The Intervention Point:

Cholera Prevention in Urban and Rural Bangladesh

Maimuna S. Majumder

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I. Introduction

Annually, 3 to 5 million individuals are diagnosed cholera, an acute diarrheal infection that is caused by ingestion of food or water that contains the *Vibrio cholerae* bacteria. However, this number is a small fraction of the true cases; three-fourths of infected individuals demonstrate no symptoms but remain infective, resulting in considerable underestimation of prevalence. (Cholera 2008) Because cholera is a waterborne disease, it can be transmitted quickly in environments with inadequate sewage and sanitation systems where infected waste can easily contaminate drinking water (Sasaki 2008). The adequacy of water and sanitation infrastructure and socioeconomic status are crucial factors in influencing the transmission of cholera (Albert 1994; Okun 1988). As a result of such infrastructure deficiencies, Bangladesh continues to struggle with endemic cholera, reporting 1 million cases yearly (Cholera 2008). Such disease burden results in incalculable lost wages and treatment expenses, extracted from an already impoverished society. The monetary costs of contracting cholera are substantial. According to the World Health Organization (WHO), in Africa, the combined cost of medicines, consultation and hospitalization, cholera testing, and productive time lost due to illness and death was nearly $700 per case estimate in 2007 (Kirigia et al. 2009). Similar losses can be expected in other cholera-endemic regions. In the face of such severe economic consequences, prevention strategies must be advanced in order for cholera control regimes to be sustainable.

This paper uses the existing literature to formulate hypotheses regarding the most effective intervention point for preventing cholera in urban and rural Bangladesh populations respectively. Then, by analyzing cholera incidence[1] data obtained from the International Centre of Diarrheal Disease Research, Bangladesh in Dhaka (urban location) and Matlab (rural location), conclusions are drawn regarding which individual characteristics contribute most to cholera contraction. The individual attributes serve as surrogates for three primary determinants of cholera: water, sanitation, and socioeconomic status. By understanding what characteristic makes individuals most susceptible to cholera, one may begin to understand what determinant makes the given population most susceptible. Such knowledge is invaluable to identifying the most effective intervention points for preventing cholera in urban and rural Bangladesh.

[1] The case data in this paper is referred to as cholera incidence data; however, the author believes that this data may categorically be a type of prevalence data. Due to the short duration (24-36 hours) of illness and infectivity, the exact difference between prevalence and incidence becomes indistinct. In previous uses of these datasets in publications put forth by the International Centre of Diarrheal Disease Research, Bangladesh, both terms have been used to describe the data.

II. Background

a. Vibrio cholerae

Multiple strains of *Vibrio cholerae* currently exist. The two most prevalent are O1 and O139. O1 causes the majority of epidemics across the world, and O139 was discovered in Bangladesh in 1992. To date, it is only present in Southeast and East Asia, alongside O1 (Colwell 1996; Colwell and Huq 2001). Whether O139 will spread to other regions of the globe remains unknown. Historically, six global pandemics have taken place. The first cholera pandemic began in 1817 and originated in the Ganges River Delta in India before spreading to most of Asia and a portion of eastern Africa. The second pandemic, during the 1830s, also started in India and was even wider in geographic range, as it introduced cholera to Europe and the Americas. Midway through the 19th century, the third pandemic erupted in India, and during this pandemic, Dr. John Snow challenged the prevailing miasma theory of disease transmission. By mapping cholera incidence in London and tracing cases back to the Broad Street water pump and to specific water intake sites on the Thames, he determined that cholera was transmitted not through "bad air", but through water contaminated with *Vibrio cholerae*. The fourth, fifth, and sixth pandemics also originated in India and took place between the late 1800s and early 1900s. Each of these pandemics self-terminated not due to conferred immunity, but because the bacterium was unable to survive in its human hosts long enough to cross the Atlantic and Pacific Oceans. However, in 1961, the seventh pandemic began in Indonesia and continues today, aided by the relative ease and speed of 20th and 21st century travel. (Steinberg et al. 2001) Though cholera has been eradicated in the developed world due to improvements in water, sanitation, and hygiene quality, this most recent pandemic continues to plague developing countries in South Asia, Africa, and South America (Gleick 2008).

b. Vibrio cholerae Bangladesh

Investigating cholera in Bangladesh provides two unique opportunities. First, Bangladesh is a young, democratic nation with a strong complement of non-governmental organizations (NGO), which features well-informed actors operating in the healthcare sector (Majumder 2011). Consequently, preventative interventions can be implemented with greater ease in Bangladesh than in most other developing countries that lack such political and social infrastructure. Second, unlike other cholera-endemic countries, Bangladesh experiences biannual epidemic outbreaks (Akanda et al. 2011). The available literature states that the primary transmission of cholera in the spring is directly due to increased growth of the bacteria in the Bay of Bengal, which is brought to shore by the spring tidal influx. However, the secondary transmission after the monsoon floods is due to the quality of water and waste management services, which reflects the socioeconomic status for the populations served by such systems. (Akanda et al. 2011; Ali 2002; Emch et al. 2010)

c. Critical Factors: Water, Sanitation, and Socioeconomic Status

An extensive review of the current literature suggests that water, sanitation, and socioeconomic status are the primary determinants of increased cholera burden (Emch

1999; Okun 1988). Therefore, three primary points of intervention to reduce disease burden are:

1. Water (Quantity and Quality)
2. Sanitation
3. Socioeconomic Status

While water and sanitation play a direct role in the physical transmission of cholera, socioeconomic status is somewhat subtler in its impact. Improving socioeconomic status has been encouraged in the context of cholera mitigation, not because poverty directly causes cholera, but because it impedes accessibility to adequate water and sanitation. Financial and social capital is strongly correlated with water and sanitation security, which is central to reducing cholera transmission (Emch 1999; Okun 1988).

Increasing accessibility to sanitation has been promoted primarily via sanitary latrine installation[2]. Unlike conventional open latrines that are uncovered and expose waste to annual monsoon season flooding, sanitary latrines are covered and often include drainage systems for the waste to reach a designated cesspool (Ali 2002; Khan and Shahidullah 1982). Therefore, sanitary latrines provide a physical barrier between waste-thriving bacteria and human hosts and also discourage open defecation, which in turn prevents contamination of surface water with human waste, thus reducing morbidity and mortality due to cholera (Taha et al. 2000).

Water quality control via chemical treatment and boiling has been promoted in urban regions that receive piped water because these methods kill the bacteria that contaminate surface water sources. Tubewell installation[3] in rural communities – where piped water is largely unavailable – works similarly; groundwater is far less susceptible to bacterial

[2] A study conducted by Ali (2002) determined the effectiveness of sanitary latrine usage as a preventative intervention method. Cholera incidence data was obtained from hospital records and a surveillance system was used to document sanitation in the study area population. Data was obtained during two time periods—from 1983 to 1987 (first study period) and from 1992 to 1996 (second study period). Sanitation level was based on the respective proportions of individuals engaging in open defecation, using open latrines, or using sanitary latrines. In order to determine trends conclusively, the data was analyzed with a simple regression model. The linear regression constant between cholera incidence and poor sanitation condition was 0.223 and 0.311 for the first and second study periods, respectively. Therefore, the study concluded that poorer sanitation conditions correlate with increased cholera incidence. (Ali 2002)

[3] Shallow wells, which tap into groundwater aquifers close to the surface, were originally installed to serve as an alternative to surface water and consequently prevent outbreaks of cholera (Nickson et al. 1998; Smith et al. 2000). These tubewells were typically less than 200 m deep and obtained water from shallow aquifers that were susceptible to arsenic contamination from metal deposits in the surrounding soils (Charlet and Polya 2006; Islam and Rahman 1997). However, when they were first installed in the 1940s, arsenic was not a recognized hazard. As a result, water-testing procedures did not test for the metal when assessing well water quality, thus putting millions of Bangladeshi citizens at risk for arsenic poisoning and its carcinogenic effects. (Karim 1999; Yu et al. 2003) Comparatively, deep-level calibrated tubewells, which have mouths that protrude above the surface of the earth and reach into deeper aquifers, are less likely to be contaminated with bacteria and naturally occurring arsenic (Charlet and Polya 2006; Mosler et al. 2010).

contamination than surface water sources (Sasaki et al. 2008; Taha et al. 2000)[4]. Meanwhile, increasing accessibility to greater quantities of water has been promoted under the premise that if water is more readily available, individuals will no longer face the risk of using and consuming water that has been contaminated with cholera due to long periods of transportation or storage (Sasaki et al. 2008).

d. Primary Hypotheses

With these three critical determinants in mind, primary hypotheses considering both Dhaka and Matlab were developed and are presented below. Using the literature as well as the author's personal experiences, the importance of each of determinant to cholera contraction was considered in both study areas (Dhaka and Matlab) respectively. Dhaka is the urban capital city of Bangladesh, and Matlab is a rural, near-coastal community.

Dhaka: Primary Hypothesis
Water quality control will be significantly more preventative against cholera than socioeconomic status and sanitation accessibility in Dhaka, Bangladesh.

Rationale:
Though improvements in sanitation via installation of sanitary latrines will prevent contamination of surface water sources, the majority of citizens drink piped water in Dhaka (DWASA 2010). Meanwhile, irrespective of how many sanitary latrines are installed, waste from faulty sewage pipes will continue to regularly contaminate piped water, thus facilitating the transmission of waterborne diseases (DWASA 2010). In Dhaka, the primary method by which piped water can be made safe to drink is through boiling; this activity requires access to fuel, which is contingent upon socioeconomic status (Majumder 2010). Because socioeconomic status is a determinant for water quality, its importance to cholera contraction will closely follow. Therefore, water quality control will be most crucial to cholera prevention in Dhaka, Bangladesh, whereas sanitation accessibility will not be as vital.

Matlab: Primary Hypothesis
Water quality control and sanitation accessibility will both be imperative to augment cholera prevention in Matlab, Bangladesh; however, water quality control will be the

[4] From 1997 to 2001, a study conducted by Sack (2003) determined the effectiveness of tubewell usage as a preventative intervention method for cholera in rural Bangladesh. The study enrolled 5670 subjects who sought medical care at local hospitals due to acute watery diarrhea. They were tested for cholera and were questioned about their water use habits. The study found that in one rural region, subjects who bathed exclusively with tubewell water were 0.4 times as likely to have cholera as those who used some combination of tubewell, pond, river, and/or canal water to bathe. In another region, subjects who washed clothes and utensils with tubewell water exclusively were 0.5 times as likely to have cholera as those who used a combination of other water sources. The conclusions of this study suggest that individuals who do not use tubewell water exclusively are at higher risk for cholera. (Sack 2003)

more significant of the two. Socioeconomic status will be inconclusive.

Rationale:

Rural development programs (RDPs) have significantly empowered the people of Matlab[5] through means of microfinance, small business development, and investment in communal entrepreneurship (Ahmed et al. 2003; Aziz and Mosley 1991). As a result, the vast majority of the population is above the international poverty line[6] ($1.25/day) (Ravallion et al. 2009). Because financial disparities are relatively low in Matlab, socioeconomic status is largely homogenous. As a result, the importance of socioeconomic status to cholera contraction in Matlab will likely be inconclusive.

Due to lack of expansive piped water systems in rural Bangladesh, most of the population has clean tubewell water available for use (Wu et al. 2011). Sanitary latrines prevent the accidental contamination of such tubewells with *Vibrio cholerae* and other bacteria. Thus, sanitation accessibility is likely more important to preventing cholera transmission in Matlab than it is in Dhaka. Frequently, however, individuals do not use tubewell water exclusively but also utilize contaminated sources (i.e. ponds, lakes, and other surface water sources) as well, thus putting them in danger of contracting cholera (Majumder 2011). Because of this, both water quality and sanitation accessibility will be critical to cholera prevention in Matlab, Bangladesh; however, water quality is likely to be more so.

[5] As part of its planned expansion in 1992, the non-profit organization BRAC (Bangladesh Rural Advancement Committee) established its rural development program (RDP) in Matlab, Bangladesh.
[6] In this sense, though Matlab is rural due to its comparatively small population size and lack of modern infrastructure and amenities, quality of life and purchasing power exceed that of Dhaka.

III. Methods

a. Disease Incidence Data

To address the primary hypotheses (Section II-d), 10 years (2000-2009) of sequentially sampled (1 /50 admitted patients) disease incidence data were obtained from surveys administered at the International Centre of Diarrheal Disease Research, Bangladesh (ICDDRB) clinics in both Dhaka and Matlab. The surveys consisted of demographic, socioeconomic, and health-related questions. Questions were entered into SPSS as column variables. "Access to a sanitary latrine" was used as a surrogate variable for sanitation accessibility, and "boiling or treatment of drinking water" was used as a surrogate for water quality. "Monthly household income" was also included in the analysis, because socioeconomic status is a common determinant of both sanitation accessibility and water quality (Emch 1999).

The consideration of these three surrogate variables ensured adequate representation of the three most commonly referenced determinants of cholera: sanitation accessibility; water quality; and socioeconomic status (Emch 1999; Okun 1988). As a result, access to a sanitary latrine, boiling or treatment of drinking water, and high (Table 1.) monthly household income can be considered preventative against cholera. The analysis assesses the impact of these three variables on cholera incidence and extrapolated the intervention potential of each variable[7].

Table 1. Variable legend

D+	Boiled or treated drinking water
D-	Did not boil or treat drinking water
L+	Used sanitary latrine
L-	Did not use sanitary latrine
I+	High household income (>5000 Tk*/month)
I-	Low household income (<5000 Tk*/month)
*Abbreviation for taka, the Bangladeshi national currency (exchange rate: 1 USD = 70 Tk.)	

b. Prevention Profile Framework

In these two datasets, possible attributes existed for each of the 3 variables: preventative

[7] Only patients aged 15 and older were considered in the analysis. At the age of 15, individuals are generally considered adults in Bangladesh, and thus responsible for their own daily behavior and income. (Majumder 2010; Majumder 2011)

(+) and non-preventative (-) (Table 1). As such, there are a total of 6 attributes, and each patient is represented by 3 attributes total – one for each variable. After data delineation[8], each of the 2856 cholera cases in the dataset can be sorted into 8 (2^3) categories, or **prevention profiles** (Table 2). The prevention profiles describe the preventative "personalities" of the patients in the dataset. Each of the 8 personalities can be described by the 3 variables and their 6 respective "attributes".

Assumption: If the 3 non-preventative attributes (**D+, L+,** and **I+**) – individually or together – cause the majority of cholera cases in this dataset, the following inferences can be made regarding causation:

1. Cases that exhibit only one non-preventative attribute were – with statistical certainty – caused by that attribute itself. Namely:

(D+ L+ I-) individuals contracted cholera because of low household income;

(D+ L- I+) individuals contracted cholera because they did not use a sanitary latrine; and

(D- L+ I+) individuals contracted cholera because they did not boil or treat their drinking water.

2. Cases that exhibit multiple non-preventative attributes exhibit confounding amongst attributes; as a result, one singular cause of disease cannot be confidently established. In such cases, we may instead infer that each non-preventative attribute played a role in the contraction of the disease.

c. Relative and Absolute Intervention Potentials

By understanding which personalities are most and least susceptible to cholera, one can mathematically deduce which of the 6 attributes is most and least preventative. With this knowledge, one can begin to realize the "intervention potential" of each of the 6 attributes. An attribute that causes many cholera cases will demonstrate high absolute intervention potential (AIP); intervening through a strategy that aims to eliminate this n has high potential to reduce disease incidence. Meanwhile, an attribute that appears frequently in patients – but cannot be deduced as causal because of confounding attributes – has a high relative intervention potential (RIP) and should be strongly correlated with absolute intervention potential. The attribute with the highest absolute and relative intervention potential should be the best point of intervention for cholera in the given population.[9]

[8] Delineation was conducted via probability analysis of the available data such that each of the cases could be sorted into one of eight potential categories or "prevention profiles" (Table 2 and Table 3).

[9] These statistics were developed by the author under the supervision and guidance of the ICDDR,B for use on the two datasets described in this paper. They are intended only to offer a method by which the significance of each attribute – in the context of patient-only datasets, like those analyzed in this paper – can be compared against one another. In this sense, they are strictly experimental statistics that, while mathematically-sound, were designed to help the reader better grasp the nature of the data available and the analysis performed.

IV. Dhaka Dataset

a. Data Delineation and Probability Analysis

Total Cholera Cases: 2856
Total **D-**: 2039
Total **D+**: 817
Total **L-**: 1104
Total **L+**: 1752
Total **I-**: 1735
Total **I+**: 1121

D- ∩ I- = 1412
L- ∩ I- = 834
D- ∩ L- = 976
D- ∩ L- ∩ I- = 751

D- ∩ I- ∪ $(L-)^c$ = 661
L- ∩ I- ∪ $(D-)^c$ = 83
D- ∩ L- ∪ $(I-)^c$ = 225

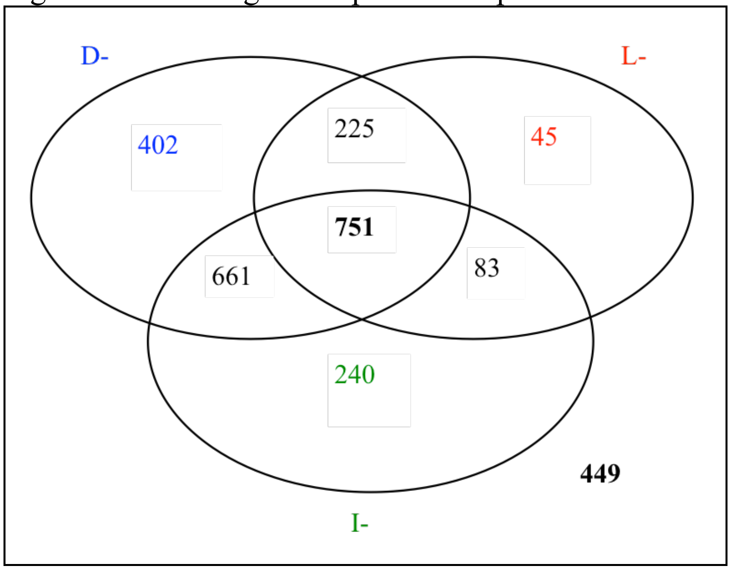
D+ ∩ I+ = 494
L+ ∩ I+ = 851
D+ ∩ L+ = 689
D+ ∩ L+ ∩ I+ = 449

D+ ∩ I+ ∪ $(L+)^c$ = 45
L+ ∩ I+ ∪ $(D+)^c$ = 402
D+ ∩ L+ ∪ $(I+)^c$ = 240

Table 2. Prevention profiles for Dhaka, Bangladesh

D+	L+	I+	=	449
D+	L+	I-	=	240
D+	L-	I+	=	45
D+	L-	I-	=	83
D-	L+	I+	=	402
D-	L+	I-	=	661
D-	L-	I+	=	225
D-	L-	I-	=	751

Figure 1. Venn diagram of prevention profiles for Dhaka, Bangladesh



b. Hypothesis Testing and Results

To address the primary hypothesis formulated in Section II-d by means of the framework introduced in Section III-b, four sub-hypotheses follow and are specified below:

*First, one must confirm the assumption presented in Section II-b by demonstrating that the majority of cholera patients in the dataset demonstrated at least one non-preventative (**D-**, **L-**, and/or **I-**) attribute.*

Sub-Hypothesis 1: The majority of cholera cases in this dataset did not boil or treat drinking water (D-), did not have access to a sanitary latrine (L-), and/or had low monthly household income (I-).

Rationale 1: In Figure 1, all of the cases that are **D-**, **L-**, and/or **I-** fall within the bounds of the three intersecting circles. If all 7 of these numbers are summed, then:

402 + 225+ 45 + 661+ 751 + 83 + 240 = **D-** ∪ **L-** ∪ **I-** = **2407** cholera cases did not boil or treat drinking water, did not have access to a sanitary latrine, and/or had low monthly household income.

Referring to Figure 1 again, the number outside of the three intersecting circles **(449)** reflects those cases that were defined as **(D+ L+ I+)**. Therefore, the total number of cases in the dataset is:

2407 + 449 = 2856 total cholera cases

As such:

(2407/2856) x 100% = 84.3% of cholera cases in this dataset did not boil or treat drinking water, had low monthly household income, and/or did not have access to a sanitary latrine. The majority of cholera cases in this data set are accounted for by these three attributes alone[10].

Sub-Hypothesis 2: Increasing household income would be a more effective intervention point against cholera than improving access to a sanitary latrine.

Rationale 2*:* The **(D+ L- I+)** prevention profile characterizes individuals that contracted cholera because they did not use a sanitary latrine. These cases drank boiled or treated water and had high monthly household income, but did not have access to a sanitary latrine. This number is **45**.

The **(D+ L+ I-)** prevention profile represents individuals that contracted cholera because they had a low household income. These cases drank boiled or treated water and used sanitary latrines, but had low monthly household income. This number is **240**, which is **5x** the number of cases that occurred due to not having access to a sanitary latrine.

By extension, increasing household income would prevent more cholera cases than improving access a sanitary latrine.

Sub-Hypothesis 3: Boiling or treatment of drinking water would be a more effective intervention point against cholera than improving access to a sanitary latrine or increasing household income.

The **(D- L+ I+)** prevention profile characterizes individuals who contracted cholera because they did not drink boiled or treated water. These cholera cases had access to a sanitary latrine and high monthly household income, but did not boil or treat their drinking water. This number is **402**, nearly **10x** the number of cases that occurred due to not using a sanitary latrine and over **1.5x** the number of cases that occurred due to low household income.

By extrapolation, boiling or treatment of drinking water would prevent more cholera cases than improving access to a sanitary latrine or increasing monthly household income.

Therefore based upon the available data from Dhaka, boiling or treatment of drinking water is the most effective intervention point against cholera amongst the variables considered.

To further bolster sub-hypotheses 2 and 3, one may compare the expected intervention potentials for each non-preventative attribute (Section III-c).

[10] 15.7% of cases may be explained by other variables that contribute to cholera contraction, such as improper handling of foodstuffs and unclean methods of washing dining utensils. For instance, water supplies used for agriculture may be responsible for cholera transmission, as irrigation water contaminated with raw sewage can transform vegetables into cholera carriers (Dubois et al. 2006).

Sub-Hypothesis 4: Low household income (I-) exhibits a higher intervention potential than not using a sanitary latrine (L-). Not boiling or treating drinking water (D-) exhibits a higher intervention potential than not using a sanitary latrine (L-) or having a low household income (I-).

Rationale 4: The author has formulated the following equations to provide the reader with quantitative, interpretable metrics for relative and absolute intervention potentials (Section III-c):

Relative Intervention Potential:

$$\mathbf{RIP_X = R_X / (RD\text{-} + RI\text{-} + RL\text{-})}$$

Where **RD-** = (All **D-** Cases)/(Total Cases)
RI- = (All **I-** Cases)/(Total Cases)
RL- = (All **L-** Cases)/(Total Cases)
$\mathbf{R_X}$ = Dependent on the attribute for which the relative intervention point (RIP) is being calculated (For instance, if one is calculating the RIP for not boiling or treating drinking water (**D-**), then $R_X = R_{D-}$)
$\mathbf{RIP_X}$ = Dependent on the attribute for which the relative intervention point is being calculated (For instance, if one is calculating the RIP for not boiling or treating drinking water (**D-**), then $RIP_X = RIP_{D-}$)

Given the data aforementioned:

RD- = 2039/2856 = .71
RI- = 1735/2856 = .61
RL- = 1104/2856 = .39
(RD- + RI- + RL-) = 1.71

Thus,

$\mathbf{RIP_{D-}}$ = .42
$\mathbf{RIP_{I-}}$ = .36
$\mathbf{RIP_{L-}}$ = .22

Likewise,

Absolute Intervention Potential:

$$\mathbf{AIP_X = X/(OD\text{-} + OI\text{-} + OL\text{-})}$$

Where **OD-** = **(D- I+ L+)**
OI- = **(D+ I- L+)**
OL- = **(D+ I+ L-)**

X = Dependent on the attribute for which the absolute intervention point (AIP) is being calculated (For instance, if one is calculating the AIP for not boiling or treating drinking water (**D-**), then X = O**D-**)

Given the data aforementioned:

(OD- + OI- + OL-) = 402 + 240 + 45 = 687
$\mathbf{AIP}_{\mathbf{D-}}$ = 402/687 = .59
$\mathbf{AIP}_{\mathbf{I-}}$ = 240/687 = .35
$\mathbf{AIP}_{\mathbf{L-}}$ = 45/687 = .06

Not boiling or treating drinking water (**D-**) has the highest relative and absolute intervention potential; low household income (**I-**) comes in second; and not using a sanitary latrine (**L-**) ends last. Because not boiling or treating drinking water (**D-**) equates to drinking bacterially contaminated water, the most effective point of intervention based upon the available dataset for cholera in Dhaka, Bangladesh is water quality.

V. Matlab Dataset

a. Data Delineation and Probability Analysis

Total Cholera Cases: 697
Total **D-**: 660
Total **D+**: 37
Total **L-**: 632
Total **L+**: 65
Total **I-**: 2
Total **I+**: 695

D- ∩ I- = 2
L- ∩ I- = 2
D- ∩ L- = 597
D- ∩ L- ∩ I- = 2

D- ∩ I- ∪ $(L-)^c$ = 0
L- ∩ I- ∪ $(D-)^c$ = 0
D- ∩ L- ∪ $(I-)^c$ = 595

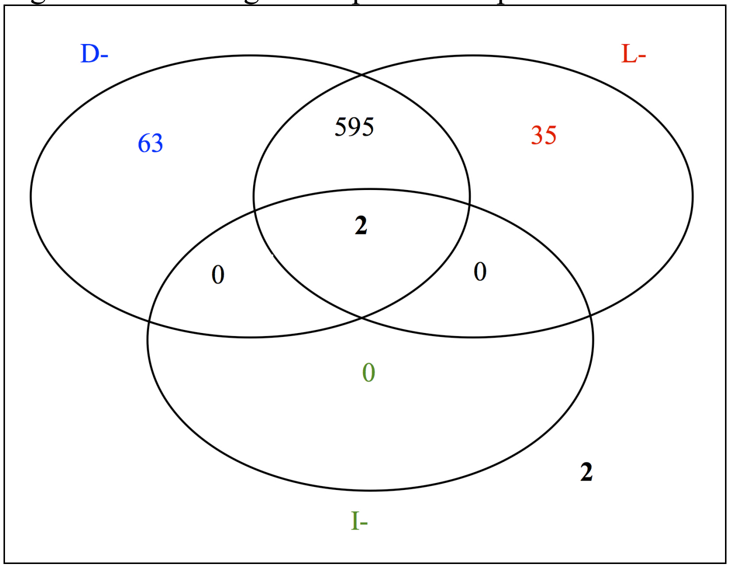
D+ ∩ I+ = 37
L+ ∩ I+ = 65
D+ ∩ L+ = 2
D+ ∩ L+ ∩ I+ = 2

D+ ∩ I+ ∪ $(L+)^c$ = 35
L+ ∩ I+ ∪ $(D+)^c$ = 63
D+ ∩ L+ ∪ $(I+)^c$ = 0

Table 2. Prevention profiles for Matlab, Bangladesh

D+	L+	I+	=	2
D+	L+	I-	=	0
D+	L-	I+	=	35
D+	L-	I-	=	0
D-	L+	I+	=	63
D-	L+	I-	=	0
D-	L-	I+	=	595
D-	L-	I-	=	2

Figure 2. Venn diagram of prevention profiles for Matlab, Bangladesh



b. Hypothesis Testing and Results

Note: As first mentioned in Section II-d, socioeconomic status in Matlab, Bangladesh is relatively homogeneous; majority of citizens earn more than 5000 Tk. every month. Therefore, three of the four prevention profiles that include the attribute **(I-)** have no representation (n = 0). As a result, the importance of monthly household income – and thus, socioeconomic status – cannot be inferred from the dataset available to the author and will not be addressed directly via hypothesis testing.

To address the primary hypothesis formulated in Section II-d by means of the framework introduced in Section III-b, three sub-hypotheses follow:

*First, one must confirm the assumption presented in Section II-b by demonstrating that the majority of cholera patients in the dataset demonstrated at least one non-preventative (**D-**, **L-**, and/or **I-**) attribute.*

Sub-Hypothesis 1: The majority of cholera cases in the Matlab dataset did not boil or treat drinking water (D-), did not have access to a sanitary latrine (L-), and/or had low monthly household income (I-).

Rationale 1: In Figure 2, all of the cases that are **D-**, **L-**, and/or **I-** fall within the bounds of the three intersecting circles. If all 7 of these numbers are summed, then:

2 + 595 + 0 + 63 + 0 + 35 + 0 = **D-** ∪ **L-** ∪ **I-** = **695** cholera cases did not boil or treat drinking water, did not have access to a sanitary latrine, and/or had low monthly household income.

Referring to Figure 2 again, the number outside of the three intersecting circles **(2)** expresses those remaining cases in the dataset that were defined as **(D+ L+ I+)**.

Therefore, the total number of cases in the dataset is:

695 + 2 = 697 total cholera cases

As such:

(695/697) x 100% = 99.7% of cholera cases in this dataset did not boil or treat drinking water, had low monthly household income, and/or did not have access to a sanitary latrine. The majority of cholera cases in this data set are accounted for by these three attributes alone

Like the Dhaka dataset, it is worth noting that the other 0.3% of cases may be explained by other variables that contribute to cholera contraction[11].

Sub-Hypothesis 2: Boiling or treatment of drinking water combined with improving access to a sanitary latrine would be a more effective intervention point against cholera than either intervention individually.

Rationale 2: The **(D- L- I+)** prevention profile characterizes individuals that contracted cholera because they did not boil or treat their drinking water nor did they use a sanitary latrine. These cases had high monthly household income, but did not drink boiled or treated water nor did they have access to a sanitary latrine. This number is **595**, which is **17x** the number of cases that occurred due to not using a sanitary latrine (n = 35) and nearly **10x** the number of cases that occurred due to not drinking boiled or treated water (n = 63).

By extension, boiling or treatment of drinking water and improving access to sanitary latrines – though valuable alone – would prevent more cholera cases if implemented together. A combined intervention that includes both boiling and treatment of drinking water and increasing access to sanitary latrines would be most effective against cholera amongst the variables considered.

If such an aforementioned combined intervention is applied, boiling or treatment of drinking water should be emphasized, because the number of cases that occurred due to not drinking boiled or treated water (n = 63)[12] is nearly double the number of cases that occurred due to not using a sanitary latrine (n = 35)[13].

To further bolster sub-hypotheses 2 and 3, one may compare the expected intervention potentials for each non-preventative attribute (Section III-c).

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[11] See Footnote 9.

[12] The (D- L+ I+) prevention profile characterizes individuals that contracted cholera because they did not drink boiled or treated water. These cholera cases had access to a sanitary latrine and high monthly household income, but did not boil or treat their drinking water. This number is 63.

[13] The (D+ L- I+) prevention profile characterizes individuals that contracted cholera because they did not have access to a sanitary latrine. These cholera cases boiled or treated their drinking water and high monthly household income, but did use a sanitary latrine. This number is 35.

Sub-Hypothesis 3: Low household income (I-) exhibits a lower intervention potential than not using a sanitary latrine (L-). Not boiling or treating drinking water (D-) exhibits a higher intervention potential than not using a sanitary latrine (L-) or having a low household income (I-).

Rationale 3:

Relative Intervention Potential:

$\mathbf{RIP_X = R_X / (RD\text{-} + RL\text{-} + RI\text{-})}$

Where **RD-** = (All **D-** Cases)/(Total Cases)
RL- = (All **L-** Cases)/(Total Cases)
RI- = (All **I-** Cases)/(Total Cases)
$\mathbf{R_X}$ = Dependent on the attribute for which the relative intervention point (RIP) is being calculated (For instance, if one is calculating the RIP for not boiling or treating drinking water (**D-**), then $R_X = R_{D-}$)
$\mathbf{RIP_X}$ = Dependent on the attribute for which the relative intervention point is being calculated (For instance, if one is calculating the RIP for not boiling or treating drinking water (**D-**), then $RIP_X = RIP_{D-}$)

Given the data aforementioned:

RD- = 660/697 = .95
RL- = 632/697 = .91
RI- = 2/697 = .003

(RD- + RL- + RI-) = 1.863

Thus,

$\mathbf{RIP_{D-}}$ = .51
$\mathbf{RIP_{L-}}$ = .49
$\mathbf{RIP_{I-}}$ = 0.00 (Inconclusive)

Likewise,

Absolute Intervention Potential:

$\mathbf{AIP_X = X/(OD\text{-} + OL\text{-} + OI\text{-})}$

Where **OD-** = **(D- I+ L+)**
OL- = **(D+ I+ L-)**
OI- = **(D+ I- L+)**

X = Dependent on the attribute for which the absolute intervention point (AIP) is being calculated (For instance, if one is calculating the AIP for not boiling or treating drinking water (**D-**), then X = O**D-**)

Given the data aforementioned:

(OD- + OL- + OI-) = 63 + 35 + 0 = 98
AIP_{D-} = 63/98 = .64
AIP_{L-} = 35/98 = .36
AIP_{I-} = 0/98 = 0.00 (Inconclusive)

Not boiling or treating drinking water (**D-**) has the highest relative and absolute intervention potential; not using a sanitary latrine (**L-**) comes in second; and low household income (**I-**) is inconclusive due to lack of variability within the population. Because not boiling or treating drinking water (**D-**) equates to drinking bacterially contaminated water, the most effective point of intervention for cholera in Matlab, Bangladesh is water quality.

VI. Comparison of Results

a. Quantitative Results

In both Dhaka and Matlab, Bangladesh, water quality proved to be the most crucial independent determinant to cholera contraction. Because socioeconomic status was homogeneous its explanatory power was inconclusive in Matlab, whereas in Dhaka, it followed closely in second place. Sanitation demonstrated critical importance – especially in combination with water quality – in Matlab, but exhibited the least significance in Dhaka. (Table 3)

Table 3. Comparison of quantitative results

	Dhaka	**Matlab**
RIP_{D-}	.42	.51
RIP_{L-}	.22	.49
RIP_{I-}	.36	0.00 (Inconclusive)
AIP_{D-}	.59	.64
AIP_{L-}	.06	.36
AIP_{I-}	.35	0.00 (Inconclusive)

b. Qualitative Account

As described qualitatively in Section II-d, the two populations are inherently different in access to and quality of water and sanitation infrastructure, as well as socioeconomic status. The quantitative results (Section VI-a) obtained via probability analysis of the Dhaka and Matlab datasets (Section IV and V respectively) support the primary hypotheses presented in Section II-d. To recount:

- In Dhaka, most of the population uses piped water, which is frequently contaminated by sewage. Improving sanitation accessibility does not prevent the waste from leaking into the water system; therefore, it is the least influential of the determinants. Boiling water via the use of fuel, which is a costly luxury in Dhaka, is the primary means by which piped water is sanitized; therefore, socioeconomic status is closely linked to cholera contraction. However, water quality is – independently and directly – most imperative to cholera prevention.
- In Matlab, RDPs have homogenized socioeconomic status amongst the population, thus making its influence to cholera transmission inconclusive given the dataset available. Because the majority of the population has tubewell water available to it, sanitation accessibility is crucial to maintain the cleanliness of such water supplies. That said, the population also uses contaminated surface water sources; therefore, water quality is – independently and directly – most imperative to cholera prevention.

In order to succeed, cholera intervention groups must consider such structural and societal differences during development and implementation.

VII. Discussion

The data analyses in this paper demonstrate that water quality is contingent upon sanitation accessibility in Matlab, but in Dhaka, the two factors are independent. Though a variety of studies have effectively explored the impact of water quality and sanitation on cholera contraction in Matlab, no such study has been conducted in Dhaka, making this paper a compelling addition to the existing literature[14]. However, most studies based out of ICDDRB's Matlab catchment area have focused on either water or sanitation as determinants of cholera and have not compared their relative importance to cholera contraction. This said, such studies typically find that water quality via access to tubewells or other means of clean water and sanitation accessibility via sanitary latrines are critical to cholera prevention (i.e. Aziz and Mosley 1991; Emch 1999; Wu et al. 2011). Such results are consistent with those discussed in this paper (Section VI).

Additionally, a prominent paper authored by John Briscoe in 1978 proposes a more nuanced theory that the author feels is worthy of further investigation. In his study, Briscoe found that cleanliness of drinking water supply in Matlab, Bangladesh was not as crucial to cholera contraction as presupposed. Specifically, he proposed that the protection provided by drinking bacteria-free water was overwhelmed by other sources of transmission such as exposure to polluted surface water through bathing, food preparation, and utensil washing. (Briscoe 1978)

The author believes that testing Briscoe's theory through subsequent analysis of the datasets described in Section III-a could be a meaningful supplement to this paper in the future. The datasets are robust in that there were no missing cases amongst the variables selected for analysis; total n-values for both datasets were large enough to perform statistical analysis; and datasets were cleanly organized, thus permitting the use of easily executable SPSS scripts (Appendix II) for computerized data delineation. However, because the datasets contain case data only, standard case-control statistics such as odds and risk ratios could not be calculated due to lack of control data. For this reason, the author developed the experimental statistics described in Section III-c, which could be used in subsequent analysis of the aforementioned datasets.

[14] The author believes that such a study has not been conducted on ICDDRB's Dhaka dataset because traditionally, the Matlab catchment area has been more conducive to cholera research than the Dhaka clinic. The Matlab catchment area enrolls approximately 200,000 citizens in a healthcare system operated by the ICDDRB as an organization; this provides the potential to follow the life-long health record of any enrolled individual. The Dhaka clinic collects patient data as detailed in Section III-a, but it serves primarily as a hospital rather than a research location. (Majumder 2010; Majumder 2011)

VIII. Conclusions and Recommendations

a. Cholera Control in Dhaka, Bangladesh

Based off of the author's analysis of the Dhaka dataset (Section IV), water quality is the most effective point of intervention for cholera prevention in Dhaka, Bangladesh. Because most citizens of Dhaka have access to piped water, water quality interventions may take place:

1. Before point-of-use: Water may be sanitized (i.e. chlorination) prior to distribution via piped systems.

Private corporations, not-for-profit organizations, and governmental programs may best subsidize such large-scale infrastructural interventions (VIII-a1).

2. At point-of-use: Water may be sanitized through systems (i.e. fiber filtration) attached to piped water faucets.
3. After point-of-use: Water may be sanitized after collection of water (i.e. boiling with low-cost fuel).

Families or communities who use a given water faucet may best subsidize such interventions (VIII-a2 and VIII-a3). However, external players – such as private corporations, not-for-profit organizations, and governmental programs – may make them more affordable through sponsorship. For instance, textile corporations could provide low-cost fiber filters[15] and community water boiling points could be built and operated with the assistance of fuel corporations[16].

b. Cholera Control in Matlab, Bangladesh

In Matlab, tubewells are readily available to provide clean water; however, they are not always used as an exclusive water source; surface water sources are often concurrently

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[15] A study from 1999 to 2002 demonstrated the effectiveness of using sari or nylon cloth to reduce the burden of cholera (or is this truly incidence?) incidence. In the study, laboratory experiments initially demonstrated that a sari or nylon cloth folded to produce 8 cloth layers is effective in removing *Vibrio cholerae*. Researchers then performed a study in a rural region to see if this method of cholera prevention would be effectively implemented in the field. The villages that used sari cloth as a filter experienced less than half the cholera incidence when compared to the control villages that did not use any form of water filtration. A key finding from this study was the high acceptance rate by the community residents regarding this particular mechanism of water filtration; only 0.6% of the study communities were noncompliant. (Colwell et al. 2003) This demonstrates that not only could water filtration effectively decontaminate the water of *Vibrio cholerae*, but it could also be a feasible solution that the people of Bangladesh would accept and utilize.

[16] To the author's knowledge, there exists no precedent for such a community water boiling point, but offers an interesting alternative to independent, household water boiling for individuals who cannot afford fuel for their homes.

utilized. Accordingly, education that clearly expresses the benefits of exclusively using tubewell water must be provided. Furthermore, tubewells are easily contaminated due to a lack of sanitation accessibility, which promotes open defecation. Therefore, though water quality is the best point of intervention for cholera prevention in Matlab, Bangladesh, water contamination can be most effectively avoided by installing sanitary latrines. Families or communities may best subsidize such an infrastructural intervention, thus allowing them to take ownership of their health. However, external players may make them more feasible by offering financial aid for necessary construction materials.

c. Cholera Control Implementation

External players must also supplement the aforementioned infrastructural improvements (VII-a and VII-b) with infrastructure education that will allow the target population to recognize the need for the changes that must be made and how to most effectively utilize them (Stanton and Clemens 1987; Yusuf and Hussain 1990). Furthermore, such education requires awareness and observance of local value systems, which can best be facilitated through community involvement and engagement in the development of such intervention projects (Day et al. 1995; Watt and Rodmell 1987). When encouraging a community to place value in water and sanitation systems, external players must frame such infrastructure in a way that makes it relevant to the community's existing priorities (Madan 1987). By seeking guidance from community leaders, external players can best appeal to the present concerns of the populace. For example, in order for a Dhaka slum community to prioritize maintenance of a community water boiling point, lesson plans must first emphasize the importance of such infrastructure to health and livelihood, which optimally should fit within existing priorities in the cultural value system (Majumder 2010). Only then will the instructive, infrastructure education (i.e. regarding maintenance procedures for the water boiling point) component be well received, thus improving the likelihood of compliance, appropriate use and maintenance of new infrastructure (Brieger 1996; Shediac-Riskallah and Bone 1998).

d. Concluding Statements

When resources are limited, external players – and their communities of interest – must be pragmatic in their spending in order to realize the greatest possible impact of their investments. In both Dhaka and Matlab, Bangladesh, the most critical determinant to cholera contraction – as ascertained from the datasets analyzed – is water quality. However, in Matlab, lack of accessibility to sanitation is the leading cause of water source contamination. Therefore, the most effective point of intervention for cholera prevention is sanitation accessibility. Meanwhile, in Dhaka, Bangladesh, the most effective point of intervention for cholera prevention – as ascertained from the dataset analyzed – is water quality. With this in mind, external players must be conscientious of the fact that the effectiveness of an intervention will vary greatly by location and local context. Understanding the unique infrastructural vulnerabilities of a given community is crucial to the development of an appropriate intervention strategy. However, external players implementing such programs must also promote community involvement and engagement to achieve long-term sustainable success.

IX. Appendix I: SPSS Variables

Treatment of drinking water: `"watreat"`

```
0 = "none"
1 = "boiling"
2 = "alum/tablet"
3 = "sieving"
4 = "filter"
5 = "other"
```

Place of defecation: `"defeca"`

```
1 = "sanitary"
2 = "semi-sanitary"
3 = "service"
4 = "dughole"
5 = "open pit"
6 = "hanging"
7 = "no fixed place"
9 = "unknown"
```

Monthly household income: `"faminc"`
Computed by adding income of father and mother (defined as head male and female in the home) together; represents whole number average incomes for a household in any given month

X. Appendix II: SPSS Sample Scripts

Script 1

Task: Select only individuals that are older than 15 years old in the dataset. Cross-tabulate water treatment vs. place of defecation and family income for selected cases. Yield tables.

```
temporary.
recode agemm (lo thru 179.99=1) (180.00 thru  hi=2).
value labels agemm 1 '<15 yr'  2 '15+ yr'.
select if agemm eq 2.
recode watreat  (9=sysmis).
recode watreat  (1 thru 5=1).
value labels watreat 0' Not boiled' 1'Boiled'.
recode defeca  (9=sysmis).
recode  defeca (1 thru 2=0) (3 thru 7=1).
value labels defeca 0'sanitary' 1'unsanitary'.
compute faminc = (incfath+incmoth).
recode faminc (lo thru 5000=1) (5001 thru hi=2).
value labels faminc  1' upto Tk. 5000'  2 'Tk 5001 +'.
cross tabs defeca faminc
   by watreat /cell count row col.
execute.
```

Script 2

Task: Select only individuals that are older than 15 years old in the dataset. Then, select only individuals that did not boil or treat their water. Cross-tabulate place of defecation vs. family income for selected cases. Yield tables.

```
temporary.
recode agemm (lo thru 179.99=1) (180.00 thru  hi=2).
value labels agemm 1 '<15 yr'  2 '15+ yr'.
select if agemm eq 2.
recode watreat  (9=sysmis).
recode watreat  (1 thru 5=1).
value labels watreat 0' Not boiled' 1'Boiled'.
select if watreat eq 0.
recode defeca  (9=sysmis).
recode  defeca (1 thru 2=0) (3 thru 7=1).
value labels defeca 0'sanitary' 1'unsanitary'.
compute faminc = (incfath+incmoth).
recode faminc (lo thru 5000=1) (5001 thru hi=2).
value labels faminc  1' upto Tk. 5000'  2 'Tk 5001 +'.
cross tabs faminc
   by defeca /cell count row col.
execute.
```

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