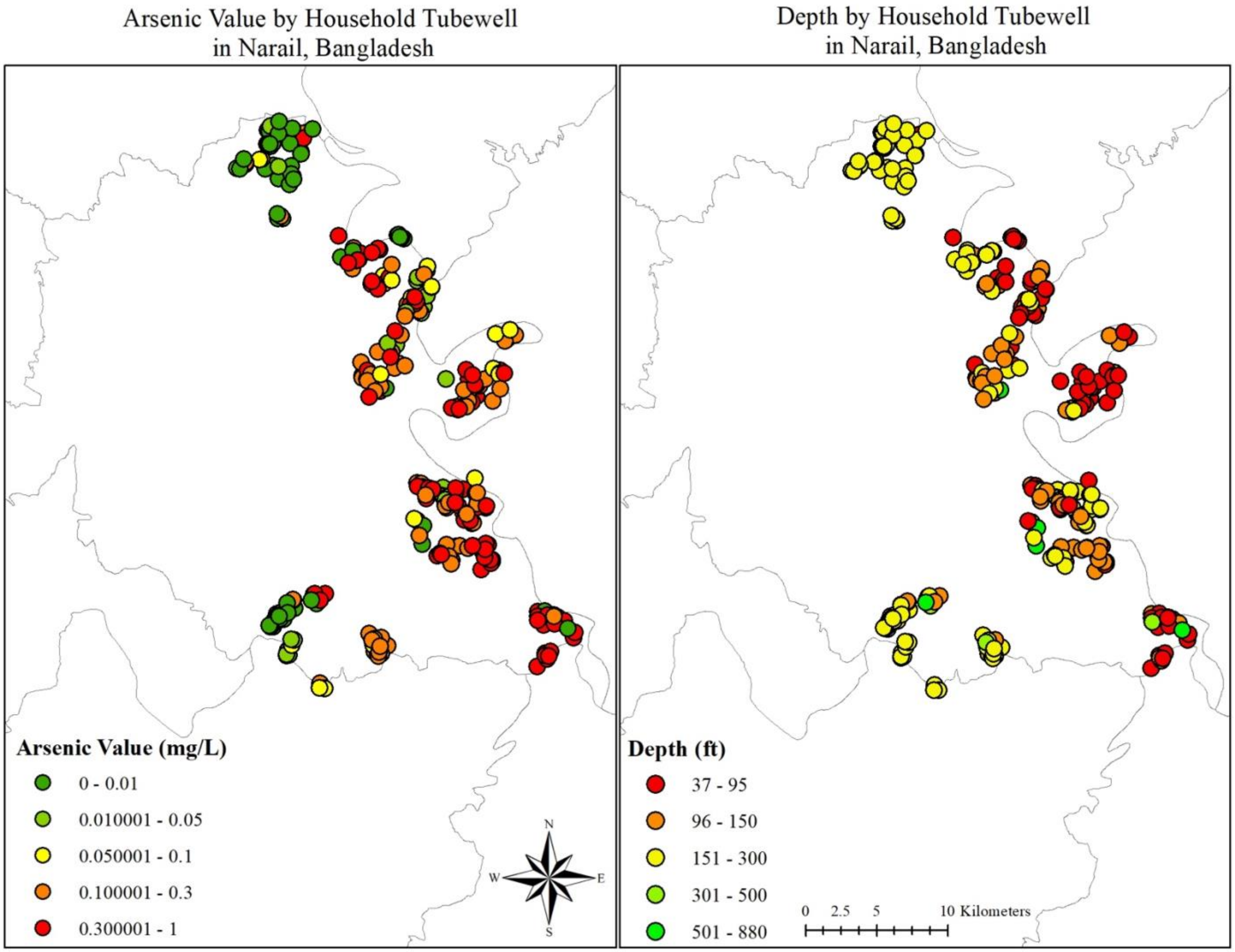
4. Results

4.1. Exploratory Analysis

Through the exploratory analysis, it was found that a large number of tested household tubewells met the criteria for unsafe levels of arsenic contamination by either the WHO (n=293) and/or the Bangladeshi (n=239) standard(s) for drinking water.

Given the differences observed in tubewell depth during the exploratory analysis, a T-test was conducted, and it was determined that tubewell depth differed significantly by levels of contamination (safe vs. unsafe) for both the Bangladeshi and WHO standards ($p < 0.0001$). Also, it was found that tubewells deemed safe by the Bangladeshi standard still had, on average, 0.008 mg/L concentration of arsenic; whereas, tubewells deemed safe by the WHO standard had an average concentration of 0.000 mg/L As. In addition, when examining the relationship between tubewell type (deep vs. shallow) and arsenic concentration, although 100% of the deep tubewells included in the dataset were deemed safe by Bangladeshi standards, only 18% were considered safe by WHO standards. A visualization of the spatial distribution of arsenic value and depth by household tubewell can be seen in Figure 2.

Figure 2. Map of Arsenic Value and Depth by Household Tubewell



Furthermore, our data shows that over three-quarters of those surveyed reported that their household tubewells were used for drinking and other household activities, such as agriculture. Among those whose household tubewells surpassed the Bangladeshi threshold for arsenic contamination, approximately 69% still reported using the tubewell for drinking; when those whose household tubewells surpassed the WHO arsenic threshold were asked, this number increased to over 73%. A more detailed analysis of tubewell attributes is provided in Table 1.

Table 1. Tubewell Attributes

	Overall (n=320)	**Bangladesh**		**WHO**	
		Safe (n=81)	**Unsafe** (n=239)	**Safe** (n=27)	**Unsafe** (n=293)
Tubewell Ownership n (%)					
Self	288 (90.00)	70 (86.42)	218 (91.21)	25 (92.59)	263 (89.76)
Government	30 (9.38)	9 (11.11)	21 (8.79)	2 (7.41)	28 (9.56)
NGO	2 (0.62)	2 (2.47)	0 (0.00)	0 (0.00)	2 (0.68)
Tubewell Type n (%)					
Deep	11 (3.44)	11 (13.58)	0 (0.00)	2 (7.41)	9 (3.07)
Shallow	309 (96.56)	70 (86.42)	239 (100.00)	25 (92.59)	284 (96.93)
Tubewell Uses					

n (%)					
Drinking	241 (75.31)	77 (95.06)	164 (68.62)	26 (96.30)	215 (73.38)
Cooking	137 (42.81)	73 (90.12)	64 (26.78)	26 (96.30)	111 (37.88)
Bathing	173 (54.06)	69 (85.19)	104 (43.51)	26 (96.30)	147 (50.17)
Other	250 (78.13)	72 (88.89)	178 (74.48)	24 (88.89)	226 (77.13)
Tubewell Depth (ft) Mean ± SD	164.67 ± 109.54	236.68 ± 169.61	140.27 ± 63.65	218.30 ± 109.76	159.73 ± 108.38
Years Since Installation Mean ± SD	8.11 ± 6.97	7.61 ± 6.60	8.28 ± 7.10	6.81 ± 5.91	8.23 ± 7.06
Arsenic Value Mean ± SD	0.26 ± 0.22	0.008 ± 0.007	0.34 ± 0.19	0.000 ± 0.000	0.28 ± 0.21

In exploring household attributes, it was found that almost one-fifth of the women surveyed in this sample could only sign their names or considered themselves illiterate.

Moreover, it was also found that only about one-fifth of those surveyed had any previous WASH training. Related perhaps is the finding that at least fifty percent of people in any subset of the population by safety standard (and overall) had latrines within thirty feet of their tubewells and almost fifty percent of people reported using shallow tubewells that were painted red as a source of drinking water.

In-depth exploratory analyses of household and WASH attributes can be referenced in Tables 2 and 3, respectively.

Table 2. Household Attributes

	Overall (n=320)	**Bangladesh**		**WHO**	
		Safe (n=81)	**Unsafe** (n=239)	**Safe** (n=27)	**Unsafe** (n=293)
Respondent's Age (years) (n=319) Mean ± SD	36.64 ± 9.56	36.67 ± 9.38	36.63 ± 9.64	36.07 ± 8.06	36.69 ± 9.70
Respondent's Education n (%)					
Only Signature/Illiterate	58 (18.13)	18 (22.22)	40 (16.74)	2 (7.41)	56 (19.11)
Class 1-10	230 (71.88)	58 (71.60)	172 (71.97)	23 (85.19)	207 (70.65)
Higher Education	32 (10.00)	5 (6.17)	27 (11.30)	2 (7.41)	30 (10.24)
Highest Education in Family n (%)					
Only Signature/Illiterate	1 (0.31)	0 (0.00)	1 (0.42)	0 (0.00)	1 (0.34)
Class 1-10	177 (55.31)	52 (64.20)	125 (52.30)	15 (55.56)	162 (55.29)
Higher Education	142 (44.38)	29 (35.80)	113 (47.28)	12 (44.44)	130 (44.37)
Source of Income n (%)					

Agriculture	137 (42.81)	33 (40.74)	104 (43.51)	11 (40.74)	126 (43.00
Business	74 (23.13)	17 (20.99)	57 (23.85)	5 (18.52)	69 (23.55)
Service	55 (17.19)	19 (23.46)	36 (15.06)	10 (37.04)	45 (15.36)
Remittance	16 (5.00)	4 (4.94)	12 (5.02)	0 (0.00)	16 (5.46)
Daily Labor	37 (11.56)	8 (9.88)	29 (12.13)	1 (3.70)	36 (12.29)
Pension	1 (0.31)	0 (0.00)	1 (0.42)	0 (0.00)	1 (0.34)
Home Ownership n (%)					
Self-Owned	313 (97.81)	80 (98.77)	233 (97.49)	27 (100.00)	286 (97.61)
Government	1 (0.31)	0 (0.00)	1 (0.42)	0 (0.00)	1 (0.34)
Government Land, Self House	2 (0.63)	1 (1.23)	1 (0.42)	0 (0.00)	2 (0.68)
Relative	1 (0.31)	0 (0.00)	1 (0.42)	0 (0.00)	1 (0.34)
Other's Land, Self House	2 (0.63)	0 (0.00)	2 (0.84)	0 (0.00)	2 (0.68)
Other's House	1 (0.31)	0 (0.00)	1 (0.42)	0 (0.00)	1 (0.34)
Land Size (decimals) (n=316) Mean ± SD	142.72 ± 215.79	122.63 ± 202.75	149.59 ± 220.07	173.63 ± 253.38	139.81 ± 212.19

Table 3. WASH Attributes

	Overall (n=320)	Bangladesh		WHO	
		Safe (n=81)	**Unsafe** (n=239)	**Safe** (n=27)	**Unsafe** (n=293)
Latrine within 30ft of Tubewell n (%)	181 (56.56)	41 (50.62)	140 (58.58)	14 (51.85)	167 (57.00)
Previous WASH Training n (%)	63 (19.69)	14 (17.28)	49 (20.50)	6 (22.22)	57 (19.45)
Drinking Water Source					
Deep Tubewell	112 (35.00)	12 (14.81)	100 (41.84)	2 (7.41)	110 (37.54)
Shallow Tubewell (Green)	55 (17.19)	31 (38.27)	24 (10.04)	3 (11.11)	52 (17.75)
Shallow Tubewell (Red)	151 (47.19)	38 (46.91)	113 (47.28)	22 (81.48)	129 (44.03)
Rainwater Harvesting System	1 (0.31)	0 (0.00)	1 (0.42)	0 (0.00)	1 (0.34)
Pond Sand Filter	1 (0.31)	0 (0.00)	1 (0.42)	0 (0.00)	1 (0.34)
Drinking Water Tested n (%)					
Yes	241 (75.31)	46 (56.79)	195 (81.59)	8 (29.63)	233 (79.52)
No	75 (23.44)	35 (43.21)	40 (16.74)	19 (70.37)	56 (19.11)

Maybe	4 (1.25)	0 (0.00)	4 (1.67)	0 (0.00)	4 (1.37)
Drinking Water Test Results (n=241) n (%)					
Green	154 (63.90)	43 (93.48)	111 (56.92)	6 (75.00)	148 (63.52)
Red	85 (35.27)	2 (4.35)	83 (42.56)	1 (12.50)	84 (36.05)
Don't Know	2 (0.83)	1 (2.17)	1 (0.51)	1 (12.50)	1 (0.43)

4.2. Association of Tubewell Attributes and Contamination of Household Tubewell

4.2.1. Bangladeshi Threshold

The logistic regression model relating tubewell attributes to unsafe levels of arsenic contamination in household tubewells by Bangladeshi standards (Table 4) showed two variables of interest (tubewell ownership and depth) as being significant. Both of these variables subsequently remained in the logistic regression model using the stepwise selection method, indicating that tubewell depth ($p< 0.0001$) and ownership ($p=0.0416$) together create the most parsimonious model. It was found that tubewells that were government-owned were 0.238 times less likely to exceed the Bangladeshi threshold for contamination as compared to those which are self-owned, holding years since installation and depth constant ($p=0.0455$). To correctly interpret our findings for tubewell depth, a continuous variable, a standard amount of difference to be investigated must be established. To do this, a univariate analysis of tubewell depth was done by the class of deep and shallow. In doing so, it was found that the cutoff used to determine whether a tubewell is deep or shallow is of whether it is greater than or less than approximately 500 feet. By multiplying our tubewell depth estimate (0.0109) by this coefficient and exponentiating it we get an odds ratio of 232.758. Therefore, we find that among tubewells with the same ownership status and years since installation, tubewells that are 500 feet deeper than their counterparts are approximately 233 times less likely to have unsafe levels of arsenic contamination by the Bangladeshi standard ($p< 0.0001$).

Table 4. Logistic Regression Analysis to assess association between tubewell attributes and odds of the household tubewell surpassing the Bangladeshi threshold for acceptable levels of arsenic in drinking water

Variable	**OR**	**p-value**	**95% Wald Confidence Limits**	
			Lower	**Upper**
Ownership*				
Self	Reference			
Government	0.238	0.0455	0.058	0.972
Years since installation	1.009	0.6799	0.967	1.052
Depth (ft)*	1.011	<0.0001	1.007	1.015

* remained in logistic regression model when using the stepwise selection method

4.2.2. WHO Threshold

In the logistic regression model examining the association between tubewell attributes and unsafe levels of arsenic contamination in household tubewells by WHO standards (Table 5), only the tubewell depth was found to be significant and was entered into the logistic regression model using the stepwise selection method, indicating that it constituted the most parsimonious model. The approach detailed above in Section 4.2.1. to interpret the tubewell depth variable was utilized once more. By exponentiating the product of our tubewell depth estimate of 0.00567 and our coefficient of 500, we arrived at the value of 17.030. Therefore, it was found that among tubewells with the same ownership status and years since installation, tubewells that are 500 feet deeper than their counterparts are approximately 17 times less likely to have unsafe levels of arsenic contamination by the WHO standard (p=0.0090).

Table 5. Logistic Regression Analysis to assess association between tubewell attributes and odds of the household tubewell surpassing the WHO threshold for acceptable levels of arsenic in drinking water

Variable	**OR**	**p-value**	**95% Wald Confidence Limits**	
			Lower	**Upper**
Ownership				
Self	Reference			
Government	0.208	0.1461	0.025	1.729
Years since installation	0.980	0.5639	0.915	1.050
Depth (ft)*	1.006	0.0090	1.001	1.010

* remained in logistic regression model when using the stepwise selection method

4.2.3. Continuous Arsenic Value

When the relationship between tubewell attributes and the continuous arsenic concentration of a tubewell was examined using a multivariable linear regression model (Table 6), the tubewell depth variable was found to be a significant contributor to arsenic levels ($p < 0.0001$) and was subsequently entered into a linear regression model using a stepwise selection method. It was found that for every increase of one foot in the depth of a tubewell, the arsenic concentration of the tubewell dropped by 0.00055 mg/L, holding all other variables constant. To further examine the 500 feet tubewell depth difference from the logistic regression analyses in Sections 4.2.1 and 4.2.2., we would like to note that our linear model indicates that, holding all other variables constant, an increase in tubewell depth by 500 feet would result in a decrease of approximately 0.275 mg/L in arsenic concentration.

Table 6. Multivariate Linear Regression Analysis to assess association between tubewell attributes and continuous arsenic level measurement

Variable	Parameter Estimate	Standard Error	t value	p-value
Intercept	0.29835	0.04692	6.36	<0.0001
Ownership	0.03867	0.04432	0.87	0.3837
Years since installation	0.00075799	0.00173	0.44	0.6623
Depth (ft)*	-0.00055072	0.00012588	-4.38	<0.0001

* remained in linear regression model when using the stepwise selection method

4.3. Association of Household Attributes and Contamination of Household Tubewell

4.3.1. Bangladeshi Threshold

The logistic regression model relating household attributes to unsafe levels of arsenic contamination in household tubewells by Bangladeshi standards (Table 7) identified the service industry category of the variable indicating primary source of income, as being significant. We found that households whose primary source of income was the service industry were 1.832 times more likely to have a household tubewell that surpassed Bangladeshi safety standards for arsenic contamination as compared to households whose primary source of income was the agriculture industry, holding all other variables constant. However, when a logistic regression analysis was run using the stepwise model selection method, no variables remained in the model.

Table 7. Logistic Regression Analysis to assess association between household attributes and odds of the household tubewell surpassing the Bangladeshi threshold for acceptable levels of arsenic in drinking water

Variable	OR	p-value	95% Wald Confidence Limits	
			Lower	Upper
Source of Income				
Agriculture	Reference			
Business	0.948	0.5963	0.468	1.923
Service	1.832	0.0469	0.902	3.720
Daily Labor	0.801	0.3611	0.320	2.004
Land Size (decimals)	0.999	0.4439	0.998	1.001
Previous WASH Training				
Yes	Reference			
No	1.181	0.6416	0.586	2.381
Respondent's Age	0.995	0.7645	0.966	1.026
Latrine within 30ft of tubewell				
Yes	0.699	0.1898	0.409	1.194
No	Reference			
Respondent's Education Level				
Signature only/Illiterate	0.967	0.4302	0.462	2.021

Class 1-10	Reference			
Higher Education	0.467	0.1770	0.163	1.341

*no variables remained in logistic regression model when using the stepwise selection method

4.3.2. WHO Threshold

The logistic regression model relating household attributes to unsafe levels of arsenic contamination in household tubewells by WHO standards (Table 8) found that households whose primary source of income was the service industry were 3.242 times more likely to have a household tubewell that surpassed WHO safety standards for arsenic contamination as compared to households whose primary source of income was the agriculture industry, when controlling for confounders. No variables remained in the model when using the stepwise selection method.

Table 8. Logistic Regression Analysis to assess association between household attributes and odds of the household tubewell surpassing the WHO threshold for acceptable levels of arsenic in drinking water

Variable	**OR**	**p-value**	**95% Wald Confidence Limits**	
			Lower	**Upper**
Source of Income				
Agriculture	Reference			
Business	0.979	0.9078	0.316	3.028
Service	3.242	0.0053	1.232	8.534
Daily Labor	0.356	0.1791	0.043	2.967
Land Size (decimals)	1.000	0.6341	0.999	1.002
Previous WASH Training				
Yes	Reference			
No	0.709	0.5025	0.259	1.938

Respondent's Age	0.994	0.8021	0.948	1.042
Latrine within 30ft of tubewell				
Yes	0.721	0.4333	0.319	1.632
No	Reference			
Respondent's Education Level				
Signature only/Illiterate	0.335	0.4890	0.071	1.579
Class 1-10	Reference			
Higher Education	0.370	0.6071	0.077	1.785

*no variables remained in logistic regression model when using the stepwise selection method

4.3.3. Continuous Arsenic Value

When the relationship between household attributes and the continuous arsenic concentration of a tubewell was examined using a multivariable linear regression model, no variables were found to be significant and subsequently, no variables remained in the linear regression model using a stepwise selection method.

4.4. Association of Household Attributes and Contamination of Alternative Source of Drinking Water

4.4.1. Bangladeshi Threshold

In the logistic regression model examining the association between household attributes of those with household tubewells deemed unsafe by Bangladeshi standards and the continued use of unsafe drinking water sources (Table 9), it was found that respondent's age was a significant variable.

Therefore, among those with unsafe household tubewells, the odds of those who were one year older using unsafe alternative drinking water sources were 1.048 times more than the odds of those one year younger than them using unsafe alternative drinking water sources (p= 0.0133), given that all other variables were held constant. Both respondent's age and source of income remained in the logistic regression model when using the stepwise selection method.

Table 9. Logistic Regression Analysis to assess association between household attributes and odds of drinking from an alternative water source that surpasses the Bangladeshi threshold for acceptable levels of arsenic in drinking water

Variable	OR	p-value	95% Wald Confidence Limits	
			Lower	Upper
Source of Income*				
Agriculture	Reference			
Business	1.879	0.8133	0.859	4.107
Service	2.123	0.8817	0.823	5.474
Daily Labor	4.105	0.0880	1.313	12.834
Land Size (decimals)	1.000	0.9753	0.999	1.001
Previous WASH Training				
Yes	Reference			
No	0.865	0.7068	0.406	1.843
Respondent's Age*	1.048	0.0133	1.010	1.087
Latrine within 30ft of tubewell				
Yes	1.220	0.5445	0.642	2.318
No	Reference			
Respondent's Education Level				
Signature only/Illiterate	1.421	0.9057	0.540	3.741

Class 1-10	Reference			
Higher Education	2.290	0.2293	0.841	6.238

* remained in logistic regression model when using the stepwise selection method

4.4.2. WHO Threshold

Finally, in the logistic regression model examining the association between household attributes of those with household tubewells deemed unsafe by WHO standards and the use of unsafe alternative drinking water sources (Table 10), it was found that respondent's age was a significant variable. Therefore, among those with unsafe household tubewells, the odds of those who were one year older using unsafe alternative drinking water sources were 1.043 times more than the odds of those one year younger than them using unsafe alternative drinking water sources, given that all other variables were held constant (p= 0.0162). Both respondent's age and source of income remained in the logistic regression model when using the stepwise selection method.

Table 10. Logistic Regression Analysis to assess association between household attributes and odds of drinking from an alternative water source that surpasses the WHO threshold for acceptable levels of arsenic in drinking water

Variable	**OR**	**p-value**	**95% Wald Confidence Limits**	
			Lower	**Upper**
Source of Income*				
Agriculture	Reference			
Business	1.905	0.8763	0.915	3.964
Service	2.294	0.6771	0.931	5.655
Daily Labor	3.572	0.1380	1.227	10.393
Land Size (decimals)	1.000	0.5221	0.998	1.001

Previous WASH Training				
Yes	Reference			
No	0.922	0.8251	0.447	1.900
Respondent's Age*	1.043	0.0162	1.008	1.080
Latrine within 30ft of tubewell				
Yes	1.034	0.9126	0.570	1.875
No	Reference			
Respondent's Education Level				
Signature only/Illiterate	1.556	0.8324	0.625	3.874
Class 1-10	Reference			
Higher than class 10	1.957	0.3884	0.743	5.160

* remained in logistic regression model when using the stepwise selection method

5. Discussion

5.1. Key Findings

There are many major findings presented within this thesis that indicate the need for further research and could hold key implications for public health professionals' efforts in mitigating arsenic exposure in the Narail district of Bangladesh. It was found that there is a significant association between tubewell attributes, such as depth and ownership, and the likelihood of unsafe concentrations of arsenic. Source of income was found to be significantly associated with unsafe arsenic concentrations in hand-pumped household tubewells. Furthermore, household attributes such as primary source of income and respondent's age were found to be significant predictors of the arsenic-safety of alternative drinking water sources, among those who had arsenic-unsafe household tubewells.

Given the extensive exposure to arsenic-contaminated water in this area, it becomes critical that public health professionals push for continued exposure mitigation efforts and further research focused on identifying key factors to target in future interventions by pinpointing high-risk waterpoints and subpopulations.

5.2. Discussion on Exploratory Analysis

The large proportion of the sample population that has not had any previous WASH training and the large proportion of the sample population that has a latrine situated within thirty feet of their household tubewells indicate a need for future research on the levels of microbiological contamination of these tubewells. These findings also indicate the need for greater provision of WASH resources in this population that can allow them to access chemically- and microbiologically-safe water. Providing chemically- and microbiologically-safe water is especially important given that household tubewells are used for a wide range of activities thus, increasing the routes through which exposure to contaminants can occur in this population.

Furthermore, the observable clustering in the spatial distribution of tubewells with low arsenic value and intermediate depth as seen in Figure 2, warrants further research on the use of intermediate-depth wells, in lieu of deep wells, as an effective exposure mitigation strategy.

5.3. Discussion on the Association of Tubewell Attributes and Contamination of Household Tubewell

The magnitude of the relationship demonstrated between tubewell depth and odds of unsafe levels of arsenic concentration is staggering. The analysis indicates that having a tubewell that is 500 feet deeper than its shallower counterpart, all other variables being adjusted for, could reduce one's odds of exposure to unsafe levels of arsenic by up to 233 percent. This depth finding makes a strong case for more investment in ensuring access to sufficiently deep water options within this region. Additionally, this finding is confirmed by the literature which supports the use of sufficiently deep water options as an effective exposure mitigation tool (Kinniburgh & Smedley, 2001).

Furthermore, government-owned tubewells were observed to be significantly less likely to exceed the Bangladeshi arsenic safety standards for drinking water compared to their privately-owned counterparts. This finding is also grounded in existing literature which suggests that privately-owned water options may not be managed or maintained with the same level of care as those of other ownership statuses which encourage efforts to maintain the resource for the entire community (Khan & Yang, 2014). This finding suggests that renewed government intervention efforts are warranted in exposure mitigation efforts.

5.4. Discussion on the Association of Household Attributes and Contamination of Household Tubewell

When examining household-level characteristics, we found that those households whose primary source of income was from the service industry were more likely, by both standards, to have unsafe household tubewells compared to those households whose primary source of income was agriculture. This is an interesting finding in that some of the literature suggests that agricultural laborers are often considered to be of the lowest socioeconomic class in this region, and thus are often at the highest risk of exposure (Parvez et al., 2006). Our finding contradicts this idea.

It is plausible that the finding of this thesis may be a result of a few concurrent forces. It may be that although the agricultural laborers are more socioeconomically disadvantaged, they place more value in, and therefore seek out, an arsenic-safe water option because they use the same water for their crops. It is also possible that the data shows a lighter burden of arsenic-unsafe tubewells on agricultural laborers as they have been given greater priority in past arsenic mitigation interventions. Lastly, it may also be the case that those who are employed in the service industry reside or work in more urban areas which have greater availability of alternative water sources than rural areas. Therefore, those in the service industry may place less value in having a household tubewell that is arsenic-safe. Qualitative research methods may play a particularly important role in further exploring and explaining the finding that holders of specific occupations have greater odds of having unsafe household tubewells.

5.5. Discussion on the Association of Household Attributes and Contamination of Alternative Source of Drinking Water

Additionally, it was found that among those with unsafe household tubewells, respondents who are older are significantly more likely to consume drinking water from an unsafe alternative source than their younger counterparts. This finding is related to findings in the literature which suggest that older individuals tend to demonstrate less arsenic-related knowledge (Hadi, 2003; Paul, 2004). Therefore, it is plausible that individuals were unable to understand or recall the color demarcations of safe versus unsafe tubewells. It is important to evaluate the effectiveness of current health education methodologies employed in this population, given the large proportion of people who cannot read or write. The finding that older respondents are more likely to use arsenic-unsafe alternative drinking water sources could also be explained by the fact that older individuals may not be able to walk as far as younger individuals to consistently access safe tubewells; therefore, they may opt for unsafe tubewells that have a lower arsenic concentration than the one they were previously using.

5.6. Limitations

Bias: Given that the surveys were verbally administered by interviewers, the data collected is vulnerable to response bias, wherein respondents may either, subconsciously or consciously, provide answers they believe the interviewer would want to hear or may exaggerate specific responses in the hopes of receiving a public health intervention. For example, if deep tubewells are inconveniently placed in the community, respondents may exaggerate the distance or time needed for water collection in the hopes that it would motivate public health actors to provide funds for more deep tubewells. This limitation was mitigated by surveying multiple households per Ward.

Sample Size & Variable Exclusion: Given the sample selection method, which relied on the overlap of two independent research endeavors, the sample size in this data analysis is relatively small. Relatedly, some variable categories were excluded from the multivariable analyses due to the small number of respondents within them. However, given the random sampling methodology, we can assume that our findings are still generalizable to the study population and further research can be conducted to examine the variables excluded from analyses herein.

Data Quality: Given the length of the survey and the fact that data collection, coding, entry, and analysis were all done by different people, it is possible that the data quality could have been impacted. Furthermore, given the fact that the depth of tubewells was self-reported by respondents and was not verified by researchers, it is possible that the data quality has been impacted. However, given that the trends found herein are strongly supported by literature, this is not a major concern.

6. Recommendations

This research holds many key implications for future research and arsenic mitigation efforts in this region including the following recommendations to:

- Increase the density of sufficiently deep tubewells throughout the region as depth of tubewell is significantly associated with arsenic concentration and lack of easily accessible intermediate-depth or deep tubewells may increase the risk of exposure among specific subpopulations.
    - Keep other standards of water safety in mind as you introduce water options to ensure that not only is arsenic exposure mitigated, but so is the overall disease burden of the population.
- Conduct further research to investigate the link between tubewell ownership and arsenic concentration. Within this region, we must also conduct more research to identify the possible differences in tubewell installation and maintenance which may have increased the safety of government-owned tubewells in regard to their levels of arsenic concentration.
- Ensure that arsenic mitigation efforts such as allocation of deep tubewells and other resources are equitable and targeted to those most affected by the problem. In doing so, it is important to more heavily emphasize the role that qualitative research methods can play in understanding the nuances of individuals' experiences regarding access to and use of safe water options.
- Given that out of the 241 respondents who reported using an alternative source for drinking water, 35% were using red sources, determine whether the red/green color demarcation is culturally appropriate and widely understood in this population.

  - Furthermore, given the observed dose-response nature of arsenic exposure and the lack of sufficient access to safe tubewells, develop and implement alternative means of labeling arsenic concentrations, in lieu of the binary classification currently utilized.

- Adjust the Bangladeshi standard of acceptable levels of arsenic concentration in drinking water to that of or below the WHO standard.

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8. Appendices

8.1. Appendix A

Environment and Population Research Centre (EPRC)

Creating arsenic safe villages with user women-led sustainable improvement of Water, Sanitation and Hygiene in Narail District

Code Plan of Water, Sanitation and Personal hygiene- Related Questionnaire

Baseline Survey: December 2013

A. Personal Information

Finał Sl Number	Direct
Date	Direct
Respondent Mobile Number	Direct
qa1 Respondent's Name	Direct
qa2 Respondent's Husband /Father's Name	Direct
qa3 Respondent's Age	Direct (Year)
qa4 Respondent's Education Level	1-10 Class=Direct, SSC=11, HSC=12, BA=13, MA=14, Only signature=66, Illiterate = 88
qa5 Respondent's Sex	Male=1, Female=2
qa6 Village	Devdun=1, Kalna=8, Doa Mollickpur=9, Char Kalna=10, Par Mollickpur=11, Chagolchira=13, Char Mollickpur=14, Dasbaria=19, Billduria=27, Rajapur=28, Noragati=29, Pakimara=30, Charbollahati=31, Pohardanga=32, Khasial=38, Vombag=39, Bisnopur=40, Putimari=42, Morichpasa=44, Pocchim Chaicoi=45, Rampur=51, Madovpasa=53, Chalitatola=56, Panipara=57, Mulosri=58, Shurigati=62, Patna=63, Bornal=64, Hedayetpur=67, Mongalhat=70, Chaicoi Danoyed=71, Kamtana=72, Beltia=74, Gobindropur=75, Astail=76, Char Bogjuri=78, Pachuria=79, Pukurkul=81, Babupur=82, Doluya=84, D Pachuria=86, Char Doulatpur=87, Mulovi Danoyed=88, Kollanpur=89, Cilimpur=90, Dokkhin Pankarchar=92, Keshabpur=93, Tona=95, Pakuria=96, Sorospur=97, Heslagati=98, Etna=99, Charkhali=100, Uttar Kumardanga=101, Fokirerchar=102, Sarsona=103, Kochubaria=104, Dinonathpara=105, Araj=106, Kahuria

	Hindupara=107, Lahuria Pocchimpara=109, Lahuria Posashipara=110, Lahuria Egarnali=112, Lahuria Tetulbaria=113, Lahuria Dicrechar=114, Lahuria Tikhpara=115, Danoyed Puraton=116, Char Danoyed=117, Ariyara=118, Kumardanga=120, Uttar Pankarchar=121, Uttar Khasial=122
qa7 Ward	Direct
qa8 Union	Joynagar=1, Khasial=2, Pohadanga=3, Hamidpur=4, Bornal Illisabad, Lohagara=6, Mollikpur=7, Joypur=8, Lahuria=9, Etna=10
qa9 Upazila	Kalia=1, Lohagara=2
qa10 Occupation	House wife =1, Agriculture =2, Business =3, Service =4, Remittance =5, Daily Labor =6, Teacher =7, Fishermen =8, Student =9, Unemployed =10, Van puller =11,
Tubewell Type:	Deep =1, Shallow =2
Depth (ft)	Direct (Feet)
Installation Year	Direct (Year)
Ownership	Self =1, Government=2, NGO=3
GPS (Lat) N	Direct
GPS (Lon) E	Direct
Arsenic Value	Direct (mg/l)
Number of Households Using	Direct
Platform Condition	Good=1, Broken=2, Not=3
Used for Drinking	Yes=1, No=2
Used for Cooking	Yes=1, No=2
Used for Bathing	Yes=1, No=2
Used for Other Purposes	Yes=1, No=2
Latrine situated within 30 feet of tubewell	Yes=1, No=2

B. Family information (General)

qb1 Total Number of Family Member	Direct
qb1a. Number of Children (2 to 5 years)	Direct

qb1b. Number of Children (less than 2 years)	Direct
qb2. Main source of income	Agriculture =2, Business =3, Service =4, Remittance =5, Daily Labor =6, Pension =9,
qb3. Highest education level among family members	1-10 Class=Direct, SSC=11, HSC=12, BA=13, MA=14, Only signature=66, Illiterate = 88,
qb4. Land size	
qb4a Total land size	Direct (Desimel)
qb4b Total agriculutural land size	Direct (Desimel)
qb5. Home Ownership Status	Self =1, Rented =2, Government =3, Government land and self house =4, Relative =5, Other's land and self house =6, House of Father in law =7, Brother's house =8, others (Uncle) =9
qb6.1, qb6.2, qb6.3, qb6.4, qb6.5, qb6.6, qb6.7 Asset	Television =1, Radio/cassette player =2, Motorcycle =3, Van / Cycle =4, Electricity =5, Mobile =6, Nothing =7, Solar energy =8, Refrigerator =9
qb8 Received any training about water, sanitation or personal hygiene	Yes =1, No =2
Received any training about:	
qb8a11, qb8a12 Water	Drink Arsenic free water =1, Drink good water =2, Always keep cover on water pot/ storage = 3, Should drink deep tube well water =4, Water-related = 5, Drink boiled water = 6, Drink safe water =7, Not applicable =99
qb8a21, qb8a22 Sanitation	Do not open defecate =1, Should not break water seal =2, Have fence =3, Keep clean =4, Hand wash with soap or ash =5, Always keep soap in latrine = 6, Use hygienic latrine =7, Use Ring slub latrine =8, Use separate sandal for latrine = 9, Keep water and soap = 10, Maintain personal cleanliness = 11, Sanitation-related = 12
qb8a31, qb8a32 Hygiene	Keep children clean =1, Wash hands before eating and after latrine use = 2, keep clean house = 3, Nail cutting =4, Keep household waste in ground hole = 5, Keep body clean = 6, Keep clothing clean =7, Do not throw waste anywhere = 8,

	Wash both hands with soap =9, Keep cover on food = 10, Wash hands before feeding children =11, Hygiene- related =15, Wash hands with soap/ash =16

C. Water-Related Questions

qc1.1, qc1.2,qc1.3 Problems that occur after drinking arsenic water	Arsenicosis =1, Black spot on hands and legs =2, Eye problem =3, Gastric =4, Dysentery =8, Cancer =12, Allergy =14, Skin diseases =16, Diarrhea = 18, Hepatitis = 19, Goiter = 20, Fever =22, Kidney Diseases = 23, Poison = 24, Spore on hand = 25, Cholera = 27, Pain = 33, Tuberculosis = 36, Diseases =39, Hair fall = 40, Leprosy = 48, Breathing problem =54
qc2 Source of Drinking water	Deep tube well =1, Shallow tube well (green) =2, Shallow tube well (red) =3, Rain water harvesting system =5, Well =6, Pond =7, River =8, Pond sand filter =9
qc3 Who installed the water option?	Self =1, Neighbors =2, Government =3, NGO =4, Mosque =5, School =6, Some family = 7
qc4 When was the water option installed?	Direct (years ago)
qc5 Water quality test after installation?	Yes =1, No =2, Do not know =88
qc5.1 If yes, what color paint on tube well?	Green =1, Red = 2, Not colored =3
qc7 How many families use this option?	Direct (Number)
qc8 Water available all around the year?	Yes =1, No =2, Average =3, Low = 4
qc9.1, qc9.2 Water collection Time Distance	Direct (Minutes), Direct (Feet)
qc10 Satisfaction with water use?	Yes =1, No =2, Less =3

8.2. Appendix B

April 15, 2019

Mahnoor Mahmood
Global Health Department

Rollins School of Public Health

RE: **Determination: No IRB Review Required**

Title: *Presence & Consumption of Arsenic-Contaminated Water*

Responsible Party/Investigator: Mahnoor Mahmood

Dear Ms. Mahmood:

Thank you for requesting a determination from our office about the above-referenced project. Based on our review of the materials you provided, we have determined that it does not require IRB review because it does not meet the definition of "research" with "human subjects" or "clinical investigation" as set forth in Emory policies and procedures and federal rules, if applicable. Specifically, in this project, you hope to provide meaningful programmatic recommendations regarding risk factors for presence and consumption of arsenic-contaminated water.

Please note that this determination does not mean that you cannot publish the results. This determination could be affected by substantive changes in the study design, subject populations, or identifiability of data. If the project changes in any substantive way, please contact our office for clarification.

Thank you for consulting the IRB.

Sincerely,

Ashton Hughes

Research Protocol Analyst

Emory University Institutional Review Board

Office Phone: 404-727-3508