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Framework for Integrated Complex Urban Systems (FICUS)

Development of a Cholera Epidemiological Risk Assessment Framework

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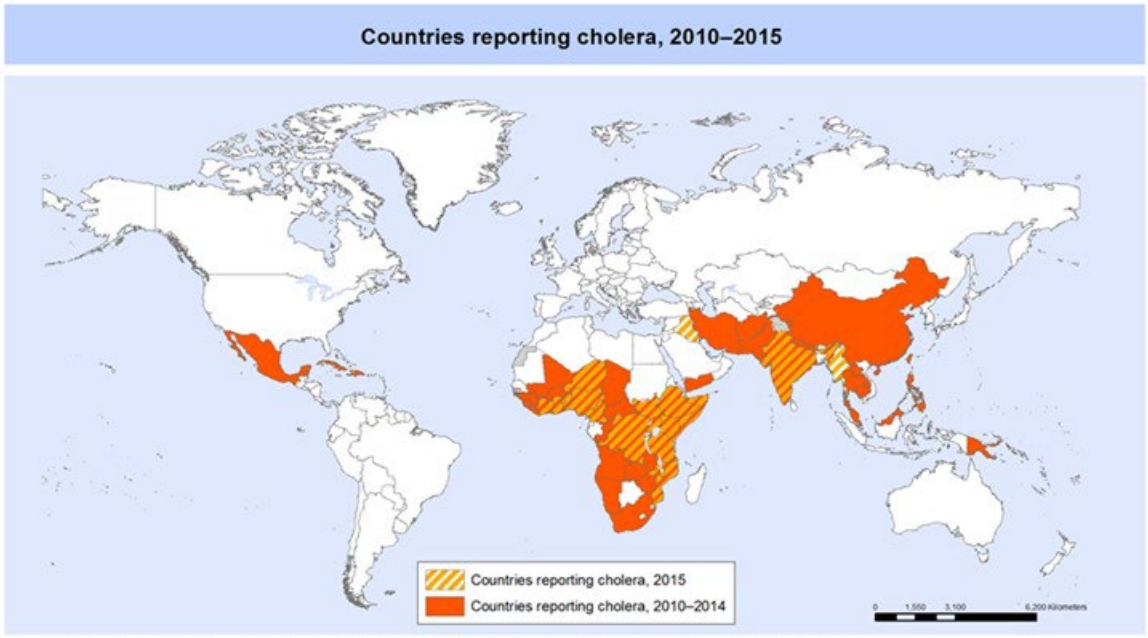
Carey L. Baxter, Jamie Fishman, James D. Westervelt,
Charles R. Ehlschlaeger, and Jeffrey A. Burkhalter

September 2019



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Final Technical Report (TR)

Approved for public release; distribution is unlimited.

Prepared for Assistant Secretary of the Army for Acquisition, Logistics, and Technology
103 Army Pentagon
Washington, DC 20314-1000

Under Program Element 622784T41, “Military Facilities Engineering Technology”

Abstract

This report presents technical explanations and specific enumerations for a cholera risk framework developed as a part of a multi-year project funded by the Army Research, Development, Test and Evaluation Program. This effort employed a novel data-conflation technology called the Framework for the Integration of Complex Urban Systems (FICUS), which uses a broad base of peer-reviewed research on established indicators of sociocultural or health-driven risk conditions of interest for intelligence or threat analysis in a given region. Researchers performed a specialized case study that incorporates results and data from previous programmatic work, including FICUS development and an existing theoretical humanitarian crisis (HC) framework. New data required for this framework included identification of conditions for contracting cholera, micro-survey data from global resources, and a digital population model that matches the survey data to existing population census data. The cholera framework research succeeded in using relevant microdata from the HC framework, then manipulating the HC framework to better inform cholera risk modeling. In general, the use of risk-analysis frameworks with FICUS is intended to produce case studies that provide non-obvious insights to the user while accounting for and reducing data gaps and uncertainties.

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Preface

This study was conducted for the Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA[ALT]) under Research, Development, Test, and Evaluation (RDT&E) Program Element 622784T41, "Military Facilities Engineering Technology"; Project P2 458304, "Framework for Integrating the Complexity of Urban Systems (FICUS)." The technical monitor was Ritchie L. Rodebaugh, CEERD-TZT.

The work was performed by the Land and Heritage Conservation Branch of the Installations Division (CEERD-CNC), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Dr. Michael L. Hargrave was Chief, CEERD-CNC; Michelle J. Hanson was Chief, CEERD-CN; and Ritchie L. Rodebaugh, CEERD-TZT was the Technical Director for Geospatial Research and Engineering. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Lance D. Hansen.

COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

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1 Introduction

1.1 Background

The Framework for Integrating the Complexity of Urban Systems (FICUS) program is sponsored by the Army for Acquisition, Logistics, and Technology (ASA[ALT]) and dedicated to empowering military planners with the data and knowledge for understanding megacities and other dense urban environments (DUEs). The purpose of the FICUS research effort is to design and develop a computational framework to support federated models of complex urban systems and enable information support to the Joint Intelligence Preparation of the Operational Environment (JIPOE). Understanding DUEs requires integrated, accurate, regional, and neighborhood scale conceptual and computational models detailing operationally relevant information about the environmental, infrastructural, and social systems.

In developing the overall FICUS capabilities, a subset of ERDC researchers demonstrated how broad theory-based frameworks can inform more specific risk evaluation frameworks and vice versa. The ability to link and fluctuate between theory and data-driven frameworks enhances the JIPOE process by representing the full range of complexity in urban systems.

To execute this demonstration, ERDC researchers began with a theory-driven framework provided by the U.S. Pacific Command (USPACOM) Joint Intelligence Operations Center (JICPAC). JICPAC operates a data fusion center that conducts current situation analysis, collection management and long-range assessments and threat estimates. Their humanitarian crisis (HC) framework portrays risk for humanitarian crises based on five theoretical conditions—natural hazards, human behavior impact, services failure, readiness and response inadequacy, and resilience deficiencies. ERDC researchers chose to use the HC framework to develop a data-driven, cholera risk framework. Again, with the purpose of illustrating mutual benefit.

Cholera remains a major public health problem primarily affecting developing world populations with limited access to adequate water and sanitation resources. Outbreaks continue to occur in places like Haiti, Democratic Republic of the Congo, Afghanistan, and Bangladesh. Technological innovations in geographic information system (GIS) and predictive

modeling have allowed for more efficient and accurate disease outbreak and health risk models to support planning and prevention. However, the scale and scope of the data can critically impact the modeling effectiveness, and structured, high-quality data is often lacking in developing regions. To address this shortfall, ERDC, in partnership with the University of Illinois CyberGIS Center, directed research toward quantifying the utility of demographic information to inform neighborhood scale medical models. ERDC developed a cholera risk model, entitled Spatial Temporal Epidemiological Modeling and Simulation (STEMS) from traditional indicator-based frameworks, adding a new approach that accounts for uncertainties in the data and model logic. This enables insight into whether the available data provides enough credible information for decision making.

Researchers chose Bangladesh as a case study for modeling cholera risk. Siddique et al. (1992) states "Cholera epidemics are repeated disasters in Bangladesh; however, unlike other disasters they are nearly always predictable." The vast amount of literature concerning cholera in Bangladesh is the foundation for these metrics. The literature concludes that a combination of variables creates optimal conditions for cholera. These optimal conditions are warm temperatures, heavy rainfall followed by flooding, and inadequate water and sanitation infrastructure (e.g., Jutla et al., 2013; Emch, 1999). Inadequate water and sanitation infrastructure are often correlated with socioeconomic status, gender, age, urban/rural, ethnicity, population density, etc. (Jutla et al., 2013; Emch, 1999). This framework encompasses the conditions which correlate to cholera risk, broken down into smaller components. By utilizing this framework methodology, which observes risk across multiple levels of indicators, it is hoped that specific targeting for humanitarian aid and disaster relief can be increased while cholera risk overall is decreased.

1.1.1 FICUS demographic models

Under the FICUS research effort, researchers at the Army's Engineer Research and Development Center (ERDC) developed a methodology to represent the combination of sociocultural data layers in a way that end users will understand and will ultimately improve the utility of the information for characterizing DUEs. A conflation model forms the basis of the methodology. The conflation model combines massive demographic databases into map layers of social, infrastructural, and environmental metrics that could be aligned specifically to operational use.

Unique to the FICUS model is its ability to account for all input data error and model uncertainties. The model requires that source data be constructed using a spatial temporal uncertainty model presenting alternative representations of the data layers based on the known errors and uncertainties.

The model uses data from host nations' census, the U.S. Agency for International Development (USAID), and Department of Defense sponsored surveys. The model also requires Subject Matter Experts (SMEs) to represent the range of framework weighting factors based on their knowledge of the completeness of the available data sources for operational needs. Monte Carlo simulation is then applied to survey responses as they are applied to the framework—creating a range of likely results for each of the framework components.

The presentation of the variability allows decision makers to understand the utility of available data. The results are generated in the form of geospatial thematic maps at a resolution of 200 meters per grid cell. Each grid cell contains the range and distribution of possible metric values for the population within 800 meters of that location. Figure 1 is an example of metric outputs from the FICUS model.

Details of the FICUS model are published in Ehlschlaeger et al (2016). Overall, the technique is composed of six steps, illustrated in Figure 2. The first three steps focus on simulating the population within the landscape. This includes accurately representing population densities and fitting population demographics within that representation. Key to this is understanding the environmental factors that influence the attractiveness of a site for a household to locate. The last three steps generate indicator maps of the simulated households. These steps focus on retaining the errors and uncertainties of the input data in a way that end users will understand the impacts on their application and ultimately improve the utility of the information for decision makers.

Figure 1. Estimated average wealth inequity between Muslims and Hindus near Dhaka, Bangladesh.

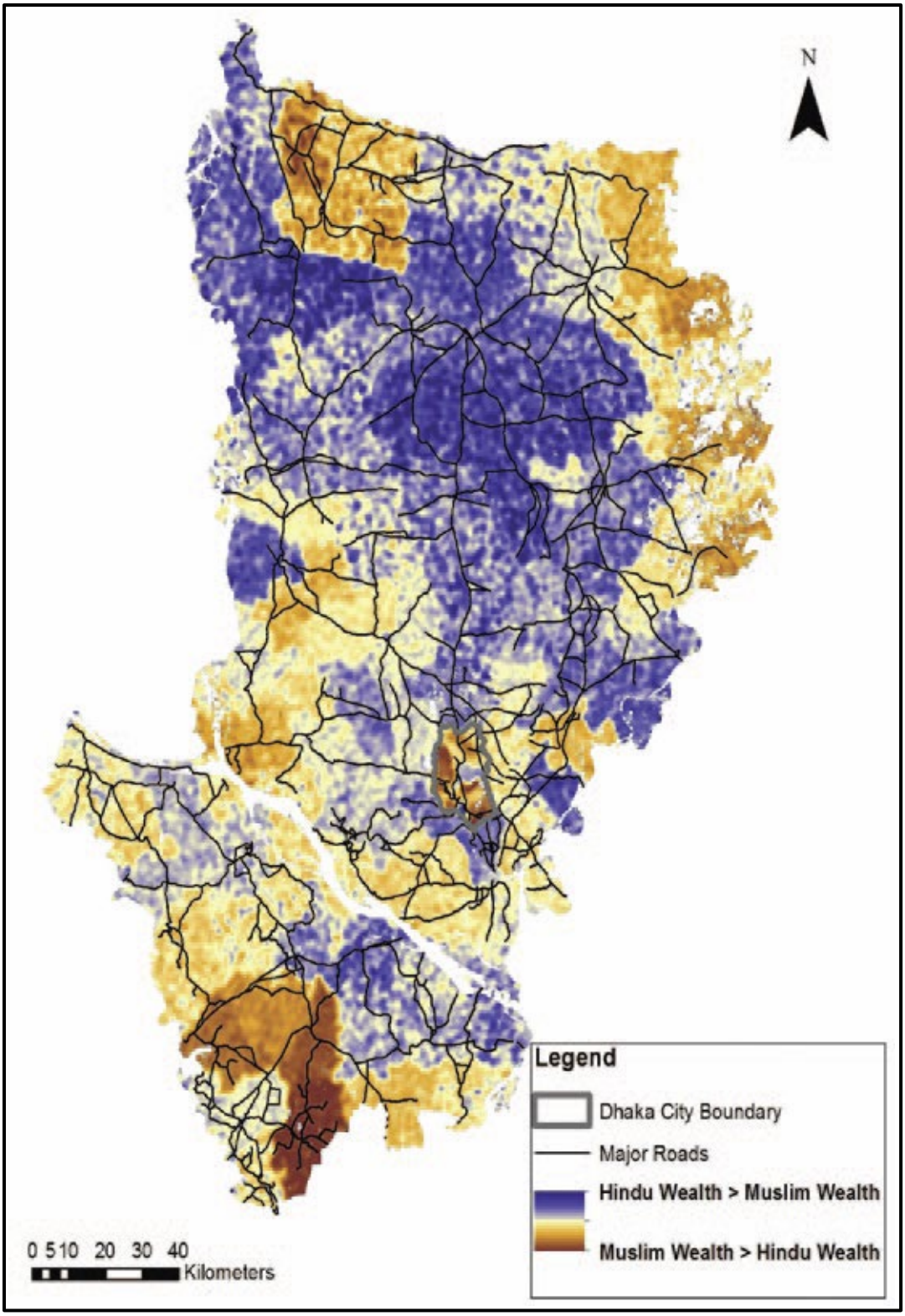
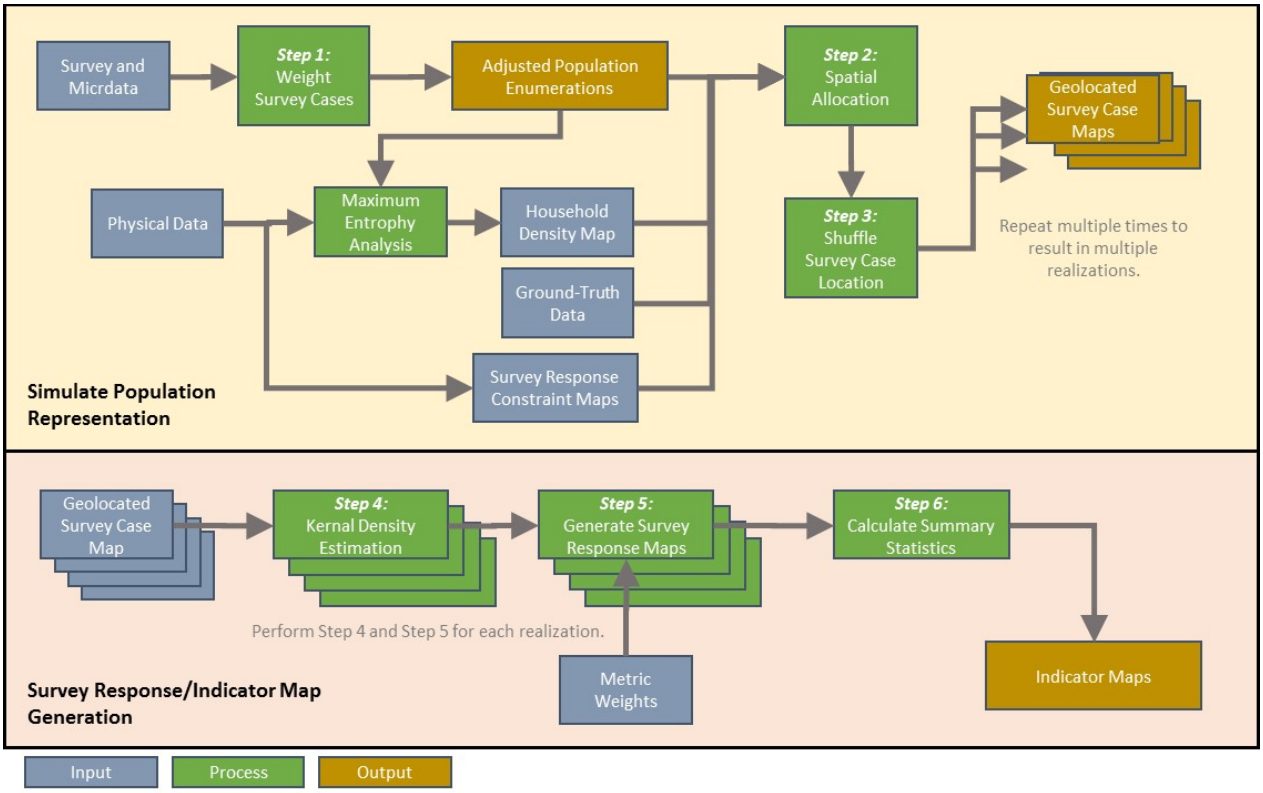


Figure 2. Survey response mapping process.



1. **Weight Survey Cases.** Survey cases are replicated a number of times to match demographic characteristics in the overall estimated population enumerations. The replication process fits the results and are weighted using a sum of least squares minimizing specific desirable survey responses.
2. **Spatial Allocation.** Household survey cases are realized into plausible geographic locations. Ultimate household location maps are based on a household density maps, ground truth data, and survey shuffling for optimization. The process of Maximum Entrophy analysis generates household density maps.
3. **Shuffle Survey Case Location**. Survey case locations are shuffled to improve spatial statistics. This optimizes a set of proportional and spatial statistics for each population realization to create realistic clustering of survey responses.
4. **Kernel Density Estimation**. For each desired combination of survey responses, proportion maps are generated on each population realization throughout the study area representing the percentages of simulated survey cases with such responses. This kernel density estimation process is done cell by cell across a regularized grid.
5. **Generate Survey Response Maps.** Map algebra analysis generates survey response maps 1 to n realizations.

6. **Calculate Summary Statistics.** Throughout the study area, box plot summary statistic maps are compiled on the minimum, maximum, median, medium, first quartile, third quartile of realizations at all study area locations, as well as the standard deviation and interquartile range for these locations. Both the summary statistics and the kernel analysis for each realization provide error and uncertainty estimates.

Steps one through four are done repeatedly for dozens, hundreds, or even thousands of alternative realizations to create enough realizations to provide representative distributions for important survey answers at critical geographic locations. For example, a survey response that is answered seldom would require a larger number of realizations for its Poisson distribution to reflect the variation of reality while a survey response answered by about 50% of the households or people would take fewer realizations to define the resulting normal distribution.

1.1.2 Humanitarian crisis framework

Table 1 depicts the HC framework of conditions, factors, and indicators. Each level measures a different dimension of potential risk or stress. JICPAC established the illustrative framework and chose Bangladesh as a case study for demonstrating the usefulness and functionality of a computational framework for better informed decision making.

The purpose of the HC framework is to show estimated risk levels in a way that allows for comparison within and across nations. While the entirety of the HC framework could be considered the highest level of the framework, as it portrays risk for humanitarian crises as a whole, the five conditions are technically the highest level of the HC framework. Each condition encompasses a broad category of events and circumstances that cause or lead to humanitarian crises. The first condition, Natural Hazards, encompasses measures of crises that often happen within a small temporal range, but can affect large populations and whose effects can have ramifications for years to come. The second condition, Human Behavioral Impact, encapsulates negative human impacts on the natural environment, people, and infrastructure/built environment that can potentially increase risk of a crisis. Service Failure, the third condition, focuses on the failure of entities (mostly public, but private can be included) to provide basic services to citizens.

Table 1. Humanitarian crisis framework.

	Conditions	Factors	Indicators
Humanitarian Crisis	Natural Hazards	Geophysical Effects/Consequences	Earthquake/Earth Movement
			Landslide
			Volcanic Activity
		Climatological Effects/Consequences	Flood
			Severe Storm (thunderstorm, hurricane, tornado, cyclone, winter storms, etc.)
			Tsunami/Tidal Surge
			Drought
		Ecosystem Disruptions	Epidemics/Pandemic
			Severe Insect Infestation
			Commodity Destruction/Infection
			Wildfire
	Human-Behavioral Impact	Contamination and Degradation	Food Processing Contamination
			Chemical or Other Industrial
			Nuclear/Radiological
			Biological (Animal Husbandry)
		Vulnerable Groups	IDPs/Refugees
			Undernourished Population (Not Gov't Priority, Resiliency)
			Casualties, Injured, Sick
			Targeted Groups (Genocide/Violence)
		Substandard Conditions	Civil Infrastructure Failure (Dams, Levies, Bridges, Buildings, Roads)
			Hazardous Working Conditions (Mine, Ag, Industrial)
			Overcrowding and Dangerous Housing
			Polluted and Disease-Bearing Environment (Swamps, Etc.)
	Services Failure	Law Enforcement/Policing Deficiencies	Policing/Patrol Deficits
			Inadequate Investigations and Prosecution
			Prisons and Jails (lack of capacity)
			Inadequate Facilities/ Property Protection
		Health & Medical Service Insufficiencies	Doctor (Health Care Professionals) and Access to Primary Care
			Hospitals/Clinics and Secondary Care (Medical Specialists)
			Availability of Pharmaceuticals (Antibiotics)
			Delayed or Deficient Mortuary Affairs
		Utilities Disruption	Inadequate Sanitation
			Water Shortfalls
			Lack of Communications Availability
			Energy Deficits
	Readiness and Response Inadequacy	Lack of Preparation and Warning	Pre-Positioning Supplies
			Hazard Plans, Personnel Training, and Exercises
			Established Detection Sensors (Buoy's Etc.)
			Dissemination/ Alert Broadcast Deficits
		Emergency Response Shortfalls	Inadequate Fire and EMS Services
			Extraction and Debris Removal (Equipment)
			Inadequate Search and Rescue
			Insufficient Lift/Evacuation, Transportation Capacity
		Civil/Military Authority Failures	[Lack of] Established / Delegated Authority
			Insufficient Interoperable Communications
			Lack of Technical/ Functional Response Competency
			Breakdown of Situational Awareness (COP)
	Resilience Deficiencies	Insufficient Investment/Assistance	Insurance/ Reinsurance
			Insufficient Loans/ Debt Forbearance and Cancellation
			Foreign/Federal Relief/Grants/Social Funds (Aid)
			Decreased Foreign Investment Based on Assessed Risk
		Malfunctioning Commerce / Services	Absenteeism and Work Stoppages
			Production Decreases
			Failure of Normal Trade to Return
			Failure to Re-Establish Markets (Retail, Groceries, Etc.)
		Inadequate Construction/Reconstruction	Insufficient Rebuilding of Shelter/Housing
			Sustained Lack of Operational Utilities (the Grid)
			Delays to Re-establishment of Transportation Systems
			Diminished Agricultural Production

These services include rule of law, policing/justice, health and medical care, and public utilities. The last two conditions—Readiness and Response Inadequacies, and Resilience Deficiencies—primarily account for the ability of a system to accommodate, respond, and recover from humanitarian crises and disasters.

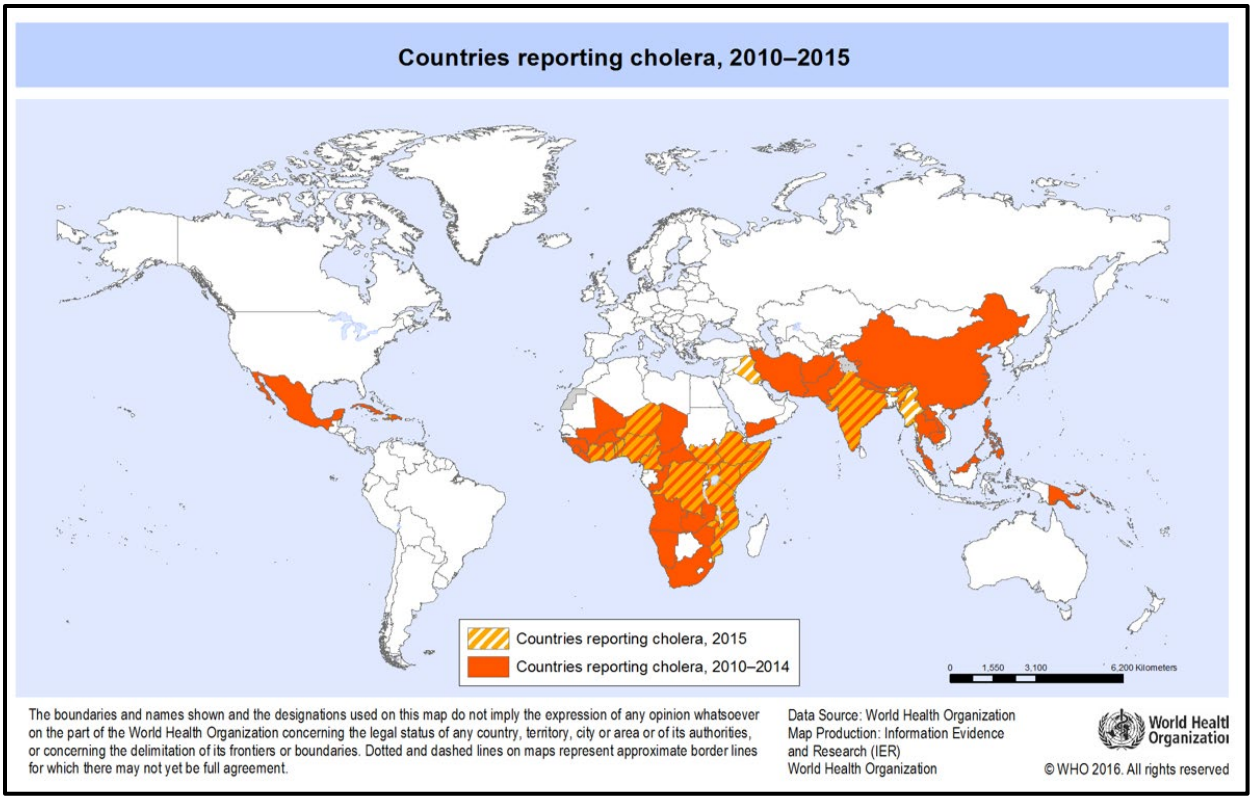
1.1.3 Cholera: an epidemiological overview

Cholera is an acute diarrheal infection caused by ingestion of food or water contaminated with the waterborne bacterium Vibrio cholerae. If the infection is untreated, it can kill within hours of consumption of the contaminated matter. According to the World Health Organization (WHO), an estimated 1.3 to 4.0 million cholera cases occur worldwide every year, with 21,000 to 143,000 of those cases resulting in death (WHO 2016). While the majority of cases develop mild to moderate symptoms, the acute watery diarrhea (leading to severe dehydration) can be successfully treated with oral rehydration solutions, intravenous fluids, and antibiotics (WHO 2016). The availability of safe water and sanitation, as well as oral cholera vaccines (such as those provided by the WHO), are critical to controlling the spread and transmission of cholera.

Humanitarian crises, including natural disasters, can increase the risk of contracting cholera for vulnerable populations. For example, following the 2010 earthquake in Haiti, poor sanitation management combined with environmental and climatological conditions led to a cholera outbreak that killed thousands (Enserink 2011, Jutla et al. 2013).

Cholera remains a global public health issue (Figure 3), which is especially prevalent in sub-Saharan Africa and Southeast Asia. Cholera remains endemic within Bangladesh due to multiple factors, including climate, topography, and lack of access to proper sanitation and clean water in peri-urban slums and rural areas (Ali et al. 2002, Schwartz et al. 2006, Siddique et al. 1992). Both the primary and secondary effects of the frequent flooding of Bangladesh's many rivers, especially during the monsoons, has exacerbated cholera outbreaks for decades (Schwartz et al. 2006). Because of this, Bangladesh – and more specifically, the Chittagong Division – was selected as a case study for the creation of a cholera risk computational framework, largely based on the HC computational framework.

Figure 3. Global reported cases of cholera 2010-2015.



Source: World Health Organization (WHO).

1.2 Objective

The goal of this effort is to demonstrate how broad military operational frameworks can inform a more specific risk evaluation frameworks (i.e., humanitarian crisis to cholera) and vice versa. The objective is not to provide a completed framework for operational use. Rather, the objective is to demonstrate the quantitative use of existing data to inform better decision making.

1.3 Approach

This document contains the technical explanation of the cholera framework. Chapter 2 describes the process and techniques. The Appendix supports this discussion with the Bangladesh case study. Chapter 3 concludes with anticipated use and application of the techniques.

2 Developing the Framework

The HC framework was a theory or knowledge-driven framework; essentially, the framework components (conditions, factors, and indicators) were identified and developed based on established literature. Researchers then had to attempt to match the available data sources to the indicator requirements. For example, the indicator "Lack of Communications Availability" called for metrics reflecting the percentage of communication towers, direct subscriber line (DSL), and fiber optic lines disabled by crisis; percentage of population with access to communication (radio, television, cell phones, internet, newspapers) (compared with historical data); and satisfaction with access to communication. Some of this data was included within the national census and survey data (as detailed in section 1.1.1), but other data gaps remained. These data gaps are reflected in the higher uncertainty values for the indicator, which account for unknown components (section 2.2.4).

The cholera risk assessment framework (Table 2) was created in order to augment the HC framework with a more specific risk assessment, and to demonstrate methods for reducing uncertainties and unknowns in computational frameworks. Researchers utilized a combined approach of knowledge-driven and data-driven methodologies to build the cholera framework. First, a literature review was conducted to identify indicators of cholera risk. If these indicators were already accounted for in the HC framework components, then that indicator/factor/condition was incorporated into the cholera framework (a knowledge-driven approach) (Tables 1 and 2). Examples of these include the indicators Inadequate Sanitation, Water Shortfalls, and Energy Deficits within the Utilities Disruption factor. However, if these indicators of cholera risk were not accounted for in the HC framework components, the survey and census data sources were examined to see if they could inform new indicators (a data-driven approach). Individual data metrics were then grouped into indicators based on their similarity in addressing cholera risk. In some cases, these new indicators were incorporated into HC framework factors. Examples of these include the Age, Children, Literacy, and Education indicators within the Vulnerable Groups factor. As researchers defined these indicators themselves, the uncertainty was automatically reduced.

Table 2. The cholera risk framework.

	Conditions	Factors	Indicators
Cholera Risk	Natural Hazards	Geophysical Effects/Consequences	Proximity to Bodies of Water
			Water Quality
		Climatological Effects/Consequences	Flood
			Severe Storm
			Average Rainfall
			Sea Level Rise
			Max Daily Temperature
		Ecosystem Disruptions	Epidemics/Pandemics
	Human Behavioral Impact	Vulnerable Groups	Age
			Children
			Literacy
			Education
			Urbanity
			Undernourished Population
			Casualties, Injured, Sick
			Targeted Groups
			Women and Gender
		Substandard Conditions	Overcrowding
			Dangerous Housing
			Polluted and Disease-Bearing Environment
		Household Civil Infrastructure Failure	Household Water Infrastructure
			Household Toilet Infrastructure
			Household Electricity Infrastructure
	Service Failure	Health and Medical Service Insufficiencies	Doctor and Access to Primary Care
			Hospitals/Clinics and Secondary Care
			Household Health Practices
			Treatment for Diarrhea
		Utilities Disruption	Inadequate Sanitation
			Water Shortfalls
			Energy Deficits
	Resilience Deficiencies	Household Economic Resilience	Socioeconomic Status
			Household Ownership

Although it was informed by the HC framework in its inception, the cholera risk framework has the potential to inform the HC framework in turn. For example, the cholera risk framework could be added as an additional metric within the "Epidemics/Pandemics" indicator in the HC framework to better understand how cholera can contribute to or result from humanitarian crises. Depending on the level of influence the user of the HC framework wants cholera to have, the cholera risk framework could even be inserted at the factor or condition level.

This is a pre-crisis risk framework, with the overarching goal of identifying where cholera epidemics could occur at a neighborhood scale. While there may be correlation between the probability (likelihood of occurring) and severity (intensity of outbreak) of cholera epidemics, this framework is more focused on the former. For example, this cholera risk framework may not have been useful for predicting the current cholera outbreak in Yemen. As of late June 2017, the cholera crisis in Yemen has infected more

than 200,000 people, of which 1,300 (1/4 of whom are children) have died from the disease (WHO & UNICEF, 2017). Yemen, being in the midst of a civil war which has been ongoing for several years, would be not be considered a pre-crisis environment. This outbreak, which increases at a rate of over 5,000 new cases a day, is the direct result of the destruction of urban infrastructure (sewage, water, electricity, etc.) due to conflict (Bruwer, 2017). The compromise of high-quality infrastructure would likely not be captured in microdata used to inform this framework but has led to one of the greatest cholera outbreaks in modern history (BBC 2017).

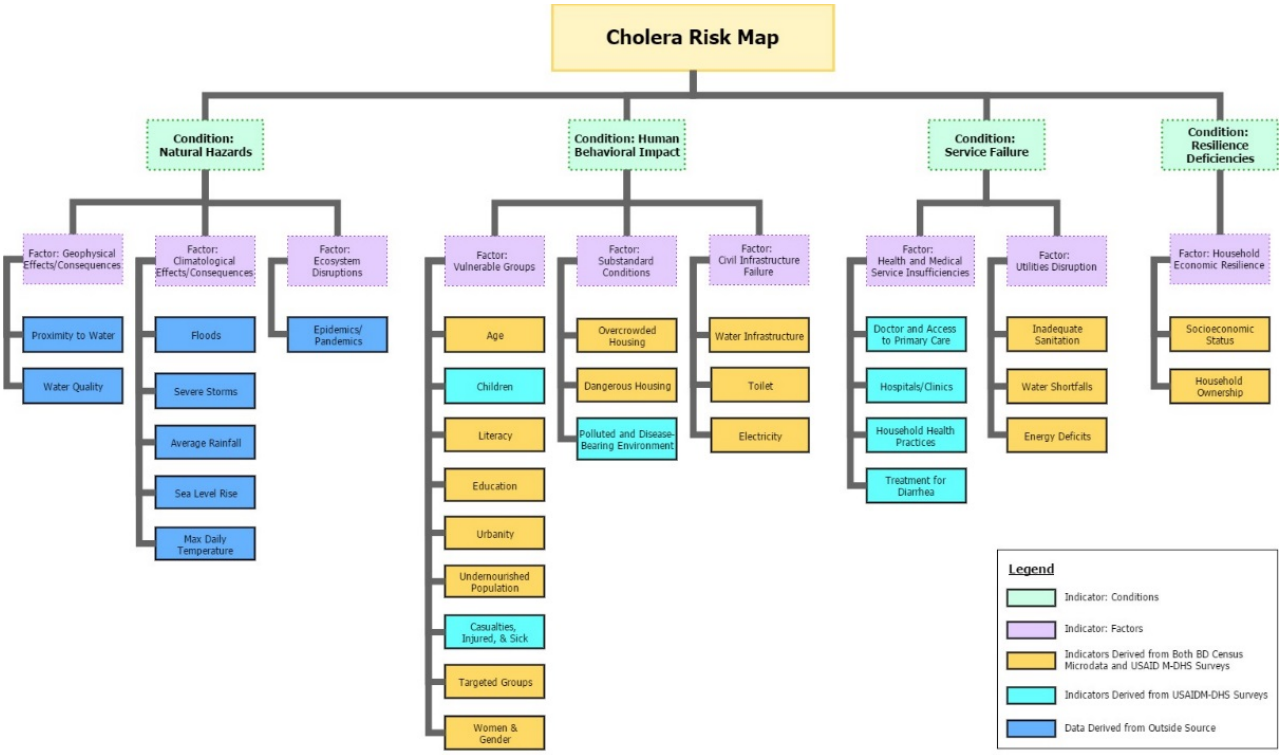
In sum, any kind of large-scale conflict weakens the overall effectiveness and accuracy of this computational risk framework. Not only does the current framework fail to consider levels of state/government functionality and civil affairs, but the microdata informing the risk of a cholera outbreak – specifically indicators focusing on infrastructure – would be made irrelevant in light of ongoing conflict. This is why the researchers stress the focus on probability of cholera epidemics, and the pre-crisis environment framing mechanism. However, the framework structure offers the flexibility to adjust weights, uncertainty quantifiers, and incorporate insight from SMEs. This could allow researchers to produce a more informed cholera risk framework for a non-pre-crisis environment.

2.1 Input data

The data currently informing the cholera risk assessment framework consists of national census microdata on Bangladesh and the USAID Demographic and Health Survey (USAID DHS), as also mentioned in section 1.1.1. Figure 4 displays the conditions (green), factors (purple), and indicators of the cholera risk framework, as well as the data informing each indicator. Indicators informed by only the USAID DHS results are in teal. Indicators informed by both the USAID DHS and the census microdata are in yellow. Any indicators informed by external sources (blue), such as climate and temperature data, resulted in randomly generated maps that can be updated through the incorporation of non-survey data into FICUS.

Unlike the HC framework, nearly all of the data inputs for the cholera framework reflected quantitative, not qualitative, measures and metrics. For example, metrics for the indicator “Toilet” would measure if a household shared a toilet or what kind of toilet they had access to, rather than if they would consider access to sanitation infrastructure to be an issue for their household.

Figure 4. Alignment of survey data to the cholera framework.



2.2 Risk value

Each metric variable must be normalized for apples-to-apples comparisons. User assigns a range of values between 0 and 1 to all possible survey question responses representing the possible extent of risk contribution. Threshold values are shown in Table 3. A value of "0" equates to total chaos, while a value of "1" equates to no perceived risk.

Table 3. Normalizing survey responses. Each question response is normalized based on a range of values between 0 and 1 representing the possible extent of risk contribution.

Color	Metric Value	Description
	1	Minimal risk. Has no impact on risk.
	0.75	Minimal risk. If the weights of all metrics with a .75 value sum to 2.0 or greater, indicator will be slight risk or worse even if all other metrics have a 1.0 value.
	.500…1	Minimal risk. If the sum of all weights with a metric value of .500…1 is 1.0, any other metric has a value < 1.0, indicator will be slight risk or worse.
	0.5	Slight risk. If the weights of all metrics with a .5 value sum to 2.0 or greater, indicator will be slight risk or worse even if all other metrics have a 1.0 value.
	0.2500…1	Slight risk. If the sum of all weights with a metric value of .500…1 is 1.0, any other metric has a value < 1.0, indicator will be medium risk or worse.
	0.25	Medium risk
	.12500…1	Medium risk.
	0.125	High risk
	0.0625	Extreme risk

If the level of risk is uncertain, a range (min and max) of values may be selected. The wider the range, the less certain of the risk contribution. The tighter the range, the more certain of the risk contribution.

2.3 Weights

Screening requires the evaluation of a combination of indicators. Multiple indicators are often aggregated into a factor or condition, usually for comparison across locations or to indicate change over time. Weights are assigned to metrics, indicators, factors, and conditions—allowing each component level to be rolled-up to the next. Components are weighted against the other components within that level (i.e., all the metrics in one indicator, all the indicators in one factor, etc.). Users define weights as a numerical value between 0 and 1 based on contribution to risk, 0 being the least important/constraining on the next level up, and 1 being the most important/constraining. Again, weights can be defined in terms of a range given an uncertain risk contribution level.

If all weights within a grouping add up to 1, then each unit contributes to the accumulation of risk. For example, when characterizing healthcare deficiencies, the availability of doctors, facilities, and pharmaceuticals all contribute to overall risk.

If any one (or more) weight within a grouping equals 1, then it (or they) drives the overall risk. For example, when characterizing climatological consequences, either flood, severe storm, or drought can impose the overall risk. In this example, all three characterizations would receive a weight of one, and regardless of the event the largest value becomes the overall risk value.

2.4 Unknown components

We know that this is not a complete list of metrics, indicator, factors, or conditions. There are potentially other variables that were not considered. In this situation, users can opt to add an unknown component. This inserts a random value that accounts for additional variables. It is given a weight and treated the same as any other component.

2.5 Roll-up computation

2.5.1 Favorability functions

Favorability functions calculate the overall component values using the risk value and the weight. Favorability functions were originally known as sieve mapping (McHarg 1969) and also called map overlays. Before map overlay existed as a computer algorithm, clear acetate maps were inked for locations least favorable to an activity or land use. Stacking the acetate maps on top of each would provide a visual method to assess each location's suitability or risk. Bonham-Carter (1995) described digital map overlay as favorability functions, which includes easier weighting of individual maps and exact measures of suitability or risk. Traditionally, there has been two general types of favorability functions used, additive-based favorability (Equation 1), known as the weighted linear combination (WLC) (Malcwewski 2000) or Constraint-Based Favorability Function (CBFF) (equation 2).

$$\mathbf{M}_y = \sum_{i=1}^{n} w_i \mathbf{M}_i / w_i \quad (1)$$

$$\mathbf{M}_y = \prod_{i=1}^{n} w_i \mathbf{M}_i / w_i \quad (2)$$

where

$\mathbf{M}$ = a map with values between 0.0 and 1.0
$\mathbf{M}_y$ = the resulting indicator or risk assessment map
$\mathbf{M}_i$ = the i^{th} of n criteria maps
w_i = the i^{th} weight to its criteria map.

WLC-based risk assessments have the problem when a large risk becomes masked by other no/low risks at the same location. For example, a location where gang violence creates a high risk should have high risk even though other criteria, such as well funded after school programs, indicates a low risk. On the other hand, CBFF risk assessment does not allow for groups of criteria to positively reinforce each other—every criterion constrains the indicator to the value of criteria and no higher.

An ideal favorability function will allow both additive and constraint-based characteristics to be declared both within criteria map locations and the

criteria map weighting. Equation (3), named the *power-based favorability function* (PBFF) achieves this goal:

$$\mathbf{M}_r = \prod_{i=1}^{n} \mathbf{M}_{i,r}^{w_i}, 1.0 \leq \sum_{i=1}^{n} w_i \quad (3)$$

where

$\mathbf{M}$ = a map with values between 0.0 and 1.0
$\mathbf{M}_r$ = the r^{th} realization map of indicator values
$\mathbf{M}_i$ = the i^{th} of n criteria maps
w_i = the i^{th} weight to its criteria map.

While PBFF's equation (3) is less intuitive than WLC and CBFF, having criteria variables be the constant of a power function allows it to be equivalent to WLC when the criteria weights sum to 1.0. Also, PBFF allows criteria weights to act influence the indicator like both WLC and CBFF when criteria weights sum to be greater than 1.0. For example, if a criterion has a weight of 1.0, its indicator will have the same or lower risk value, just as in CBFF. Criteria with weight less than 1.0 in PBFF will allow the indicator to have a higher value when other criteria are positive. Thanks to the product function in PBFF, criteria map locations can also be constraints when those locations are given a value of 0.0 or other extremely low values.

Another benefit to using PBFF, similar to CBFF's, is in the calibration process. Risk model developers can adjust individual criteria map weights or the values within the criteria map locations to calibrate to the desired indicator values without having to adjust other criteria map weights. Traditional risk assessment techniques require carefully choosing the indicator's criteria weights, adjusting all of them whenever calibration is done. PBFF provides for an opportunity for non-linear optimization algorithms, such as neural nets or genetic algorithms, to create criteria map weights as well as the function variables that minimize the errors to known indicator values.

2.5.2 Quantifying errors and uncertainty

A stated goal of the FICUS effort was to explicitly represent errors and uncertainties within all products. For the PBFF to specifically quantify uncertainty, equation (5) becomes the Uncertainty Quantified (UQ) PBFF.

$$\mathbf{M}_r = \mathbf{M}_{u,r}^{w_u} \times \prod_{i=1}^{n} \mathbf{M}_{i,r}^{w_i}, 1.0 \leq w_u + \sum_{i=1}^{n} w_i \quad (5)$$

where

$\mathbf{M}_{u,r}$ = the r^{th} realization map of simulated uncertainty for an indicator
w_u = the weight of that uncertainty

The simulated uncertainty map should be a random field of values between 0.0 and 1.0 with a histogram like the distribution of values within the criteria maps. The random field should have spatial autocorrelation to the largest spatial dependence of the criteria maps. For example, if the criteria maps used kernel analysis on demographic factors, the random field should have positive spatial autocorrelation equal to the kernel analysis diameter. While this research used the random field described in Ehlschlaeger (2002), there are many theoretical random field models to choose from, for example GSLIB (Geostatistical Software LIBrary) (Deutsch & Journel 1992). While equation (5) explicitly represents the known uncertainties in the modeling process, the modelers were expected to represent the unknown uncertainties as well. In regard to UQ PBFF, modelers were expected to estimate the range of values for all weights, w_u and w_i, that might exist accounting for the lack of perfect understanding between the criteria and the indicator. We asked the modelers to imagine new criteria that would better explain the indicator. Then, modelers were asked to estimate which of those currently unavailable criteria had the least correlation with available criteria. Uncorrelated unavailable criteria would be indicated by higher values and greater ranges of the uncertainty weight w_u. This uncertainty weight has the same behavior on the risk assessment model as the criteria weights.

3 Conclusion

The cholera risk assessment framework was created with the goal of demonstrating the ease of utilizing a more general, knowledge-driven risk assessment framework (in this case, one which focuses on humanitarian crises) to inform a more specific, data-driven framework. Both the HC and cholera frameworks augment each other; and when used together, they can reduce overall uncertainties and increase risk awareness within the operational environment.

Implementing quantitative measures for the frameworks enables the ability to more easily compare changes as new data is made available. Further, it offers the ability to trace backwards from the factors down to the metrics, so one can explore the impact of changing the weights of different components at the higher level, allowing accurate calibration of the analytic framework. Finally, the explicit accounting for uncertainty at each level allows analysts to more accurately represent their understanding of the framework values, particularly when SMEs are not available. This reduces the uncertainty of those judgments.

There are likely to be gaps in the framework that are either not obvious or obscured by other framework components. Finding these gaps is vital to ensure the highest accuracy possible. This is a point where the hybrid approach, the incorporation of existing data and theoretical methods, can identify and address critical gaps in the framework. Both data availability and theoretical methods inform framework development in distinct ways. The geospatial risk maps provide intuitive methods for calibration and validation via qualitative techniques. When framework map errors are identified, there is an explicit connection to all modeling decisions and data streams to determine whether there is a logical flaw in the framework model or calibration is necessary to improve the analytic framework.

The HC and cholera framework exercises serve as a good starting point for linking indicators to higher level planning objectives. With the addition of spatially representing quantitative metrics, incorporating uncertainty, and weighting the importance of individual components, analysts have the ability to more accurately and precisely communicate knowledge of the operating environment. This, in turn, provides a genuine pathway for the data-to-decisions paradigm.

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Acronyms and Abbreviations

Term	Definition
ANSI	American National Standards Institute
(ASA[ALT])	Army for Acquisition, Logistics, and Technology
BBC	British Broadcasting Company
BCG	Bacillus Calmette–Guérin
CBFF	Constraint-Based Favorability Function
CDC	Center for Disease Control
CEERD	U.S. Army Corps of Engineers, Engineer Research and Development Center
CERL	Construction Engineering Research Laboratory
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station (data)
CHT	Chittagong Hill Tracts
DHS	Demographic and Health Survey
DSL	Direct Subscriber Line
ERDC	U.S. Army Engineer Research and Development Center
FICUS	Framework for Integrated Complex Urban Systems
GIS	Geographic Information System
GSLIB	Geostatistical Software Library
HC	Humanitarian Crisis
JICPAC	Joint Intelligence Operations Center
JIPOE	Joint Intelligence Preparation of the Operational Environment
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NSN	National Supply Number
OMB	Office of Management and Budget
PBFF	Power-Based Favorability Function
SAR	Same As Report
SF	Standard Form
STEMS	Spatial Temporal Epidemiological Modeling and Simulation
TR	Technical Report
UN	United Nations
UNICEF	United Nations Children's Fund
UNISDR	United Nations International Strategy for Disaster Reduction
UQ	Uncertainty Quantified
USACE	U.S. Army Corps of Engineers
USAID	U.S. Agency for International Development
USPACOM	US Pacific Command
WHO	World Health Organization
WLC	Weighted Linear Combination

Appendix A: Metadata for Cholera Framework and Components

A.1 Cholera risk framework overview

This framework focuses on the potential impacts that natural hazards, human behavior, service failure, and resilience deficiencies could have on infrastructure, as well as living and working conditions of humans in the face of potential waterborne disease outbreaks. It is these conditions, factors, indicators, and metrics that most represent how the natural and human environments can affect an individual's risk to contract cholera.

This framework aims to identify households in Bangladesh that are at risk of contracting cholera. According to Sarker et al., 2015, "In Bangladesh, there is no well-documented data on the actual number of cholera cases but expert estimates suggest an incidence of approximately 450,000–1,000,000 cases each year, of which, at least 300,000 are severe cholera cases."

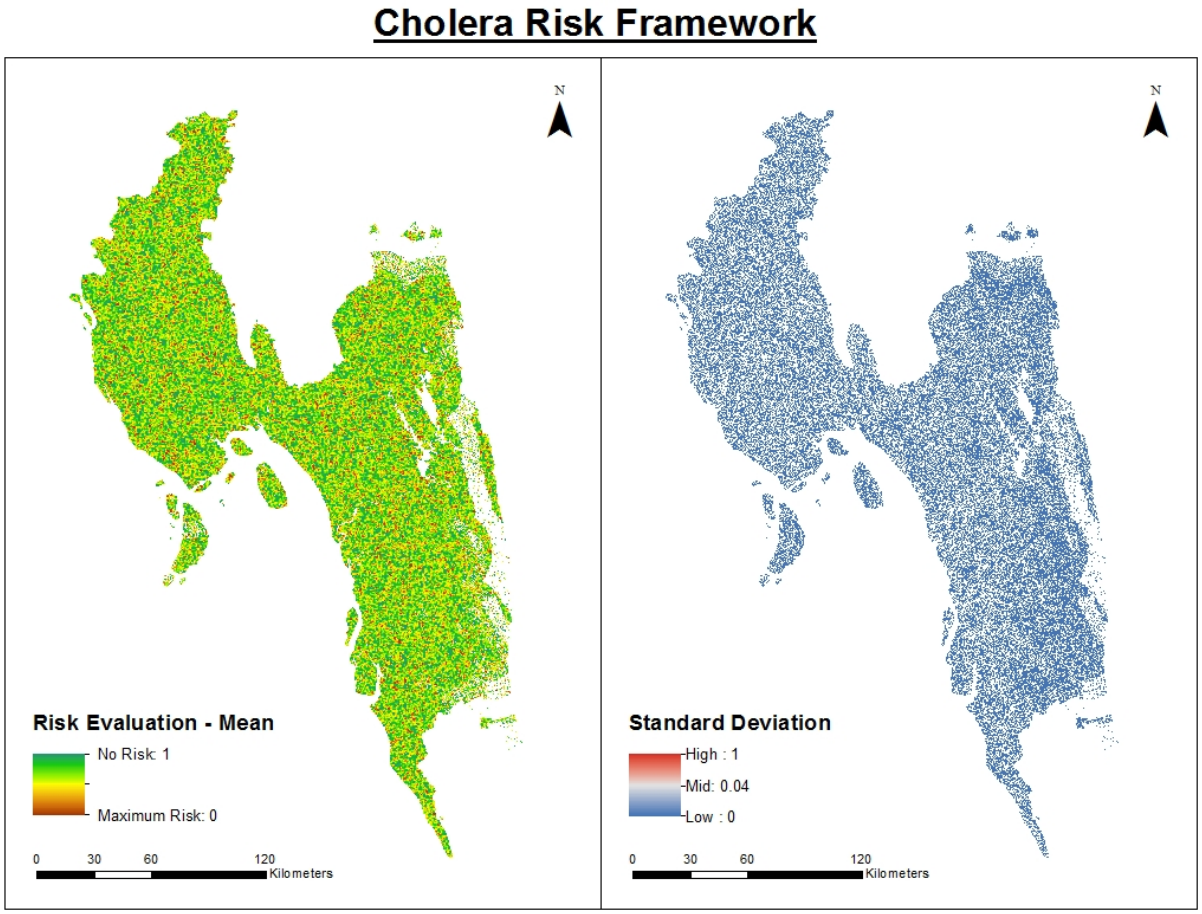
Conditions within this framework include Natural Hazards, Human Behavioral Impacts, Service Failure, and Resilience Deficiencies.

Condition weighting logic

All four conditions within the cholera risk framework are given both a minimum and a maximum value of 0.25. This is because none of the factors will, by themselves, determine the condition's risk value.

Condition (Heading Number)	Weight Minimum Value	Weight Maximum Value
Natural Hazards (2)	0.25	0.25
Human Behavioral Impacts (3)	0.25	0.25
Service Failure (4)	0.25	0.25
Resilience Deficiencies (5)	0.25	0.25

Example outcome



A.2 Natural hazards condition overview

This condition encompasses all categories of natural hazards and shows natural hazards contributions to cholera risk. The United Nations (UNISDR 2009, pg. 17) defines a "hazard" as a

> dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Only the Ecosystem Disruptions factor currently has available metric and indicator data.

Factors within this condition include Geophysical Effects & Consequences, Climatological Effects & Consequences, and Ecosystem Disruptions. It is these factors, indicators, and metrics that most represent how the natural environment can affect an individual's risk to contract cholera.

Factor weighting logic

Geophysical Effects & Consequences and Climatological Effects & Consequences are both given a minimum weight of 0.4 and maximum weight of 0.6, as they are equally important in predicting the condition opposed to Ecosystem Disruptions which has less impact on predicting cholera risk was given a minimum weight of 0.2 and maximum weight of 0.4.

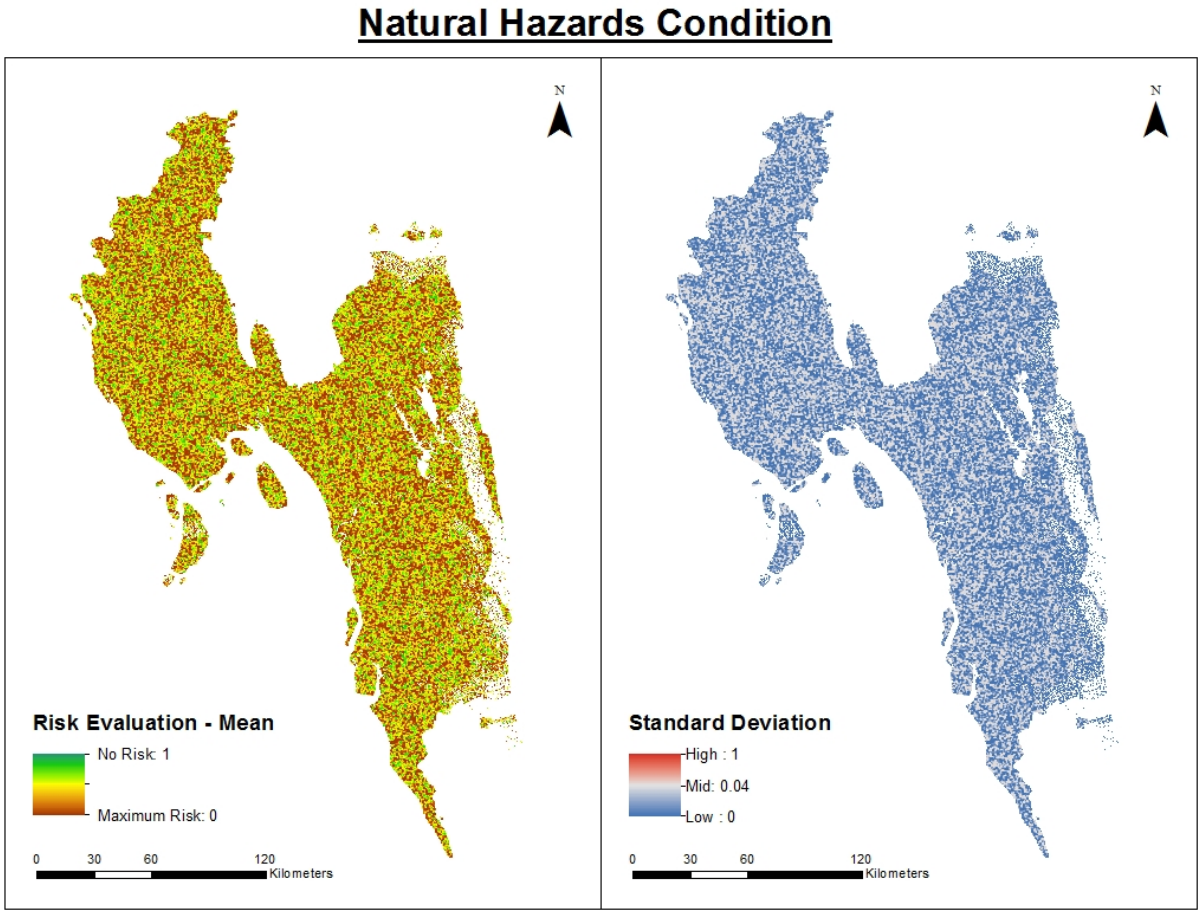
Factor	Weight Minimum Value	Weight Maximum Value
Geophysical Effects and Consequences	0.4	0.6
Climatological Effects and Consequences	0.4	0.6
Ecosystem Disruptions	0.2	0.4

Uncertainty values

This condition is given a range of uncertainty values from 0.1 to 0.3 because of the perceived ability of the existing factors to fully address the themes of the condition. The factors Geophysical Effects & Consequences, Climatological Effects & Consequences, and Ecosystem Disruptions address many issues regarding the natural environment and potential hazards that could arise that would increase local and regional risk to waterborne disease outbreaks.

Condition Uncertainty Min:	0.1
Condition Uncertainty Max:	0.3

Example outcome



References

United Nations International Strategy for Disaster Reduction (UNISDR) 2009. *2009 UNISDR Terminology on Disaster Risk Reduction*. Geneva, Switzerland. May 2009.

A.2.1 Geophysical effects/consequences factor overview

The Geophysical Effects and Consequences factor is built on indicators and metrics focusing on geological hazards. Geological hazards include internal earth processes, such as earthquakes, volcanic activity and emissions, and related geophysical processes such as mass movements, landslides, rockslides, surface collapses, and debris or mud flows. (UNISDR 2009). Tsunami risk measures could be placed within this factor as an indicator, but instead it is under the Climatological Effects/Consequences factor.

For the humanitarian crisis framework, this factor includes the indicators of earthquake/earth movement, landslide, and volcanic activity. For the cholera framework this factor focuses on the geophysical effects of the natural environment on cholera growth, incidence, and outbreak. It is these indicators and metrics that most represent how the environment can impact an individual's predisposition to contracting cholera.

Indicators within this factor include Proximity to Bodies of Warm Water and Water Quality. None of these indicators are available from Phase Zero Assessment of Urban Security Threats research, as there is no metric data for any of them. Some indicators may be supported by other data streams in the USG.

Indicator weighting logic

As both proximity to bodies of warm water and the quality of that water are equally determinant in cholera risk based on geophysical effects/consequences, the indicators are both the most constraining on the factor. Each indicator is given both a minimum and maximum value of 1.0.

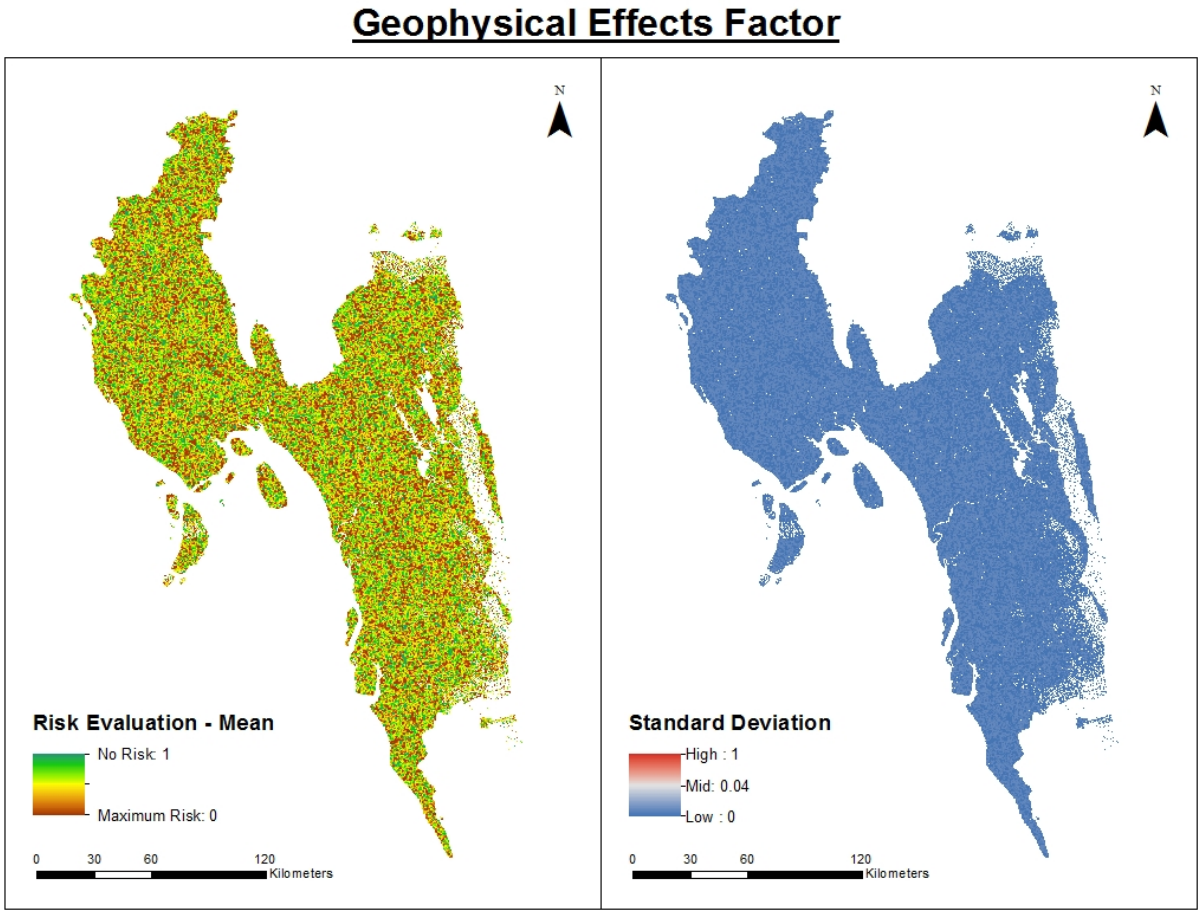
Indicator	Weight Minimum Value	Weight Maximum Value
Proximity to Bodies of Warm Water	1.0	1.0
Water Quality	1.0	1.0

Uncertainty values

This factor is given a range of uncertainty values from 0.1 to 0.3 because of the perceived ability of the existing indicators to fully address the themes of the factor. The addition of other indicators and metrics which measure geophysical effects that attribute to cholera incidence could further decrease the uncertainty values.

Factor Uncertainty Min:	0.1
Factor Uncertainty Max:	0.3

Example outcome



References

United Nations International Strategy for Disaster Reduction (UNISDR) 2009. *2009 UNISDR Terminology on Disaster Risk Reduction*. Geneva, Switzerland. May 2009.

A.2.1.1 Indicator: Proximity to bodies of warm water

The Proximity to Bodies of Warm Water indicator accounts for the relative distance a household resides to a body of water, as well as potential increases in sea surface temperature. The latter is a quality that can be associated with cholera outbreaks, as the cholera microbe experiences dramatic growth around 30 degrees Celsius. At the household level, distance to potentially infected bodies of water can account for elements that can potentially lead to a dangerous living environment, such as building structure or quality of drinking water source.

Metric weighting logic

As cholera risk in this indicator is both contingent on being close to water and the temperature of that water, the metrics are equally constraining on the indicator.

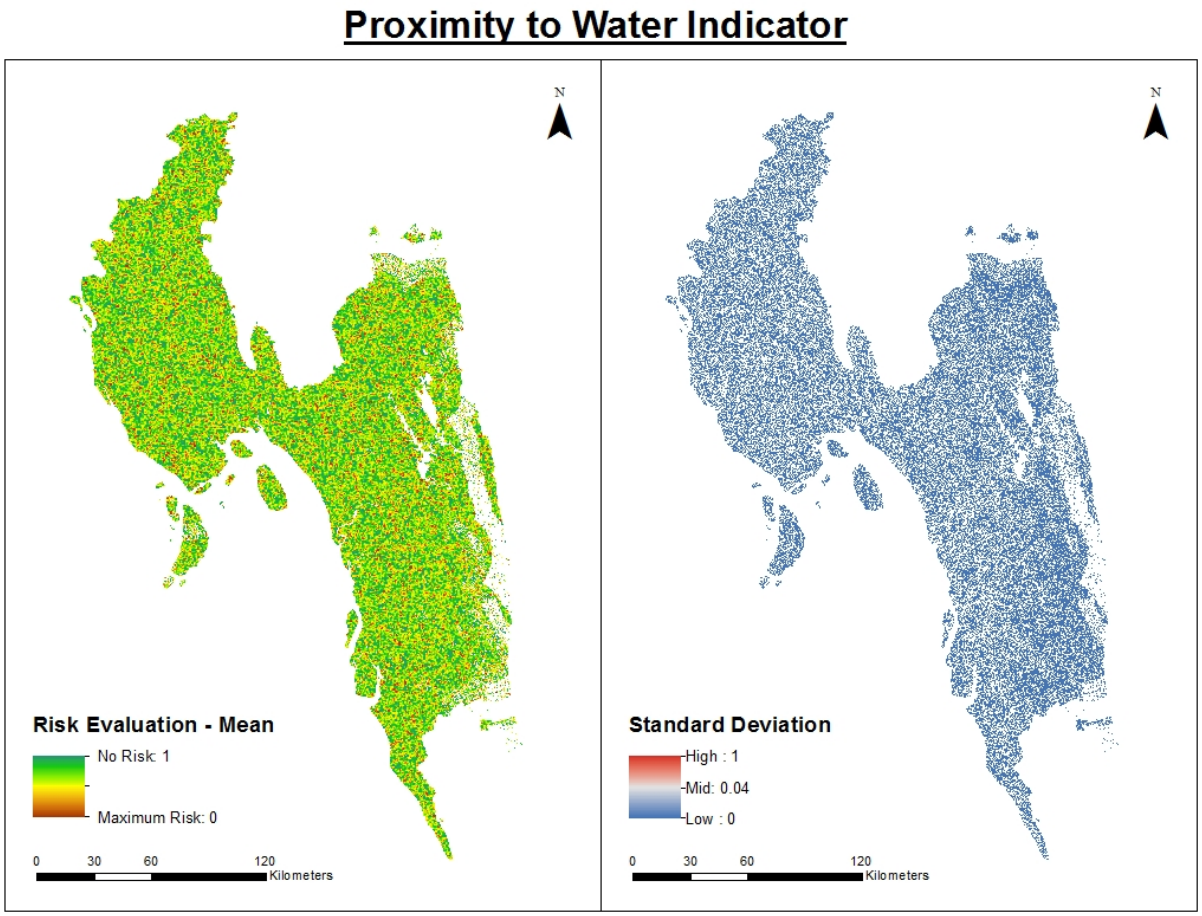
Metric	Weight Minimum Value	Weight Maximum Value
Distance to Nearest Water Body	0.5	0.5
Sea Surface Temperature	0.5	0.5

Uncertainty values

This indicator is given an uncertainty minimum value of 0.10 and an uncertainty maximum value of 0.15 as it is well documented in the literature that the distance to nearest water body that is unusually warm is a significant variable in cholera outbreaks. Adding more robust data at the household level for distances to could decrease the uncertainty values.

Indicator Uncertainty Min:	0.10
Indicator Uncertainty Max:	0.15

Example outcome



Metric: Distance to Nearest Water Body

Indicator:	Proximity to Bodies of Water
Factor:	Geophysical Effects/Consequences
Condition:	Natural Hazards
Framework:	Cholera
Survey:	N/A
Survey Date:	N/A
Other Data Sources:	Ali et al. (2002, 2); Emch (1999); Jutla et al. (2013); Glass et al. (1982)
Logic:	As public sewage systems do not exist in rural areas, latrines tend to be located near bodies of water. In the rainy season, theses uncovered holes in the ground can contaminate surface water. Emch (1999) found that while not statistically significant, distance from main river decreases risk of cholera.

	Ali et al (2002, 2) uses “Distance to nearest water body” in their model which aims to predict cholera morbidity. Distance to nearest water body plays a small, but significant role in the regressions for both classical cholera (1983-1987) and El Tor (1992-1996) outbreaks in Bangladesh. The distance to nearest water body is in meters, spanning from 0 to 2660.1 meters (0 to 1.65 miles). Jutla et al. (2013) finds that “In the Indus river basin, all locations of reported outbreaks have been within 25 miles of the nearest river.” They conclude that “Epidemic cholera regions are located away from but within 25 miles of a major river system.” Glass et al. (1982) found that cholera is more common in villages that are not adjacent to the main river. This aligns with Jutla et al. (2013).
Example Realization Metric Map:	Unavailable. Metric data was downloaded from the source as a table.

References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

Emch, Michael. "Diarrheal disease risk in Matlab, Bangladesh." *Social science & medicine* 49, no. 4 (1999): 519-530.

Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., & Black, R. E. 1982. Endemic cholera in rural Bangladesh, 1966–1980.*American journal of epidemiology*, *116*(6), 959-970.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A.,... & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Metric: Sea Surface Temperature

Indicator:	Sea Surface Temperature
Factor:	Geophysical Effects/Consequences
Condition:	Natural Hazards
Framework:	Cholera
Metric Assigned Values:	Min: 1.0 Max: 1.0
Survey:	N/A
Survey Date:	N/A
Other Data Sources:	Emch et al. (2010); Huq et al (1984); Jutla et al. (2013); de Magny et al. (2008); Perez-Saez et al. (2016)

Logic:	Huq et al (1984) found that by increasing water temperatures up to 30 degrees C, V. cholera experiences dramatic growth, especially with salinity of 15% with a pH of 8.5. These conditions are ripe in estuarine environments. De Magny et al. (2008) found that sea surface temperature (sst) was not statistically significant as a predictor for cholera outbreaks. Interestingly, they did determine that Bangladesh appears to have longer lead time (roughly 1 month) on environmental factors preceding outbreaks. They also discuss that "the strong El Niño that occurred in 1998 [was] found to be associated with the largest number of cholera cases for both Kolkata and Matlab and offer challenging examples of cholera and climate interaction." El Niño has warm SST. Emch et al. (2010) found that Sea Surface Height is significant, but sea surface temperature is not. Overall, Emch (2010) concludes that in pre-monsoon season, environmental factors drive cholera incidents, whereas, post-monsoon season sees socioeconomic factors (water quality/sanitation) drive cholera occurrences. Jutla et al. (2013) finds increased water temperatures are linked to cholera out breaks. "Warm water temperatures between 19 and 28 degrees Celsius are related to an increase concentration of cholera bacteria. (p.604)" Perez-Saez et al. (2016) state that "informal settlements, which often constitute hotspots of cholera transmission are widespread in [Dhaka], and vulnerable to the intense yearly monsoon flooding which gains particular intensity in high El Niño Southern Oscillation years."
Example Realization Metric Map:	Unavailable. Metric data was downloaded from the source as a table.

References

Emch, M., Yunus, M., Escamilla, V., Feldacker, C., & Ali, M. 2010. Local population and regional environmental drivers of cholera in Bangladesh. *Environmental Health*, *9*(1), 1.

Huq, A. N. W. A. R. U. L., West, P. A., Small, E. B., Huq, M. I., & Colwell, R. R. 1984. Influence of water temperature, salinity, and pH on survival and growth of toxigenic Vibrio cholerae serovar 01 associated with live copepods in laboratory microcosms. Applied and Environmental Microbiology, 48(2), 420-424.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A.,... & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

de Magny, G. C., Murtugudde, R., Sapiano, M. R., Nizam, A., Brown, C. W., Busalacchi, A. J., & Calkins, J. 2008. Environmental signatures associated with cholera epidemics. *Proceedings of the National Academy of Sciences*, *105*(46), 17676-17681.

Perez-Saez et al. 2016. Climate-driven endemic cholera is modulated by human mobility in a megacity. *Advances in Water Resources*. http://dx.doi.org/10.1016/j.advwatres.2016.11.013

A.2.1.2 Indicator: Water quality

The Water Quality indicator accounts for the quality of nearby water sources, for drinking or otherwise. At the household level, this can account for elements that can potentially lead to a dangerous living environment, such as building structure or quality of drinking water source.

Metric weighting logic

The metric is informed purely by the water quality. Thus, to inform the indicator, minimum and maximum weights must be 1.0.

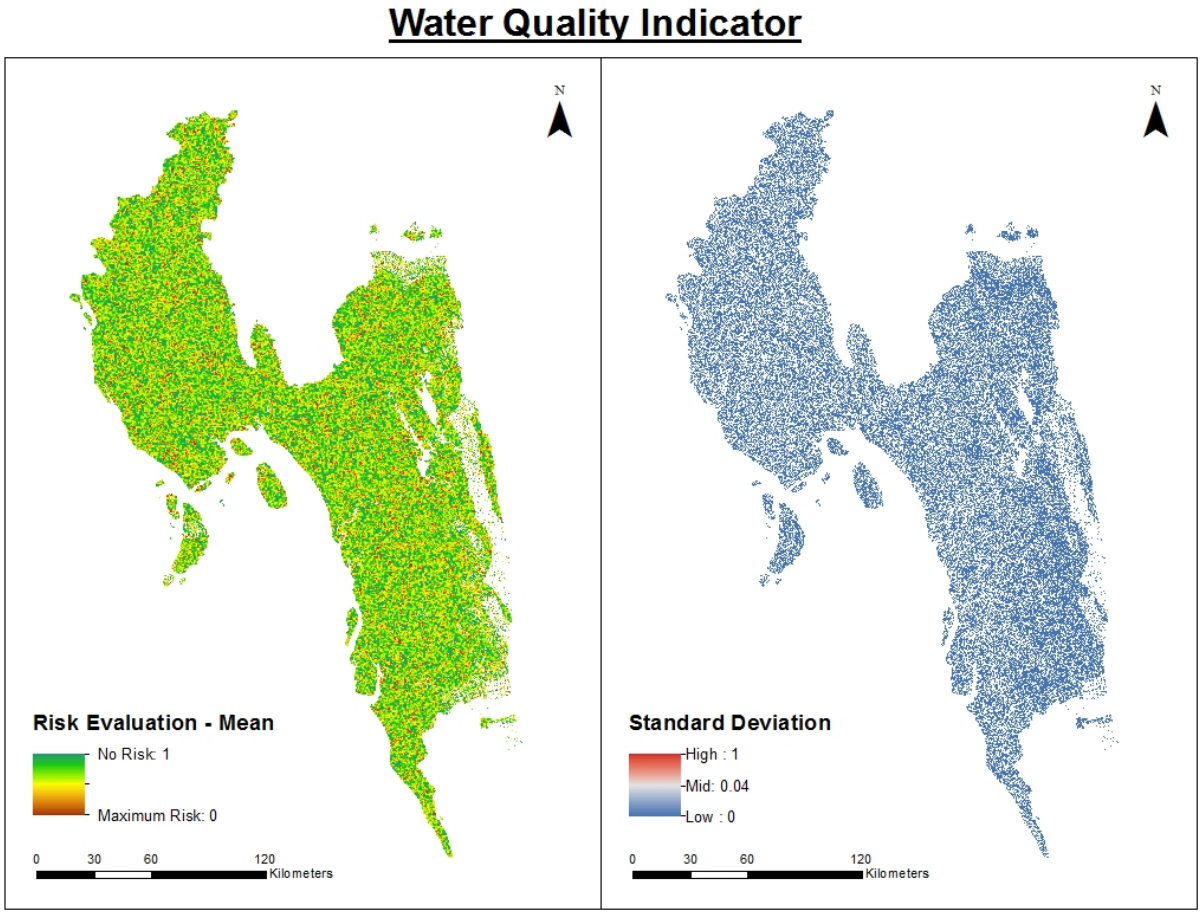
Metric	Weight Minimum Value	Weight Maximum Value
Water Quality	1.0	1.0

Uncertainty values

This indicator is given an uncertainty minimum value of 0.4 and an uncertainty maximum value of 0.6. Adding more data on effects of water quality could decrease the uncertainty values.

Indicator Uncertainty Min:	0.4
Indicator Uncertainty Max:	0.6

Example outcome



Metric: Water Quality

Indicator:	Water Quality
Factor:	Geophysical Effects/Consequences
Condition:	Natural Hazards
Framework:	Cholera
Metric Assigned Values:	Min: 1.0 Max: 1.0
Survey:	N/A
Survey Date:	N/A
Other Data Sources:	Emch et al. (2010); Jutla et al. (2013); Khan et al. (1981)
Logic:	Jutla et al. (2013) finds that "Increased salinity creates favorable environmental conditions for growth of cholera bacteria (p. 601)."

	Khan et al. (1981) found that cholera attack rates were higher for families with access to canal water as opposed to river water or tank water. Emch et al. (2010) found that ocean chlorophyll concentration "(OCC) is positively associated with cholera during the pre-monsoon period, but not for the post-monsoon period."
Example Realization Metric Map:	Unavailable. Metric data was downloaded from the source as a table.

Refernces

Emch, M., Yunus, M., Escamilla, V., Feldacker, C., & Ali, M. 2010. Local population and regional environmental drivers of cholera in Bangladesh. *Environmental Health*, *9*(1), 1.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Khan, M. U., Mosley, W. H., Chakraborty, J., Sarder, A. M., & Khan, M. R. 1981. The relationship of cholera to water source and use in rural Bangladesh. International journal of epidemiology, 10(1), 23-26.

A.2.2 Climatological effects/consequences factor overview

The Climatological Effects and Consequences factor is built on indicators and metrics focusing on hydro-meteorological natural hazards. These are defined as a process or phenomenon of atmospheric, hydrological or oceanographic nature that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (UNISDR 2009). Hydro-meteorological hazards include tropical cyclones (also known as typhoons and hurricanes), thunderstorms, hailstorms, tornados, blizzards, heavy snowfall, avalanches, coastal storm surges, floods including flash floods, drought, heatwaves and cold spells. Hydro-meteorological conditions also can be a factor in other hazards such as landslides, wildland fires, locust plagues, epidemics, and in the transport and dispersal of toxic substances and volcanic eruption material." (UNISDR 2009, p. 18). As such, there may be some metrics that are used multiple times within the framework, as they apply to multiple indicators/factors.

For the cholera framework, this factor includes the indicators of flood, severe storm, average rainfall, sea level rise, and maximum daily temperature as each play a role in how the environment can impact an individual's predisposition to contracting cholera.

Indicators within this factor include Flood, Severe Storm, Average Rainfall, Sea Level Rise, and Max Daily Temperature.

Indicator weighting logic

Flooding's contribution to cholera risk is weighted highest, with a minimum value of 0.4 and a maximum value of 0.6, as severe cholera tends to break out following flooding events (Perez-Saez et al., 2016). The other indicators are equally weighted on the factor, given a minimum of 0.15 and a maximum of 0.35.

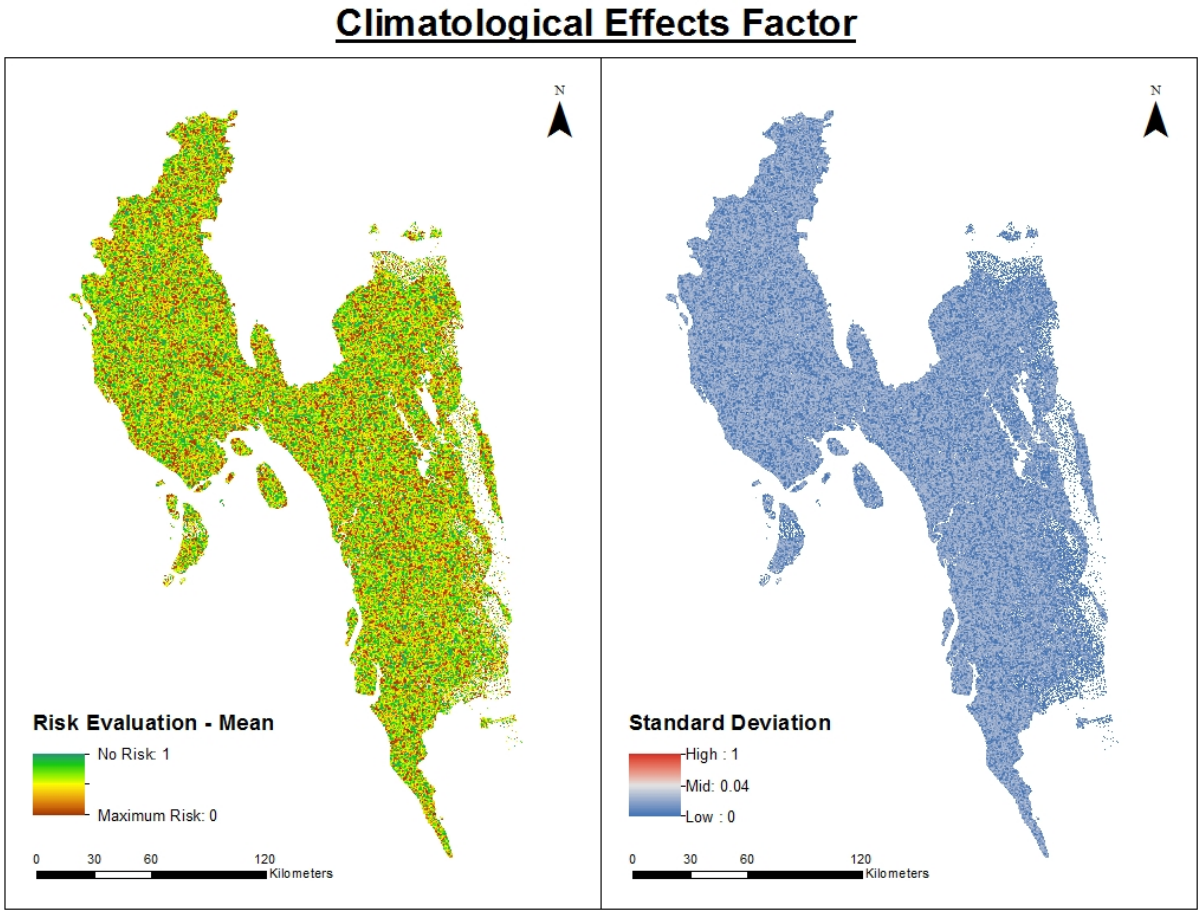
Indicator	Weight Minimum Value	Weight Maximum Value
Flooding's contribution to cholera risk	0.5	0.7
Severe Storm's contribution to cholera risk	0.15	0.35
Monthly Average Rainfall's contribution to cholera risk	0.15	0.35
Sea Level Rise's contribution to cholera risk	0.05	0.25
Max Daily Temperature's contribution to cholera risk	0.15	0.35

Uncertainty values

While the factors do encompass multiple aspects of climate-related natural hazards, these low uncertainty values reflect the potential for additional factors to be added to increase accuracy.

Factor Uncertainty Min:	0.1
Factor Uncertainty Max:	0.3

Example outcome



References

Perez-Saez et al., 2016. Climate-driven endemic cholera is modulated by human mobility in a megacity. *Advances in Water Resources*. http://dx.doi.org/10.1016/j.advwatres.2016.11.013.

A.2.2.1 Indicator: flooding

According to the National Flood Insurance Program (NFIP), a flood is defined as (2016):

- A general and temporary condition of partial or complete inundation of 2 or more acres of normally dry land area or of 2 or more properties from:
  - Overflow of inland or tidal waters; or
  - Unusual and rapid accumulation or runoff of surface waters from any source; or

    - Mudflow; or
- Collapse or subsidence of land along the shore of a lake or similar body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels that result in a flood as defined above.

PACOM specifies that metrics should include: number of floods, percentage of buildings damaged, destroyed, or rendered uninhabitable due to floods; percentage of commercial and residential land area rendered unusable due to floods; number of casualties due to floods; number of infections/diseases resulting from bacteria/chemicals/mold/mildew exposure from floods; crude mortality rate; monetary damages due to floods; and population density in vulnerable areas.

For mapping cholera risk at the household level, this can account for elements that can potentially lead to a dangerous living environment, such as quality of drinking water source because severe cholera cases increase during flooding events (Perez-Saez et al. 2016).

Metric weighting logic

The metric is purely informed by flooding events and so, to fully inform the indicator, both minimum and maximum values are given a 1.0 weighting.

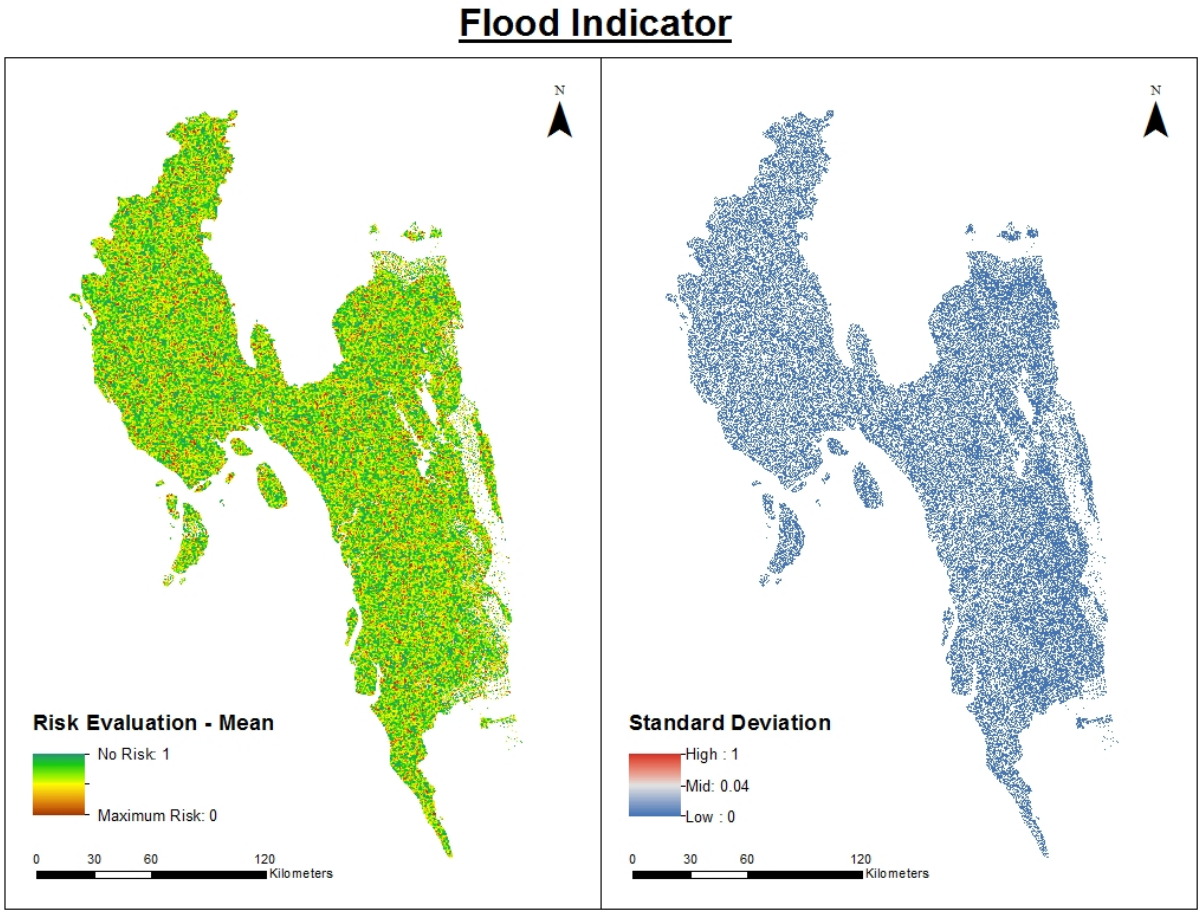
Metric	Weight Minimum Value	Weight Maximum Value
Flood	1.0	1.0

Uncertainty values

This indicator is given an uncertainty minimum value of 0.4 and an uncertainty maximum value of 0.6. Adding more data on effects of flooding could decrease the uncertainty values as it is still not understood exactly why (Emch, 1999).

Indicator Uncertainty Min:	0.4
Indicator Uncertainty Max:	0.6

Example outcome



References

Emch, M., Yunus, M., Escamilla, V., Feldacker, C., & Ali, M. 2010. Local population and regional environmental drivers of cholera in Bangladesh. *Environmental Health*, *9*(1), 1.

National Flood Insurance Program (NFIP) 2016. "Definitions." *FEMA*. May 2016. https://www.fema.gov/national-flood-insurance-program/definitions#F.

Perez-Saez et al. 2016. Climate-driven endemic cholera is modulated by human mobility in a megacity. *Advances in Water Resources*. http://dx.doi.org/10.1016/j.advwatres.2016.11.013.

Metric: Flooding events

Indicator:	Flood
Factor:	Climatological Effects/Consequences
Condition:	Natural Factors Condition

Framework:	Cholera
Metric Assigned Values:	Min: 1.0 Max: 1.0
Survey:	N/A
Survey Date:	N/A
Other Data Sources:	Emch, 1999; Griffth et al. (2006); Hashizume et al. (2008); Jutla et al. (2013); Perez-Saez et al. (2016)
Logic:	Griffth et al. (2006) states that "Natural disasters, such as flooding, can disrupt sanitary conditions and concentrate the population to the extent that there are inadequate hygiene services." The paper went on to cite that, "In West and Southern Africa, the most commonly cited risk factor was heavy rainfall and flooding, which accounted for 33% and 39% of all the risk factor reports, respectively. In contrast, rainfall and flooding only accounted for 10% of reports in East Africa." Hashizume et al. (2008) studied the diarrheal disease that followed the 1998 flooding of Dhaka, Bangladesh which affected 4 million people – almost 40% of the population. The flood period was defined as the river level exceeding the danger level of 6 meters (which maxed at 7 m) and lasted 8 weeks. The post-flood period was the following six months. During the flood period, 41.5% of diarrheal patients had cholera, opposed to post-flood patients of which 28.6% of patients had cholera. Emch (1999) finds that, "Flood-control was related to both types of diarrhea but it is not understood why." Jutla et al. (2013) discusses flooding and cholera outbreaks in Pakistan in 2005 & 2010. In 2010, 600,000 sought treatment for diarrheal disease, but a breakout did not occur in 2005. That is due to the cold weather at the time of the 2005 flooding preventing the growth and spread of V. cholera. Jutla expands that a decrease in water level are linked to cholera outbreaks due to the increased salinity's ability to create favorable conditions for growth of cholera bacteria. Additionally "increased rainfall and poor sanitation yields a higher likelihood of a cholera epidemic." Perez-Saez et al. (2016) discusses how severe cholera cases increase during flooding events.
Example Realization Metric Map:	Unavailable. Metric data was downloaded from the source as a table.

References

Emch, M., Yunus, M., Escamilla, V., Feldacker, C., & Ali, M. 2010. Local population and regional environmental drivers of cholera in Bangladesh. *Environmental Health*, *9*(1), 1.

Griffith, D. C., Kelly-Hope, L. A., & Miller, M. A. 2006. Review of reported cholera outbreaks worldwide, 1995–2005. *The American journal of tropical medicine and hygiene*, *75*(5), 973-977.

Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A.,... & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Perez-Saez et al., 2016. Climate-driven endemic cholera is modulated by human mobility in a megacity. *Advances in Water Resources*. http://dx.doi.org/10.1016/j.advwatres.2016.11.013

A.2.2.2 Indicator: Severe storm

The definition for "severe storm" in terms of what makes up this indicator is purposefully left broad – it includes thunderstorms, hurricanes, tornados, cyclones, severe winter storms, etc. As each geographical region experiences varying types and degrees of severe weather, it would be irrational to narrow down the kinds of metrics that can fit into this indicator.

PACOM specifies that metrics should include: number of severe storms (wind gusts in excess of 58 mph or equivalent OR hail of one inch in diameter or larger; OR classification as tornado, cyclone, hurricane, winter storm); percentage of buildings damaged, destroyed, or rendered uninhabitable due to severe storms; percentage of commercial or residential land area rendered unusable due to severe storms; number of casualties due to severe storms; crude mortality rate; monetary damages due to severe storms; and population density in vulnerable areas.

Regarding specific risk to cholera outbreaks, severe storms such as El Niño – Southern Oscillation (ENSO) and heavy rainfall have been found to be associated with cholera (Colwell, 1996; Jutla et al., 2013; Pascual et al., 2000).

Metric weighting logic

The metric is purely informed by severe storm events and so, to fully inform the indicator, both minimum and maximum values are given a 1.0 weighing.

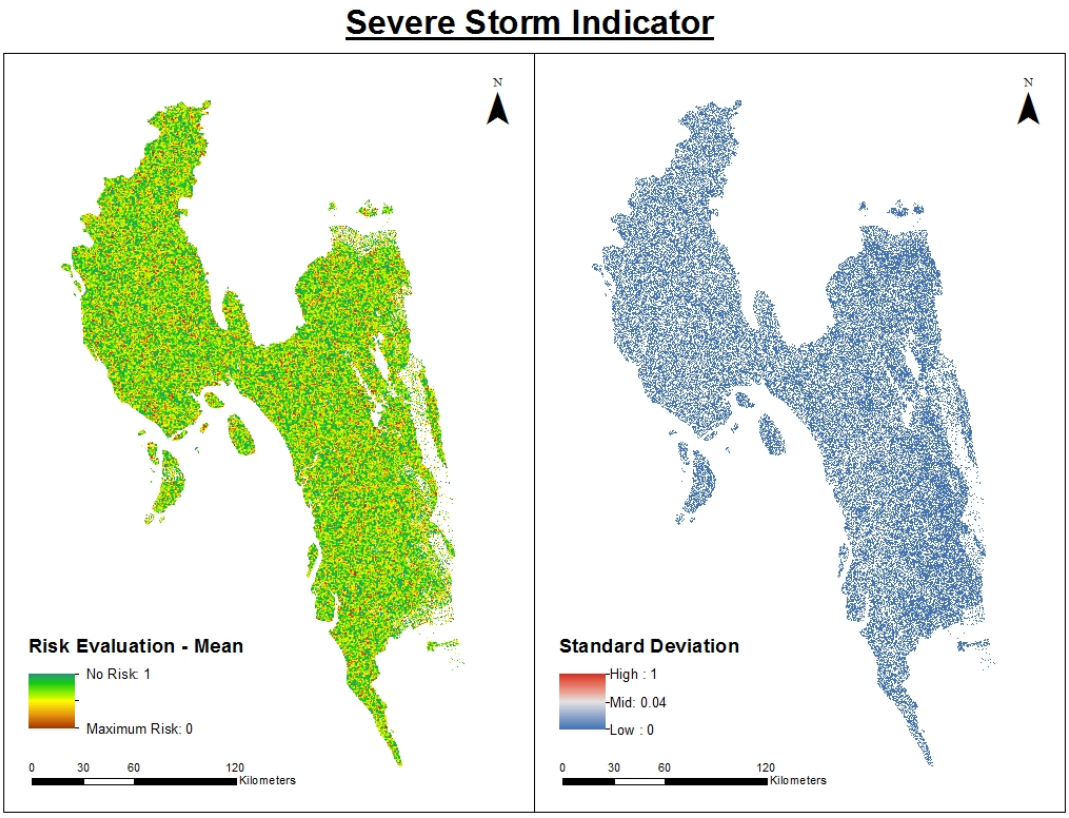
Metric	Weight Minimum Value	Weight Maximum Value
Severe Storm	1.0	1.0

Uncertainty values

This indicator is given an uncertainty minimum value of 0.4 and an uncertainty maximum value of 0.6. Adding more data on effects of severe storms could decrease the uncertainty values.

Indicator Uncertainty Min:	0.4
Indicator Uncertainty Max:	0.6

Example outcome



References

Colwell, R. R. 1996. Global climate and infectious disease: The cholera paradigm. *Science, 274*(5295), 2025-2031. Retrieved from https://erdclibrary.idm.oclc.org/login?url=http://search.proquest.com/docview/213559223?accountid=26153.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Pascual, M., Rodó, X., Ellner, S. P., Colwell, R., & Bouma, M. J. 2000. Cholera dynamics and El Niño-southern oscillation. *Science*, *289*(5485), 1766-1769.

Metric: Severe Storm

Indicator:	Severe Storm
Factor:	Climatological Effects/Consequences
Condition:	Natural Hazards
Framework:	Cholera
Metric Assigned Values:	Min: 1.0 Max: 1.0
Survey:	N/A
Survey Date:	N/A
Other Data Sources:	Jutla et al. (2013); Colwell (1996); Pascual et al. (2000)
Logic:	Jutla et al. (2013) find in the literature that "an increase in cholera outbreaks following heavy rainfall is observed in epidemic regions of Africa. Similar observations have been reported in Bangladesh, Haiti, and East Africa (p.600)." Jutla expands that a decrease in water level are linked to cholera outbreaks due to the increased salinity's ability to create favorable conditions for growth of cholera bacteria. Additionally "increased rainfall and poor sanitation yields a higher likelihood of a cholera epidemic." Colwell (1996) warns of El Niño which brings rain and warm sea surface temperatures that are associated with plankton blooms. These conditions are associated with cholera outbreaks. Pascual et al. (2000) find that El Niño – Southern Oscillation (ENSO) is associated with cholera patterns, but that local temperatures mediate ENSO's influence on cholera.
Example Realization Metric Map:	Unavailable. Metric data was downloaded from the source as a table.

References

Colwell, R. R. 1996. Global climate and infectious disease: The cholera paradigm. *Science, 274*(5295), 2025-2031. Retrieved from https://erdclibrary.idm.oclc.org/login?url=http://search.proquest.com/docview/213559223?accountid=26153.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A.,... & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Pascual, M., Rodó, X., Ellner, S. P., Colwell, R., & Bouma, M. J. 2000. Cholera dynamics and El Niño-southern oscillation. *Science*, *289*(5485), 1766-1769.

A.2.2.3 Indicator: Monthly average rainfall

The Average Rainfall indicator accounts for average rainfall. It has been found in the literature that, "an increase in cholera outbreaks following heavy rainfall is observed in epidemic regions of Africa" (Jutla et al., 2013).

Metric weighting logic

The metrics "Average Rainfall" and "Standard Precipitation Index" are equally weighted on the indicator as they come from the same primary source. The primary source is "Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), a 30+ year quasi-global rainfall dataset … creates gridded rainfall time series for trend analysis and seasonal drought monitoring." The metrics derived from CHIRPS address the same concern for anticipating above average rainfall which raises the odds of a cholera outbreak.

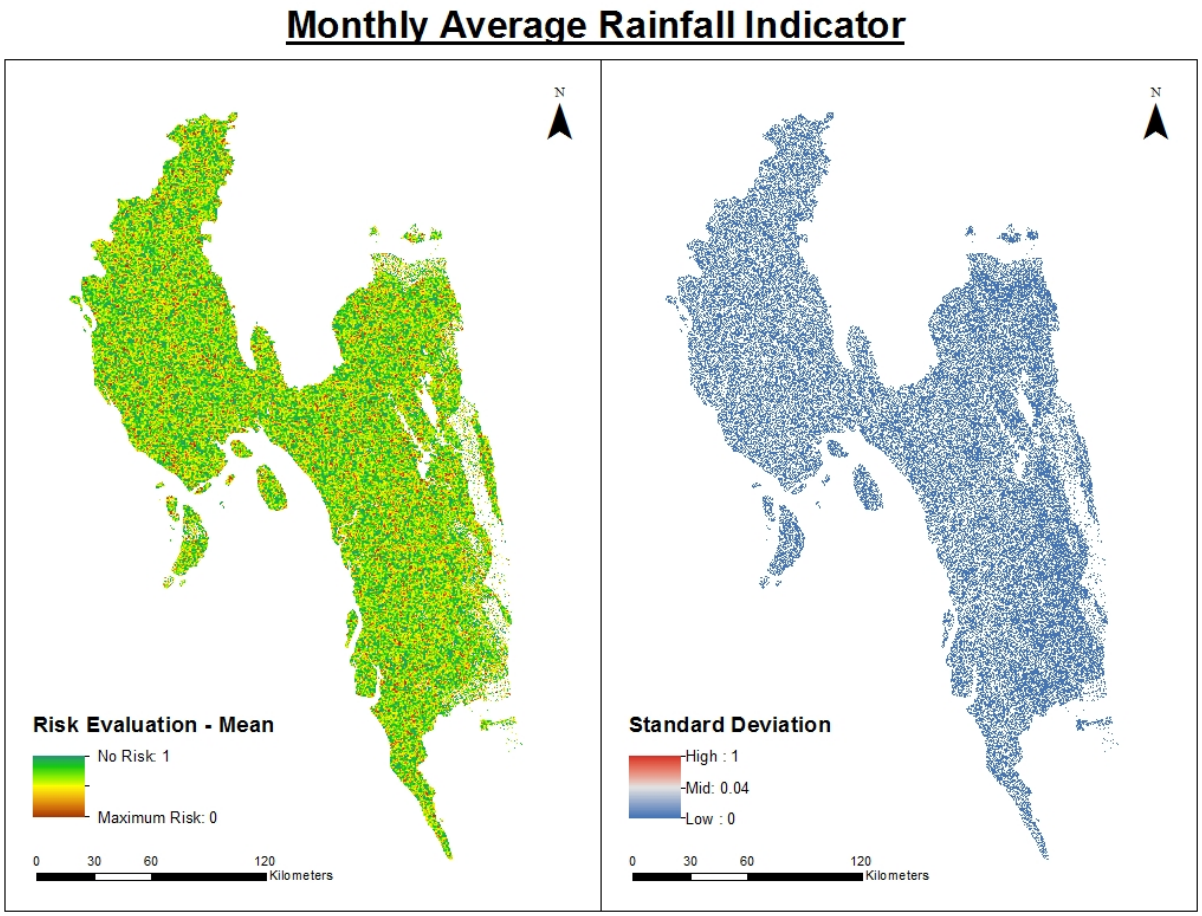
Metric	Weight Minimum Value	Weight Maximum Value
Average Rainfall	0.5	0.5
Standard Precipitation Index	0.5	0.5

Uncertainty values

This indicator is given an uncertainty minimum value of 0.4 and an uncertainty maximum value of 0.6. Adding more data on effects of average rainfall could decrease the uncertainty values.

Indicator Uncertainty Min:	0.4
Indicator Uncertainty Max:	0.6

Example outcome



References

Climate Hazard Group (CHG) 2017. "Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)". Jan. 2017. http://chg.geog.ucsb.edu/data/chirps/.

Haque, F., Hossain, M. J., Kundu, S. K., Naser, A. M., Rahman, M., & Luby, S. P. 2013. Cholera outbreaks in urban Bangladesh in 2011. *Epidemiology (Sunnyvale, Calif.)*, *3*.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Metric: Mean Rainfall

Indicator:	Average Rainfall
Factor:	Climatological Effects/Consequences
Condition:	Natural Hazards

Framework:	Cholera
Metric Assigned Values:	Min: To Be Determined (TBD) Max: TBD
Survey Date:	1982-2017
Other Data Sources:	CHG (2017); De Magny et al. (2008); Emch et al. (2010); Jutla et al. (2013)
Logic:	The primary source of the data is 5km CHIRPS Pentad series. This aggregated time series is a monthly mean precipitation in units of millimeters from January 1982 to January 2017. The data are in a multiple band ENVI Standard Format in Geographic Coordinate System. De Magny et al. (2008) find heavy rainfall to be correlated to cholera outbreaks and statistically significant in Kolkata, India, but not Matlab, Bangladesh. Jutla et al. (2013) consider environmental factors influencing epidemic cholera and state that "rainfall provides the most appropriate mechanism for spread of cholera … In fact, the odds of a cholera outbreak occurring is 1.5 times greater than for below average precipitation." Jutla expands that a decrease in water level are linked to cholera outbreaks due to the increased salinity's ability to create favorable conditions for growth of cholera bacteria. Additionally "increased rainfall and poor sanitation yields a higher likelihood of a cholera epidemic." Emch et al. (2010) states that rainfall in Bangladesh is seasonal with July to September being the monsoon months. Cholera rates are seasonal as a result. Rates are lowest during the winter months (January to March) and by comparison, four times higher before and after monsoon season (April-June & October-December), whereas rates are two times higher during the monsoon season. As cholera rates are seasonal, Haque et al. (2013) discusses an urban outbreak of cholera that occurred during the summer season. The summer season sees a low water table. This reduces water supply from tube wells. Residents tend to pour municipal tap water into the tube wells to raise pressure to initiate water flow. The tap water used to raise pressure was likely contaminated with cholera due to pipe leakages that passed through open sewers.
Example Realization Metric Map:	Unavailable. Metric data was downloaded from the source as a table.

References

Climate Hazard Group (CHG) 2017. "Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)". Jan. 2017. http://chg.geog.ucsb.edu/data/chirps/.

Emch, M., Yunus, M., Escamilla, V., Feldacker, C., & Ali, M. 2010. Local population and regional environmental drivers of cholera in Bangladesh. *Environmental Health*, *9*(1), 1.

Haque, F., Hossain, M. J., Kundu, S. K., Naser, A. M., Rahman, M., & Luby, S. P. 2013. Cholera outbreaks in urban Bangladesh in 2011. *Epidemiology (Sunnyvale, Calif.)*, *3*.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

de Magny, G. C., Murtugudde, R., Sapiano, M. R., Nizam, A., Brown, C. W., Busalacchi, A. J., & Calkins, J. 2008. Environmental signatures associated with cholera epidemics. *Proceedings of the National Academy of Sciences*, *105*(46), 17676-17681.

Metric: SPI (Drought Index)

Indicator:	Average Rainfall
Factor:	Climatological Effects/Consequences
Condition:	Natural Hazards
Framework:	Cholera
Metric Assigned Values:	Min: TBD Max: TBD
Survey:	5km CHIRPS Pentad series
Survey Date:	1982-2017
Other Data Sources:	CHG (2017); De Magny et al. (2008); Emch et al. (2010); Jutla et al. (2013)
Logic:	The CHIRPS monthly mean data were processed in R using a standardized precipitation index script. The data were processed using 3 different accumulations; 3-month, 6-month, and 12-month. The 3-month accumulation relates to seasonal estimation of precipitation anomalies. The 6-month accumulation relates to medium-term trends in precipitation patterns. The 12-month accumulation reflects the long-term patterns, usually tied to stream flows, reservoir levels, and even groundwater levels. The units are in z-scores. For example, > 1.96 is a significantly higher than normal precipitation pattern and < -1.96 is significantly lower than normal (i.e., drought). See attachments for visualization. One graphic shows the data displayed with my Time Series Analysis Tool (TSAT) and the other is the extracted data represented in Excel. De Magny et al. (2008) find heavy rainfall to be correlated to cholera outbreaks and statistically significant in Kolkata, India, but not Matlab, Bangladesh. Jutla et al. (2013) consider environmental factors influencing epidemic cholera and state that “rainfall provides the most appropriate mechanism for spread of cholera … In fact, the odds of a cholera outbreak occurring is 1.5 times greater than for below average precipitation." Emch et al. (2010) states that rainfall in Bangladesh is seasonal with July to September being the monsoon months. Cholera rates are seasonal as a result. Rates are lowest during the winter months (January to March) and by comparison, four times higher before and after monsoon season (April-June & October-December), whereas rates are two times higher during the monsoon season. Thus, this framework will differentiate predictability of cholera outbreaks via the z-scores > 1.96 which indicate that the

	accumulation was statistically significantly higher than the average at the 5% level.
Example Realization Metric Map:	Unavailable. Metric data was downloaded from the source as a table.

References

Climate Hazard Group (CHG) 2017. "Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)". Jan. 2017, Accessed at http://chg.geog.ucsb.edu/data/chirps/.

Emch, M., Yunus, M., Escamilla, V., Feldacker, C., & Ali, M. 2010. Local population and regional environmental drivers of cholera in Bangladesh. *Environmental Health*, *9*(1), 1.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

de Magny, G. C., Murtugudde, R., Sapiano, M. R., Nizam, A., Brown, C. W., Busalacchi, A. J., & Calkins, J. 2008. Environmental signatures associated with cholera epidemics. *Proceedings of the National Academy of Sciences*, *105*(46), 17676-17681.

A.2.2.4 Indicator: Sea level rise

The Sea Level Rise indicator accounts for sea surface height and future sea level rise. As the current form of this model does not yet consider future sea level rise, the only metric includes data on sea surface height. Sea surface height has been shown to be related to cholera fluctuations (Emch et al., 2010). At the household level, this can account for elements that can potentially lead to a dangerous living environment, such as quality of drinking water source.

Metric weighting logic

The metric is purely informed by sea surface height and so, to fully inform the indicator, both minimum and maximum values are given a 1.0 weighing.

Metric	Weight Minimum Value	Weight Maximum Value
Sea Surface Height	1.0	1.0

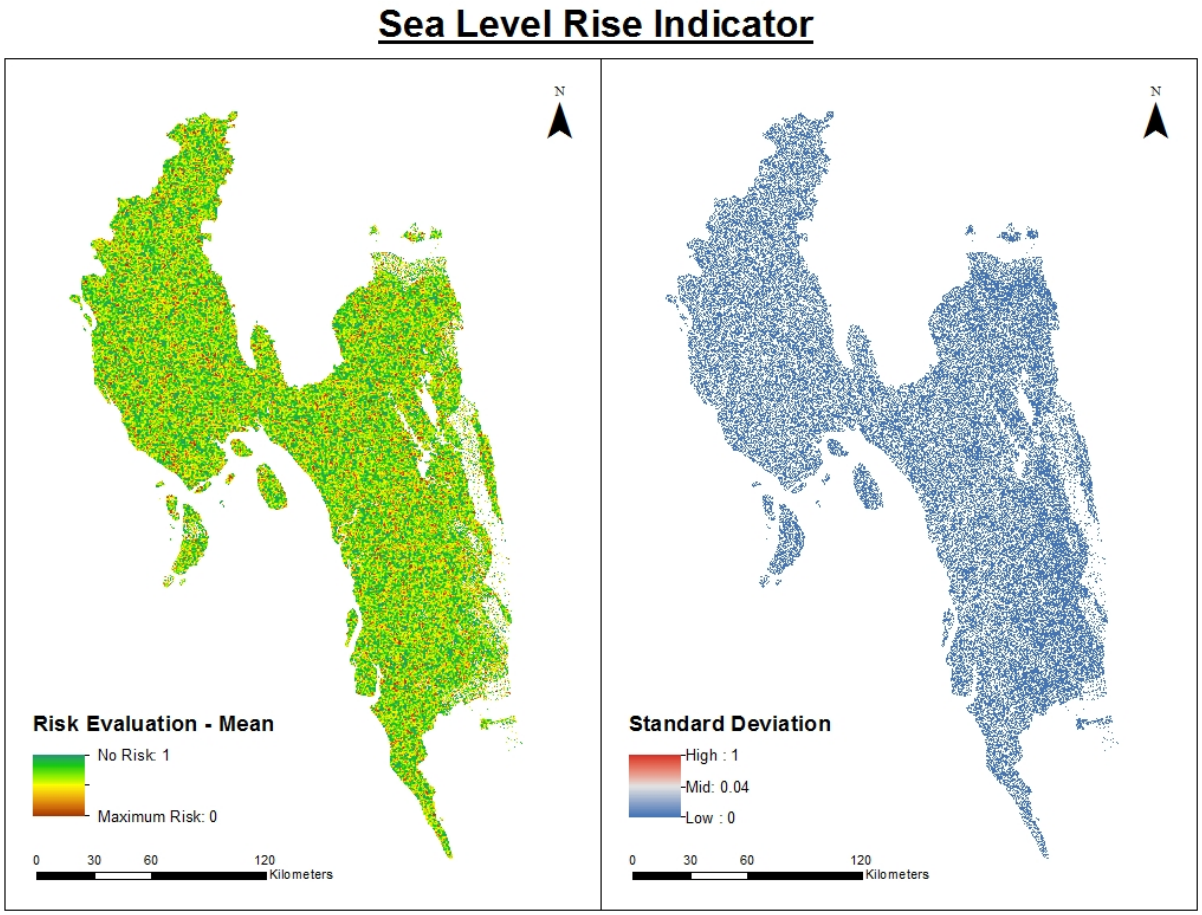
Uncertainty values

This indicator is given an uncertainty minimum value of 0.4 and an uncertainty maximum value of 0.6. Adding more data on effects of sea level rise

on cholera outbreaks and additional data such as projected sea level rise could decrease the uncertainty values.

Indicator Uncertainty Min:	0.4
Indicator Uncertainty Max:	0.6

Example outcome



References

Emch, M., Yunus, M., Escamilla, V., Feldacker, C., & Ali, M. 2010. Local population and regional environmental drivers of cholera in Bangladesh. *Environmental Health*, *9*(1), 1.

Metric: Sea Surface Height

Indicator:	Sea Level Rise
Factor:	Climatological Effects/Consequences
Condition:	Natural Hazards

Framework:	Cholera
Metric Assigned Values:	Min: 1.0 Max: 1.0
Survey:	N/A
Survey Date:	N/A
Other Data Sources:	Emch et al. 2010; Glass et al. 1982; Jutla et al. 2013; Lobitz et al. 2000
Logic:	Lobitz et al. (2000) found a positive relationship between cholera outbreaks and sea surface height. Emch et al. (2010) found a weak relationship between cholera outbreaks and sea surface height pre-monsoon season (Apr-Jun), but did not find a relationship between the two post-monsoon season (Oct-Dec). Glass et al. (1982) found that, "no constant relationship was found between the times of onset or peaks of the yearly cholera epidemic and the times of onset or peaks of the monsoon rains of river water levels." Jutla et al. (2013) found that decreased water levels increase salinity which "creates favorable environmental conditions for growth of cholera bacteria." These opposing viewpoints justify weighting the indicator less than other indicators.
Example Realization Metric Map:	Unavailable. Metric data was downloaded from the source as a table.

References

Emch, M., Yunus, M., Escamilla, V., Feldacker, C., & Ali, M. 2010. Local population and regional environmental drivers of cholera in Bangladesh. *Environmental Health*, *9*(1), 1.

Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., & Black, R. E. 1982. Endemic cholera in rural Bangladesh, 1966–1980.*American journal of epidemiology*, *116*(6), 959-970.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Lobitz, B., Beck, L., Huq, A., Wood, B., Fuchs, G., Faruque, A. S. G., & Colwell, R. 2000. Climate and infectious disease: use of remote sensing for detection of Vibrio cholerae by indirect measurement. *Proceedings of the National Academy of Sciences*, *97*(4), 1438-1443.

A.2.2.5 Indicator: Max daily temperature

The Max Daily Temperature indicator accounts for air temperature in relation to cholera growth. Metrics should include data on Max Daily Temperature as it has been found that air temperature has a significant impact on cholera incidence (Paz, 2009). At the household level, this can account for elements that can potentially lead to a dangerous living environment, such as quality of drinking water source.

Metric weighting logic

The metric "Land Surface Temperature" is derived from the primary source MODIS Terra sensor from February 2000 to present in a 5-km Climate Modeling Grid (CMG). "Land Surface Temperature" is the only metric in this indicator and thus the constraining metric on the indicator.

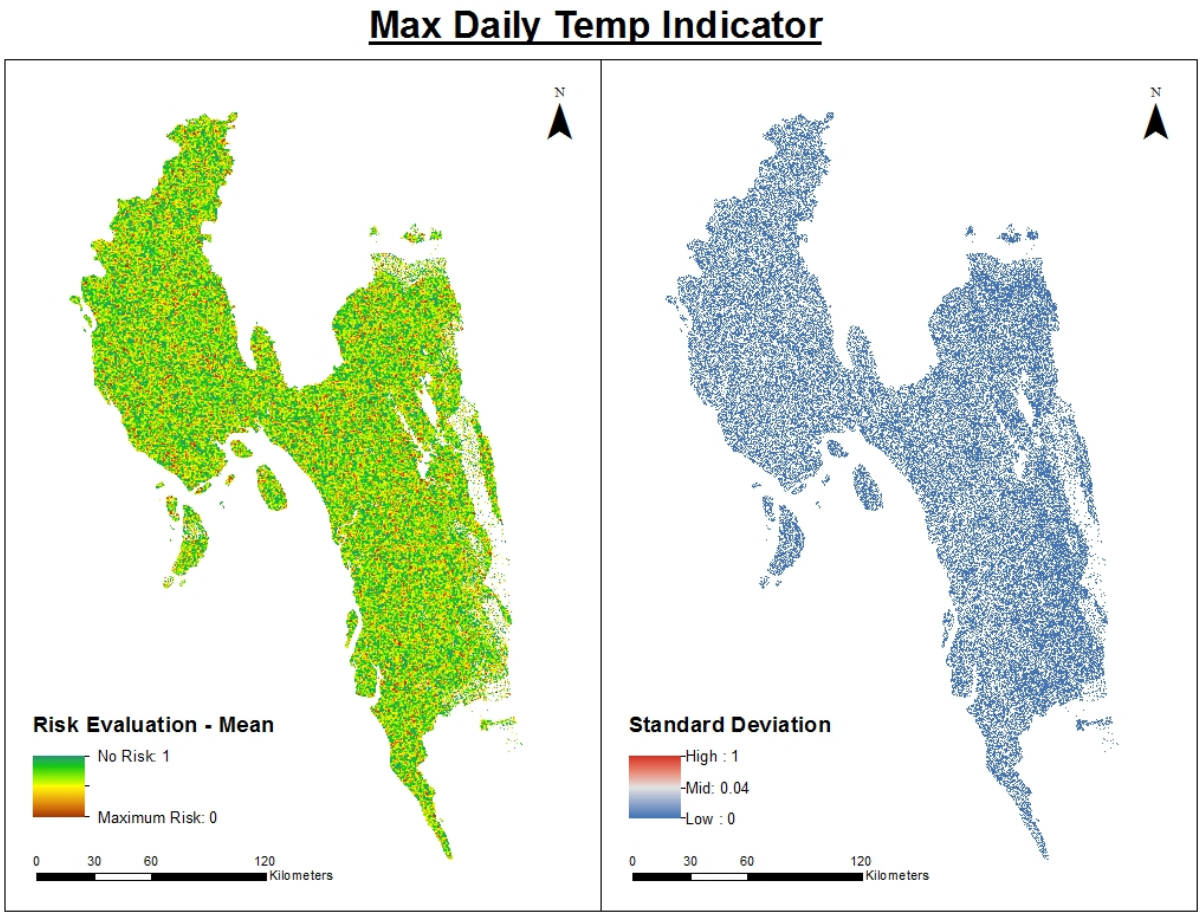
Metric	Weight Minimum Value	Weight Maximum Value
Land Surface Temperature	1.0	1.0

Uncertainty values

This indicator is given an uncertainty minimum value of 0.4 and an uncertainty maximum value of 0.6. Adding more data on effects of Max Daily Temperature could decrease the uncertainty values.

Indicator Uncertainty Min:	0.4
Indicator Uncertainty Max:	0.6

Example outcome



References

MODIS (Moderate Resolution Imaging Spectroradiometer) Terra Sensor. 2017. NASA.

Paz, S. 2009. Impact of temperature variability on cholera incidence in southeastern Africa, 1971–2006. *Ecohealth*, *6*(3), 340-345.

Metric: Land Surface Temperature

Metric:	Land Surface Temperature
Indicator:	Max Daily Temperature
Factor:	Climatological Effects/Consequences
Condition:	Natural Hazards
Framework:	Cholera
Metric Assigned Values:	Min: 1.0 Max: 1.0

Survey:	N/A
Survey Date:	N/A
Other Data Sources:	Jutla et al. (2013); MODIS (2017); Paz (2009)
Logic:	The data informing this metric is courtesy of Sean Griffin via MODIS. "The temperature data are land surface temperature in units (Kelvin) derived from the MODIS Terra sensor from February 2000 to present. The product is the 5-km CMG, product ID MOD11C3. I ran some signal processing algorithms over the data to interpolate missing pixels. I used a combination of Savitzky-Golay and harmonic analysis (i.e., Fast Fourier transform). The data are also in a multiple band ENVI Standard Format and in Geographic Coordinate System" (S. Griffin, personal communication, February 24, 2017). Jutla et al. (2013) consider environmental factors influencing epidemic cholera and state that the figure below "shows that about 50% or more cholera outbreaks occurred when the air temperature is >31°C." For example, Jutla et al. (2013) discusses flooding and cholera outbreaks in Pakistan in 2005 & 2010. In 2010, 600,000 sought treatment for diarrheal disease, but a breakout did not occur in 2005. That is due to the cold weather at the time of the 2005 flooding preventing the growth and spread of V. cholera. Jutla et al. (2013) found that elevated air temperature help to produce conditions optimal for cholera and extremely cold conditions are not conducive to the growth and spread of cholera bacteria (p.602-603). "Incidence of cholera peaked when the air temperature reached 26 degrees Celsius (p.600)." Jutla et al. (2013) expands that "if air temperature is above the climatological average for 2 months, and is followed by above climatological average rainfall, in combination with poor or damaged water and sanitation access, it is probable that the region will experience a cholera epidemic (p. 601)". Paz (2009) found that air temperature has a significant impact on cholera incidence in the study of cholera incidence in southeastern Africa from 1971-2006. Air temperature is found to be most correlated when using the previous year's air temperature.
Example Realization Metric Map:	Unavailable. Metric data was downloaded from the source as a table.

References

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

MODIS (Moderate Resolution Imaging Spectroradiometer) Terra Sensor. 2017. NASA.

Paz, S. 2009. Impact of temperature variability on cholera incidence in southeastern Africa, 1971–2006. *Ecohealth*, *6*(3), 340-345.

A.2.3 Ecosystem disruptions factor overview

The HC framework includes epidemics/pandemics, severe insect infestation, commodity destruction/infection, and wildfires as indicators trying to inform the Ecosystem Disruptions factor. These indicators and metrics are able to most represent how the environment can impact an individual's predisposition to contracting cholera in terms of Ecosystem Disruptions.

The only indicator within this factor includes Epidemics/Pandemic (1.3.1) due to limited data on the other areas that inform the factor. Cholera and similar diseases fall under the umbrella of the Epidemics/Pandemic indicator and thus is included in the framework.

Indicator weighting logic

"Epidemics/Pandemic" is the only metric in this indicator and thus the constraining metric on the indicator and will be weighted from 1.0 to 1.0.

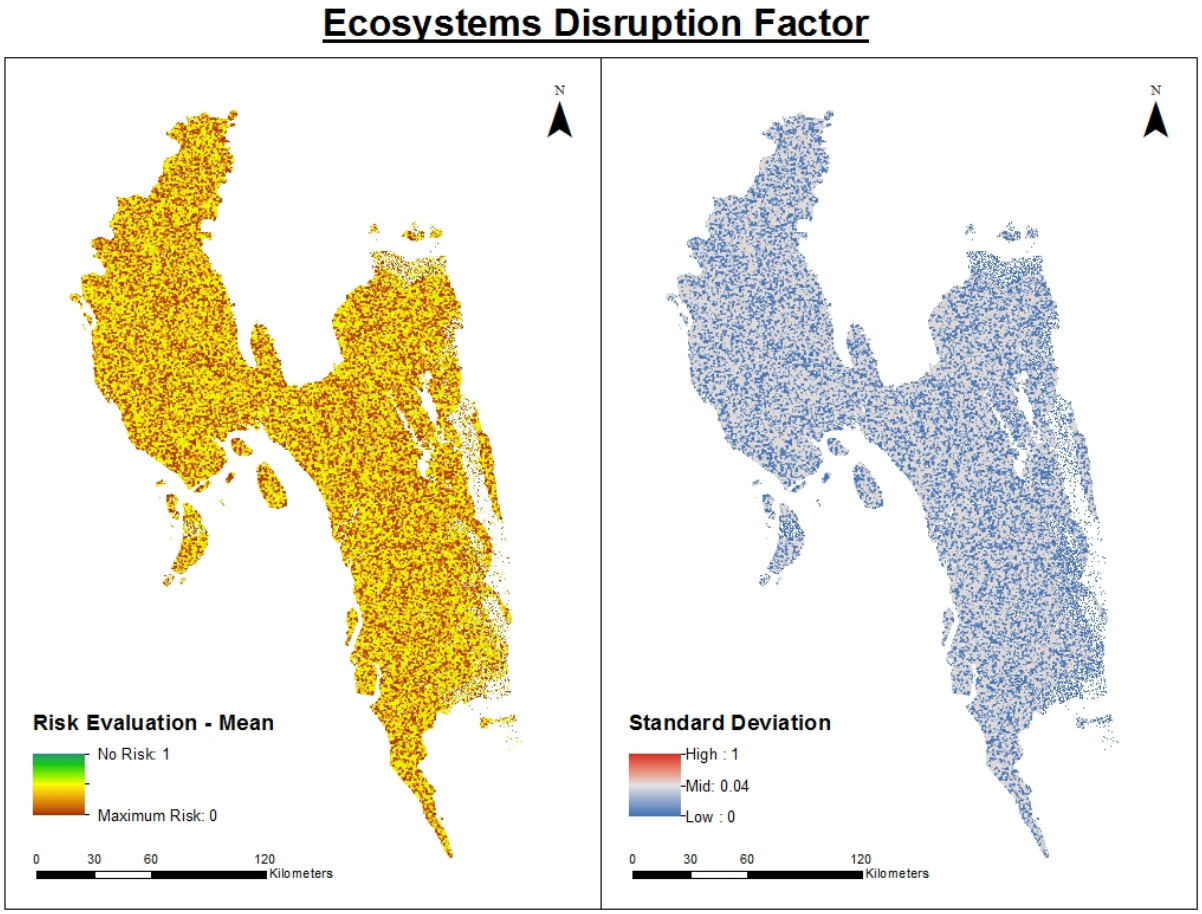
Indicator	Weight Minimum Value	Weight Maximum Value
Epidemics/Pandemic	1.0	1.0

Uncertainty values

This factor is given a range of uncertainty values from 0.4 to 0.8 because of the limited data's ability to fully address the themes of the factor. The addition of many metrics to inform other indicators that target cholera growth and outbreaks could further decrease the uncertainty values.

Factor Uncertainty Min:	0.5
Factor Uncertainty Max:	0.8

Example outcome



A.2.3.1 Indicator: Epidemics/pandemic

According to the CDC, an epidemic is defined as an increase, often sudden, in the number of cases of a disease above what is normally expected in the population in that area (2012). They occur when an agent and susceptible hosts are present in adequate numbers, and the agent can be effectively conveyed from a source to the susceptible hosts. This can result from: a recent increase in amount or virulence of the agent; the recent introduction of the agent into a new, previously unexposed setting; an enhanced mode of transmission so that more susceptible people are exposed; a change in the susceptibility of the host response to the agent, and/or; factors that increase host exposure or involve introduction through new portals of entry (Kelsey et al, 1986).

A pandemic is an epidemic that has spread over several countries and continents, usually affecting a large number of people (CDC, 2012).

Intact ecosystems maintain a diversity of species in equilibrium and can often provide a disease-regulating effect (the "regulating" ecosystem service mentioned above) if any of these species are either directly or indirectly involved in the life cycle of an infectious disease (Patz et al. 2005). Disease agents with much of their life cycle occurring external to the human host (i.e. non-vector-borne diseases) are subjected to environmental conditions, and it is these diseases for which most linkages to ecosystem conditions have been found (Patz et al. 2000). A disruption in to the disease-regulating environment can lead to an epidemic and/or a pandemic.

PACOM specifies that metrics should include: number of epidemics/pandemics; percentage of population with vaccinations; population density in vulnerable areas; number of casualties per capita; crude mortality rate; and financial impact of epidemics/pandemics.

The applicable metric to cholera outbreaks is whether or not someone has been vaccinated. Jutla et al. 2013, calls for a cholera prediction model to include vaccination of vulnerable demographic groups in advance.

Metric weighting logic

The metric "vaccinated" is the only metric in the indicator and thus is weighted with both a minimum and maximum value of 1.0

Metric	Weight Minimum Value	Weight Maximum Value
Vaccinated	1.0	1.0

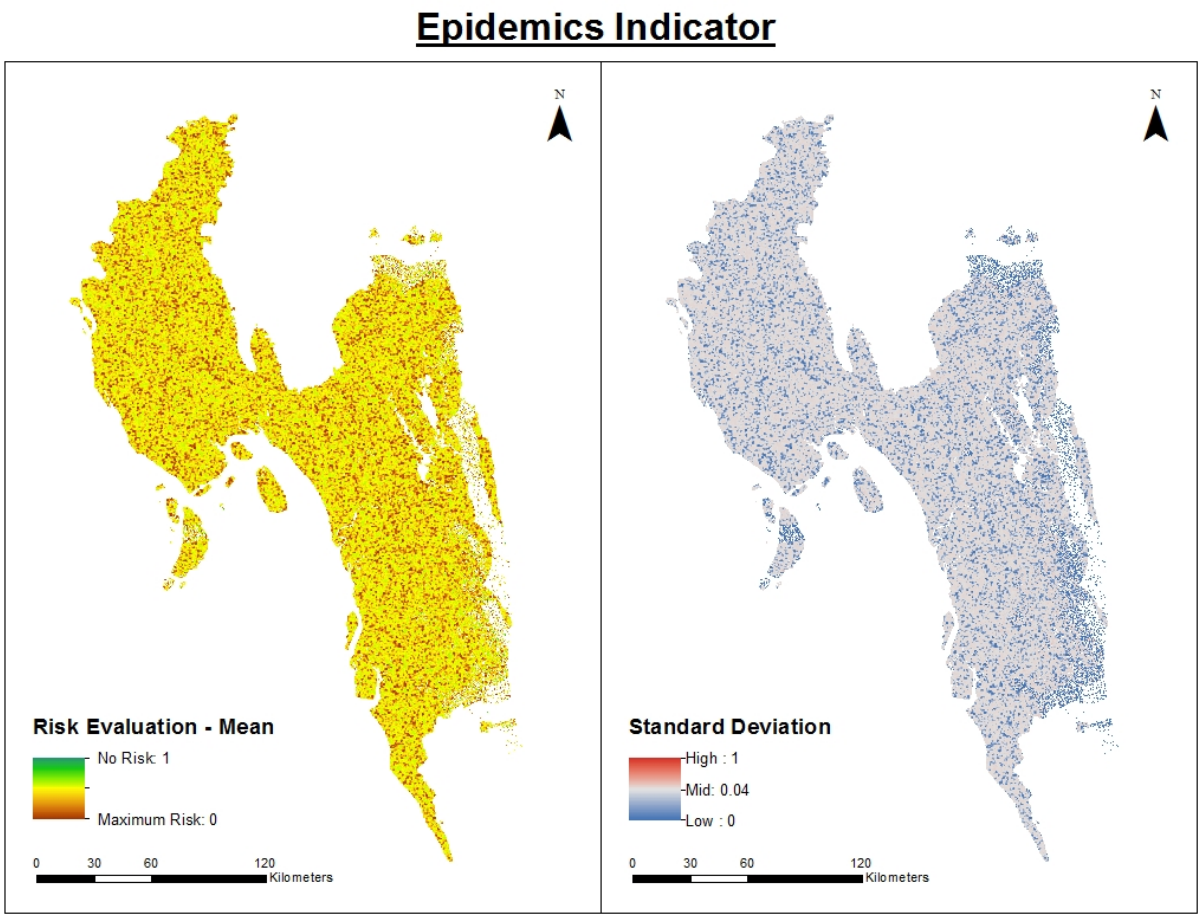
Uncertainty values

This indicator is given an uncertainty minimum of 0.7 and a maximum value of 0.9. The relatively high uncertainty values are due to the few metrics that make up the indicator. Survey data that is projected for an entire country using computer algorithms is less accurate than a government-sanctioned national survey. Compounding this uncertainty value are the questions and answers pulled from the surveys, which only address disease spread with vaccinations. Adding in historical epidemic and pandemic data could lower the indicator uncertainty values.

Alternatively, if this indicator was renamed “Vaccinations” or “Preventative Disease Measures,” it would better reflect the existing Urban Security metrics. This could lower the uncertainty values to a minimum of 0.1 and a maximum of 0.3.

Indicator Uncertainty Min:	0.7
Indicator Uncertainty Max:	0.9

Example outcome



References

Center for Disease Control (CDC) 2012. “Section 11: Epidemic Disease Occurrence.” *Principles of Epidemiology in Public Health Practice, Third Edition*. https://www.cdc.gov/OPHSS/CSELS/DSEPD/SS1978/Lesson1/Section11.html#_ref47.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Kelsey, J.L., Thompson, W.D., Evans, A.S. 1986. *Methods in observational epidemiology*. New York: Oxford University Press; 1986. p. 216.

Patz, J.A., Graczyk, T.K., Geller, N., and Vittor, A.Y. 2000. Effects of environmental change on emerging parasitic diseases. *Int J Parasitol*, 30, 1395–1405.

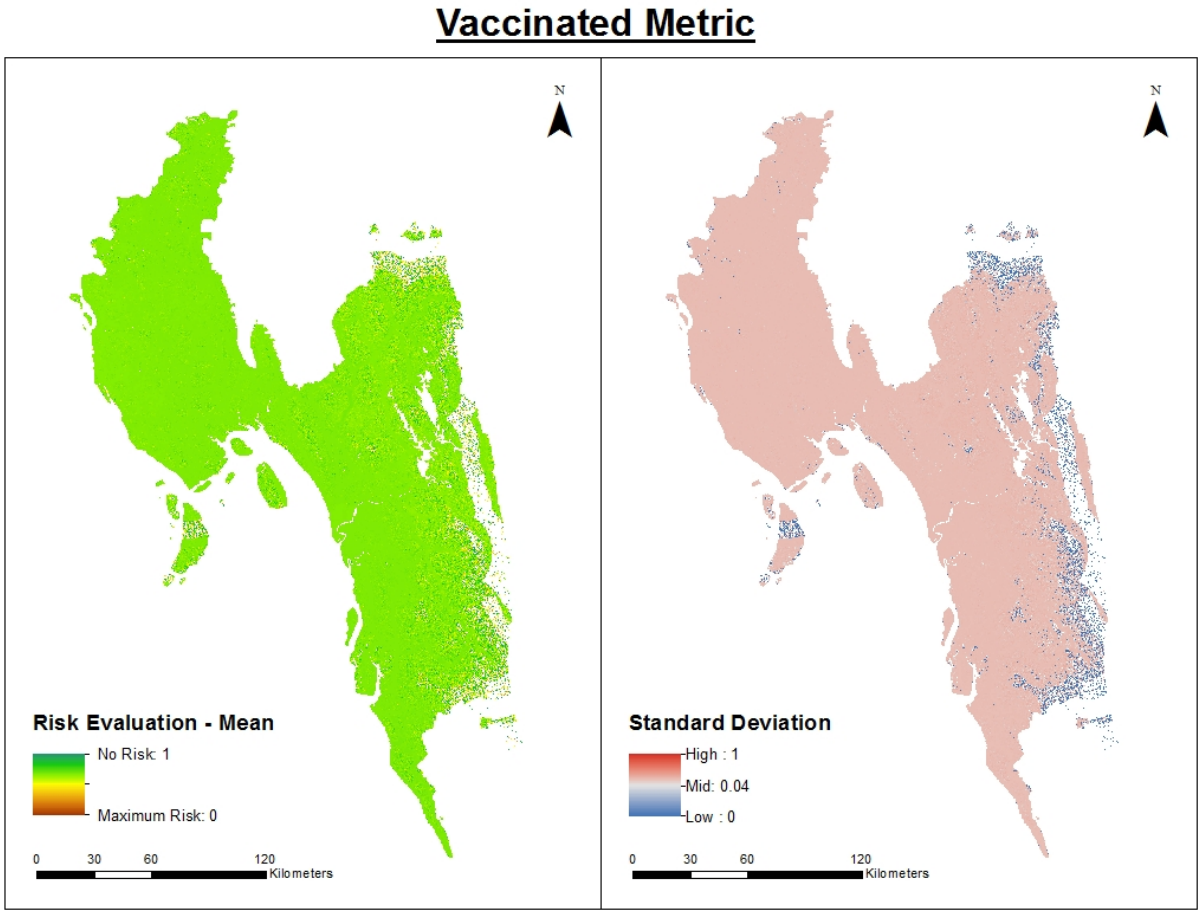
Patz, Jonathon A. and Ulisses E.C. Confalonieri 2005. "Human Health: Ecosystem Regulation of Infectious Diseases." Chapter 14 in *Ecosystems and Human Well-being: Current State and Trends, Volume 1*. Ed. Rashid Hassan, Robert Scholes, Neville Ash. Island Press, Washington DC, 2005. http://www.unep.org/maweb/documents/document.283.aspx.pdf on 20 Dec 2016.

Metric: Vaccinated

Indicator:	Epidemics/Pandemics
Factor:	Ecosystem Disruptions
Condition:	Natural Hazards
Framework:	Cholera
Metric Assigned Values:	Yes (min: 0.5, max: 1.0) No (min: 0.0625, max: 0.5)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	DHS (2016); Jutla et al. (2013); Sarker et al. (2015); UNISDR 2009
Logic:	This metric consists of answers to the question "Have you ever had a vaccination?" from the DHS survey. The "No" response is given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). The "Yes" response is given a minimum value of 0.5 and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from extreme risk to no risk. This question does not address vaccination against specific diseases, but rather is an indication to healthcare access. Vaccinations can act as preventive measures against epidemics, pandemics, and biological hazards, defined as "Process or phenomenon of organic origin or conveyed by biological vectors, including exposure to pathogenic micro-organisms, toxins and bioactive substances that may cause loss of life, injury, illness or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage" (UNISDR 2009, p 4-5). Jutla et al. 2013, calls for a cholera prediction model to include vaccination of vulnerable demographic groups in advance. Sarker et al. 2015, states that the WHO "recommends using oral cholera vaccines as a public health tool in addition to traditional prevention practices and treatments in both epidemic and endemic settings." Unfortunately, in developing countries such as Bangladesh, affordability of the vaccine prevents the expansion of cholera vaccine programs. The Expanded Program on Immunization in Bangladesh is one that uses vaccines for preventable diseases to reduce child mortality. The cost analysis conducted found that "the total societal cost per fully-vaccinated person was $3.98."

While we do not have direct data on if a person was vaccinated for cholera, it is logical to assume that if an individual has ever had a vaccination, the likelihood of having access to the cholera vaccination as well is increased.

Example realization metric map



References

Demographic & Health Survey (DHS) 2016. *Bangladesh – Stat Compiler*. Dec. 2016. http://dhsprogram.com/Where-We-Work/Country-Main.cfm?ctry_id=1&c=Bangladesh.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Sarker, A. R., Islam, Z., Khan, I. A., Saha, A., Chowdhury, F., Khan, A. I., & Khan, J. A. 2015. Estimating the cost of cholera vaccine delivery from the societal point of view: A case of introduction of cholera vaccine in Bangladesh. *Vaccine*, *33*(38), 4916-4921.

United Nations International Strategy for Disaster Reduction (UNISDR) 2009. *2009 UNISDR Terminology on Disaster Risk Reduction*. Geneva, Switzerland. May 2009.

A.3 Human behavioral impact condition overview

This condition encompasses potential risks and hazards caused by humans. It focuses on the potential impacts that human behavior could have on infrastructure, as well as living and working conditions of humans. It is these factors, indicators, and metrics that most represent how the local environment can affect an individual's risk to contract cholera.

Factors within this condition include Vulnerable Groups, Substandard Conditions, and Household Civil Infrastructure Failure.

Factor weighting logic

The Substandard Conditions factor within the Human Behavioral Impact condition was given both a minimum and a maximum value of 0.5. Both the Vulnerable Groups and Household Civil Infrastructure Failure factors were given minimum and maximum weight values of 0.25. This is because the Substandard Conditions has the ability to better determine the condition's risk value, whereas Vulnerable Groups and Household Civil Infrastructure Failures still have the ability to determine the condition's risk value, but would be incomplete without Substandard Conditions.

Factor	Weight Minimum Value	Weight Maximum Value
Vulnerable Group	0.25	0.25
Substandard Conditions	0.5	0.5
Household Civil Infrastructure Failure	0.25	0.25

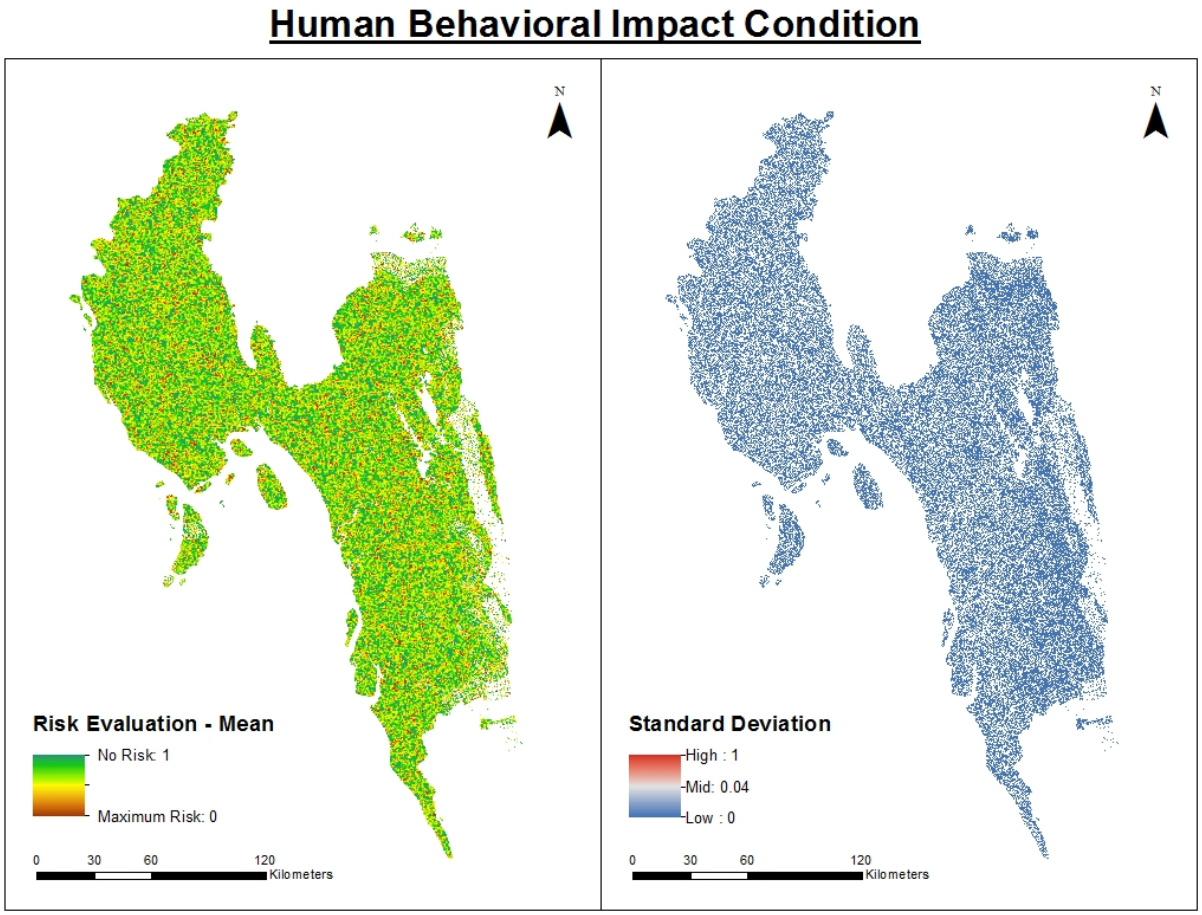
Uncertainty values

This condition is given a range of uncertainty values from 0.1 to 0.3 because of the perceived ability of the existing factors to fully address the themes of the condition. The factors Vulnerable Groups, Substandard Conditions, and Household Civil Infrastructure Failure address many issues regarding the local human environment such as vulnerable groups, polluted environment, and household features that could increase local risk to waterborne disease outbreaks. The addition of other factors, indicators,

and metrics which measure quality of life, such as specific treatments for severe diarrhea, could further decrease the uncertainty values.

Condition Uncertainty Min:	0.1
Condition Uncertainty Max:	0.3

Example outcome



A.3.1 Vulnerable groups factor overview

This factor assesses the presence of groups of people who are, due to their current circumstances, more vulnerable to humanitarian crises, specifically cholera outbreaks. There are various definitions of "vulnerability" that are relevant here:

"Vulnerability: The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a haz-

> ard. This definition identifies vulnerability as a characteristic of the element of interest (community, system or asset) which is independent of its exposure. However, in common use the word is often used more broadly to include the element's exposure." (UNISDR 2009, pg 30)
>
> *"Vulnerability and vulnerability assessment generally relate to the identification of factors (such as social, physical, economic and environmental factors) that, on the one hand, render people or systems susceptible to impacts resulting from natural hazards and climate change, and on the other hand, describe their adapt to adverse impacts of natural hazards. Vulnerability and hence the susceptibility, coping capacities and adaptive capacities of people and systems, however, are not static but are subject to strong dynamics."* (Birkmann, et al. 2011, pg 15)
>
> *"…Vulnerability refers to social, physical, economic and environment-related factors that make people or systems susceptible to the impacts of natural hazards and adverse consequences of climate change. Additionally, the Index examines the abilities and capacities of people or systems to cope with and adapt to negative impacts of natural hazards."* (Welle, et al. 2012, pg 14)

Within the HC framework, this factor includes indicators of IDPs/Refugees; Undernourished Population; Casualties, Injured, Sick; and Targeted Groups. This factor was expanded by the authors to target cholera and so new indicators were created to better inform the framework to vulnerable groups to cholera. These new indicators are: Age, Children, Literacy, Education, Urbanity, and Women & Gender.

Indicator weighting logic

Three of the nine indicators within the Vulnerable Groups factor are given a minimum of 0.3 and a maximum value of 0.5. This is because Age, Children, and Women & Gender are equally important on the predicting the factor as they are more commonly included in studies of cholera. Three of the nine indicators within the Vulnerable Groups factor are given a minimum of 0.2 and a maximum value of 0.4. This is because Literacy, Education, and Targeted Groups are equally important on the predicting the factor as they are more commonly included in studies of cholera. The indicators Urbanity, Undernourished Population, and Casualties, Injured, Sick are weighted with a minimum value of 0.1 and a maximum value of 0.2, as there are fewer metrics informing them.

Indicator	Weight Minimum Value	Weight Maximum Value
Age	0.3	0.5
Children	0.3	0.5
Literacy	0.2	0.4
Education	0.2	0.4
Urbanity	0.1	0.3
Undernourished Population	0.1	0.3
Casualties, Injured, Sick	0.1	0.3
Targeted Groups	0.2	0.4
Women and Gender	0.3	0.5

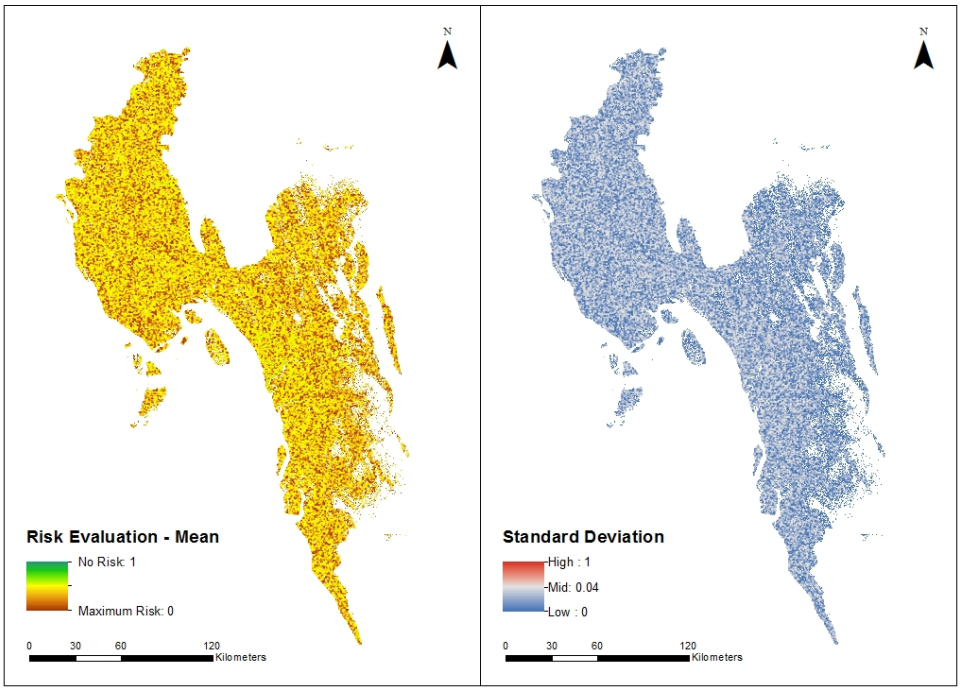
Uncertainty values

This factor is given a range of uncertainty values from 0.10 to 0.15 because of the perceived ability of the existing indicators to fully address the themes of the factor. Uncertainty is non-zero in order to account for inaccuracies in the existing data.

Factor Uncertainty Min:	0.10
Factor Uncertainty Max:	0.15

Example outcome

Vulnerable Groups Factor



References

Birkmann, Jorn, Torsten Welle, Dunja Krause, Jan Wolfertz, Dona-Catalina Suarez, and Neysa Jacqueline Setiadi (2011), "2. WorldRiskIndex: Concept and results," *WorldRiskReport 2011*, Alliance Development Works, Berlin, Germany, 2011, pp 13-42.

United Nations International Strategy for Disaster Reduction (UNISDR) 2009. *2009 UNISDR Terminology on Disaster Risk Reduction*. Geneva, Switzerland. May 2009.

Welle,Torsten, Jorn Birkmann, Jakob Rhyner, Maximilian Witting, and Jan Wolfertz (2012), "2. WorldRiskIndex 2012: Concept, updating and results," *WorldRiskReport 2012*, Alliance Development Works, Berlin, Germany, 2012, pp 11-23.

A.3.1.1 Indicator: Age

The age indicator accounts for variations is risk for cholera among varying age groups. Metrics should include data on age that has been assessed from the literature and applied to the results of the Integrated Public Use Microdata Series (IPUMS) and DHS.

Metric weighting logic

The metrics within the age indicator are given minimum and maximum weight values of 0.333. Even though gender, as a potential contributor to cholera risk, may be accounted for in other metrics/indicators (e.g. Sex in the Women and Gender indicator), it does not impact the metric weighting logic of this particular indicator.

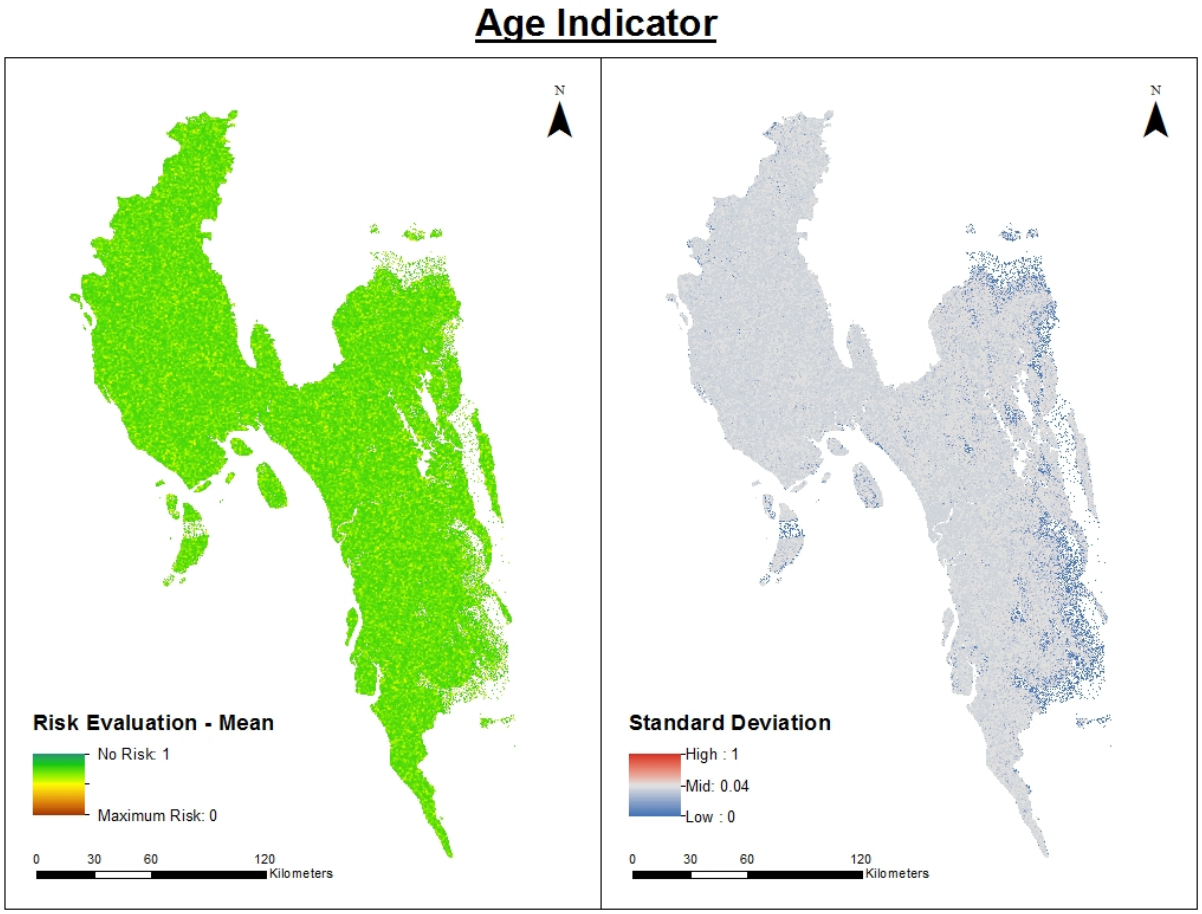
Metric	Weight Minimum Value	Weight Maximum Value
Age – Men	0.333	0.333
Age – Women	0.333	0.333
Child Age	0.333	0.333

Uncertainty values

This indicator is given an uncertainty minimum value of 0.1 and an uncertainty maximum value of 0.2. The indicator has a low uncertainty as there are many sources in the literature that support the findings that different ages and genders are more susceptible to cholera risk.

Indicator Uncertainty Min:	0.1
Indicator Uncertainty Max:	0.2

Example outcome



Metric: Respondent Age – Men

Indicator:	Age	
Factor:	Vulnerable Groups	
Condition:	Human Behavioral Impact	
Framework:	Cholera	
Metric Assigned Values:	15-19 (min: 0.5, max: 0.9)	40-44 (min: 0.75, max: 1.0)
	20-24 (min: 0.75, max: 1.0)	45-49 (min: 0.75, max: 1.0)
	25-29 (min: 0.75, max: 1.0)	50-54 (min: 0.75, max: 1.0)
	30-34 (min: 0.75, max: 1.0)	55-59 (min: 0.5, max: 0.9)
	35-39 (min: 0.75, max: 1.0)	60-64 (min: 0.5, max: 0.9)
Survey:	DHS - Men	
Survey Date:	2011	
Other Data Sources:	Glass et al. 1982; Clemens et al. 1986; Siddique et al (1992)	

Logic:

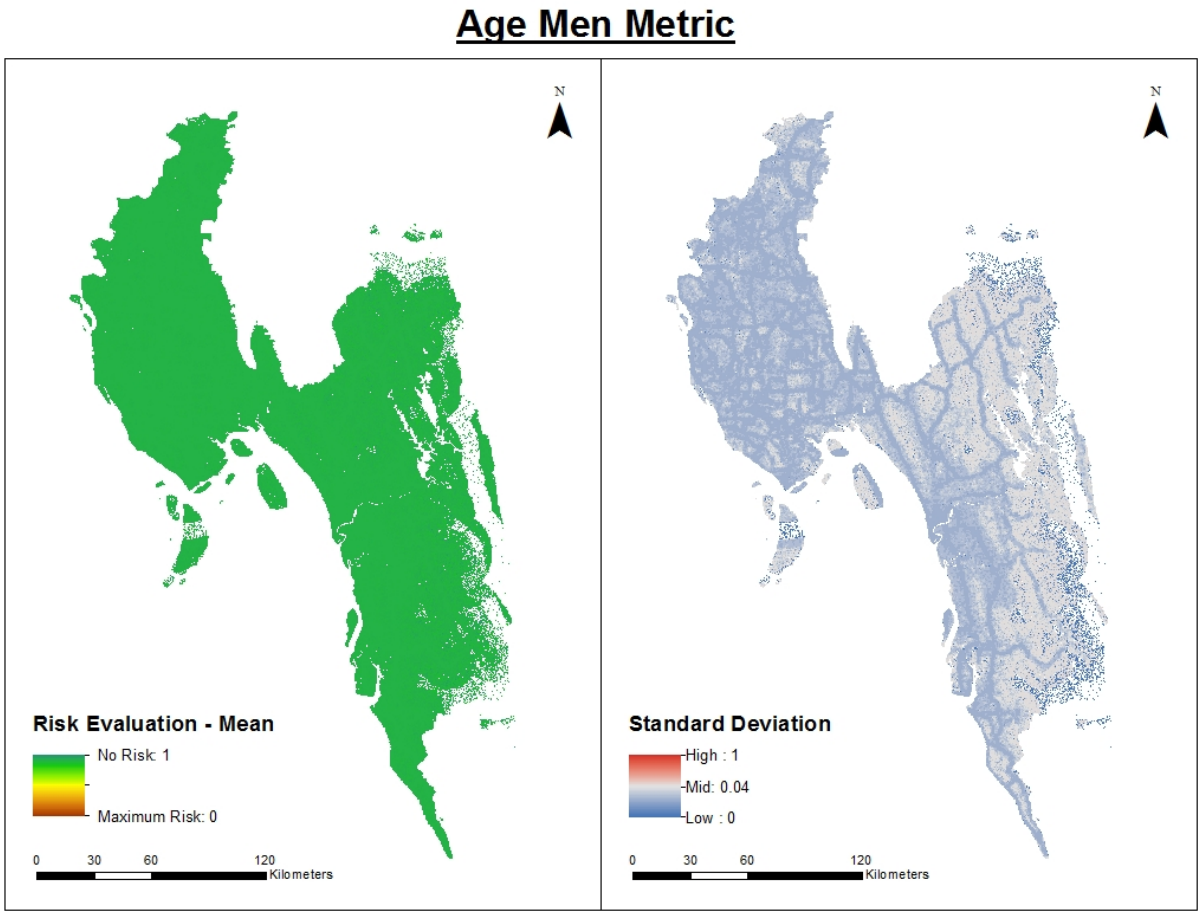
This metric consists of answers to the question of respondent age for the male portion of the DHS survey. Answers of 15-19, 55-59, and 60-64 are given a minimum value of 0.5 (slight risk, $\frac{1}{2}^1$) and a maximum value of 0.9 (minimal risk). This reflects the increased vulnerability of the young and old to contracting cholera. All other ages are given a minimum value of 0.75 (minimal risk) and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from slight risk to no risk.

Glass et al. found that, "children 2-9 years old and adult women are most commonly hospitalized for cholera."

Siddique et al (1992) found that of laboratory confirmed adults 15-39 with cholera, between the years 1985-1991, men were 44.6% of the patients. The difference was negligible for adults over the age of 40.

Clemens et al. stated that only persons aged 2-15 and females over 15 years of age qualified for the vaccine trial as they are at the highest risk for cholera in Matlab, Bangladesh having cited Glass et al. 1982.

Example realization metric map



References

Clemens, J., Harris, J., Khan, M. R., Kay, B., Yunus, M. D., Svennerholm, A. M.,... & Atkinson, W. 1986. Field trial of oral cholera vaccines in Bangladesh. *The Lancet*, *328*(8499), 124-127.

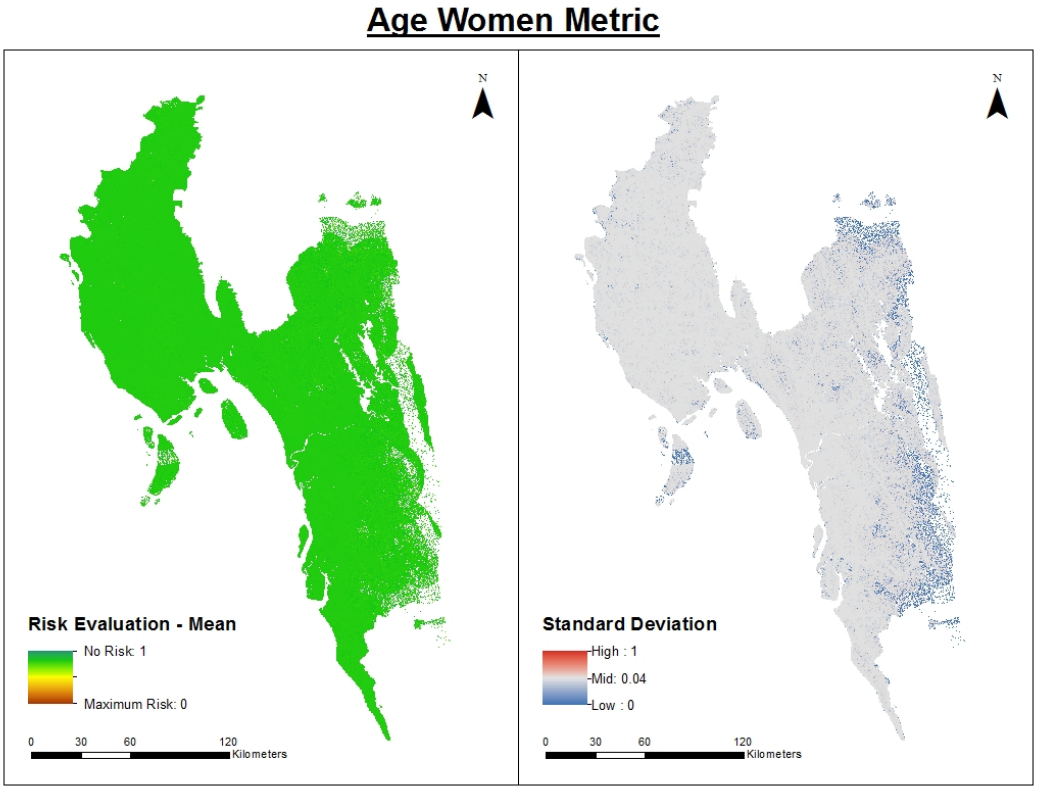
Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., & Black, R. E. 1982. Endemic cholera in rural Bangladesh, 1966–1980. *American journal of epidemiology*, *116*(6), 959-970.

Siddique, A. K., Zaman, K., Baqui, A. H., Akram, K., Mutsuddy, P., Eusof, A., & Sack, R. B. 1992. Cholera epidemics in Bangladesh: 1985-1991. *Journal of diarrhoeal diseases research*, 79-86.

Metric: Respondent Age - Women

Indicator:	Age	
Factor:	Vulnerable Groups	
Condition:	Human Behavioral Impact	
Framework:	Cholera	
Metric Assigned Values:	15-19 (min: 0.5, max: 0.9)	40-44 (min: 0.75, max: 0.9)
	20-24 (min: 0.5, max: 0.9)	45-49 (min: 0.75, max: 0.9)
	25-29 (min: 0.5, max: 0.9)	50-54 (min: 0.75, max: 0.9)
	30-34 (min: 0.5, max: 0.9)	55-59 (min: 0.75, max: 0.9)
	35-39 (min: 0.5, max: 0.9)	60-64 (min: 0.75, max: 0.9)
Survey:	DHS - Women	
Survey Date:	2011	
Other Data Sources:	Glass et al. 1982; Clemens et al. 1986; Siddique et al (1992)	
Logic:	Glass et al. found that, “children 2-9 years old and adult women are most commonly hospitalized for cholera.” Siddique et al (1992) found that of laboratory confirmed adults 15-39 with cholera, between the years 1985-1991, women were 55.4% of the patients. The difference was negligible for adults over the age of 40. Clemens et al. stated that only persons aged 2-15 and females over 15 years of age qualified for the vaccine trial as they are at the highest risk for cholera in Matlab, Bangladesh having cited Glass et al. 1982. This finding justifies the span of values for the assigned values to the female age metric metadata. Adult females 15-39 have been assigned an overall minimal risk with a minimum value of 0.5 (slight risk, ½[1]) and a maximum value of 0.9 (minimal risk). Adult females 40+ have been assigned a minimum value of 0.75 (minimal risk) and a maximum value of 0.9. Maps will range from slight risk to minimal risk.	

Example realization metric map



References

Clemens, J., Harris, J., Khan, M. R., Kay, B., Yunus, M. D., Svennerholm, A. M., & Atkinson, W. 1986. Field trial of oral cholera vaccines in Bangladesh. *The Lancet*, *328*(8499), 124-127.

Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., & Black, R. E. 1982. Endemic cholera in rural Bangladesh, 1966–1980.*American journal of epidemiology*, *116*(6), 959-970.

Siddique, A. K., Zaman, K., Baqui, A. H., Akram, K., Mutsuddy, P., Eusof, A., & Sack, R. B. 1992. Cholera epidemics in Bangladesh: 1985-1991.*Journal of diarrhoeal diseases research*, 79-86.

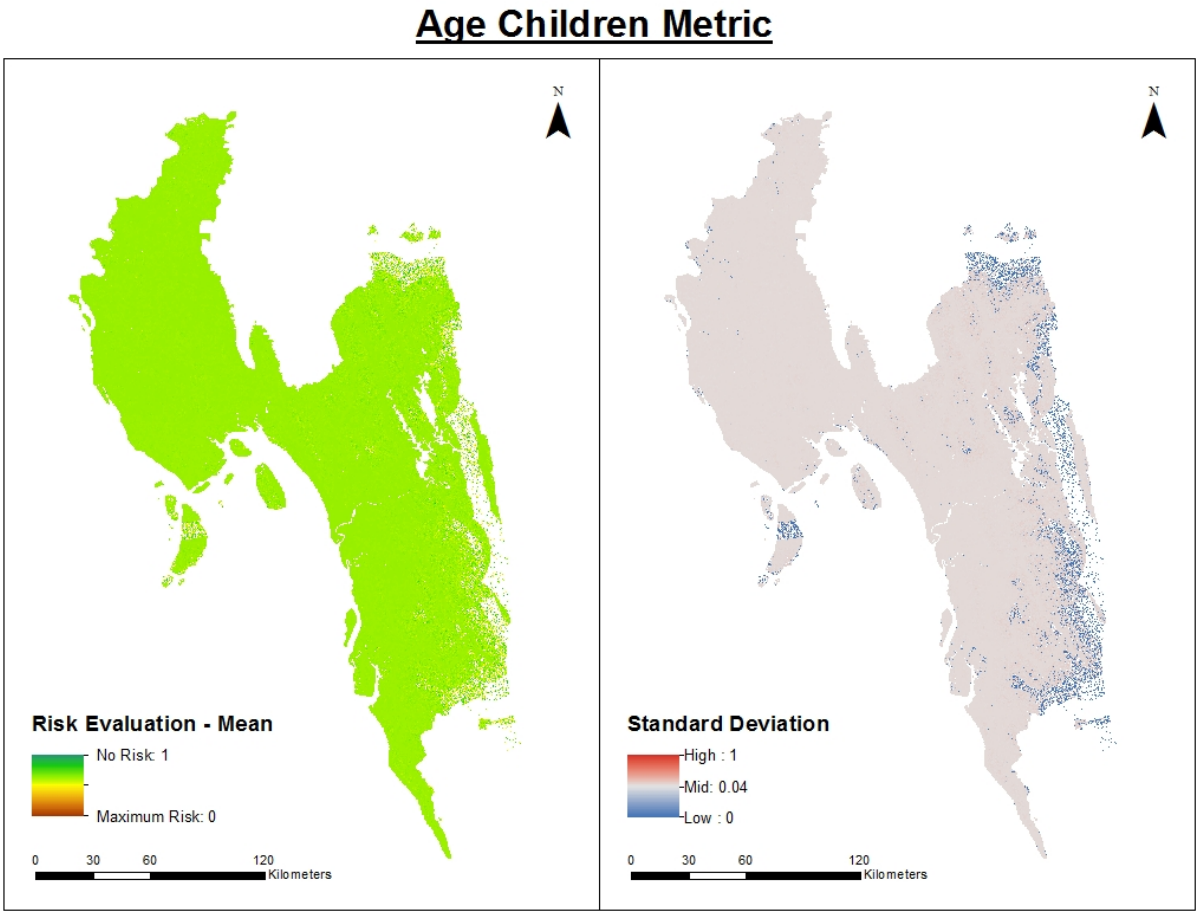
Metric: Child Age

Indicator:	Age
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera

Metric Assigned Values:	Under1Year (min: 0.125, max:0.9) 1thru3Year (min: 0.125, max: 0.75) 4thru6Year (min: 0.125, max: 0.75) 7thru12Year (min: 0.125, max: 0.75) 13thru16Year (min: 0.125, max: 0.9) 17PlusYear (min: 0.25, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 2); D'Souza, 1985; Deen et al. (2008); Emch (1999); Glass et al. (1982); Glass & Black (1992); Siddique et al (1992); Talavera & Perez (2009); World Bank Group (2016)
Logic:	Emch (1999) states that, "Diarrheal diseases are the largest cause of death among children under five." D'Souza (1985), diarrhea was estimated as the cause of death for 2.25% of infants in Matlab, Bangladesh from 1975-1977, and for children ages 1-4, 5.5%. Cause of death is not significantly differentiated by sex. Glass et al. found that, "children 2-9 years old and adult women are most commonly hospitalized for cholera." Siddique et al found that 59.2% of laboratory confirmed cholera patients between the years of 1985-1991 were below the age of 14. This indicates that children are a slightly more at-risk population in comparison to the World Bank's 1990 population estimates that children 0-14 made up 42.3% of the total population. Furthermore, children 1-9 made up 45.6% of the cholera patients. This is cause to give these age groups higher assigned risk. Glass and Black (1992) also found that children aged 2 to 15 are at greatest risk of contracting cholera. Talavera & Perez (2009) review that children are the most affected population from cholera. Deen et al (2008) compares cholera incidence across Jakarta, Indonesia, Kolkata, India, and Beira, Mozambique. Across all three locations, children ages 1-5 are the population most at risk, with the highest rates being 2.2-3.8 times higher than average. Children under 2 had even higher rates in Kolkata and Jakarta, 5.4 & 6.4 times higher respectively. Ali et al. (2002, 2) discuss that children under the age of 5 usually defecate in open places. Thus the more children under the age of 5, the more at-risk households are to experience feces spreading and contaminating surface water. Children 17+ have been assigned overall slight risk with a minimum of 0.25 (medium risk, $½^2$) and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Children 0-1 & 13-16 have been assigned an overall medium risk with a minimum value of 0.125 (high risk, $½^3$) and a maximum value of 0.9 (minimal risk). Children 1-12 have been assigned slightly higher risk with a minimum value of 0.125 and a maximum value of 0.75 (minimal risk). Maps will range from high risk to no risk. It should be noted that, as this version of the framework was constructed as a proof of research concept, only the results pertaining to the first child for whom answers were provided were used to create this metric. For questions under section 2 (Reproduction) of the women's portion of the DHS Bangladesh survey, answers were allowed

for up to 12 children. Results from these questions will only contain answers for the eldest child. For questions under Sections 4 (Pregnancy and Postnatal Care) and 5 (Child Immunization, Health, and Nutrition), answers were allowed for children from the last birth, the next-to-last birth, and the second next-to-last birth (i.e. the youngest three children of the female respondent). Results from these questions will only contain answers for the youngest child.

Example realization metric map



References

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D'Souza, S. 1985. Mortality Case Study Matlab, Bangladesh.

Deen, J. L., Von Seidlein, L., Sur, D., Agtini, M., Lucas, M. E., Lopez, A. L., & Clemens, J. D. 2008. The high burden of cholera in children: comparison of incidence from endemic areas in Asia and Africa. *PLoS Negl Trop Dis*, *2*(2), e173.

Emch, Michael. "Diarrheal disease risk in Matlab, Bangladesh." *Social science & medicine* 49, no. 4 (1999): 519-530.

Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., & Black, R. E. 1982. Endemic cholera in rural Bangladesh, 1966–1980.*American journal of epidemiology*, *116*(6), 959-970.

Glass, R. I., & Black, R. E. 1992. The epidemiology of cholera. In *Cholera* (pp. 129-154). Springer U.S.

Siddique, A. K., Zaman, K., Baqui, A. H., Akram, K., Mutsuddy, P., Eusof, A., & Sack, R. B. 1992. Cholera epidemics in Bangladesh: 1985-1991.*Journal of diarrhoeal diseases research*, 79-86.

Talavera, Arturo, and Ela M. Perez. "Is cholera disease associated with poverty?. *The Journal of Infection in Developing Countries* 3, no. 06 (2009): 408-411.

World Bank Group 2016. "World Development Indicators." 2016. http://databank.worldbank.org/data/reports.aspx?source=2&country=BGD.

A.3.1.2 Indicator: Children

The children indicator accounts for the fact that children are more at risk of cholera than adults. At the household level, this can account for the number of children that can potentially increase rates and risk of cholera, leading to a dangerous living environment.

Metric weighting logic

The metric for Children under 5 in Household is given higher weights, as there is more support for the 1-5 age group as being at higher risk for cholera as opposed to children in general. In addition, there are only few sources supporting that more children increase rates of cholera.

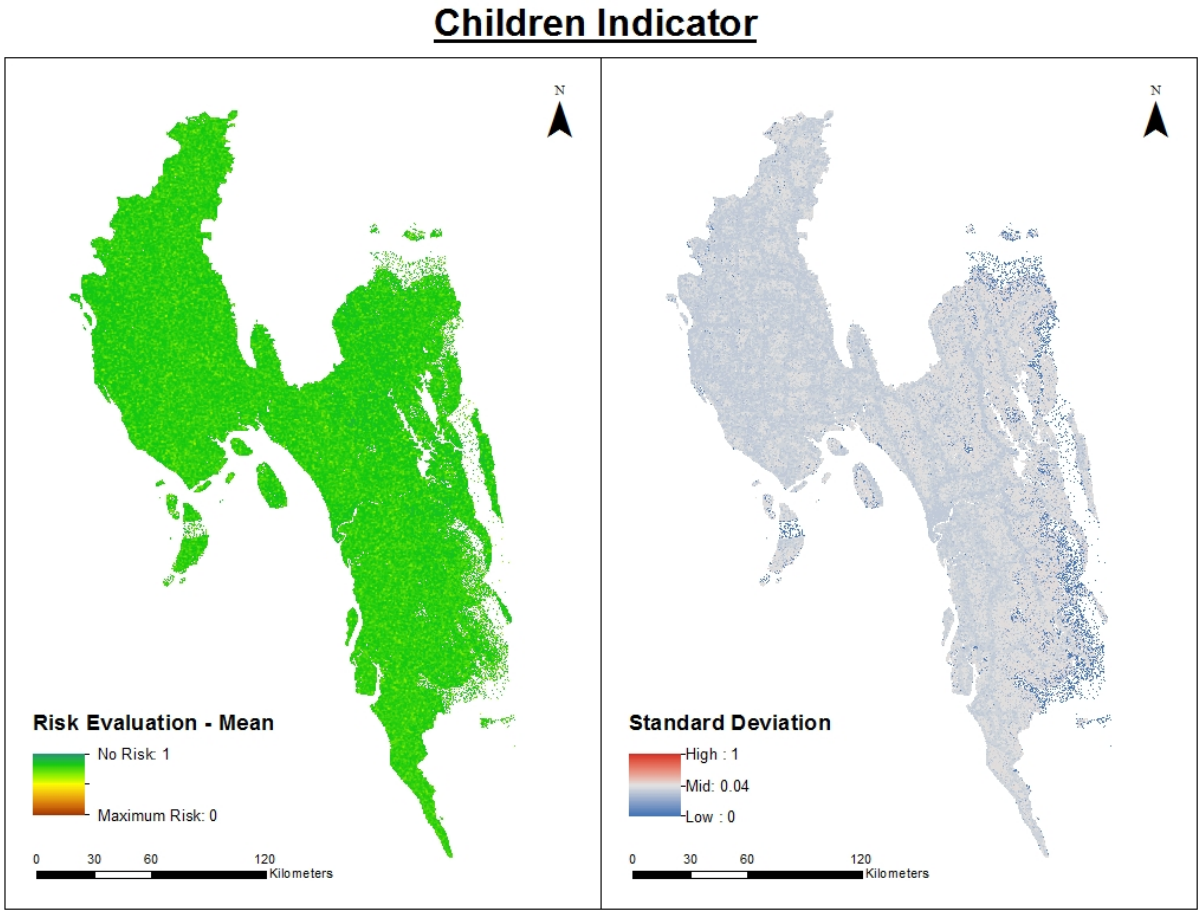
Metric	Weight Minimum Value	Weight Maximum Value
Total Number of Children – Women reporting	0.2	0.3
Total Number of Children – Men reporting	0.2	0.3
Children under 5 in Household	0.6	0.8

Uncertainty values

This indicator is given an uncertainty minimum value of 0.05 and an uncertainty maximum value of 0.10, which reflects the ability of this indicator to adequately depict the relevance of children in terms of cholera risk.

Indicator Uncertainty Min:	0.05
Indicator Uncertainty Max:	0.10

Example outcome



Metric: Total Number of Children – Women reporting

Indicator:	Children	
Factor:	Vulnerable Groups	
Condition:	Human Behavioral Impact	
Framework:	Cholera	
Metric Assigned Values:	0 Children (min: 1.0, max: 1.0) 1 Child (min: 0.75, max: 1.0) 2 Children (min: 0.5, max: 1.0) 3 Children (min: 0.5, max: 1.0)	4 Children (min: 0.25, max: 0.9) 5 Children (min: 0.25, max: 0.9) 6 Children (min: 0.125, max: 0.75) 7+ Children (min: 0.125, max: 0.75)
Survey:	DHS - Women	
Survey Date:	2013	

Other Data Sources: Ali et al. (2002, 2); D'Souza, 1985; Deen et al. (2008); Emch,1999; Glass et al. 1982; Glass & Black (1992); Siddique (1992); Talavera & Perez (2009); World Bank Group (2016)

Logic: Emch (1999) states that, "Diarrheal diseases are the largest cause of death among children under five." D'Souza (1985), diarrhea was estimated as the cause of death for 2.25% of infants in Matlab, Bangladesh from 1975-1977, and for children ages 1-4, 5.5%. Cause of death is not significantly differentiated by sex.

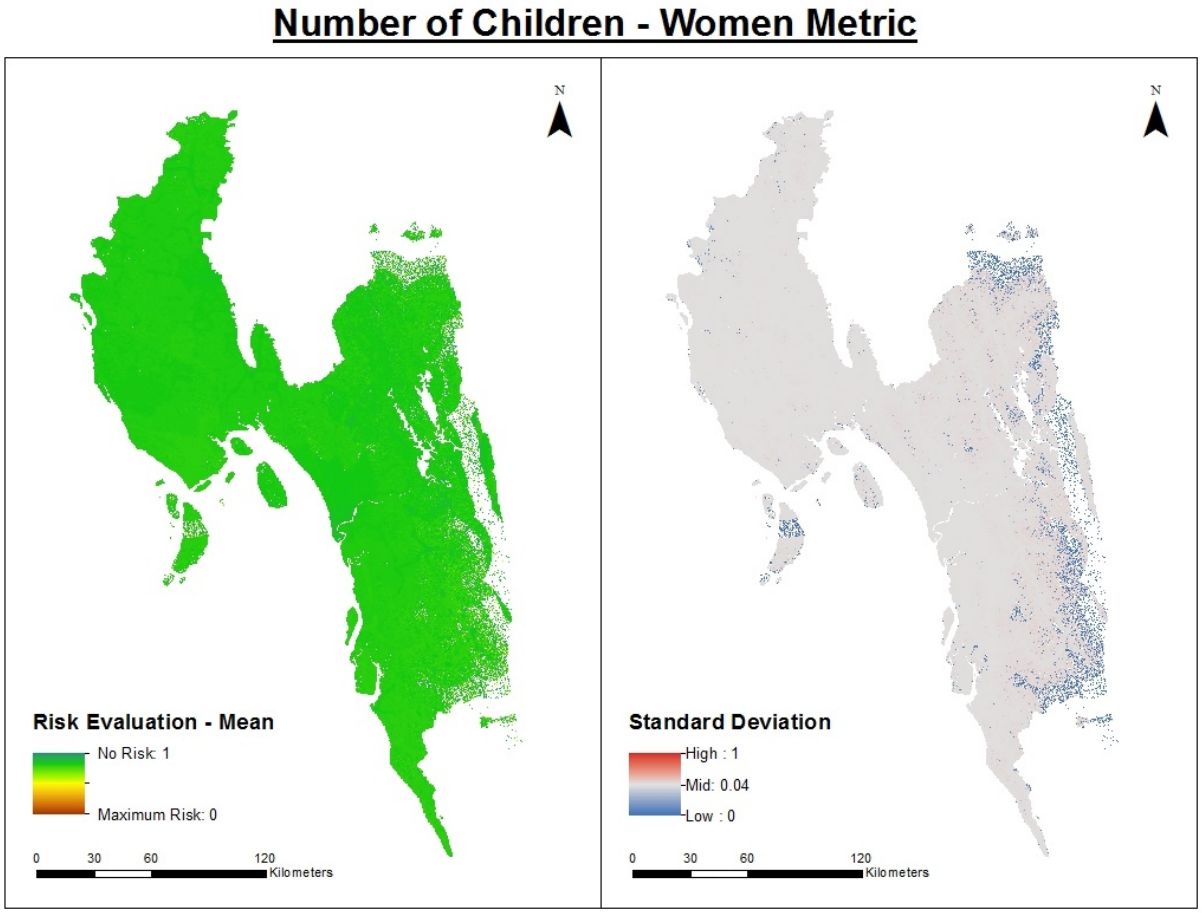
Glass et al. (1982) found that, "children 2-9 years old and adult women are most commonly hospitalized for cholera." Siddique et al found that 59.2% of laboratory confirmed cholera patients between the years of 1985-1991 were below the age of 14. This indicates that children are a slightly more at-risk population in comparison to the World Bank's 1990 population estimates that children 0-14 made up 42.3% of the total population. Glass and Black (1992) also found that children aged 2 to 15 are at greatest risk of contracting cholera.

Talavera & Perez (2009) review that children are the most affected population from cholera. Deen et al (2008) compares cholera incidence across Jakarta, Indonesia, Kolkata, India, and Beira, Mozambique. Across all three locations, children ages 1-5 are the population most at risk, with the highest rates being 2.2-3.8 times higher than average. Children under 2 had even higher rates in Kolkata and Jakarta, 5.4 & 6.4 times higher respectively.

Ali et al. (2002, 2) discuss that children under the age of 5 usually defecate in open places. Thus the more children under the age of 5, the more at-risk households are to experience feces spreading and contaminating surface water.

Households with no children are assigned both a minimum and maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Households with one child are assigned a minimum value of 0.75 (minimal risk) and a maximum value of 1.0. Households with two to three children have been assigned overall minimal risk with a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0. Household with 4-5 children are assigned overall slight risk with a minimum of 0.25 (medium risk, $½^2$) and a maximum value of 0.9 (minimal risk). Lastly, 6+ children is assigned overall medium risk are given a minimum of 0.125 (high risk, $½^3$) and a maximum value of 0.75. Maps will range from high risk to no risk.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

D'Souza, S. 1985. Mortality Case Study Matlab, Bangladesh.

Deen, J. L., Von Seidlein, L., Sur, D., Agtini, M., Lucas, M. E., Lopez, A. L., & Clemens, J. D. 2008. The high burden of cholera in children: comparison of incidence from endemic areas in Asia and Africa. *PLoS Negl Trop Dis*, *2*(2), e173.

Emch, Michael. "Diarrheal disease risk in Matlab, Bangladesh." *Social science & medicine* 49, no. 4 (1999): 519-530.

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Glass, R. I., & Black, R. E. 1992. The epidemiology of cholera. In *Cholera* (pp. 129-154). Springer U.S.

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Talavera, Arturo, and Ela M. Perez. "Is cholera disease associated with poverty? *The Journal of Infection in Developing Countries* 3, no. 06 (2009): 408-411.

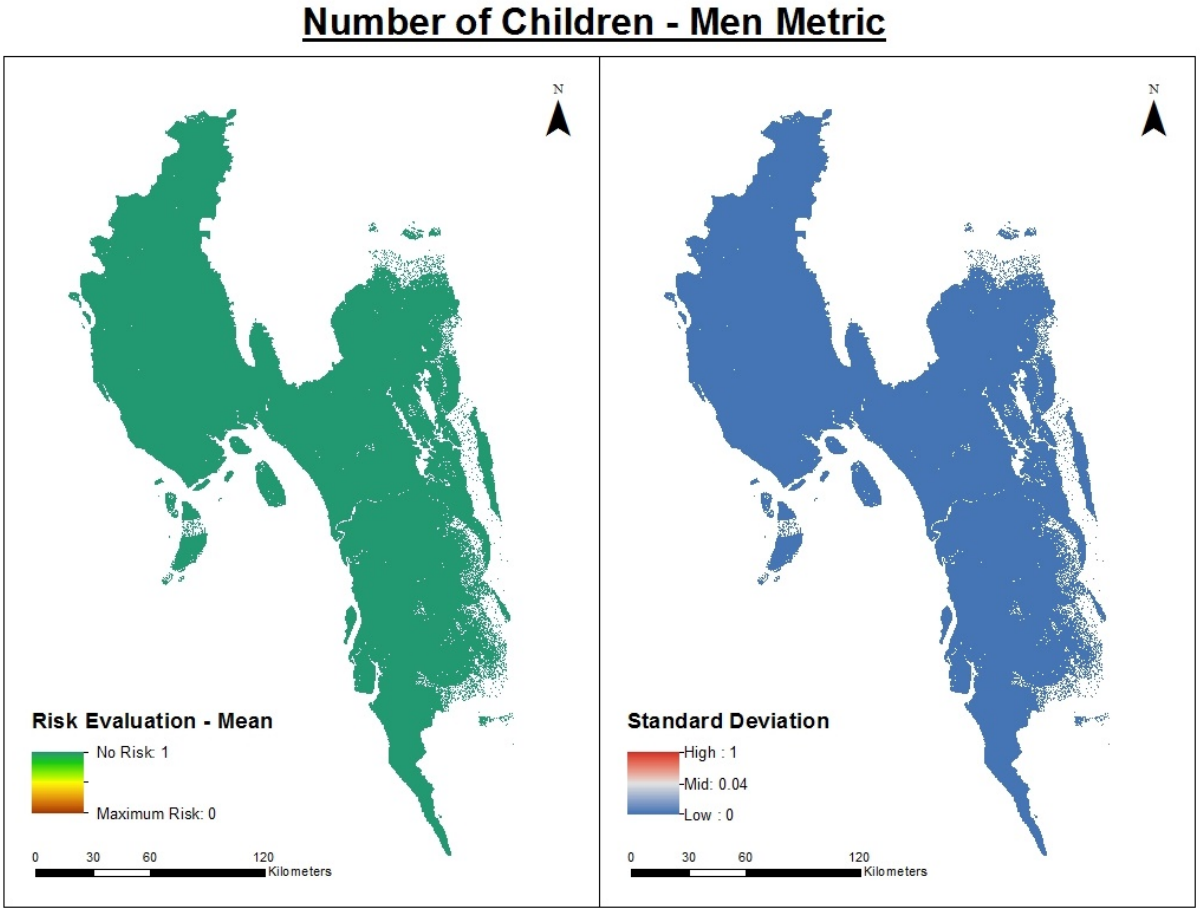
World Bank Group 2016. "World Development Indicators." 2016. http://databank.worldbank.org/data/reports.aspx?source=2&country=BGD.

Metric: Total Number of Children – Men reporting

Indicator:	Children	
Factor:	Vulnerable Groups	
Condition:	Human Behavioral Impact	
Framework:	Cholera	
Metric Assigned Values:	0 Children (min: 1.0, max: 1.0)	4 Children (min: 0.25, max: 0.9)
	1 Child (min: 0.75, max: 1.0)	5 Children (min: 0.25, max: 0.9)
	2 Children (min: 0.5, max: 1.0)	6 Children (min: 0.125, max: 0.75)
	3 Children (min: 0.5, max: 1.0)	7+ Children (min: 0.125, max: 0.75)
Survey:	DHS - Men	
Survey Date:	2011	
Other Data Sources:	Ali et al. (2002, 2); D'Souza, 1985; Deen et al. (2008); Emch,1999; Glass et al. 1982; Glass & Black (1992); Siddique (1992); Talavera & Perez (2009); World Bank Group (2016)	
Logic:	Emch (1999) states that, "Diarrheal diseases are the largest cause of death among children under five." D'Souza (1985), diarrhea was estimated as the cause of death for 2.25% of infants in Matlab, Bangladesh from 1975-1977, and for children ages 1-4, 5.5%. Cause of death is not significantly differentiated by sex. Glass et al. found that, "children 2-9 years old and adult women are most commonly hospitalized for cholera." Siddique et al found that 59.2% of laboratory confirmed cholera patients between the years of 1985-1991 were below the age of 14. This indicates that children are a slightly more at-risk population in comparison to the World Bank's 1990 population estimates that children 0-14 made up 42.3% of the total population. Glass and Black (1992) also found that children aged 2 to 15 are at greatest risk of contracting cholera. Talavera & Perez (2009) review that children are the most affected population from cholera. Deen et al (2008) compares cholera incidence across Jakarta, Indonesia, Kolkata, India, and Beira, Mozambique. Across all three locations, children ages 1-5 are the population most at risk, with the highest rates being 2.2-3.8 times higher than average. Children under 2 had even higher rates in Kolkata and Jakarta, 5.4 & 6.4 times higher respectively. Ali et al. (2002, 2) discuss that children under the age of 5 usually defecate in open places. Thus the more children under the age of 5, the more at-risk households are to experience feces spreading and contaminating surface water.	

Households with no children are assigned both a minimum and maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Households with one child are assigned a minimum value of 0.75 (minimal risk) and a maximum value of 1.0. Households with two to three children have been assigned overall minimal risk with a minimum value of 0.5 (slight risk, $\frac{1}{2}^1$) and a maximum value of 1.0. Household with 4-5 children are assigned overall slight risk with a minimum of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.9 (minimal risk). Lastly, 6+ children is assigned overall medium risk are given a minimum of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.75. Maps will range from high risk to no risk.

Example Realization Metric Map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

D'Souza, S. 1985. Mortality Case Study Matlab, Bangladesh.

Deen, J. L., Von Seidlein, L., Sur, D., Agtini, M., Lucas, M. E., Lopez, A. L., & Clemens, J. D. 2008. The high burden of cholera in children: comparison of incidence from endemic areas in Asia and Africa. *PLoS Negl Trop Dis*, *2*(2), e173.

Emch, Michael. "Diarrheal disease risk in Matlab, Bangladesh." *Social science & medicine* 49, no. 4 (1999): 519-530.

Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., & Black, R. E. 1982. Endemic cholera in rural Bangladesh, 1966–1980.*American journal of epidemiology*, *116*(6), 959-970.

Glass, R. I., & Black, R. E. 1992. The epidemiology of cholera. In *Cholera* (pp. 129-154). Springer U.S.

Siddique, A. K., Zaman, K., Baqui, A. H., Akram, K., Mutsuddy, P., Eusof, A., & Sack, R. B. 1992. Cholera epidemics in Bangladesh: 1985-1991.*Journal of diarrhoeal diseases research*, 79-86.

Talavera, Arturo, and Ela M. Perez. "Is cholera disease associated with poverty?" *The Journal of Infection in Developing Countries* 3, no. 06 (2009): 408-411.

World Bank Group 2016. "World Development Indicators." 2016. http://databank.worldbank.org/data/reports.aspx?source=2&country=BGD.

Metric: Children under 5 in Household

Indicator:	Children
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	0 Children (min: 0.8, max: 1.0) 1-2 Children (min: 0.5, max: 0.75) 3-4 Children (min: 0.25, max: 0.5) 5+ Children (min: 0.125, max: 0.5)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 2); D'Souza, 1985; Deen et al. (2008); Emch,1999; Glass et al. 1982; Glass & Black (1992); Siddique (1992); Talavera & Perez (2009); World Bank Group (2016)
Logic:	Emch (1999) states that, "Diarrheal diseases are the largest cause of death among children under five." D'Souza (1985), diarrhea was estimated as the cause of death for 2.25% of infants in Matlab, Bangladesh from 1975-1977, and for children ages 1-4, 5.5%. Cause of death is not significantly differentiated by sex. Glass et al. found that, "children 2-9 years old and adult women are most commonly hospitalized for cholera." Siddique et al found that 59.2% of laboratory confirmed cholera patients between the years of 1985-1991 were below the age of 14. This indicates that children are a slightly more at-risk population in comparison to the World

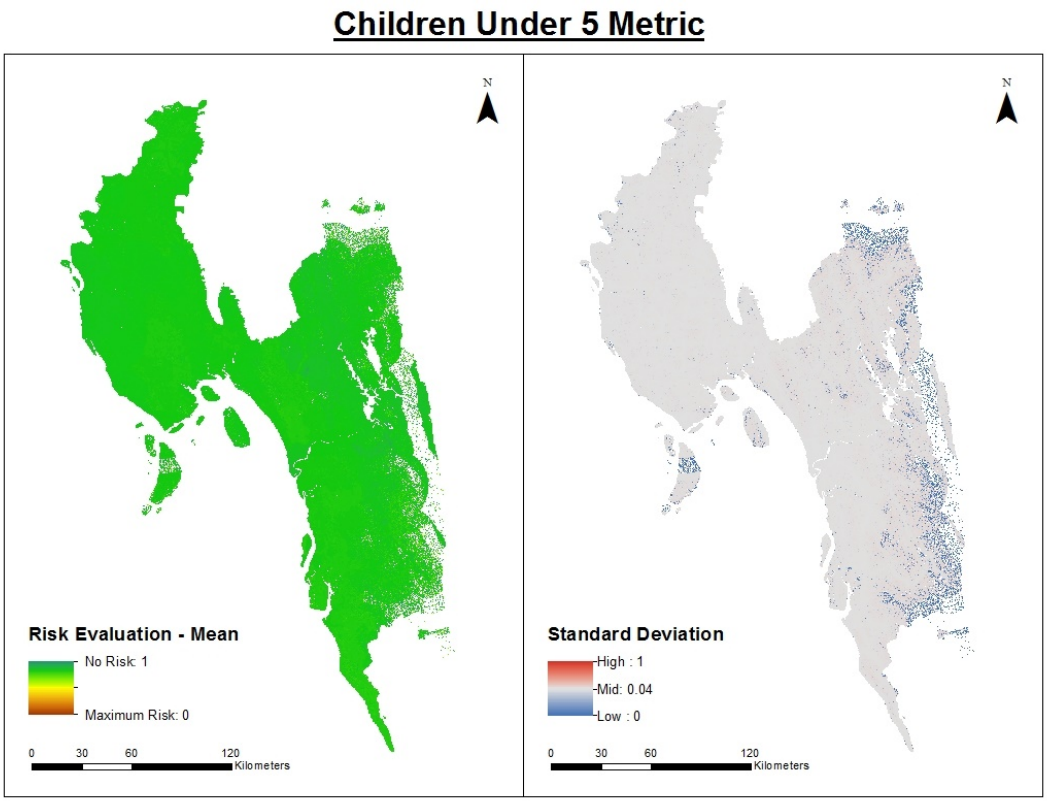
Bank's 1990 population estimates that children 0-14 made up 42.3% of the total population. Glass and Black (1992) also found that children aged 2 to 15 are at greatest risk of contracting cholera.

Ali et al. (2002, 2) discuss that children under the age of 5 usually defecate in open places. Thus the more children under the age of 5, the more at-risk households are to experience feces spreading and contaminating surface water.

Deen et al. (2008) compares cholera incidence across Jakarta, Indonesia, Kolkata, India, and Beira, Mozambique. Across all three locations, children ages 1-5 are the population most at risk, with the highest rates being 2.2-3.8 times higher than average. Children under 2 had even higher rates in Kolkata and Jakarta, 5.4 & 6.4 times higher respectively.

Households with no children under 5 are assigned a minimum value of 0.8 (minimal risk) and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Households with one to two children have been assigned a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 0.75 (minimal risk). Households with 3-4 children are assigned overall slight risk with a minimum of 0.25 (medium risk, $½^2$) and a maximum value of 0.5. Lastly, 5+ children is assigned a minimum value of 0.125 (high risk, $½^3$) and a maximum value of 0.5. Maps will range from high risk to no risk.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

D'Souza, S. 1985. Mortality Case Study Matlab, Bangladesh.

Deen, J. L., Von Seidlein, L., Sur, D., Agtini, M., Lucas, M. E., Lopez, A. L., & Clemens, J. D. 2008. The high burden of cholera in children: comparison of incidence from endemic areas in Asia and Africa. *PLoS Negl Trop Dis*, *2*(2), e173.

Emch, Michael. "Diarrheal disease risk in Matlab, Bangladesh." *Social science & medicine* 49, no. 4 (1999): 519-530.

Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., & Black, R. E. 1982. Endemic cholera in rural Bangladesh, 1966–1980.*American journal of epidemiology*, *116*(6), 959-970.

Glass, R. I., & Black, R. E. 1992. The epidemiology of cholera. In *Cholera* (pp. 129-154). Springer U.S.

Siddique, A. K., Zaman, K., Baqui, A. H., Akram, K., Mutsuddy, P., Eusof, A., & Sack, R. B. 1992. Cholera epidemics in Bangladesh: 1985-1991. *Journal of diarrhoeal diseases research*, 79-86.

Talavera, Arturo, and Ela M. Perez. "Is cholera disease associated with poverty?" *The Journal of Infection in Developing Countries* 3, no. 06 (2009): 408-411.

World Bank Group 2016. “World Development Indicators.” 2016. http://databank.worldbank.org/data/reports.aspx?source=2&country=BGD.

A.3.1.3 Indicator: Literacy

The Literacy indicator accounts for an education measure. Metrics should include data on literacy that has been assessed by the DHS and IPUMS data on the local populations. It is found in the literature that illiteracy is correlated with risk for cholera. This indicator, at the household level, can account for elements that can potentially lead to a dangerous living environment.

Metric weighting logic

The metric “Female Respondent Literacy” is weighted higher, as women are more susceptible to risk for cholera than males. Female literacy also corresponds to education levels and socioeconomic status.

Metric	Weight Minimum Value	Weight Maximum Value
Male Respondent Literacy	0.4	0.6
Female Respondent Literacy	0.6	0.9

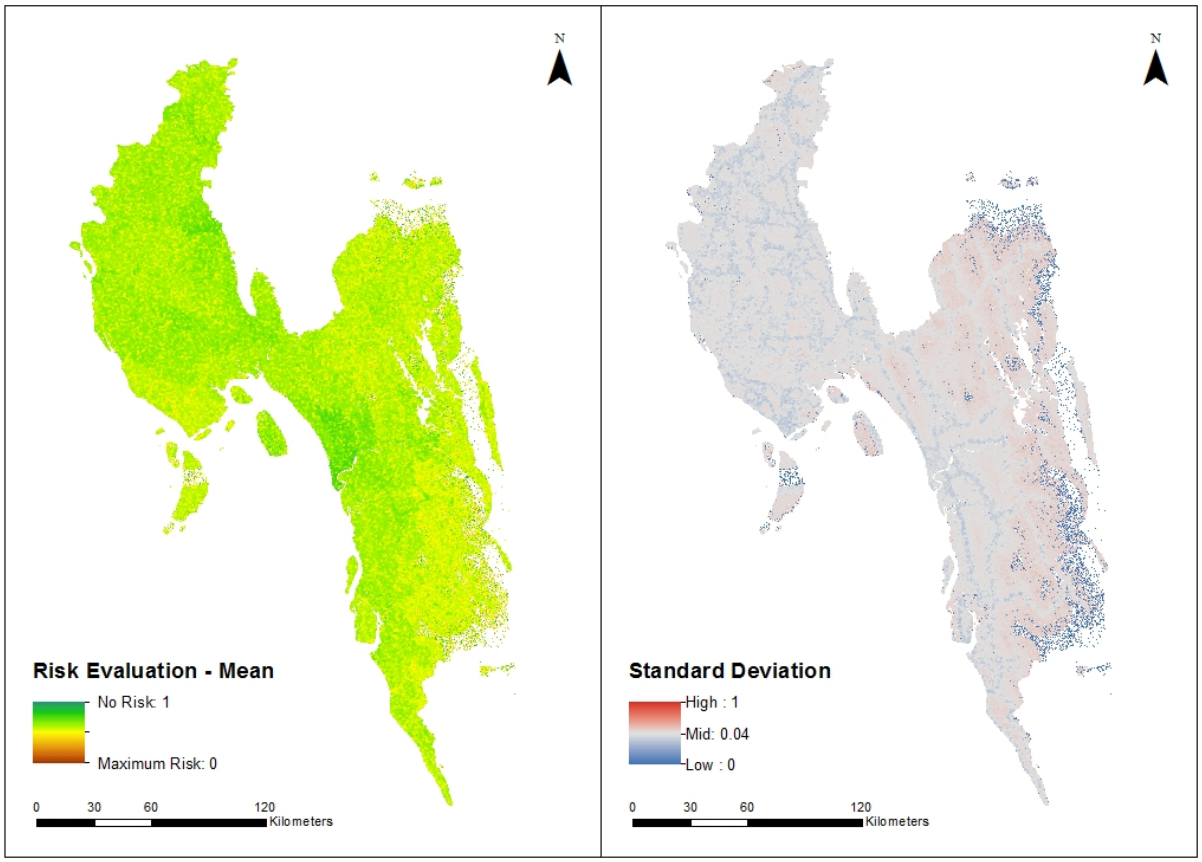
Uncertainty values

This indicator is given an uncertainty minimum value of 0.1 and an uncertainty maximum value of 0.2. Adding more data on the correlation between literacy and risk for cholera could decrease the uncertainty values.

Indicator Uncertainty Min:	0.1
Indicator Uncertainty Max:	0.2

Example outcome

Literacy Indicator



Metric: Male Respondent Literacy

Indicator:	Literacy
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera

Metric Assigned Values: NoRead (min: 0.125, max: 0.25)
1ReadPartSentences (min: 0.25, max: 0.5)
2ReadWholeSentences (min: 0.8, max: 1.0)
3NoCardWithRequiredLanguage (min: 1.0, max: 1.0)
4BlindVisuallyImpared (min: 0.125, max: 0.5)

Survey: DHS - Men

Survey Date: 2011

Other Data Sources: Abdussalam (2015); Ackers et al. (1998); Leckebusch & Abdussalam (2015)

Logic: Ackers et al. (1998) found negative correlation between female literacy and cholera incidence significant at 10% in an early 1990s study of Latin America. Abdussalam (2015) states, "in the adult literacy stratum, IR is 3.2 times higher in population with less educated literates if compared with that of the highly educated ones."

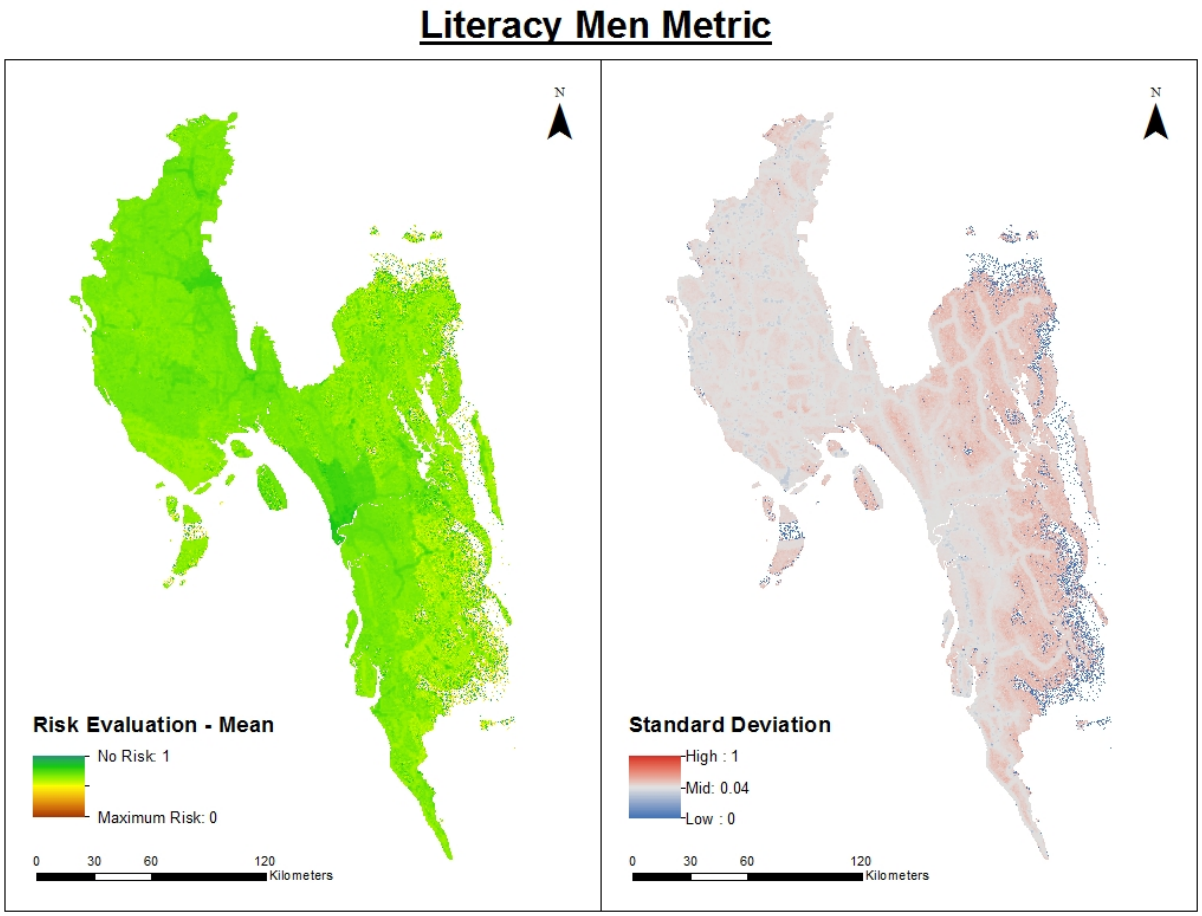
Leckebusch & Abdussalam (2015) found that improvements in "adult literacy might reduce the risk of contracting the disease" from their study in Nigeria.

The findings justify the comparative medium risk and slight risk for illiterate and low literacy respectively to literates' minimal risk.

Studies of cholera typically consider female or mother's literacy. The literature rarely mentions male literacy related to cholera and thus the metric weight is weighted less than the other metrics within the Literacy indicator (0.1-0.3).

Answers of "NoRead" are given a minimum value of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.25 (medium risk, $\frac{1}{2}^2$). Answers of "1ReadPartSentences" are given a minimum value of 0.25 and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "2ReadWholeSentences" are given a minimum value of 0.8 (minimal risk) and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "3 No Card With Required Language" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "Blind or Visually Impaired" are given a minimum value of 0.125 and a maximum value of 0.5. Maps will range from high risk to no risk.

Example realization metric map



References

Abdussalam, A. F. 2015. A Spatial Autocorrelation Analysis of Cholera Patterns and Social Risk Factors in Nigeria. *Academic Research International*, *1*(6), 136-147.

Ackers, M. L., Quick, R. E., Drasbek, C. J., Hutwagner, L., & Tauxe, R. V. 1998. Are there national risk factors for epidemic cholera? The correlation between socioeconomic and demographic indices and cholera incidence in Latin America. *International journal of epidemiology 27*(2), 330-334.

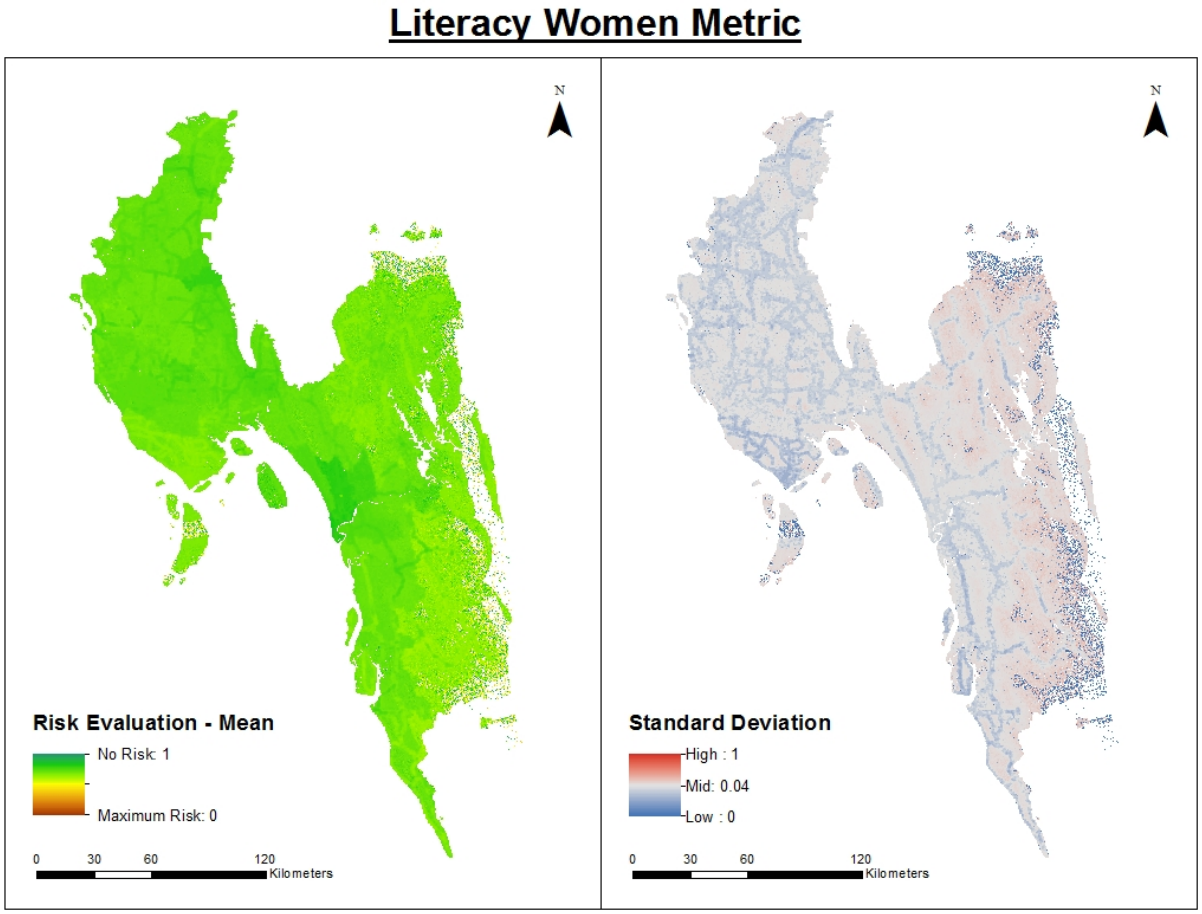
Leckebusch, G. C., & Abdussalam, A. F. 2015. Climate and socioeconomic influences on interannual variability of cholera in Nigeria. *Health & place*, *34*, 107-117.

Metric: Female Respondent Literacy

Indicator:	Literacy
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact

Framework:	Cholera
Metric Assigned Values:	NoRead (min: 0.125, max: 0.25) 1ReadPartSentences (min: 0.25, max: 0.5) 2ReadWholeSentences (min: 0.8, max: 1.0) 3NoCardWithRequiredLanguage (min: 1.0, max: 1.0) 4BlindVisuallyImpared (min: 0.125, max: 0.5)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Abdussalam (2015); Ackers et al. (1998); Leckebusch & Abdussalam (2015)
Logic:	Ackers et al. (1998) found negative correlation between female literacy and cholera incidence significant at 10% in an early 1990s study of Latin America. Abdussalam (2015) states, "in the adult literacy stratum, IR is 3.2 times higher in population with less educated literates if compared with that of the highly educated ones." Leckebusch & Abdussalam (2015) found that improvements in "adult literacy might reduce the risk of contracting the disease" from their study in Nigeria. The findings justifies the comparative medium risk and slight risk for illiterate and low literacy respectively to literates' minimal risk. 3NotTested was assigned min: 1.0 & max: 1.0 because as an erroneous case, we do not want it impacting the risk level. Studies of cholera typically consider female or mother's literacy. The literature rarely mentions male literacy related to cholera and thus the metric weight is weighted more than the other metrics within the Literacy indicator (0.7-0.9). Answers of "NoRead" are given a minimum value of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.25 (medium risk, $\frac{1}{2}^2$). Answers of "1ReadPartSentences" are given a minimum value of 0.25 and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "2ReadWholeSentences" are given a minimum value of 0.8 (minimal risk) and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "3 No Card With Required Language" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "Blind or Visually Impaired" are given a minimum value of 0.125 and a maximum value of 0.5. Maps will range from high risk to no risk.

Example realization metric map



References

Abdussalam, A. F. 2015. A Spatial Autocorrelation Analysis of Cholera Patterns and Social Risk Factors in Nigeria. *Academic Research International*, *1*(6), 136-147.

Ackers, M. L., Quick, R. E., Drasbek, C. J., Hutwagner, L., & Tauxe, R. V. 1998. Are there national risk factors for epidemic cholera? The correlation between socioeconomic and demographic indices and cholera incidence in Latin America. *International journal of epidemiology*, *27*(2), 330-334.

Leckebusch, G. C., & Abdussalam, A. F. 2015. Climate and socioeconomic influences on interannual variability of cholera in Nigeria. *Health & place*, *34*, 107-117.

A.3.1.4 Indicator: Education

The education indicator accounts for socioeconomic status and literacy measures. Metrics should include data on education that has been assessed by IPUMS & DHS data. At the household level, this can account for

elements that can potentially lead to a dangerous living environment, such as building structure or quality of drinking water source.

Metric weighting logic

The metric "Educational Attainment" is weighted higher as the detail of education attainment is more detailed and the rest evaluate the same levels of educations from DHS.

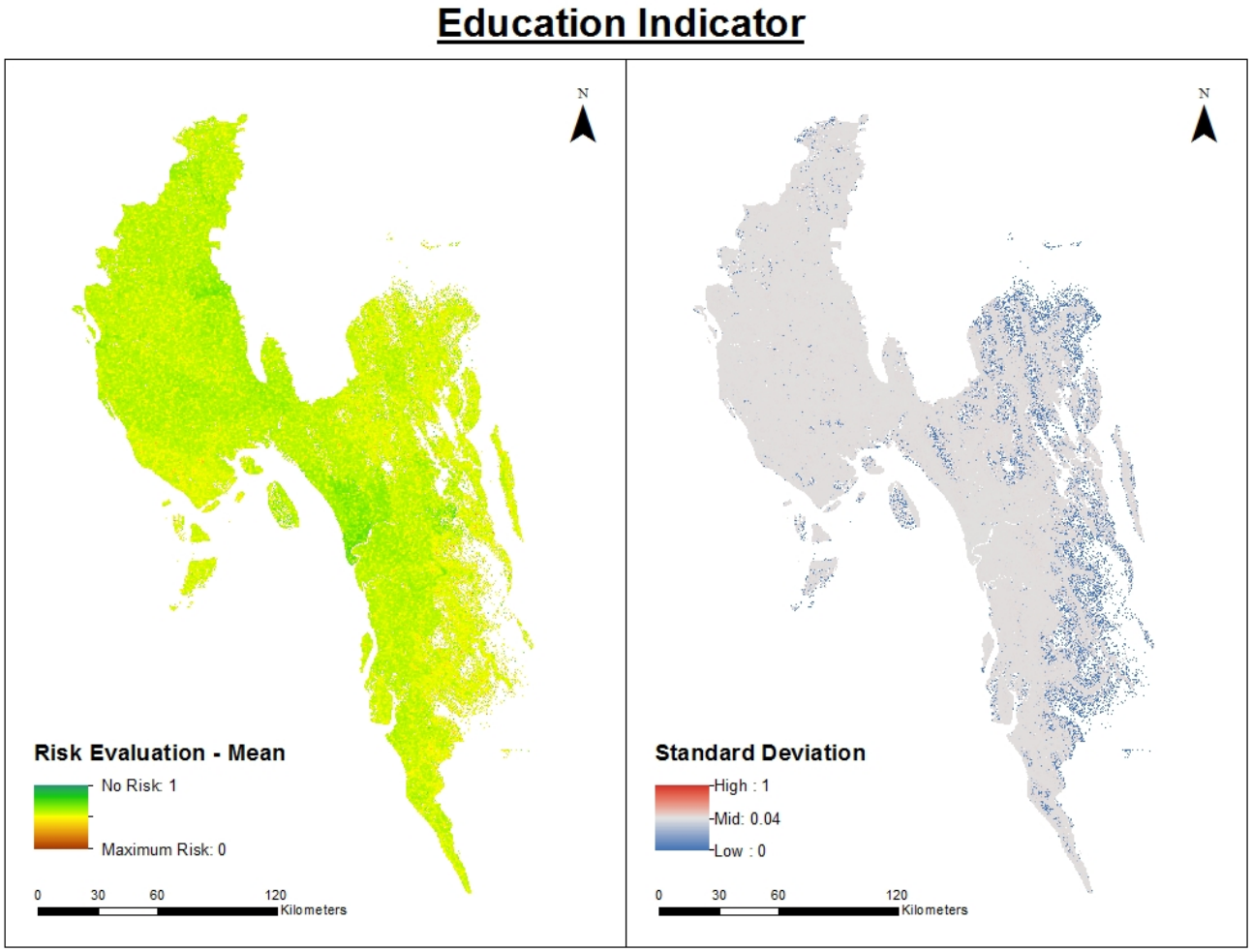
Metric	Weight Minimum Value	Weight Maximum Value
Educational Attainment	0.4	0.6
Men's Education Level	0.2	0.4
Women's Education Level	0.2	0.4
Female Respondent – Husband's Education Level	0.2	0.4

Uncertainty values

This indicator is given an uncertainty minimum value of 0.1 and an uncertainty maximum value of 0.2. Adding more data on linkages between education and cholera risk could decrease the uncertainty values.

Indicator Uncertainty Min:	0.1
Indicator Uncertainty Max:	0.2

Example outcome

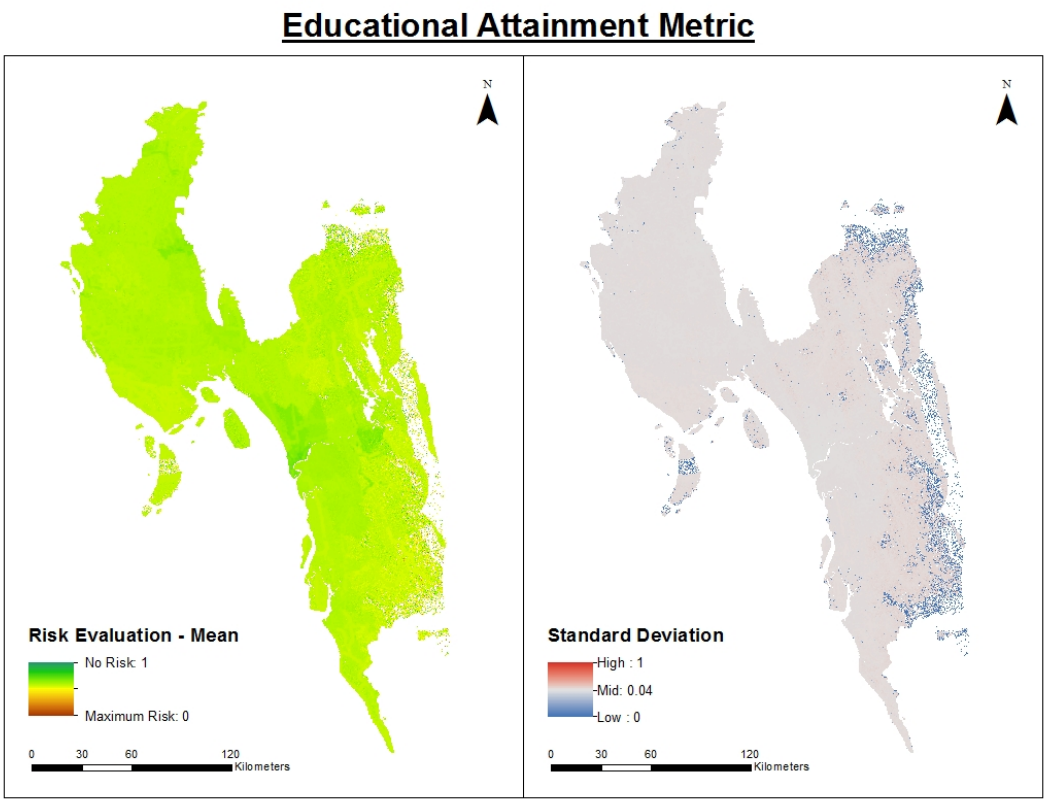


Metric: Educational Attainment

Indicator:	Education	
Factor:	Vulnerable Groups	
Condition:	Human Behavioral Impact	
Framework:	Cholera	
Metric Assigned Values:	00None (min: 0.0625, max: 0.5) 01Class1-4 (min: 0.125, max: 0.5) 05Class5-9 (min: 0.25, max: 0.75) 10ClassSSC (min: 0.25, max: 0.75) 12ClassHSC (min: 0.5, max: 1.0)	15GraduationGeneral (min: 1.0, max: 1.0) 16GraduationHonors (min: 1.0, max: 1.0) 18MastersOrHigher (min: 1.0, max: 1.0) 99NotInUniverse (min: 1.0, max: 1.0)
Survey:	IPUMS	
Survey Date:	2011	
Other Data Sources:	Ali et al. (2002, 1); Ali et al. (2002, 2); Giebultowicz et al. (2011); Hashizume et al. (2008)	

Indicator:	Education	
Logic:	Ali et al. (2002, 1) hypothesize that education level is "an indicator of mortality because it indirectly determines healthcare seeking behavior." Giebultowicz et al. (2011) states that improvements in education have helped reduce rates of diarrheal diseases in Bangladesh. Ali et al. (2002, 2) considers an individual educated if s/he has received four or more years of formal education, but this was an arbitrary unit. All in all, Ali et al. (2002, 2) find that cholera risk is high where people are poorly educated because hygiene practices of individuals are influenced by education status. Hashizume et al. (2008) studied the diarrheal disease that followed the 1998 flooding of Dhaka, Bangladesh and found that non-education was statistically significant in predicting cholera patients both during and after the flood. Not in Universe was assigned min: 1.0 & max: 1.0 because as an erroneous case, we do not want it impacting the risk level. Studies of cholera typically consider education level. As all metrics within the Education indicator get at essentially the same sentiment of education as a proxy for hygiene, the metric weight is weighted equally to the other metrics within the education indicator (1.0-1.0) as education is such an important indicator to cholera risk. Answers of "00None" of are given a minimum value 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "01Class1-4" are given a minimum of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.5. Answers of "05Class5-9" and "10ClassSSC" are given a minimum of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.75 (minimal risk). Answers of "15GraduationGeneral," "16GraduationHonors," "18MastersOrHigher," and "99NotInUniverse" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "12ClassHSC" are given a minimum value of 0.5 and a maximum value of 1.0. Maps will range from extreme risk to no risk.	

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 1). The spatial epidemiology of cholera in an endemic area of Bangladesh. *Social science & medicine*, *55*(6), 1015-1024.

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2 (2011): 490-497.

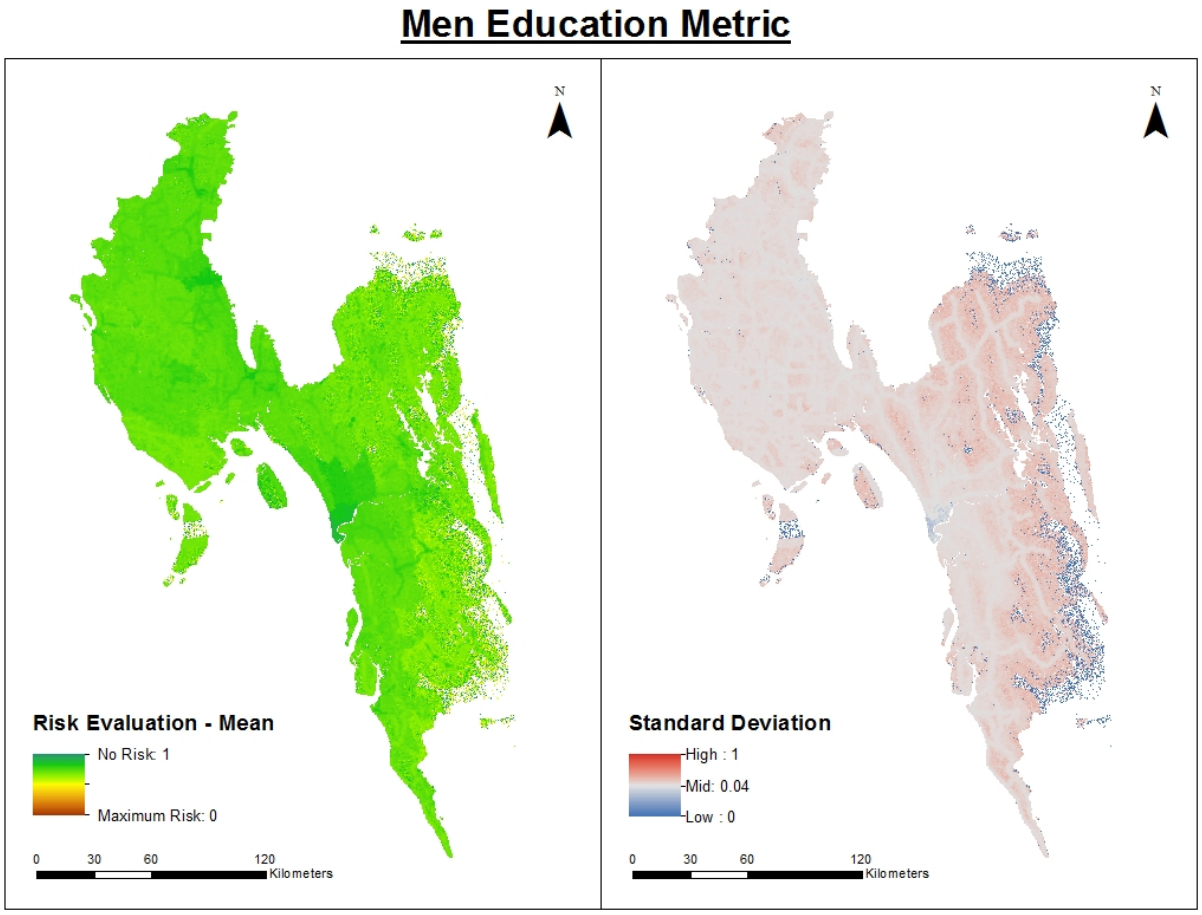
Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

Metric: Men's Education Level

Indicator:	Education
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	NoEducation (min: 0.0625, max: 0.5) 1Primary (min: 0.25, max: 0.75) 2Secondary (min: 1.0, max: 1.0) 3Higher (min: 1.0, max: 1.0)
Survey:	DHS - Men
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 1); Ali et al. (2002, 2); Giebultowicz et al. (2011); Hashizume et al. (2008); USAID (2011)
Logic:	DHS asks individuals first if they have ever attended school. If the answer is yes, they are asked "What is the highest level of school you attended: primary, secondary, or higher?" (USAID, 2011) Ali et al. (2002, 1) hypothesize that education level is "an indicator of mortality because it indirectly determines healthcare seeking behavior." Giebultowicz et al. (2011) states that improvements in education have helped reduce rates of diarrheal diseases in Bangladesh. Ali et al. (2002, 2) considers an individual educated if s/he has received four or more years of formal education, but this was an arbitrary unit. All in all, Ali et al. (2002, 2) find that cholera risk is high where people are poorly educated because hygiene practices of individuals are influenced by education status. Hashizume et al. (2008) studied the diarrheal disease that followed the 1998 flooding of Dhaka, Bangladesh and found that non-education was statistically significant in predicting cholera patients both during and after the flood.

Answers of "NoEducation" of are given a minimum value 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "1Primary" are given a minimum of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.75 (minimal risk). Answers of "2Secondary" and "3Higher" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from extreme risk to no risk.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 1). The spatial epidemiology of cholera in an endemic area of Bangladesh. *Social science & medicine*, *55*(6), 1015-1024.

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2 (2011): 490-497.

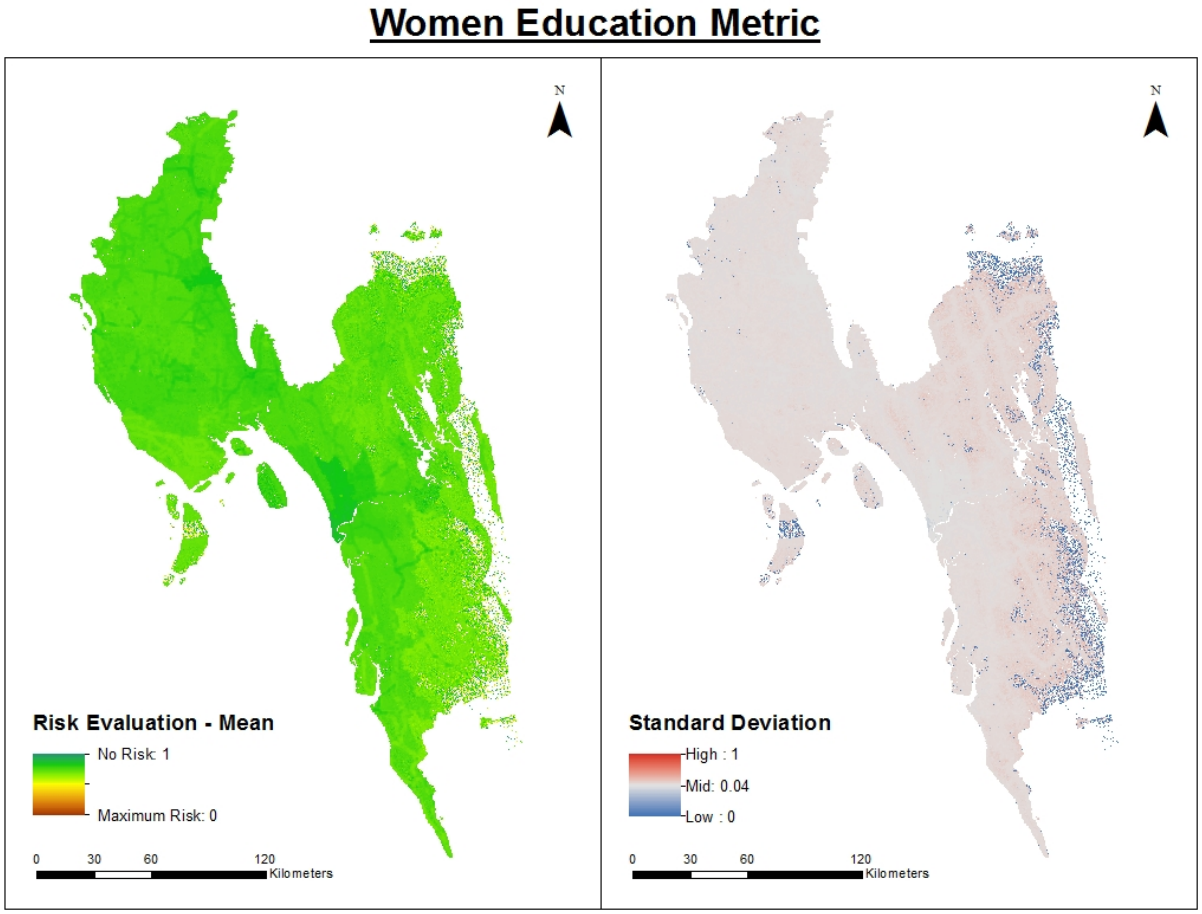
Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

USAID 2011. Demographic and Health Surveys Methodology. Questionnaires: Household, Woman's, and Man's.

Metric: Women's Education Level

Indicator:	Education
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	NoEducation (min: 0.0625, max: 0.5) 1Primary (min: 0.25, max: 0.75) 2Secondary (min: 1.0, max: 1.0) 3Higher (min: 1.0, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 1); Ali et al. (2002, 2); Giebultowicz et al. (2011); Hashizume et al. (2008); USAID (2011)
Logic:	DHS asks individuals first if they have ever attended school. If the answer is yes, they are asked "What is the highest level of school you attended: primary, secondary, or higher?" (USAID, 2011) Ali et al. (2002, 1) hypothesize that education level is "an indicator of mortality because it indirectly determines healthcare seeking behavior." Giebultowicz et al. (2011) states that improvements in education have helped reduce rates of diarrheal diseases in Bangladesh. Ali et al. (2002, 2) considers an individual educated if s/he has received four or more years of formal education, but this was an arbitrary unit. All in all, Ali et al. (2002, 2) find that cholera risk is high where people are poorly educated because hygiene practices of individuals are influenced by education status. Hashizume et al. (2008) studied the diarrheal disease that followed the 1998 flooding of Dhaka, Bangladesh and found that non-education was statistically significant in predicting cholera patients both during and after the flood. Answers of "NoEducation" of are given a minimum value 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "1Primary" are given a minimum of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.75 (minimal risk). Answers of "2Secondary" and "3Higher" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from extreme risk to no risk.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 1). The spatial epidemiology of cholera in an endemic area of Bangladesh. *Social science & medicine*, *55*(6), 1015-1024.

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2 (2011): 490-497.

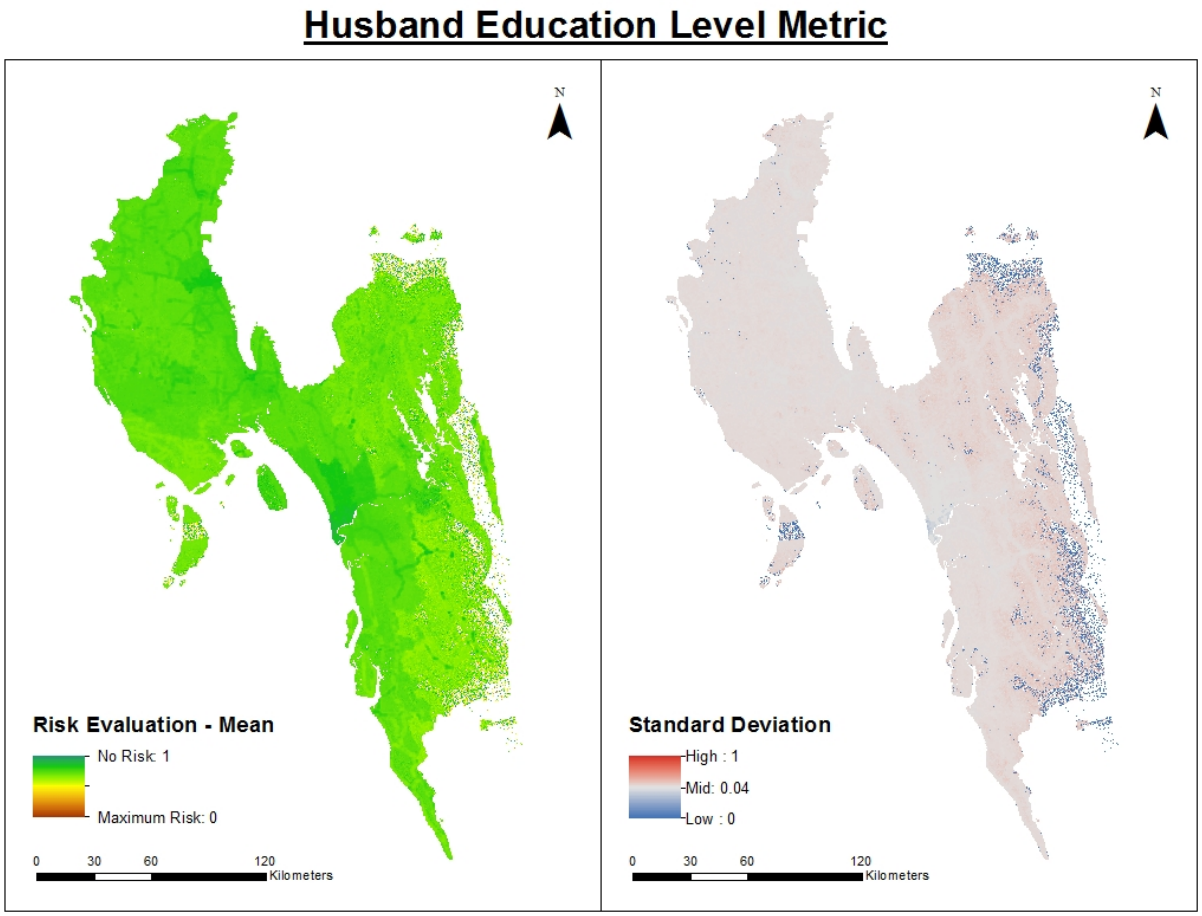
Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

USAID 2011. Demographic and Health Surveys Methodology. Questionnaires: Household, Woman's, and Man's.

Metric: Female Respondent - Husband's Education Level

Indicator:	Education
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	NoEducation (min: 0.0625, max: 0.5) 1Primary (min: 0.25, max: 0.75) 2Secondary (min: 1.0, max: 1.0) 3Higher (min: 1.0, max: 1.0) Unknown (min: 1.0, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 1); Ali et al. (2002, 2); Giebultowicz et al. (2011); Hashizume et al. (2008); USAID (2011)
Logic:	DHS asks individuals first if they have ever attended school. If the answer is yes, they are asked "What is the highest level of school you attended: primary, secondary, or higher?" (USAID, 2011) Ali et al. (2002, 1) hypothesize that education level is "an indicator of mortality because it indirectly determines healthcare seeking behavior." Giebultowicz et al. (2011) states that improvements in education have helped reduce rates of diarrheal diseases in Bangladesh. Ali et al. (2002, 2) considers an individual educated if s/he has received four or more years of formal education, but this was an arbitrary unit. All in all, Ali et al. (2002, 2) find that cholera risk is high where people are poorly educated because hygiene practices of individuals are influenced by education status. Hashizume et al. (2008) studied the diarrheal disease that followed the 1998 flooding of Dhaka, Bangladesh and found that non-education was statistically significant in predicting cholera patients both during and after the flood. Answers of "2Secondary," "3Higher," and "Unknown" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "1Primary" are given a minimum of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.75 (minimal risk). Answers of "NoEducation" of are given a minimum value 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Maps will range from extreme risk to no risk.

Example realization metric map



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Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2 (2011): 490-497.

Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

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A.3.1.5 Indicator: Urbanity

The Urbanity indicator accounts for the rural versus urban considerations when calculating risk for cholera. Metrics should include data on urbanity that has been assessed at the local level. At the household level, this can account for elements that can potentially lead to a dangerous living environment, such as building structure or quality of drinking water source.

Metric weighting logic

The metric "Urban Land Classification" is weighted less, as the American author was unable to find good definitions of the differentiation in land classification and so there is less support for it. The metric measuring if respondents live in informal settlements (floating population) is the most constraining on the indicator, and is therefore weighted the highest.

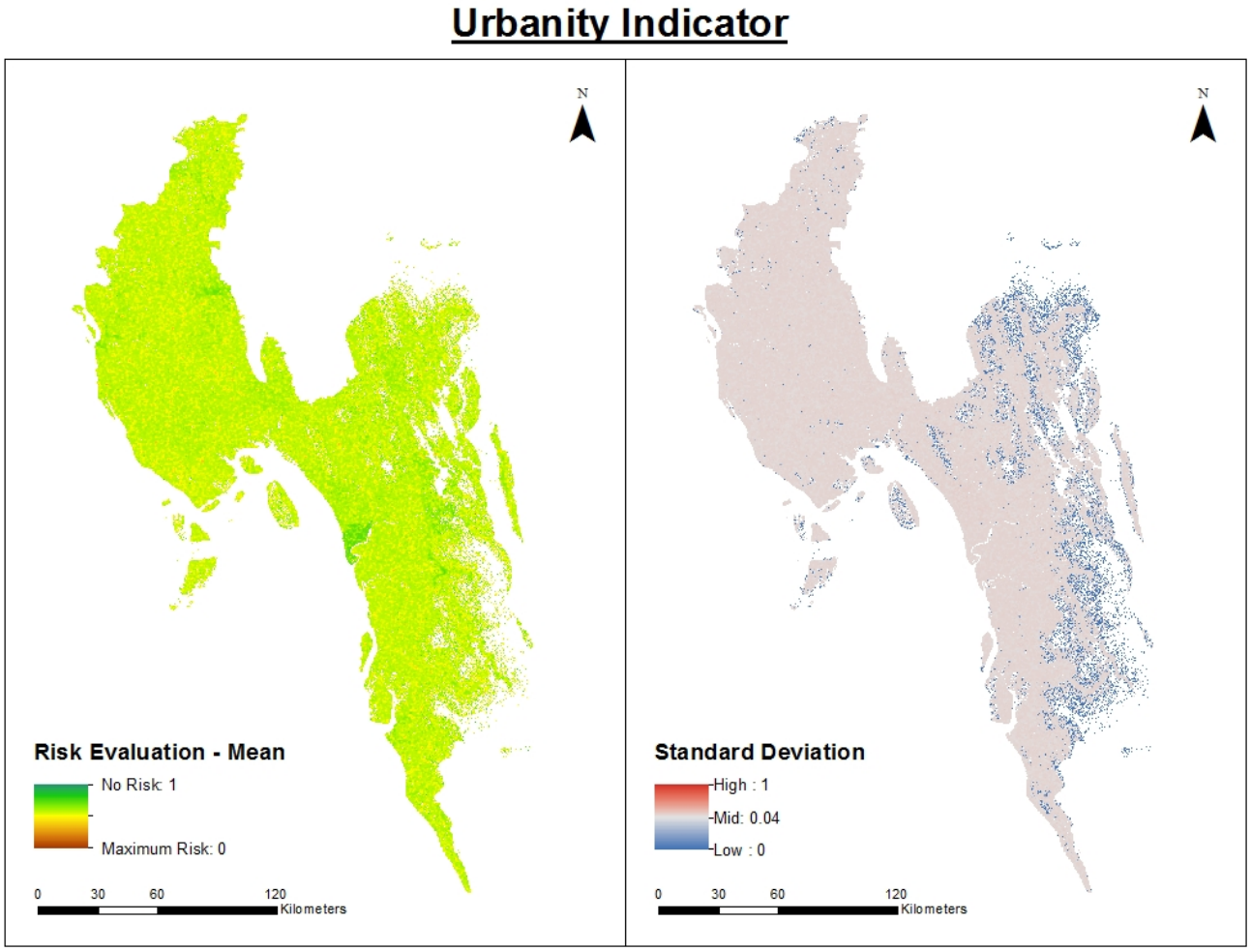
Metric	Weight Minimum Value	Weight Maximum Value
Urban Land Classification	0.1	0.3
Floating Population	0.5	0.9
Type of Place of Residence	0.3	0.5
Place of Residence Classification	0.3	0.5

Uncertainty values

This indicator is given an uncertainty minimum value of 0.1 and an uncertainty maximum value of 0.2. Adding more data on linkages between rural and/or urban living with risk of contracting cholera could decrease the uncertainty values.

Indicator Uncertainty Min:	0.1
Indicator Uncertainty Max:	0.2

Example outcome

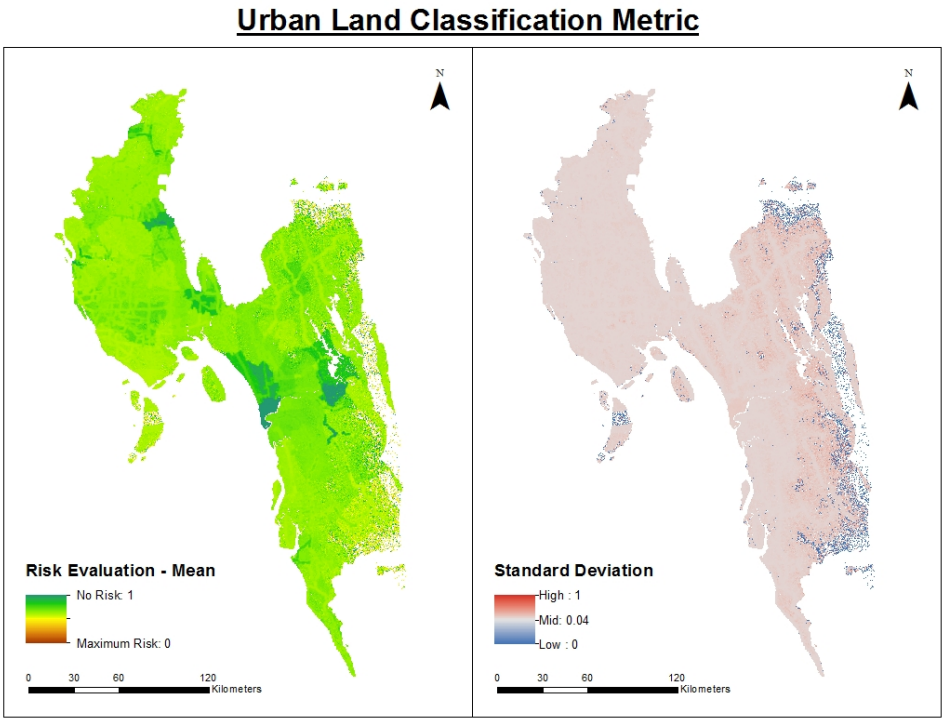


Metric: Urban Land Classification

Indicator:	Urbanity	
Factor:	Vulnerable Groups	
Condition:	Human Behavioral Impact	
Framework:	Cholera	
Metric Assigned Values:	1Rural (min: 0.0625, max: 0.5)	5CantonmentBoard (min: 0.5, max: 1.0)
	2Pourashava (min: 0.5, max: 1.0)	9CityCorporation (min: 0.5, max: 1.0)
	3UpazilaHQ (min: 0.5, max: 1.0)	2-9Urban (min: 0.5, max: 1.0)
Survey:	IPUMS	
Survey Date:	2011	

Other Data Sources:	Ali et al (2002, 1); Ali et al (2002, 2); BDweb24; DHS (2016); Giebultowicz et al. (2011); Perez-Saez et al. (2016); Siddique et al. 1992; Waldman et al. (2002); World Bank Group (2016)
Logic:	Studies of cholera typically consider urban/rural status or population density. Ali et al (2002, 1 & 2) use population density as a variable in their regressions aiming to estimate acute watery diarrhea & cholera morbidity respectively. Distance to nearest water body plays a small, but significant role in the regressions for both classical cholera (1983-1987) and El Tor (1992-1996) outbreaks in Bangladesh. Giebultowicz et al. (2011) found that in rural Bangladesh, cholera is mostly transmitted though the local environment, likely due to neighborhood scale risk factors such as population density. Thus high population density in rural areas can increase chances of cholera outbreaks. Perez-Saez et al. (2016) state that "informal settlements, which often constitute hotspots of cholera transmission are widespread in [Dhaka], and vulnerable to the intense yearly monsoon flooding which gains particular intensity in high El Niño Southern Oscillation years." Furthermore, in Brazil, Waldman et al (2002) found from the 1991-1998 outbreak, "78% of affected municipalities had populations of fewer than 30,000, and 65% lived in rural areas." Answers of "1Rural" are given a minimum value 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). All other answers are given a minimum value of 0.5 (slight risk, $\frac{1}{2}^1$) and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$), as there is no literature-supported differentiation in terms of specific urban classification and cholera risk. Maps will range from extreme risk to no risk.

Example realization metric map



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Metric: Floating Population

Indicator:	Urbanity
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	1Yes (min: 0.0625, max: 0.5) 2No (min: 1.0, max: 1.0)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	Ali et al (2002, 1); Ali et al (2002, 2); Budd, W (2013); DHS (2016); Giebultowicz et al. (2011); Hossain (2014); Li et al. (2016); Perez-Saez et al. (2016); Waldman et al (2002); World Bank Group (2016)

Logic: The World Bank's 2011 IPUMS directs interviewers to "Enter address where the floating population is found in the blank space of Quest-1a. Example: Kamlapur Rail station Kamlapur, Dhaka… Count the boarders living in the residential hotels as floating population with the help of hotel administration" World Bank Group (2016).

Few direct mentions of the floating population's explicit risk to cholera are mentioned, especially in recent years. An 1849 publication in London on cholera by Dr. W Budd states, "To no part of the community is the need of an immediate supply of pure water more urgent than to the immense floating population of the port of London" (Budd, 2013). More recently, Hossain (2014), considering the floating population as part of the slum population, states that the Bangladeshi slum censuses found that "about 50% of total slum children are found sick due to different types of waterborne diseases… High density of population, filthy environment, polluted water, and poor sanitation worsen the risks of waterborne and airborne diseases, such as cholera, diarrhea, pneumonia, influenza and tuberculosis" (Hossain, 2014, p. 31). Li et al. (2016) find that dense floating populations in Beijing were correlated with the spatial distribution of TB. As TB & cholera are communicable diseases, it can be assumed that the spatial distribution of cholera is likewise correlated floating populations.

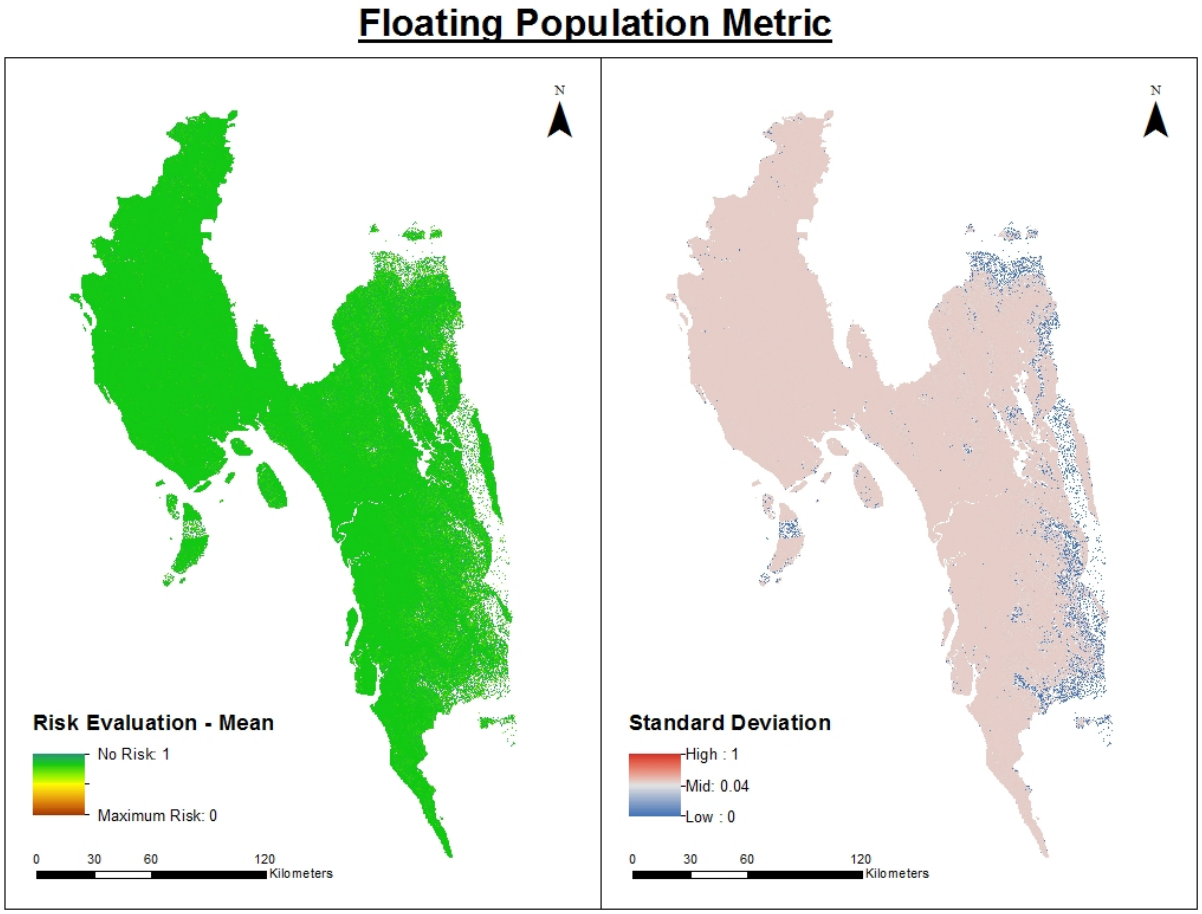
Ali et al (2002, 1 & 2) use population density as a variable in their regressions aiming to estimate acute watery diarrhea & cholera morbidity respectively. Distance to nearest water body plays a small, but significant role in the regressions for both classical cholera (1983-1987) and El Tor (1992-1996) outbreaks in Bangladesh. Giebultowicz et al. (2011) found that in rural Bangladesh, cholera is mostly transmitted though the local environment, likely due to neighborhood scale risk factors such as population density. Thus high population density in rural areas can increase chances of cholera outbreaks.

Perez-Saez et al. (2016) state that "informal settlements, which often constitute hotspots of cholera transmission are widespread in [Dhaka], and vulnerable to the intense yearly monsoon flooding which gains particular intensity in high El Niño Southern Oscillation years."

Furthermore, in Brazil, Waldman et al (2002) found from the 1991-1998 outbreak, "78% of affected municipalities had populations of fewer than 30,000, and 65% lived in rural areas."

Answers of "Yes" are given a minimum value 0.0625 (extreme risk, $½^4$) and a maximum value of 0.5 (slight risk, $½^1$). Answers of "No" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Maps will range from extreme risk to no risk.

Example realization metric map



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Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

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Metric: Type of Place of Residence Household Type

Indicator:	Urbanity
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	Urban (min:0.5, max:1.0) Rural (min:0.25, max:1.0)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Ali et al (2002, 1); Ali et al (2002, 2); Budd, W (2013); Chowdhury et al (2011); DHS (2016); Giebultowicz et al. (2011); Leckebusch & Abdussalam (2015); Perez-Saez et al. (2016); Waldman et al (2002); World Bank Group (2016)
Logic:	DHS stat compiler for the 2011 survey results from Bangladesh breaks up urban and rural. It reports that in 2011, the under-five mortality rate was 53, but in Rural areas was 66. Regarding treatment for diarrhea via either oral rehydration solution (ORS) or Recommended Home Fluids (RHF), from 2008-2011, 85% of urban residents were treated whereas 76% of rural residents were treated. In 2011, only 37.8% of rural women had a secondary education or higher compared to 55% of urban women. Furthermore, only 59.7% of rural women were literate while 72.3% of urban women were literate in 2011. Lastly, rural households only had electricity 49.3% of the time in 2011, whereas 90.2% of urban household had electricity. Ali et al (2002, 1 & 2) use population density as a variable in their regressions aiming to estimate acute watery diarrhea & cholera

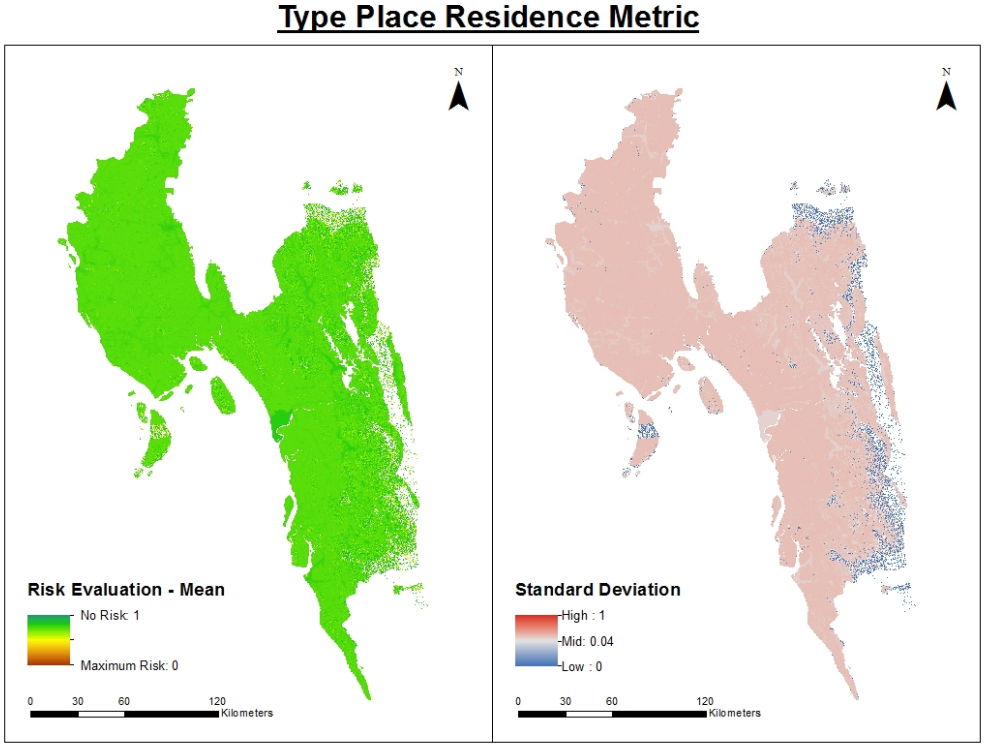
morbidity respectively. Giebultowicz et al. (2011) found that in rural Bangladesh, cholera is mostly transmitted though the local environment, likely due to neighborhood scale risk factors such as population density. Thus high population density in rural areas can increase chances of cholera outbreaks. Furthermore, in Brazil, Waldman et al (2002) found from the 1991-1998 outbreak, "78% of affected municipalities had populations of fewer than 30,000, and 65% lived in rural areas."

Leckebusch & Abdussalam (2015) state that, "Typical areas at risk might include population living in urban and peri-urban slums, these areas are mostly densely populated by low-income earners and basic infrastructures are not readily available" in Nigeria. Chowdhury et al (2011) states that, "In Bangladesh, such increases in diarrheal epidemics have been documented with a greater incidence in the capital city, Dhaka. Not only has the number of diarrheal patients seeking care increased but also the severity of disease."

Studies of cholera typically consider urban/rural status or population density, and according to the literature, rural populations with high density and urban areas with poor infrastructure are more at risk for cholera.

Answers of "Urban" are given a minimum value of 0.5 (slight risk, $\frac{1}{2}^1$) and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "Rural" are given both a minimum value of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from medium risk to no risk.

Example realization metric map



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Siddique, A. K., Zaman, K., Baqui, A. H., Akram, K., Mutsuddy, P., Eusof, A., & Sack, R. B. 1992. Cholera epidemics in Bangladesh: 1985-1991.*Journal of diarrhoeal diseases research*, 79-86.

Waldman, E. A., Antunes, J. L. F., Nichiata, L. Y. I., Takahashi, R. F., & Cacavallo, R. C. 2002. Cholera in Brazil during 1991-1998: socioeconomic characterization of affected areas. *Journal of Health, Population and Nutrition*, 85-92.

World Bank Group 2016. "World Development Indicators." 2016. http://databank.worldbank.org/data/reports.aspx?source=2&country=BGD.

Metric: Place of Residence Classification

Indicator:	Urbanity
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact

Framework: Cholera

Metric Assigned Values:

Type	Min	Max
1Capital	0.25	0.9
2SmallCity	0.50	1.00
3Town	0.25	0.9
4Countryside	0.125	0.9

Survey: DHS - Household

Survey Date: 2011

Other Data Sources: Ali et al (2002, 1); Ali et al (2002, 2); Budd, W (2013); Chowdhury et al (2011); DHS (2016); Giebultowicz et al. (2011); Leckebusch & Abdussalam (2015); Perez-Saez et al. (2016); Waldman et al (2002); World Bank Group (2016)

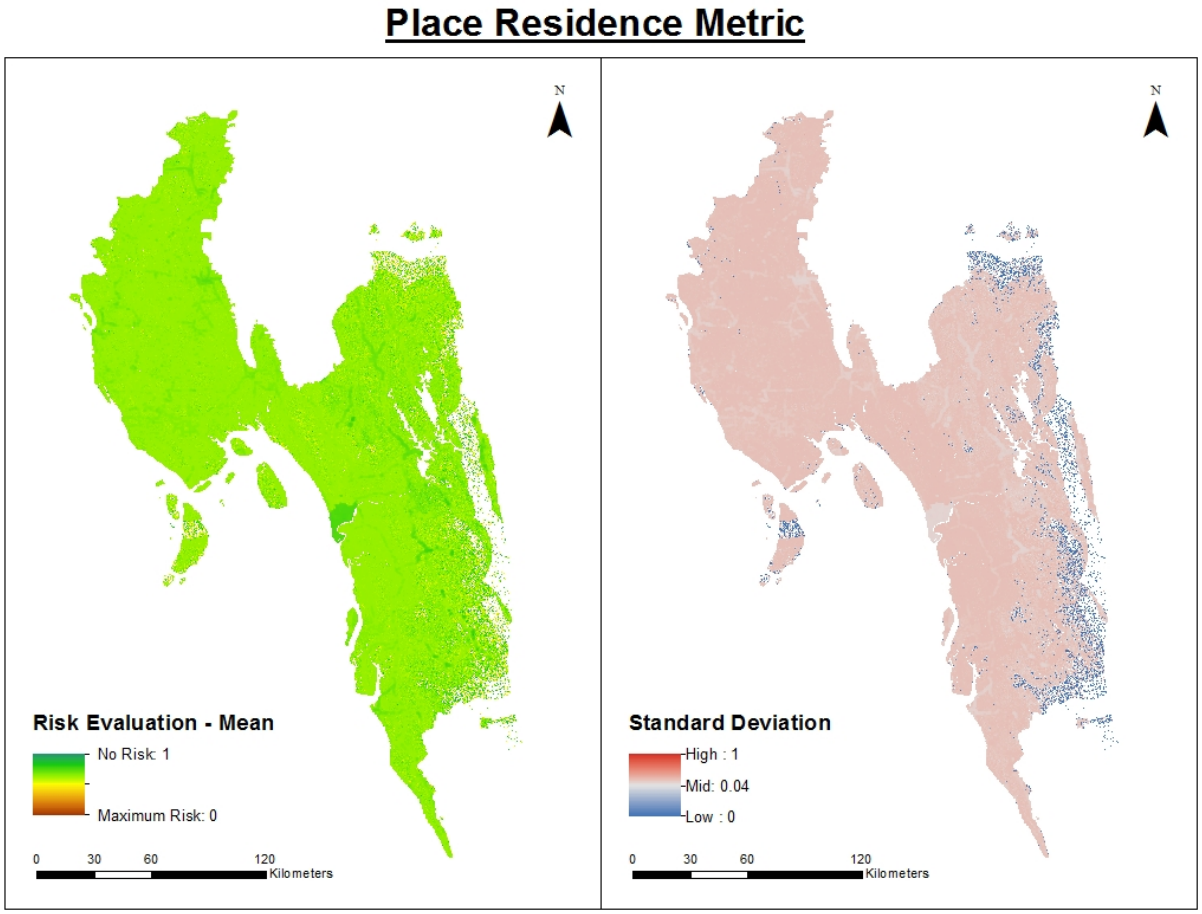
Logic: Ali et al (2002, 1 & 2) use population density as a variable in their regressions aiming to estimate acute watery diarrhea & cholera morbidity respectively. Giebultowicz et al. (2011) found that in rural Bangladesh, cholera is mostly transmitted though the local environment, likely due to neighborhood scale risk factors such as population density. Thus high population density in rural areas can increase chances of cholera outbreaks. Furthermore, in Brazil, Waldman et al (2002) found from the 1991-1998 outbreak, "78% of affected municipalities had populations of fewer than 30,000, and 65% lived in rural areas."

Perez-Saez et al. (2016) state that "informal settlements, which often constitute hotspots of cholera transmission are widespread in [Dhaka], and vulnerable to the intense yearly monsoon flooding which gains particular intensity in high El Niño Southern Oscillation years."

Leckebusch & Abdussalam (2015) state that, "Typical areas at risk might include population living in urban and peri-urban slums, these areas are mostly densely populated by low-income earners and basic infrastructures are not readily available" in Nigeria. Chowdhury et al (2011) states that, "In Bangladesh, such increases in diarrheal epidemics have been documented with a greater incidence in the capital city, Dhaka. Not only has the number of diarrheal patients seeking care increased but also the severity of disease."

Studies of cholera typically consider urban/rural status or population density, and according to the literature, rural populations with high density and urban areas with poor infrastructure are more at risk for cholera. Answers of "1Capital" and "3Town" are given a minimum of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.9 (minimal risk). Answers of "2SmallCity" are given a minimum value of 0.5 (slight risk, $\frac{1}{2}^1$) and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "4Countryside" are given a minimum value of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.9. Maps will range from high risk to no risk.

Example realization metric map



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Chowdhury, F., Rahman, M. A., Begum, Y. A., Khan, A. I., Faruque, A. S., Saha, N. C.,... & Pietroni, M. 2011. Impact of rapid urbanization on the rates of infection by Vibrio cholerae O1 and enterotoxigenic Escherichia coli in Dhaka, Bangladesh. *PLoS Negl Trop Dis*, *5*(4), e999.

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World Bank Group 2016. "World Development Indicators." 2016. http://databank.worldbank.org/data/reports.aspx?source=2&country=BGD.

A.3.1.6 Indicator: Undernourished population

The undernourished population indicator accounts for the percentage of population that is malnourished or undernourished and the number of children with acute malnutrition according to the HC framework. Metrics should include data on undernourished population that has been assessed by present and historical data at the household level, this can account for resiliency to a dangerous living environment. The only metric from DHS is if the child ate the previous day that the survey was taken. IPUMS does not have any metrics that directly relate to this indicator.

Metric weighting logic

The metric is weighted at 1.0 as it is the only available metric to support this indicator.

Metric	Weight Minimum Value	Weight Maximum Value
Child Ate Solid Food	1.0	1.0

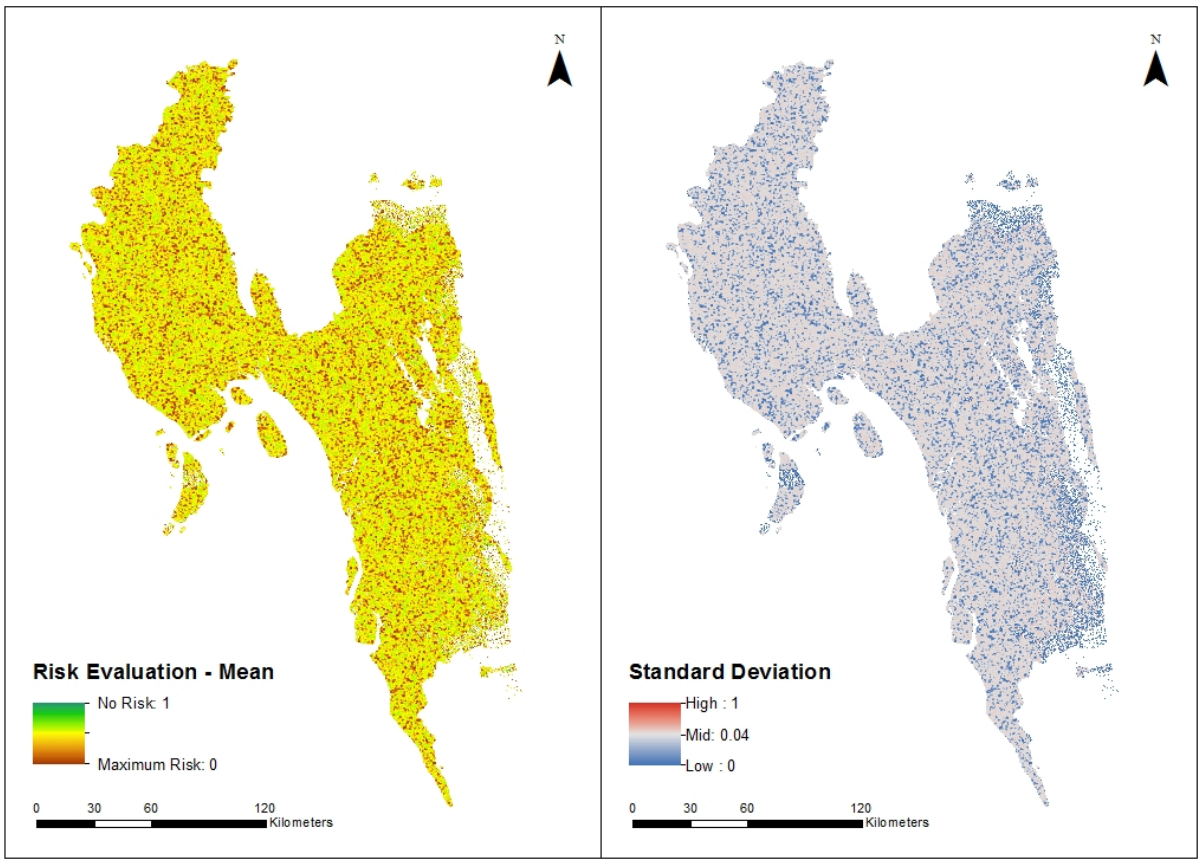
Uncertainty values

This indicator is given an uncertainty minimum value of 0.8 and an uncertainty maximum value of 0.9 as so few metrics support this indicator. Adding more data on effects of undernourished population could decrease the uncertainty values.

Indicator Uncertainty Min:	0.8
Indicator Uncertainty Max:	0.9

Example outcome

Undernourished Indicator

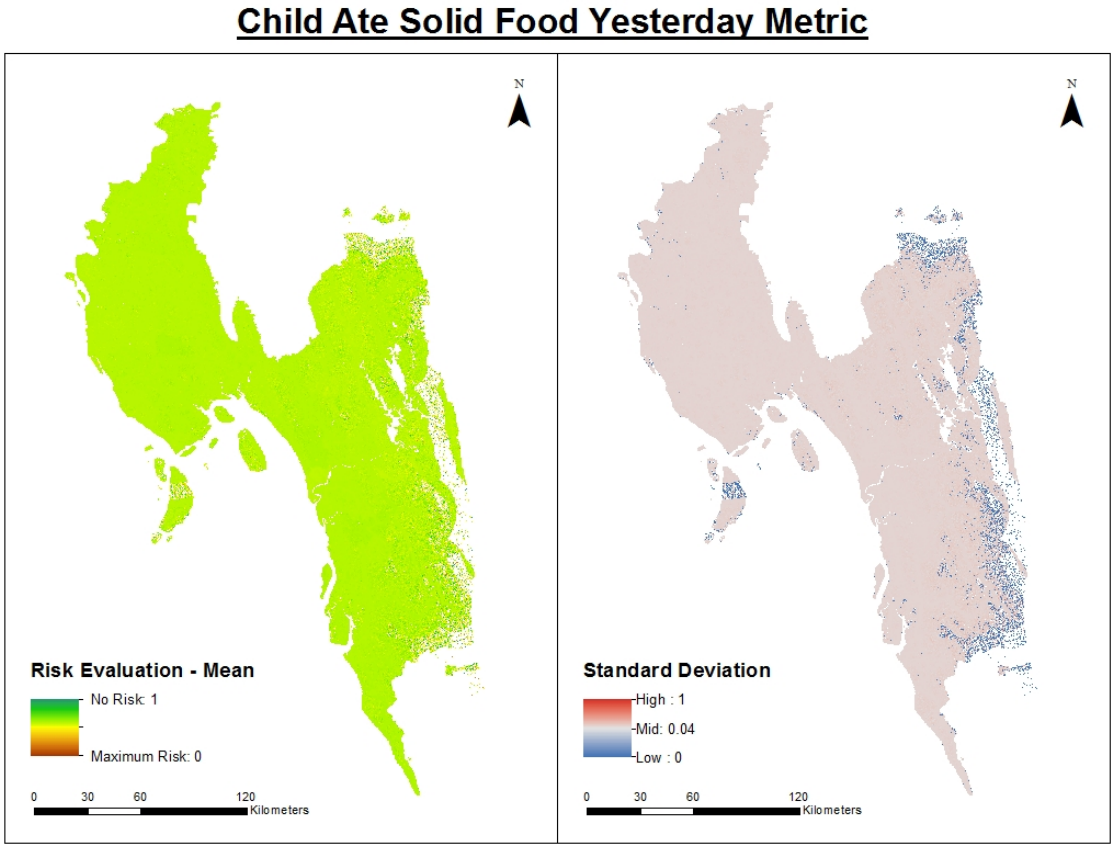


Metric: Did your Child Eat Yesterday?

Indicator:	Undernourished Population
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact

Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.0625, max: 0.5)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Hove-Musekwa et al. (2011)
Logic:	Hove-Musekwa et al. (2011) model the effects of malnutrition in the spread of cholera. They find an area with an increase in cholera cases is likely to experience an increase susceptibility to cholera due to malnutrition increases. Thus gathering data on the malnourished population is likely to better inform the number of failed recoveries from cholera, but not inform the risk of an individual getting infected with cholera. As no sources in the literature correlated well-fed with risk for cholera, this metric can be related to socioeconomic status in that these households will not be considered as in "extreme poverty." This metric consists of answers to the question "Did you child eat solid food in the last 24 hours?" from the women's portion of the DHS survey. Answers of "No" are given a minimum value 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from extreme risk to no risk. It should be noted that, as this version of the framework was constructed as a proof of research concept, only the results pertaining to the first child for whom answers were provided were used to create this metric. For questions under section 2 (Reproduction) of the women's portion of the DHS Bangladesh survey, answers were allowed for up to 12 children. Results from these questions will only contain answers for the eldest child. For questions under Sections 4 (Pregnancy and Postnatal Care) and 5 (Child Immunization, Health, and Nutrition), answers were allowed for children from the last birth, the next-to-last birth, and the second next-to-last birth (i.e. the youngest three children of the female respondent). Results from these questions will only contain answers for the youngest child.

Example realization metric map



References

Hove-Musekwa, S. D., Nyabadza, F., Chiyaka, C., Das, P., Tripathi, A., & Mukandavire, Z. 2011. Modelling and analysis of the effects of malnutrition in the spread of cholera. *Mathematical and computer modelling*, *53*(9), 1583-1595.

A.3.1.7 Indicator: Casualties, injured, and sick

The "Casualties, Injured, and Sick" indicator accounts for the number of event-related deaths, number of event-related injuries or illnesses, and the number of event-related injuries or illnesses among elderly children/adolescents, or IDPs/refugees according to the HC framework.

Metrics should include data on deaths, injuries, and illnesses that have been assessed by present and historical data at the household level, this can account for resiliency to a dangerous living environment. The only metric from DHS is if the child is still alive at the time the survey was

taken. IPUMS does not have any metrics that directly relate to this indicator.

Metric weighting logic

The metric is weighted at 1.0 as it is the only available metric to support this indicator.

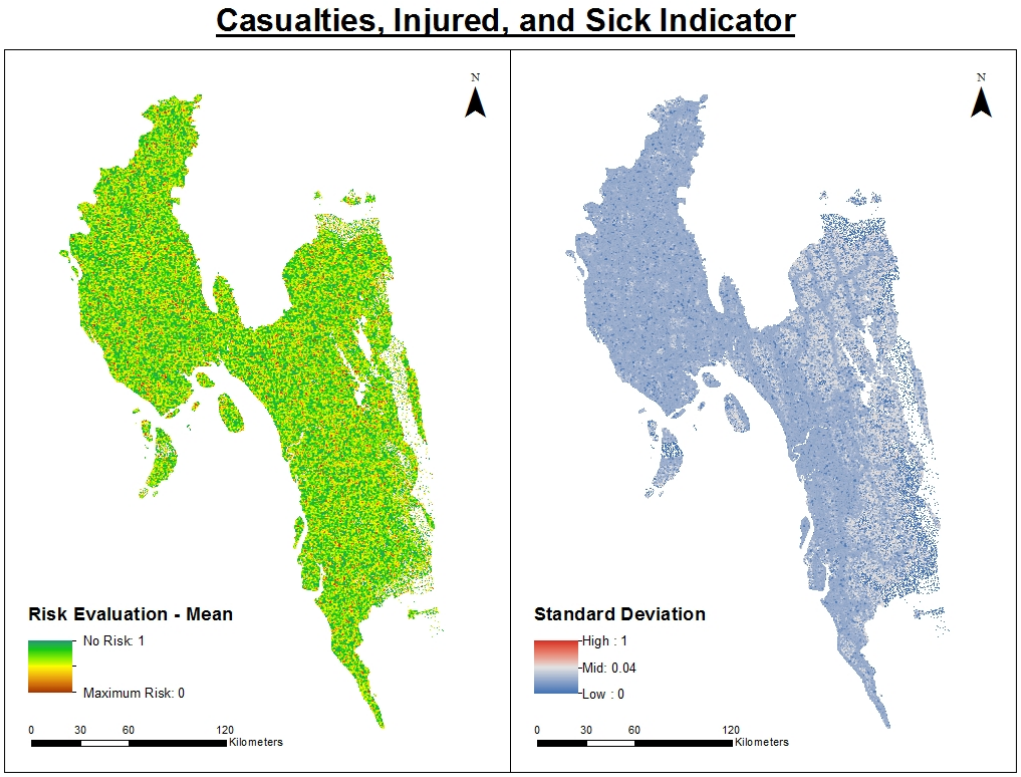
Metric	Weight Minimum Value	Weight Maximum Value
Is your child still alive?	1.0	1.0

Uncertainty values

This indicator is given an uncertainty minimum value of 0.7 and an uncertainty maximum value of 0.9 as so few metrics support this indicator. Adding more data on deaths, injuries, and illnesses could decrease the uncertainty values.

Indicator Uncertainty Min:	0.7
Indicator Uncertainty Max:	0.9

Example outcome

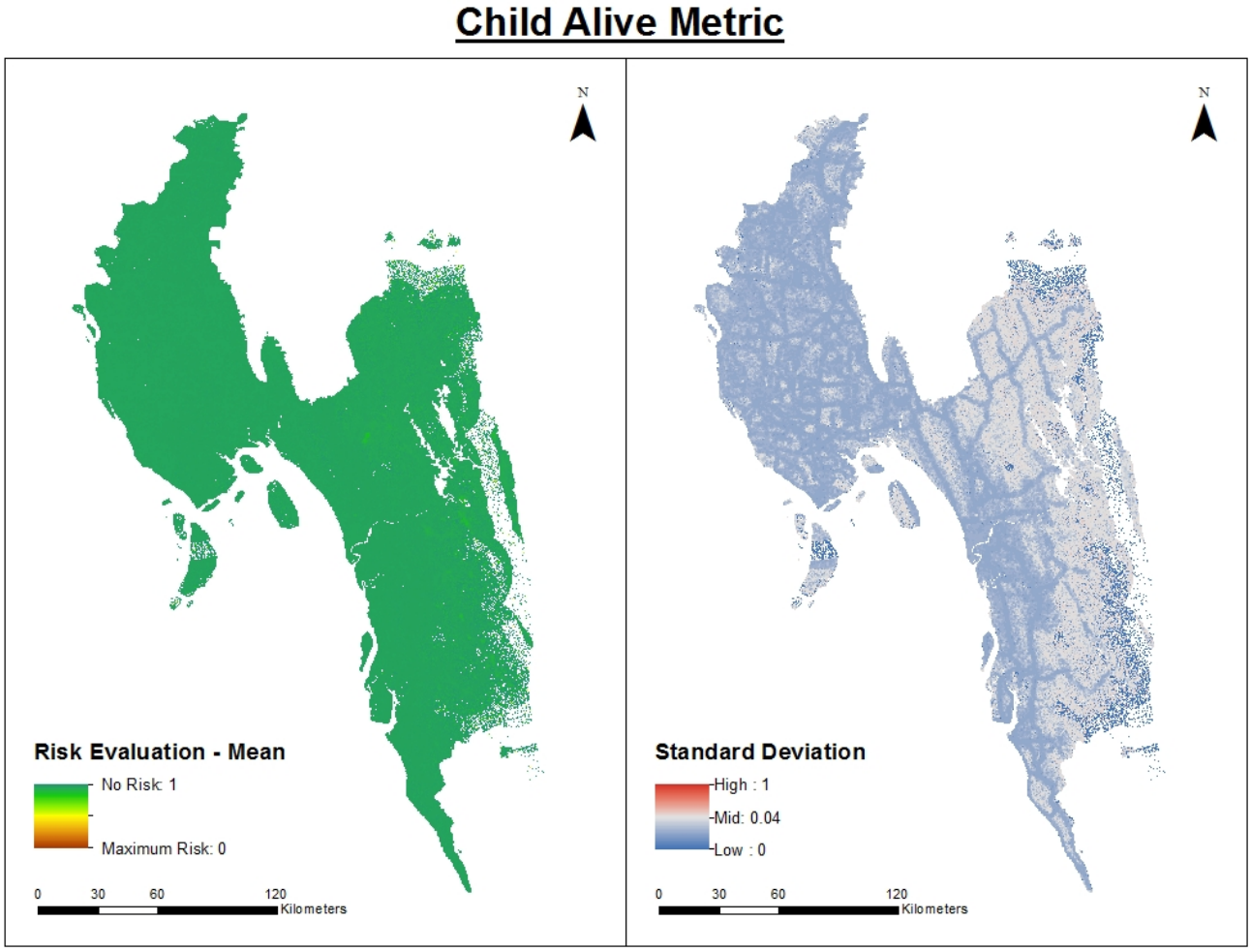


Metric: Is your child still alive?

Indicator:	Casualties, Injured, Sick
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.2, max: 0.8)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 2); D'Souza (1985); Deen et al (2008); Emch (1999); Glass et al. (1982); Glass & Black (1992); Talavera & Perez (2009); World Bank Group (2016)
Logic:	Emch (1999) states that, "Diarrheal diseases are the largest cause of death among children under five." D'Souza (1985), diarrhea was estimated as the cause of death for 2.25% of infants in Matlab, Bangladesh from 1975-1977, and for children ages 1-4, 5.5%. Cause of death is not significantly differentiated by sex. Glass et al. found that, "children 2-9 years old and adult women are most commonly hospitalized for cholera." Siddique et al found that 59.2% of laboratory confirmed cholera patients between the years of 1985-1991 were below the age of 14. This indicates that children are a slightly more at-risk population in comparison to the World Bank's 1990 population estimates that children 0-14 made up 42.3% of the total population. Furthermore, children 1-9 made up 45.6% of the cholera patients. This is cause to give these age groups higher assigned risk. Glass and Black (1992) also found that children aged 2 to 15 are at greatest risk of contracting cholera. Talavera & Perez (2009) review that children are the most affected population from cholera. Deen et al (2008) compares cholera incidence across Jakarta, Indonesia, Kolkata, India, and Beira, Mozambique. Across all three locations, children ages 1-5 are the population most at risk, with the highest rates being 2.2-3.8 times higher than average. Children under 2 had even higher rates in Kolkata and Jakarta, 5.4 & 6.4 times higher respectively. Ali et al. (2002, 2) discuss that children under the age of 5 usually defecate in open places. Thus the more children under the age of 5, the more at-risk households are to experience feces spreading and contaminating surface water. The findings justifies the higher risk for children, and as "Diarrheal diseases are the largest cause of death among children under five" in Bangladesh, it is reasonable to assign higher risk if the answer is no. Answers of "No" are given a minimum value of 0.2 (medium risk) and a maximum value of 0.8 (minimal risk). Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from medium risk to no risk. It should be noted that, as this version of the framework was constructed as a proof of research concept, only the results

pertaining to the first child for whom answers were provided were used to create this metric. For questions under section 2 (Reproduction) of the women's portion of the DHS Bangladesh survey, answers were allowed for up to 12 children. Results from these questions will only contain answers for the eldest child. For questions under Sections 4 (Pregnancy and Postnatal Care) and 5 (Child Immunization, Health, and Nutrition), answers were allowed for children from the last birth, the next-to-last birth, and the second next-to-last birth (i.e. the youngest three children of the female respondent). Results from these questions will only contain answers for the youngest child.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

D'Souza, S. 1985. Mortality Case Study Matlab, Bangladesh.

Deen, J. L., Von Seidlein, L., Sur, D., Agtini, M., Lucas, M. E., Lopez, A. L., & Clemens, J. D. 2008. The high burden of cholera in children: comparison of incidence from endemic areas in Asia and Africa. *PLoS Negl Trop Dis*, *2*(2), e173.

Emch, Michael. "Diarrheal disease risk in Matlab, Bangladesh." *Social science & medicine* 49, no. 4 (1999): 519-530.

Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., & Black, R. E. 1982. Endemic cholera in rural Bangladesh, 1966–1980.*American journal of epidemiology*, *116*(6), 959-970.

Glass, R. I., & Black, R. E. 1992. The epidemiology of cholera. In *Cholera* (pp. 129-154). Springer US.

Talavera, Arturo, and Ela M. Perez. "Is cholera disease associated with poverty?" *The Journal of Infection in Developing Countries* 3, no. 06 (2009): 408-411.

World Bank Group 2016. "World Development Indicators." 2016. http://databank.worldbank.org/data/reports.aspx?source=2&country=BGD.

A.3.1.8 Indicator: Targeted groups

This indicator accounts for acts of violence against individuals or groups targeted for their race, ethnicity, religion, gender, etc. These acts include hate crimes, genocides, and other group-identity based violence.

The "Targeted Groups" indicator accounts for the number of reported incidents of hate crimes, genocide, or other group-identity based violence, the number of casualties ("excess deaths") due to genocide or other group-identity based violence, and the crude mortality rate (CMR) according to the HC framework.

Please see metrics for specific information and logic on which groups/sub-populations are targeted, and are at an increased risk to cholera.

The metrics available from IPUMS are regarding ethnicity and if someone has a disability. Another targeted group, women, will be its own indicator.

Metric weighting logic

The metrics "Type of disability" & "Ethnic Population" are weighted the highest, as they give a general idea if the individual is subjected to potential discrimination and are therefore the most constraining on the indicator.

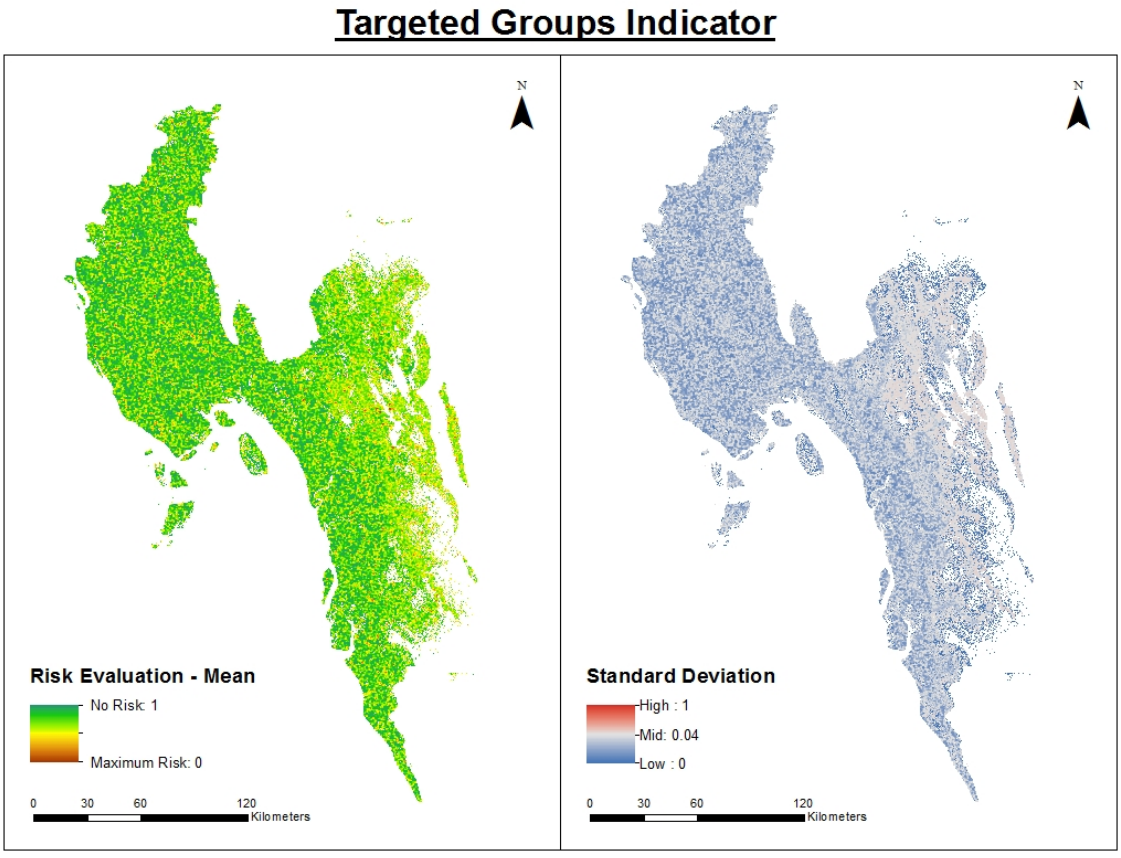
Metric	Weight Minimum Value	Weight Maximum Value
Ethnic Population	0.4	0.6
Ethnicity	0.3	0.5
Religion – Women's Survey	0.3	0.5
Religion – Men's Survey	0.2	0.4
Type of disability	0.5	0.7

Uncertainty values

This indicator is given an uncertainty minimum value of 0.4 and an uncertainty maximum value of 0.6 as few metrics support this indicator. Adding more data on other targeted groups (i.e. LGBTQIA [lesbian, gay, bisexual, transsexual, queer, intersex, asexual (or allied)], etc.) could decrease the uncertainty values.

Indicator Uncertainty Min:	0.4
Indicator Uncertainty Max:	0.6

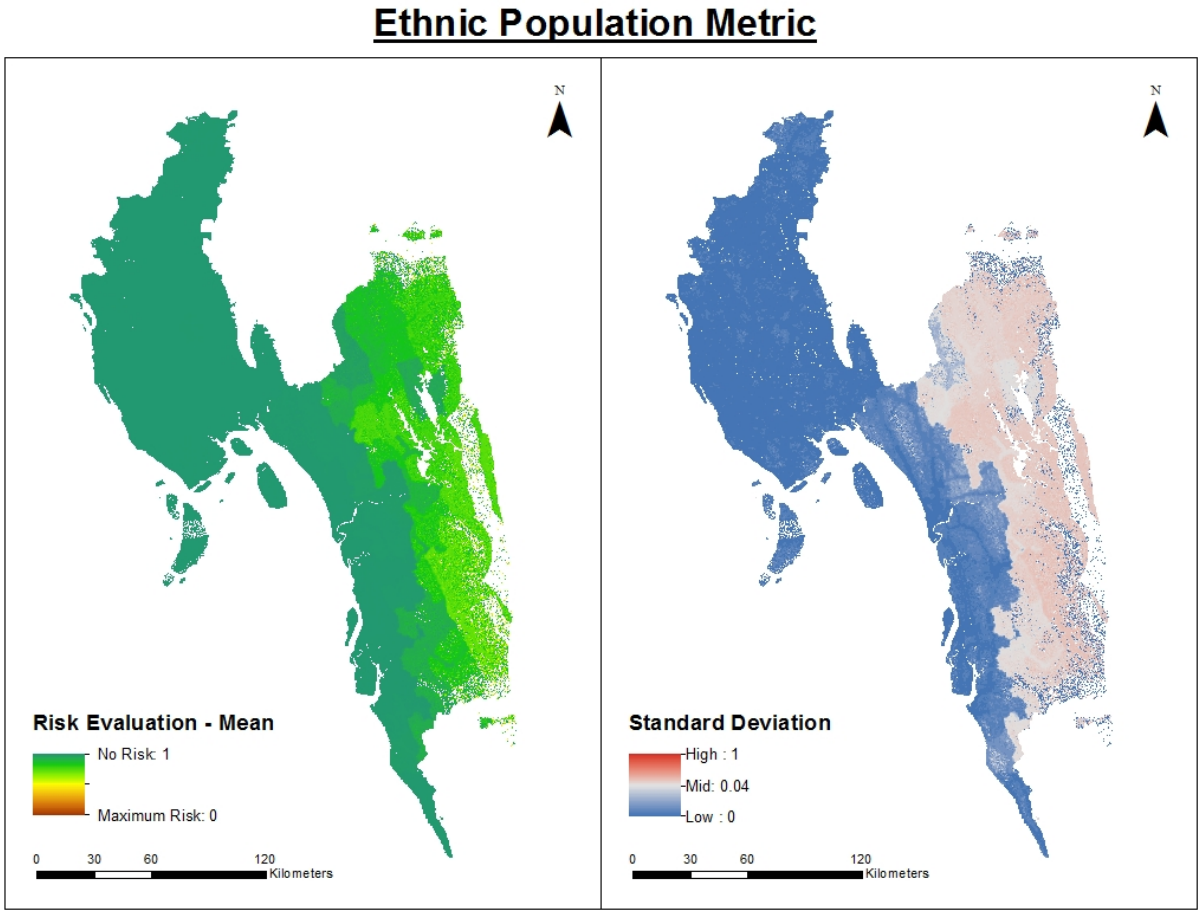
Example outcome



Metric: Ethnic Population

Indicator:	Targeted Groups
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	Yes (min: 0.0625, max: 0.9) No (min: 1.0, max: 1.0)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	U.S. Department of State (2015); Wong et al. (2010)
Logic:	The U.S. Department of State (2015) reported that on human rights in Bangladesh regarding ethnicity, they found "Instances of societal violence against religious and ethnic minorities persisted… Women, children, minority groups, persons with disabilities, indigenous people, and sexual minorities often confronted social and economic disadvantages." "NGOs reported that national origin, racial, and ethnic minorities faced discrimination." While there is not specific data found by the research team on ethnic populations in Bangladesh and cholera risk, increased cholera risk among ethnic minorities has been demonstrated elsewhere in Asia. In Singapore, from 1992-2007, found that in the years of 1996-1999, the incidence rate was disproportionately large for the Malays. The Malay population made up about 14% of the population, but experienced 28% of reported cholera cases. From 2004-2007, cholera cases were disproportionately experienced by "Others" with 9.5% of cases while only making up 3% of the population. Throughout the 15 year period, Chinese, the majority making up ~75%, experienced disproportionately less cholera cases (Wong et al., 2010). However, the lack of specific evidence for ethnic minorities' cholera risk in Bangladesh leads to a large range of risk for the assigned metric values. Answers of "Yes" are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.9 (minimal risk). Answers of "No" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from extreme risk to no risk.

Example realization metric map



References

U.S. Department of State 2015. Bureau of Democracy, Human Rights, and Labor. Country Reports on Human Rights Practices for 2015. Bangladesh.

Wong, C. S., Ang, L. W., James, L., & Goh, K. T. 2010. Epidemiological characteristics of cholera in Singapore, 1992-2007. *Annals Academy of Medicine Singapore*, *39*(7), 507.

Metric: Ethnicity

Indicator:	Targeted Groups
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera

Metric Assigned Values:

Ethnicity	Min	Max	Ethnicity	Min	Max
01Chakma	0.0625	1.000	17Monipuri	0.0625	1.000
02Marma	0.0625	1.000	18Garo	0.0625	1.000
03Tripura	0.0625	1.000	19Hajong	0.0625	1.000
04Mro	0.0625	1.000	20Khasia	0.0625	1.000
05Tanchaynga	0.0625	1.000	22Orao	0.0625	1.000
06Bawm	0.0625	1.000	23Barmon	0.0625	1.000
08Chak	0.0625	1.000	24Pahari	0.0625	1.000
09Khiyang	0.0625	1.000	25Malpahari	0.0625	1.000
10Khumi	0.0625	1.000	26Monda	0.0625	1.000
12Coach	0.0625	1.000	27Cool	0.0625	1.000
13Sawntal	0.0625	1.000	28Other	0.0625	1.000
16Rakhain	0.0625	1.000	9NotInUniverse	1.000	1.000

Survey: IPUMS

Survey Date: 2011

Other Data Sources: U.S. Department of State (2015); Wong et al. (2010)

Logic: The U.S. Department of State (2015) reported that on human rights in Bangladesh regarding ethnicity, they found "Instances of societal violence against religious and ethnic minorities persisted… (and) often confronted social and economic disadvantages."

Digging into ethnic minorities in Bangladesh, the State Department did not provide much detail. Below are some examples of discrimination against ethnic minorities; however, the research team was unable to find any documentation on specific Bangladeshi ethnic populations and an increase in cholera risk:

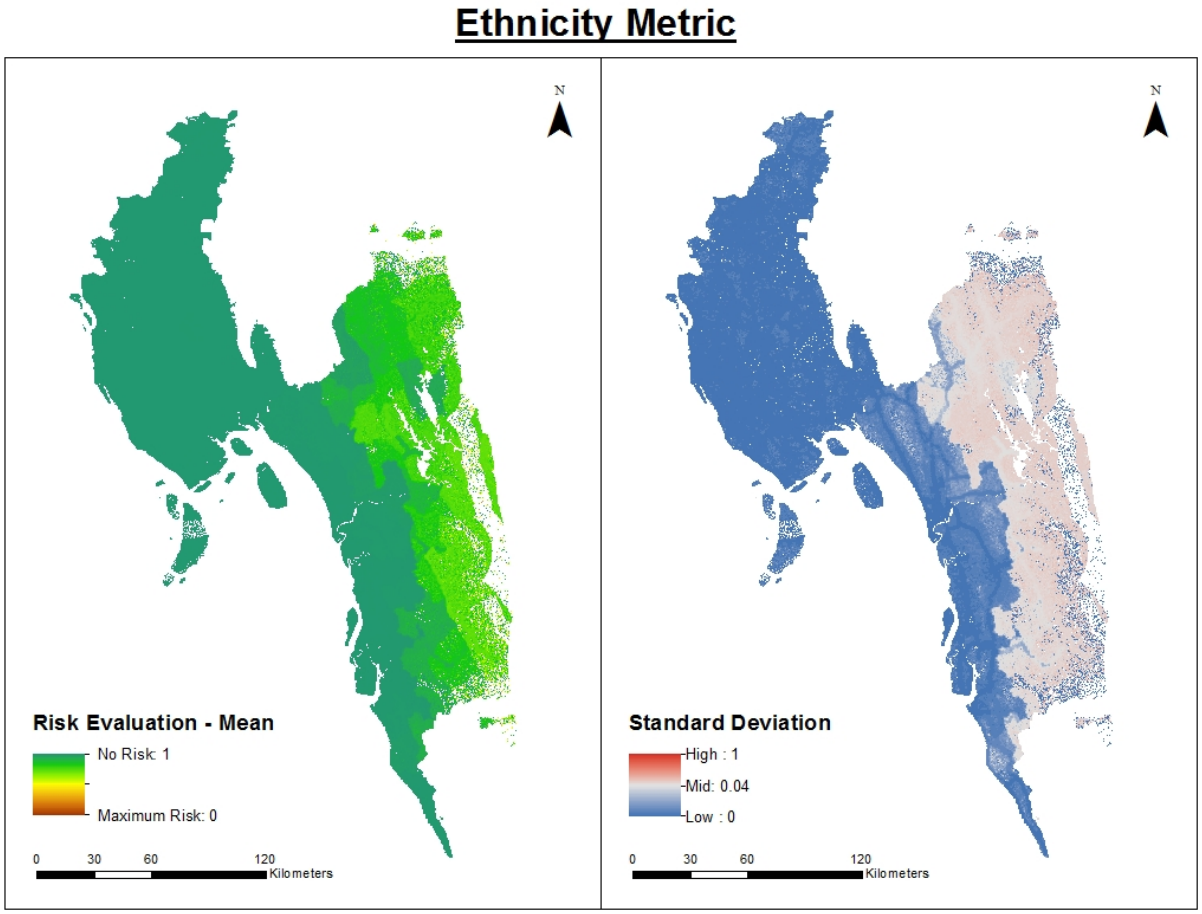
"The indigenous community experienced widespread discrimination and abuse… Indigenous persons also suffered from societal violence, including rape and killing. This violence was sometimes associated with land grabbing. According to the Kapaeeng Foundation, an indigenous rights NGO, indigenous women and girls were increasingly targeted for rape and other assaults, and the justice system often failed to protect victims or punish offenders." For example, "In May a 21-year-old indigenous Garo woman was gang-raped by five men on a microbus while returning home from work in Dhaka."

In January a dispute related to land ownership between indigenous Santal villagers in Dinajpur and members of the majority community escalated into an armed conflict.

Some NGOs reported discrimination against indigenous people in government hiring and promotions. According to the Chittagong Hill Tracts (CHT) Commission, fewer than half of indigenous children ages six through 10 were enrolled in school, in part due to a lack of indigenous-language instruction. Indigenous people at times lacked access to adequate housing and health care.

All ethnic answers are given a minimum value of 0.0625 (extreme risk, $½^4$) and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of 9NotInUniverse does not indicate ethnicity and so it is given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Maps will range from extreme risk to no risk.

Example realization metric map



References

U.S. Department of State 2015. Bureau of Democracy, Human Rights, and Labor. Country Reports on Human Rights Practices for 2015. Bangladesh.

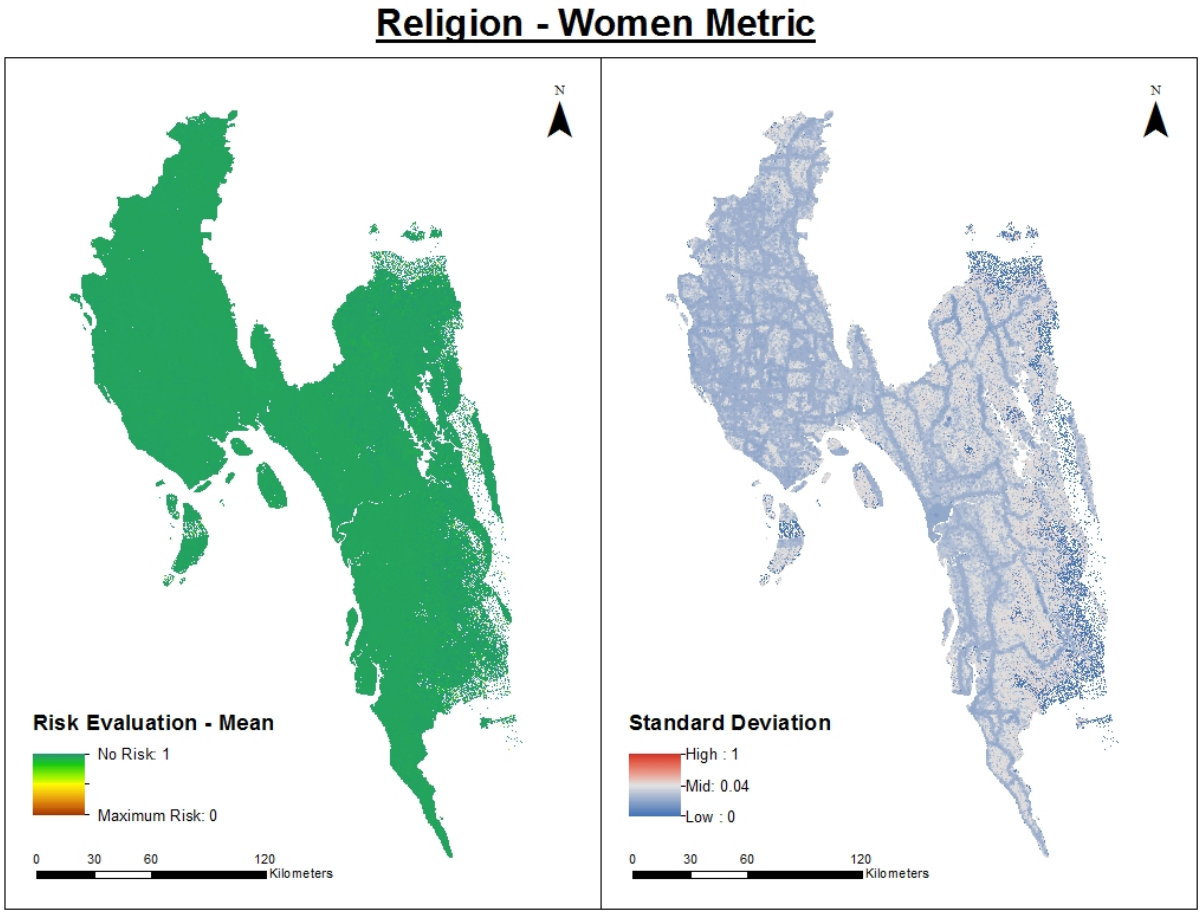
Wong, C. S., Ang, L. W., James, L., & Goh, K. T. 2010. Epidemiological characteristics of cholera in Singapore, 1992-2007. *Annals Academy of Medicine Singapore*, *39*(7), 507.

Metric: Religion - Women's

Indicator:	Targeted Groups
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	1Islam (min: 1.0, max: 1.0) 2Hinduism (min: 0.0625, max: 0.9) 3Buddhism (min: 0.0625, max: 0.9)

	4Christianity (min: 0.0625, max: 0.9)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Glass et al. (1982); USAID (2011); U.S. Department of State (2015)
Logic:	This metric represents the risk to women based on their religious affiliation. The U.S. Department of State (2015) reported that on human rights in Bangladesh regarding religion, they found "Instances of societal violence against religious and ethnic minorities persisted… Women, children, minority groups, persons with disabilities, indigenous people, and sexual minorities often confronted social and economic disadvantages." During [2015], violent extremists killed four bloggers with reputations for secularist or anti-Islamic writing. "NGOs reported that national origin, racial, and ethnic minorities faced discrimination. For example, some Dalits (lowest-caste Hindus) had restricted access to land, adequate housing, education, and employment." DHS-2011 asks about religion. The survey returned that the population is divided as 90% Islam, 9.5% Hindi, 0.2% Buddhism, 0.2% Christianity. Glass et al. (1982) found that from the study of cholera in rural Bangladesh from 1966-1980, "cholera cases were hospitalized with greater frequency from villages which were Hindu." While there was violence against secular bloggers, 9NotInUniverse does not indicate secular as the question could have been skipped. Answers of "1Islam" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). All other answers "2Hinduism," "3Buddhism," "4Christianity" are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map



References

Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., & Black, R. E. 1982. Endemic cholera in rural Bangladesh, 1966–1980.*American journal of epidemiology*, *116*(6), 959-970.

USAID 2011. Demographic and Health Surveys Methodology. Questionnaires: Household, Woman's, and Man's.

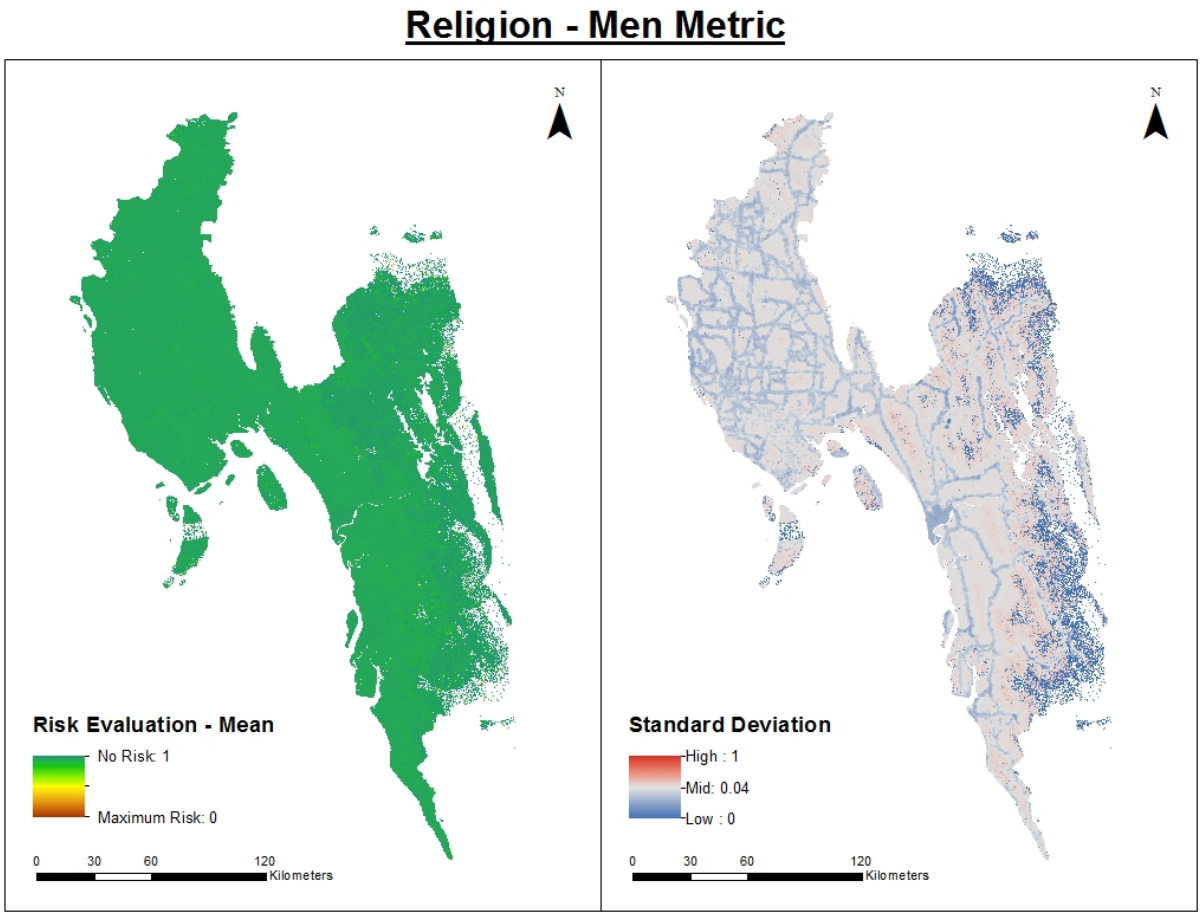
U.S. Department of State 2015. Bureau of Democracy, Human Rights, and Labor. Country Reports on Human Rights Practices for 2015. Bangladesh.

Metric: Religion - Men's

Indicator:	Targeted Groups
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera

Metric Assigned Values:	1Islam (min: 1.0, max: 1.0) 2Hinduism (min: 0.0625, max: 0.9) 3Buddhism (min: 0.0625, max: 0.9) 4Christianity (min: 0.0625, max: 0.9)
Survey:	DHS - Men
Survey Date:	2011
Other Data Sources:	Glass et al. (1982); USAID (2011); U.S. Department of State (2015)
Logic:	This metric represents the risk to men based on their religious affiliation. The U.S. Department of State (2015) reported that on human rights in Bangladesh regarding religion, they found "Instances of societal violence against religious and ethnic minorities persisted… Women, children, minority groups, persons with disabilities, indigenous people, and sexual minorities often confronted social and economic disadvantages." During [2015], violent extremists killed four bloggers with reputations for secularist or anti-Islamic writing. "NGOs reported that national origin, racial, and ethnic minorities faced discrimination. For example, some Dalits (lowest-caste Hindus) had restricted access to land, adequate housing, education, and employment." DHS-2011 asks about religion. The survey returned that the population is divided as 90% Islam, 9.5 Hindi, 0.2% Buddhism, 0.2% Christianity. Glass et al. (1982) found that from the study of cholera in rural Bangladesh from 1966-1980, "cholera cases were hospitalized with greater frequency from villages which were Hindu." While there was violence against secular bloggers, 9NotInUniverse does not indicate secular as the question could have been skipped. Answers of "1Islam" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). All other answers "2Hinduism," "3Buddhism," "4Christianity" are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map



References

Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., & Black, R. E. 1982. Endemic cholera in rural Bangladesh, 1966–1980.*American journal of epidemiology*, *116*(6), 959-970.

USAID 2011. Demographic and Health Surveys Methodology. Questionnaires: Household, Woman's, and Man's.

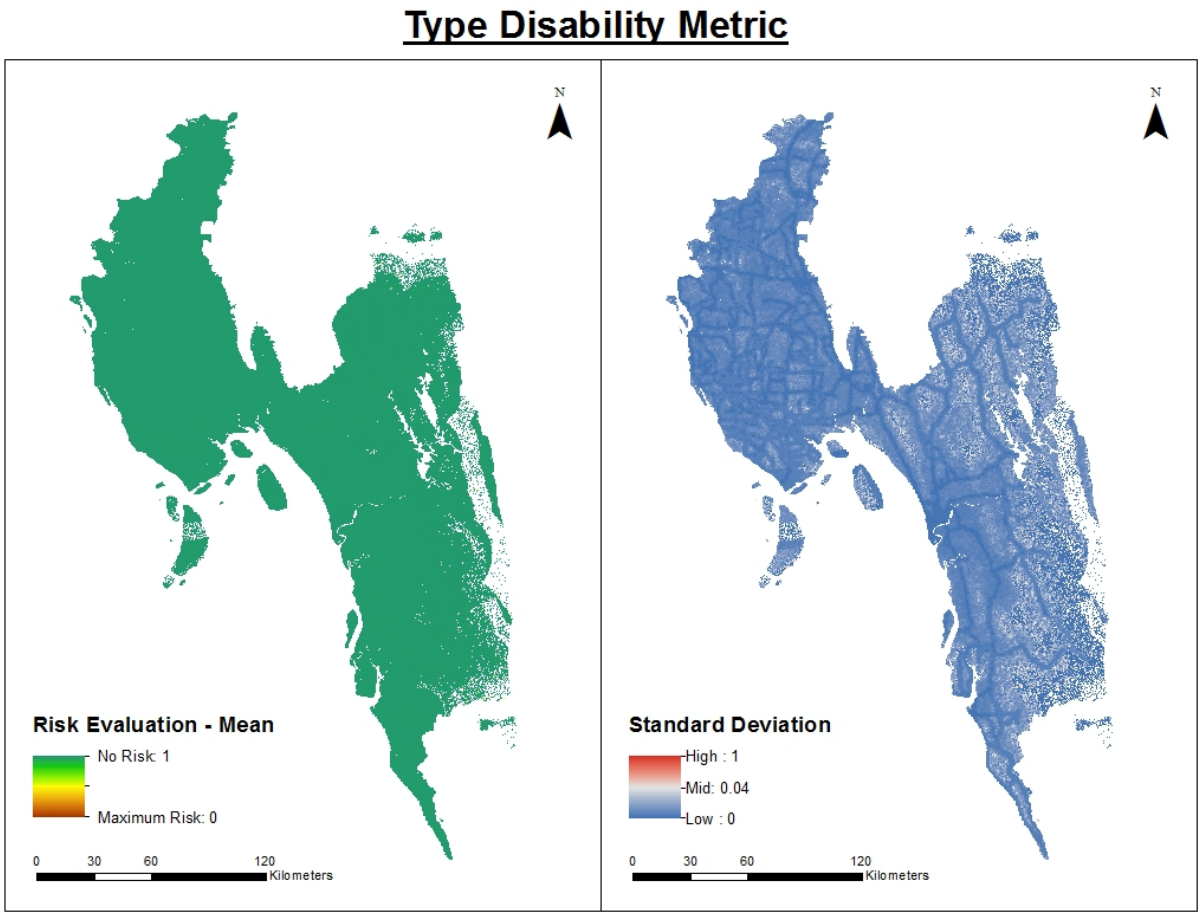
U.S. Department of State 2015. Bureau of Democracy, Human Rights, and Labor. Country Reports on Human Rights Practices for 2015. Bangladesh.

Metric: Type of Disability

Indicator:	Targeted Groups
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera

Metric Assigned Values:	None (min: 1.0, max: 1.0) Speech (min: 0.125, max: 0.9) Vision (min: 0.125, max: 0.9) Hearing (min: 0.125, max: 0.9) Physical (min: 0.125, max: 0.9) Mental (min: 0.125, max: 0.9) Autistic (min: 0.125, max: 0.9)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	U.S. Department of State (2015)
Logic:	The U.S. Department of State (2015) reported that on human rights in Bangladesh regarding discrimination against those with disabilities. "…persons with disabilities… confronted social and economic disadvantages." "Persons with disabilities faced social and economic discrimination." Specifically, "Discrimination against persons with disabilities was a problem, especially for children seeking admittance to public school…According to the NGO Action against Disability, 90% of children with disabilities did not attend public school. The government trained teachers about inclusive education and recruited disability specialists at the district level. The government also allocated stipends for students with disabilities." Thus, we believe that anyone with a reported disability is inherently at a disadvantage. Answers of "None" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). All other answers are given a minimum value of 0.125 (high risk, $½^3$) and a maximum value of 0.9 (minimal risk). Maps will range from high risk to no risk.

Example realization metric map



References

U.S. Department of State 2015. Bureau of Democracy, Human Rights, and Labor. Country Reports on Human Rights Practices for 2015. Bangladesh.

A.3.1.9 Indicator: Women and gender

This indicator accounts for inherent biases, disadvantages, and acts of violence against women. The U.S. State Department has a long section on discrimination against women in Bangladesh. The cholera literature also supports that women are more at risk of contracting cholera then men.

The "Women and Gender" indicator was not explicitly given in the HC framework, but due to the mounting evidence that this group is so at risk for violence, below average education, predisposition to cholera, and economic disadvantages, the authors took it upon themselves to add "Women and Gender" as its own indicator within the Vulnerable Groups factor.

The metrics are available from IPUMS and DHS, and are regarding gender, marital status of the woman, and if she is currently pregnant. Marital status is a key metric as domestic violence is rampant with 26% of women being victims of spousal rape.

Metric weighting logic

As "Currently Pregnant" is more indicative of increased cholera risk, and as the answers making up this metric are only asked of women, it is the most constraining on the indicator and is weighted the highest. Even though gender, as a potential contributor to cholera risk, may be accounted for in other metrics/indicators (e.g. Age – Women in the Age indicator), it does not impact the metric weighting logic of this particular indicator.

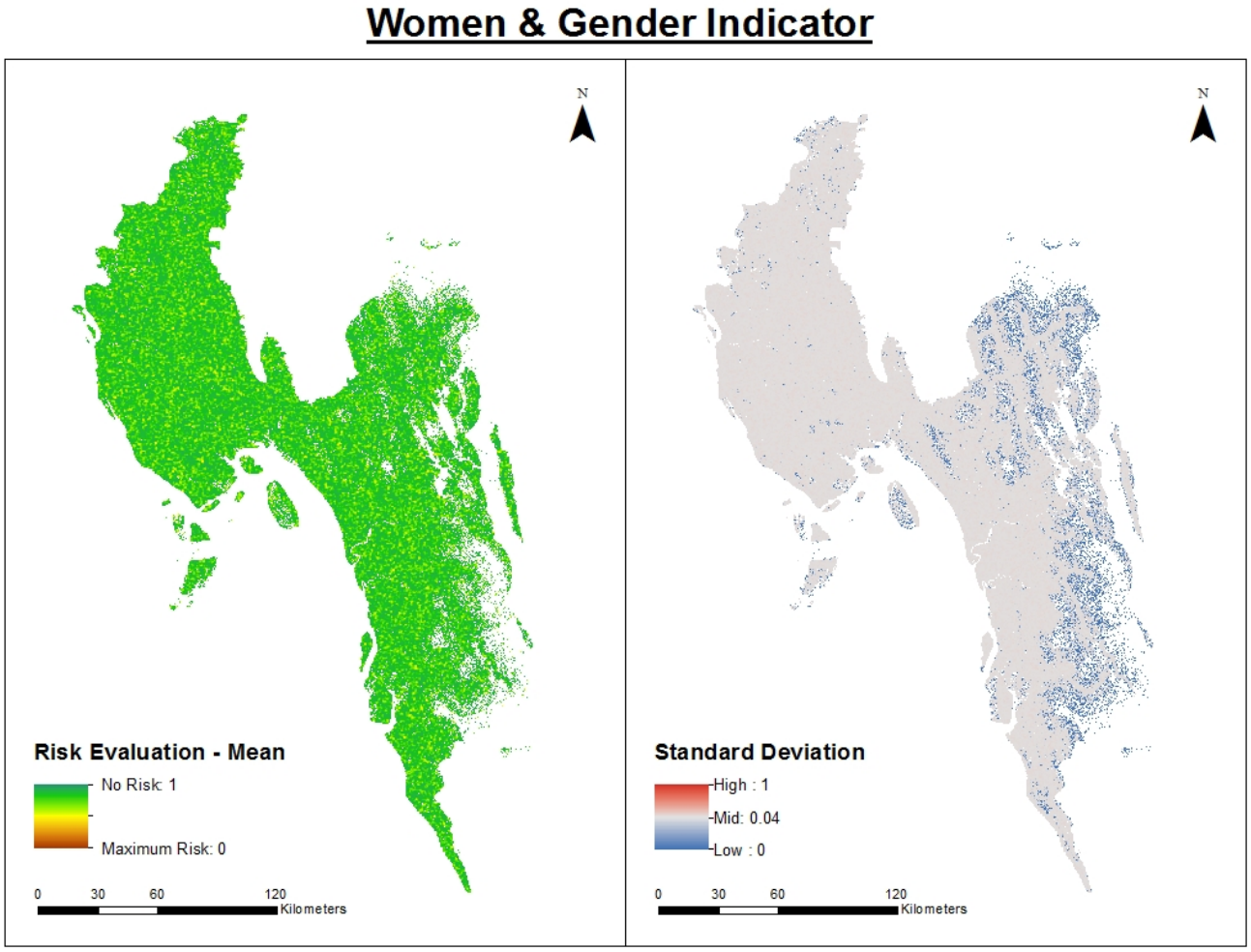
Metric	Weight Minimum Value	Weight Maximum Value
Women	0.5	0.5
Currently Pregnant	0.7	1.0

Uncertainty values

This indicator is given an uncertainty minimum value of 0.1 and an uncertainty maximum value of 0.3, as this indicator is well supported in the literature. Adding more data on correlation of cholera risk and female disposition could decrease the uncertainty values.

Indicator Uncertainty Min:	0.1
Indicator Uncertainty Max:	0.3

Example outcome



Metric: Women

Indicator:	Women and Gender
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	1Male (min: 1.0, max: 1.0) 2Female (min: 0.125, max: 0.9)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	Emch (1999); Glass et al. (1982); Siddique et al (1992); U.S. Department of State (2015)
Logic:	

The U.S. Department of State (2015) reported that on human rights in Bangladesh regarding discrimination against those with disabilities, “Women, children, minority groups, persons with disabilities, indigenous people, and sexual minorities often confronted social and economic disadvantages.”

The State Department goes on to elaborate that the law prohibits certain forms of discrimination against women, but there is weak enforcement. “Laws regarding divorce, custody, and rape differed according to an individual’s religion and were often discriminatory toward women and girls.”

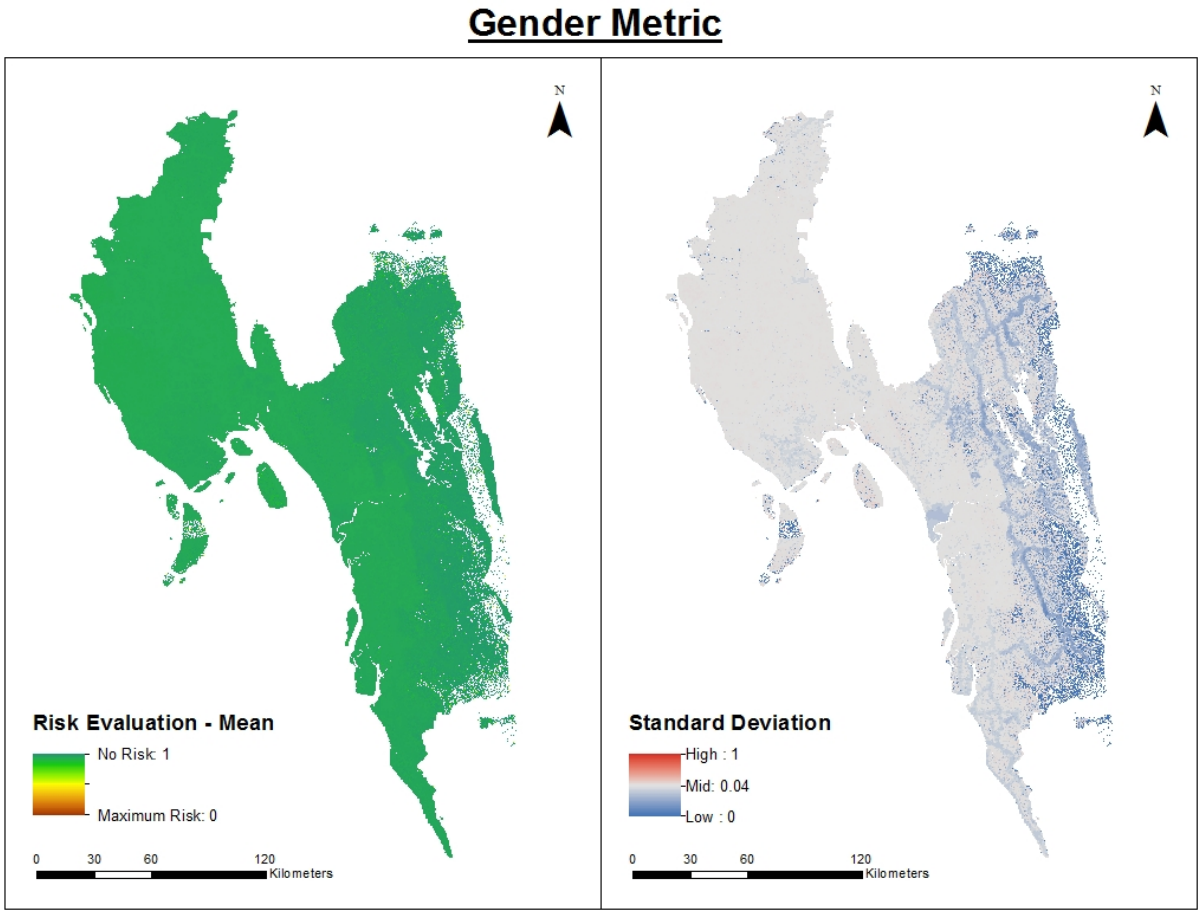
Gender-based violence is a serious problem in Bangladesh. A UN study on violence against women released in 2013, found that 55% of urban males and 57% of rural males reported having committed physical and/or sexual violence against women. Only 5% of the urban males and 12% of the rural males faced legal consequences for rape charges. The study went on to determine that the low prosecution rate or rapists supported these criminal acts.

Women have lower educational attainment levels as, “Early and forced marriage was a factor in girls’ attrition from secondary school.” Regarding employment, “There were some gender-based wage disparities in the overall economy, but wages of women and men were comparable in the garment sector.”

In regards to cholera risk, Glass et al. (1982) found that, “children 2-9 years old and adult women are most commonly hospitalized for cholera.” Siddique et al (1992) found that of laboratory confirmed adults 15-39 with cholera, between the years 1985-1991, women were 55.4% of the patients. The difference was negligible for adults over the age of 40. “In Bangladesh, women of child-bearing age have high cholera incidence rates presumable because of increase person-to person contact (Emch, 1999).”

Women, needless to say, are an at-risk subpopulation for many things. Cholera specifically, women are most likely to be hospitalized for the disease. Answers of “1Male” are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of “2Female” are given a minimum value of 0.125 (high risk, $½^3$) and a maximum value of 0.9 (minimal risk). Maps will range from high risk to no risk.

Example realization metric map



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Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., & Black, R. E. 1982. Endemic cholera in rural Bangladesh, 1966–1980.*American journal of epidemiology*, *116*(6), 959-970.

Siddique, A. K., Zaman, K., Baqui, A. H., Akram, K., Mutsuddy, P., Eusof, A., & Sack, R. B. 1992. Cholera epidemics in Bangladesh: 1985-1991.*Journal of diarrhoeal diseases research*, 79-86.

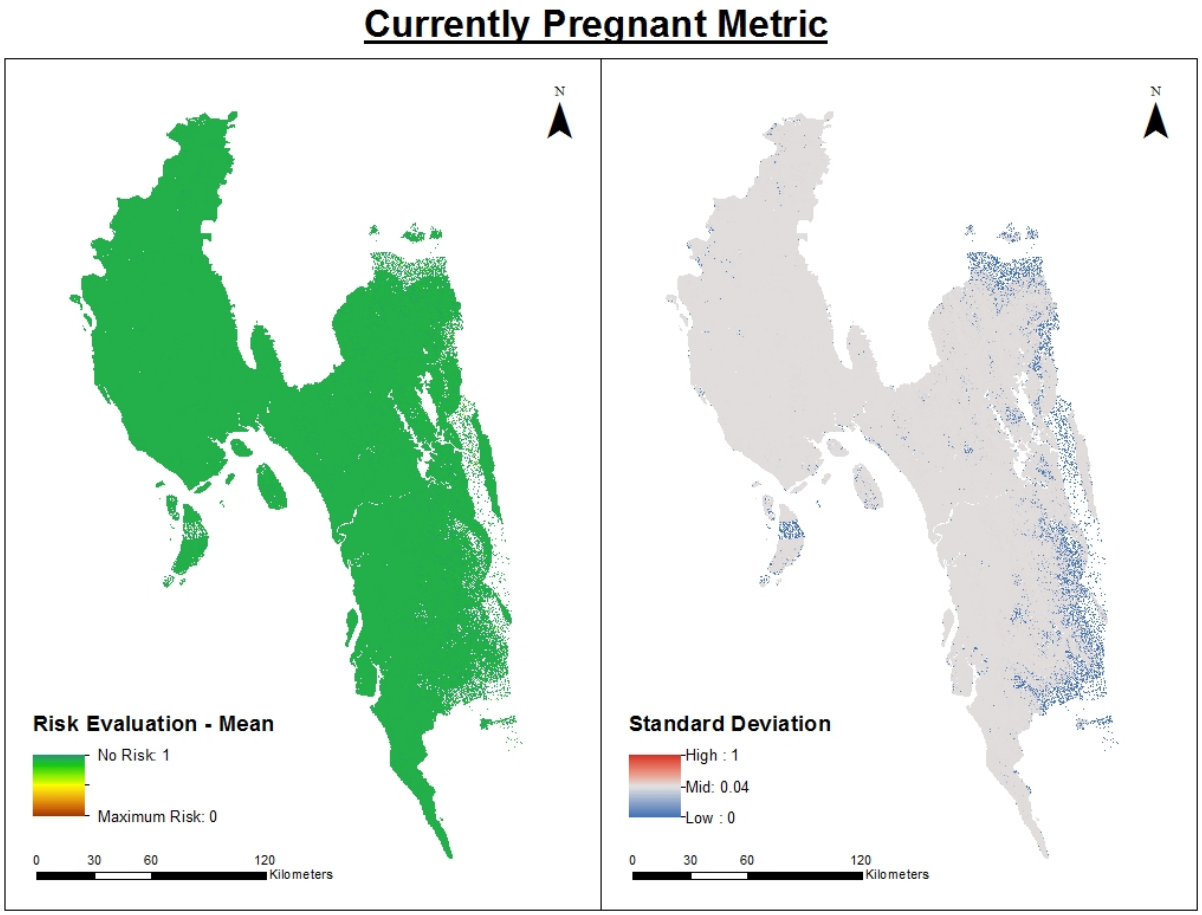
U.S. Department of State 2015. Bureau of Democracy, Human Rights, and Labor. Country Reports on Human Rights Practices for 2015. Bangladesh.

Metric: Currently Pregnant

Indicator:	Women and Gender
Factor:	Vulnerable Groups
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	No/Unsure (min: 0.8, max: 1.0) Yes (min: 0.25, max: 0.9)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Emch (1999); Glass et al. (1982); Siddique et al (1992); U.S. Department of State (2015)
Logic:	The U.S. Department of State (2015) reported that on human rights in Bangladesh regarding discrimination against those with disabilities, "Women, children, minority groups, persons with disabilities, indigenous people, and sexual minorities often confronted social and economic disadvantages." The State Department goes on to elaborate that the law prohibits certain forms of discrimination against women, but there is weak enforcement. "Laws regarding divorce, custody, and rape differed according to an individual's religion and were often discriminatory toward women and girls." Gender-based violence is a serious problem in Bangladesh. A UN study on violence against women released in 2013, found that 55% of urban males and 57% of rural males reported having committed physical and/or sexual violence against women. Only 5% of the urban males and 12% of the rural males faced legal consequences for rape charges. The study went on to determine that the low prosecution rate or rapists supported these criminal acts. In regards to pregnancy issues in Bangladesh, "According to the 2010 Bangladesh Maternal Mortality Survey, the maternal mortality ratio declined by 40% during the preceding nine years, from 322 to 194 deaths per 100,000 live births." Women have lower educational attainment levels as, "Early and forced marriage was a factor in girls' attrition from secondary school." Regarding employment, "There were some gender-based wage disparities in the overall economy, but wages of women and men were comparable in the garment sector." In regards to cholera risk, Glass et al. (1982) found that, "children 2-9 years old and adult women are most commonly hospitalized for cholera." Siddique et al (1992) found that of laboratory confirmed adults 15-39 with cholera, between the years 1985-1991, women were 55.4% of the patients. The difference was negligible for adults over the age of 40. "In Bangladesh, women of child-bearing age have high cholera incidence rates presumable because of increase person-to person contact (Emch, 1999)." This metric consists of answers from female respondents concerning the question of whether they are pregnant or not. Answers of "No/Unsure" are given an overall value of minimal risk with a minimum value of 0.8 (minimal risk) and a maximum value of 1.0 (minimal risk with no impact on risk, ½⁰). Answers of "Yes" are given a

minimum of 0.25 (medium risk, ½[2]) and a maximum value of 0.9 (minimal risk). Maps will range from medium risk to no risk.

Example realization metric map



References

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Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., & Black, R. E. 1982. Endemic cholera in rural Bangladesh, 1966–1980.*American journal of epidemiology*, *116*(6), 959-970.

Siddique, A. K., Zaman, K., Baqui, A. H., Akram, K., Mutsuddy, P., Eusof, A., & Sack, R. B. 1992. Cholera epidemics in Bangladesh: 1985-1991.*Journal of diarrhoeal diseases research*, 79-86.

U.S. Department of State 2015. Bureau of Democracy, Human Rights, and Labor. Country Reports on Human Rights Practices for 2015. Bangladesh.

A.3.2 Substandard conditions factor overview

This factor, as outlined by the HC framework, focuses on the negative human impacts on infrastructure, as well as living and working conditions. It is these indicators and metrics that most represent how the built environment can effect individual's quality of life and risk to cholera outbreaks.

Indicators within this factor in the HC framework include Civil Infrastructure Failure, Hazardous Working Conditions, Overcrowding and Dangerous Housing, and Polluted and Disease-Bearing Environment. As Civil Infrastructure Failure is a keystone issue for cholera prevention, the authors deemed it prudent to make it its own factor.

This factor was expanded by the authors to target cholera. Overcrowding & Dangerous Housing was separated into two indicators to better inform the factor.

Indicator Weighting Logic

The Dangerous Housing and Polluted & Disease-Bearing Environment indicators are given a minimum of 0.4 and a maximum value of 0.6. This is because these two indicators are equally as constraining on the factor. The indicator of Overcrowding is weighted with a minimum value of 0.2 and a maximum value of 0.4 as there are fewer metrics informing it. Furthermore, the Dangerous Housing and Polluted & Disease-Bearing Environment indicators are better supported in the literature as having greater impact on cholera outbreaks.

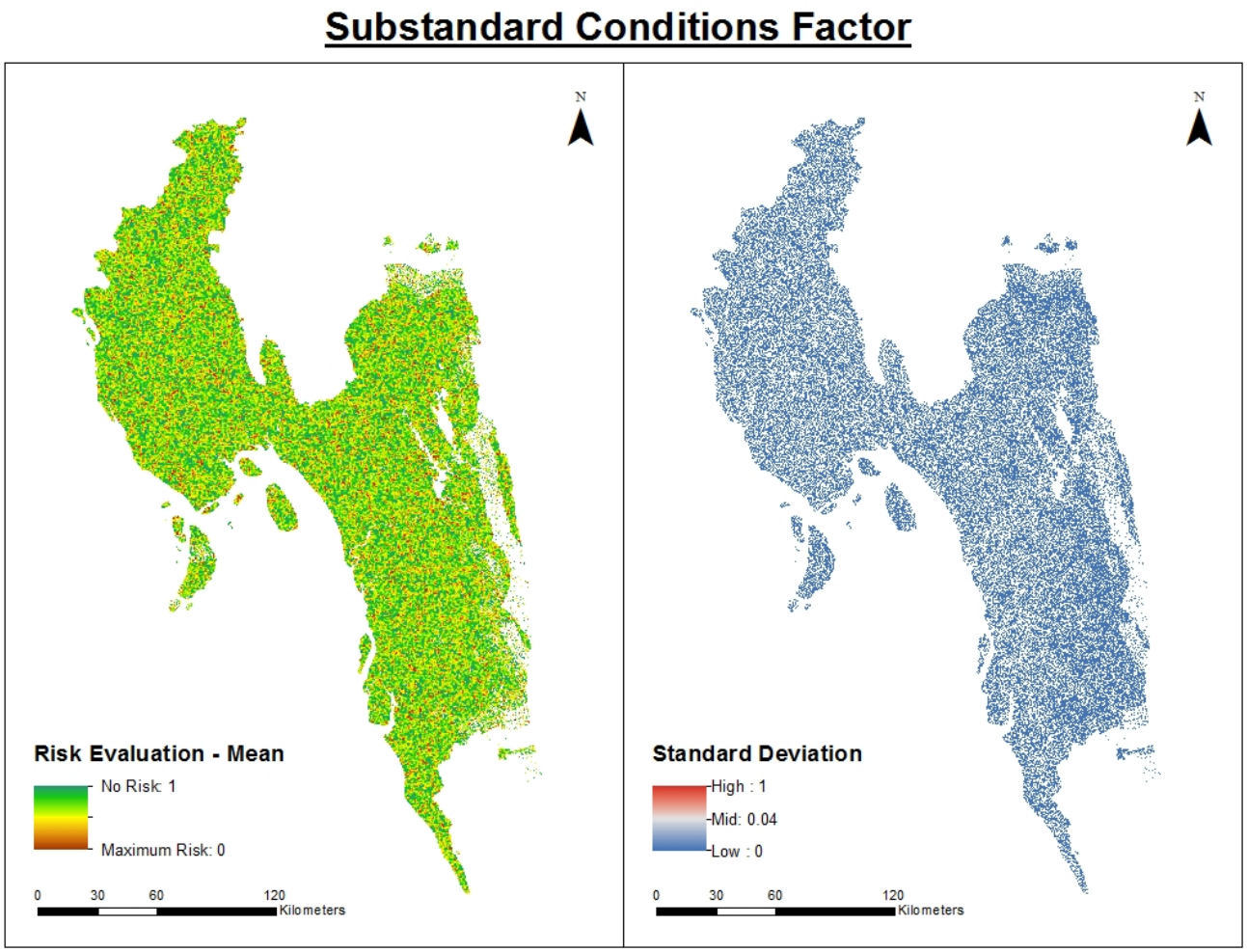
Indicator	Weight Minimum Value	Weight Maximum Value
Overcrowding	0.2	0.4
Dangerous Housing	0.4	0.6
Polluted & Disease-Bearing Environment (A.3.2.3)	0.4	0.6

Uncertainty values

This factor is given a range of uncertainty values from 0.1 to 0.3 because of the perceived ability of the existing indicators to fully address the themes of the factor. The addition of more metrics informing these indicators could further decrease the uncertainty values.

Factor Uncertainty Min:	0.1
Factor Uncertainty Max:	0.3

Example outcome



A.3.2.1 Indicator: Overcrowding

As different cities, regions, and countries will have varying definitions of what defines overcrowded, it is important for this indicator to obtain area-specific data to make up the metrics.

PACOM specifies that metrics should include the percentage of population living in overcrowded housing (inadequate living space).

Metrics included in the overcrowding indicator are “Number of sleeping rooms” and “People Per Household.” Density divided by sleeping rooms

will create the metric considered "Household Overcrowding." Due to time constraints, this metric was not made, but should be used to better inform the metric.

Metric weighting logic

The metric "Household Overcrowding," which would consist of the "People Per Household" metric divided by the "Number of Sleeping Rooms," does not currently exist due to a lack of computational capabilities. However, the research team plans to alter existing capabilities to allow for this metric to exist; and when it does, it should be weighted as the most constraining metric in the indicator. "Household Overcrowding" should be weighted both a minimum and maximum of 1.0.

For now, "People Per Household" is weighted the highest, and is more constraining then "Number of Sleeping Rooms." These two metric weighting schemas will likely remain unaltered, even with the addition of the "Household Overcrowding" metric.

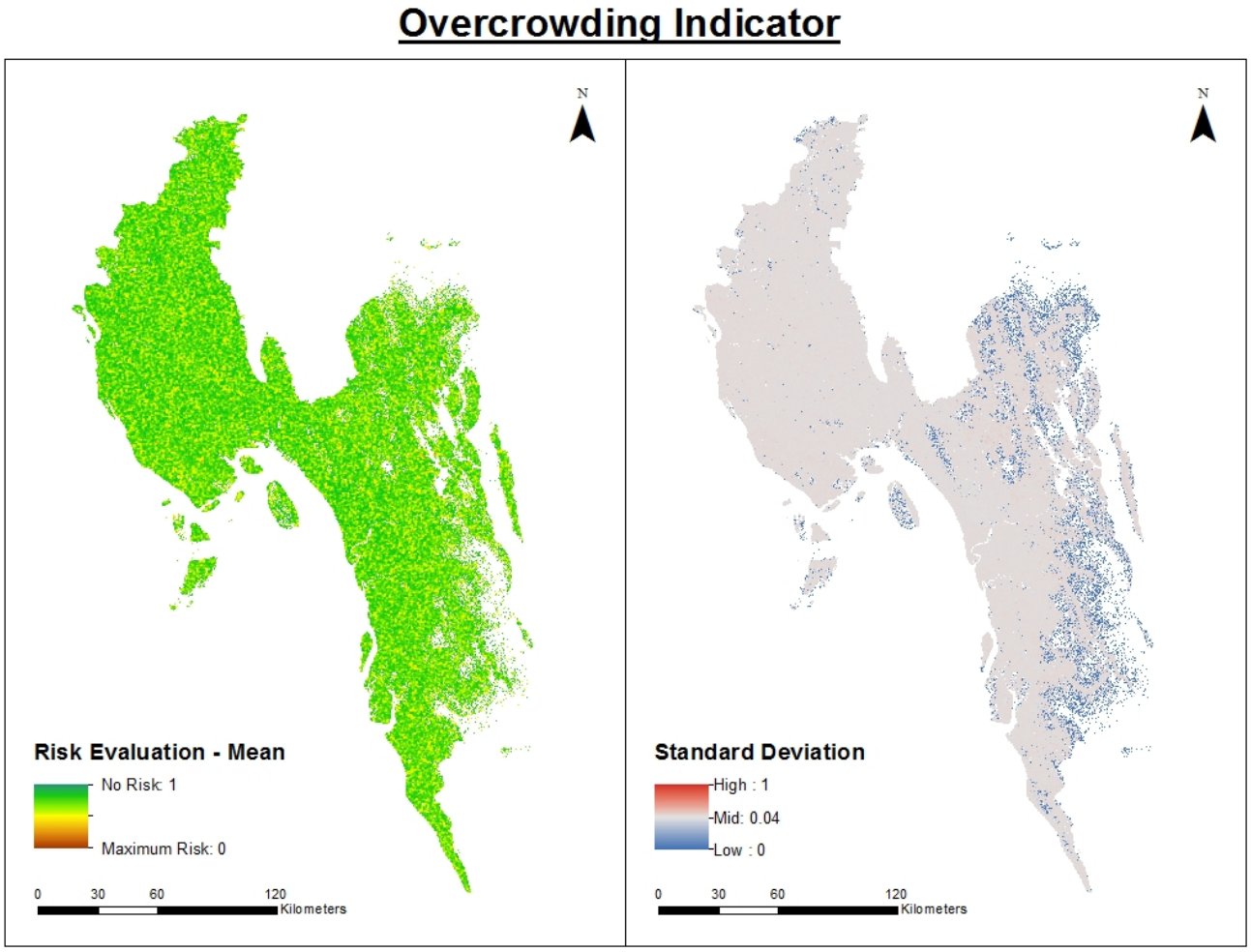
Metric	Weight Minimum Value	Weight Maximum Value
Number of Sleeping Rooms	0.4	0.6
People Per Household	0.6	0.8

Uncertainty values

This indicator is given an uncertainty minimum value of 0.2 and an uncertainty maximum value of 0.4. One key variable that is missing from this indicator is population density as we are unsure of how to calculate this value from enumerated household surveys. Adding more data on effects of overcrowding on cholera risks could decrease the uncertainty values. As there is already support in the literature for overcrowding affecting the risk of cholera, the Indicator Uncertainties for these variables are quite low.

Indicator Uncertainty Min:	0.2
Indicator Uncertainty Max:	0.4

Example outcome

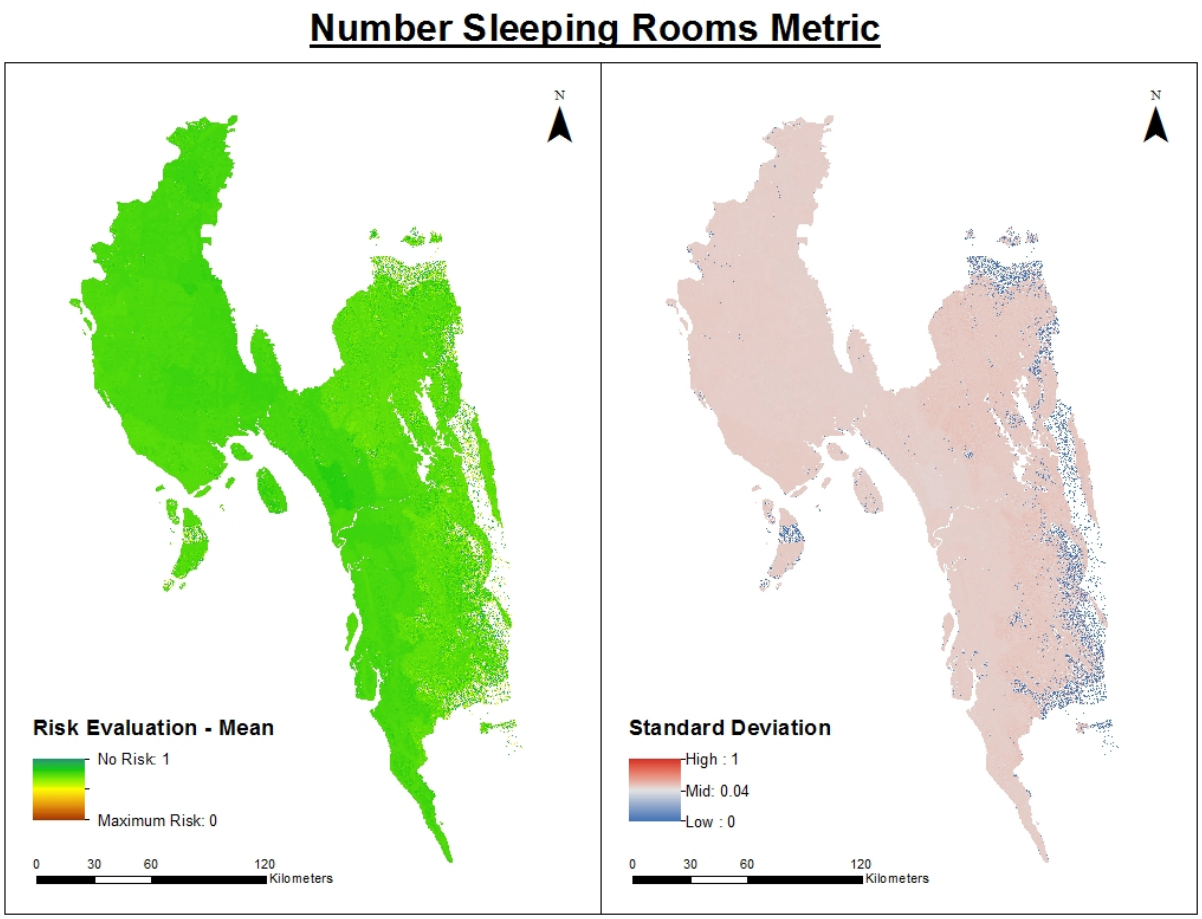


Metric: Number of Sleeping Rooms

Indicator:	Overcrowding		
Factor:	Substandard Conditions		
Condition:	Human Behavioral Impact		
Framework:	Cholera		
Metric Assigned Values:	1 Room	Min: 0.125	Max: 1
	2 Rooms	Min: 0.25	Max: 1
	3 Rooms	Min: 0.50	Max: 1
	4 Rooms	Min: 1.00	Max: 1
	5 plus Rooms	Min: 1.00	Max: 1
Survey:	DHS - Household		
Survey Date:	2011		

Other Data Sources:	Akond et al., 2008; Drasar, 1996; Kanungo et al. (2012); Leung et al., 2012; Penrose et al. (2010)
Logic:	Leung et al. (2012) found that high urbanization and high overcrowding were important predictors of cholera in Ashanti, Ghana. Drasar noted that "cholera is often associated with poverty, overcrowding, and low socioeconomic status." Akond et al. (2008) concludes that "Rapid urbanization, overcrowding and poor sanitation system greatly facilitates the greater spread of various diseases in Bangladesh." Penrose et al. (2010) found that there was approximately a two percent increase in cholera incidence for every increase in population density of 1000 people per km^2 in Dar es Salaam, Tanzania in 2006. Answers of "4 Rooms" and "5 plus Rooms" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "3 Rooms" are given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0 (minimal risk with no impact on risk). Answers of "2 Rooms" are given a minimum value of 0.25 (medium risk, $½^2$) and a maximum value of 1.0 (minimal risk with no impact on risk). Answers of "1 Room" are given a minimum value of 0.125 (high risk, $½^3$) and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Maps will range from high risk to no risk.

Example realization metric map



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Drasar, B. S. 1996. *Cholera and the ecology of Vibrio cholerae*. Springer Science & Business Media.

Kanungo, S., Sur, D., Ali, M., You, Y. A., Pal, D., Manna, B., & Nair, G. B. 2012. Clinical, epidemiological, and spatial characteristics of Vibrio parahaemolyticus diarrhea and cholera in the urban slums of Kolkata, India. *BMC public health*, *12*(1), 830.

Leung, D. T., Rahman, M. A., Mohasin, M., Patel, S. M., Aktar, A., Khanam, F., & Chowdhury, F. 2012. Memory B cell and other immune responses in children receiving two doses of an oral killed cholera vaccine compared to responses following natural cholera infection in Bangladesh. *Clinical and vaccine immunology*, *19*(5), 690-698.

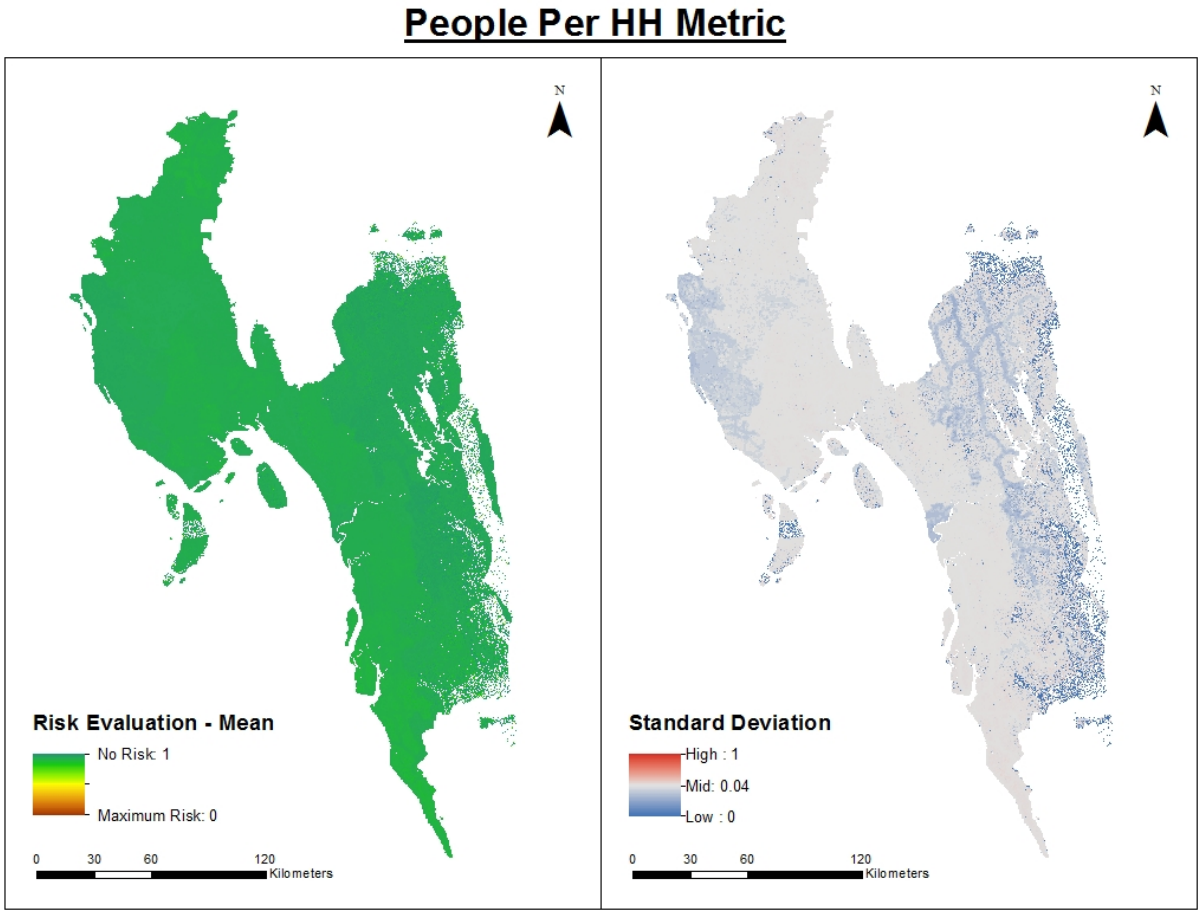
Penrose, K., De Castro, M. C., Werema, J., & Ryan, E. T. 2010. Informal urban settlements and cholera risk in Dar es Salaam, Tanzania. *PLoS Negl Trop Dis*, *4*(3), e631.

Metric: People per Household

Indicator:	Overcrowding
Factor:	Substandard Conditions
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	1-6PeoplePerHousehold (min: 1.0, max: 1.0) 7-10PeoplePerHousehold (min: 0.5, max: 0.9) 11-20PeoplePerHousehold (min: 0.25, max: 0.75) 20+PeoplePerHousehold (min: 0.0625, max: 0.5)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	Akond et al., 2008; Drasar, 1996; Leung et al., 2012
Logic:	Leung et al. (2012) found that high urbanization and high overcrowding were important predictors of cholera in Ashanti, Ghana. Drasar noted that “cholera is often associated with poverty, overcrowding, and low socioeconomic status.” Akond et al. (2008) concludes that “Rapid urbanization, overcrowding and poor sanitation system greatly facilitates the greater spread of various diseases in Bangladesh.” Penrose et al. (2010) found that there was approximately a two percent increase in cholera incidence for every increase in population density of 1000 people per km^2 in Dar es Salaam, Tanzania in 2006. Answers of one to six people per household are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of seven to 10 people per household are given

a minimum value of 0.5 (slight risk, $\frac{1}{2}^1$) and a maximum value of 0.9 (minimal risk). Answers of 11 to 20 people per household are given a minimum value of (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.75 (minimal risk). Answers of more than 20 people per household are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Maps will range from extreme risk to no risk.

Example realization metric map



References

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Drasar, B. S. 1996. *Cholera and the ecology of Vibrio cholerae*. Springer Science & Business Media.

Leung, D. T., Rahman, M. A., Mohasin, M., Patel, S. M., Aktar, A., Khanam, F., & Chowdhury, F. 2012. Memory B cell and other immune responses in children receiving two doses of an oral killed cholera vaccine compared to responses following natural cholera infection in Bangladesh. *Clinical and vaccine immunology*, *19*(5), 690-698.

A.3.2.2 Indicator: Dangerous housing

The Dangerous Housing indicator accounts for material qualities at the household and neighborhood levels. Metrics should include data on housing materials that have been assessed. At the household level, this can account for elements that can potentially lead to a dangerous living environment, such as building structure or quality of building materials.

As different cities, regions, and countries will have varying definitions of what defines dangerous housing, it is important for this indicator to obtain area-specific data to make up the metrics.

PACOM specifies that metrics should include: percentage of population living in structurally unstable or otherwise hazardous housing (e.g. chemical exposure, lead) – slums or otherwise; percentage of population living in what can be considered slums or similar.

Metric weighting logic

The metric "House Type" is weighted the most in this indicator, as it is the most specific and well used as a variable in the literature for cholera risk. As the other metrics focus more on specific household materials, rather than provide a broad overview of the household type, they are weighted lower.

Metric	Weight Minimum Value	Weight Maximum Value
Household Floor Material	0.2	0.5
Household Roof Material	0.2	0.5
Household External Wall Material	0.2	0.5
House Type	0.4	0.7

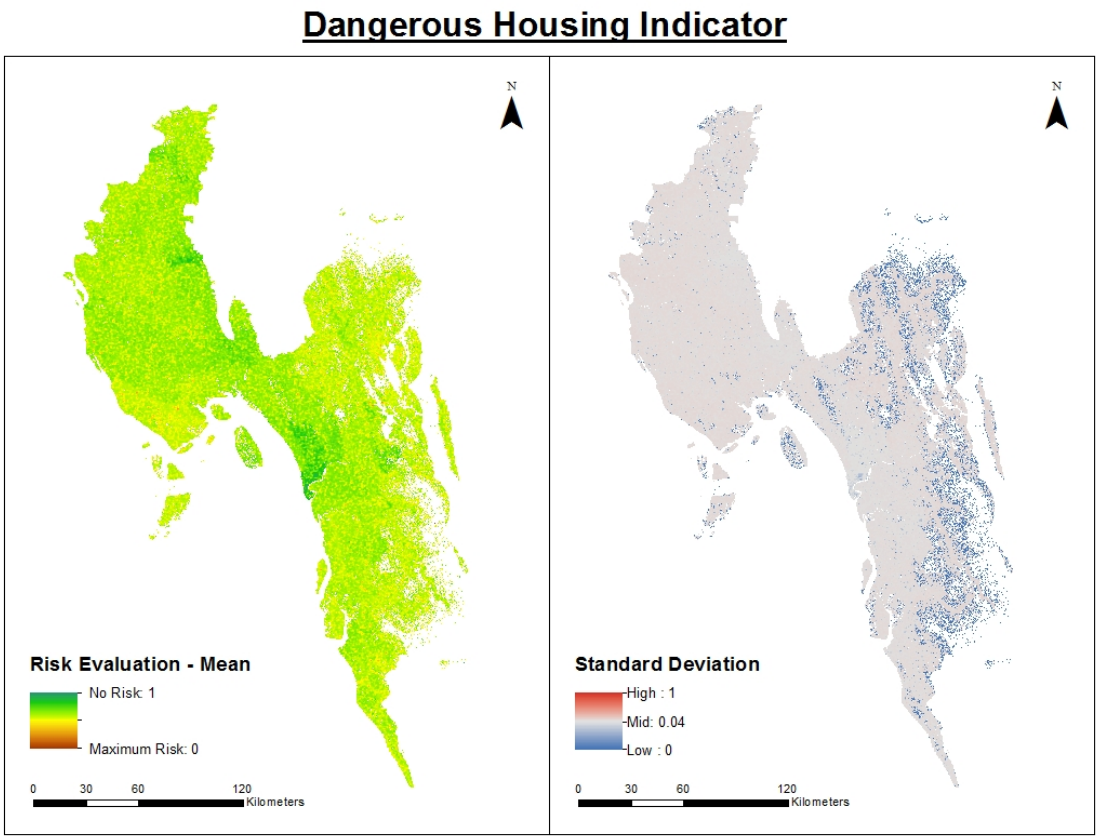
Uncertainty values

The low uncertainty values are due to the robust data collection on household materials and types by both DHS & IPUMS. Adding more data on effects of dangerous housing on cholera risks could decrease the uncertainty

values. As there is already support in the literature for overcrowding affecting the risk of cholera, the Indicator Uncertainties for these variables are quite low.

Indicator Uncertainty Min:	0.15
Indicator Uncertainty Max:	0.25

Example outcome



Metric: Household Flooring Material

Indicator:	Dangerous Housing
Factor:	Substandard Conditions
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	Finished (min: 1.0, max: 1.0) Natural (min: 0.4, max: 0.9) Rudimentary (min: 0.1, max: 0.3)
Survey:	DHS - Household
Survey Date:	2011

Other Data Sources: Emch (1999); Faruque et al. (1994); Rabbi & Dey (2013); Sasaki et al. (2008); Semba et al. (2011)

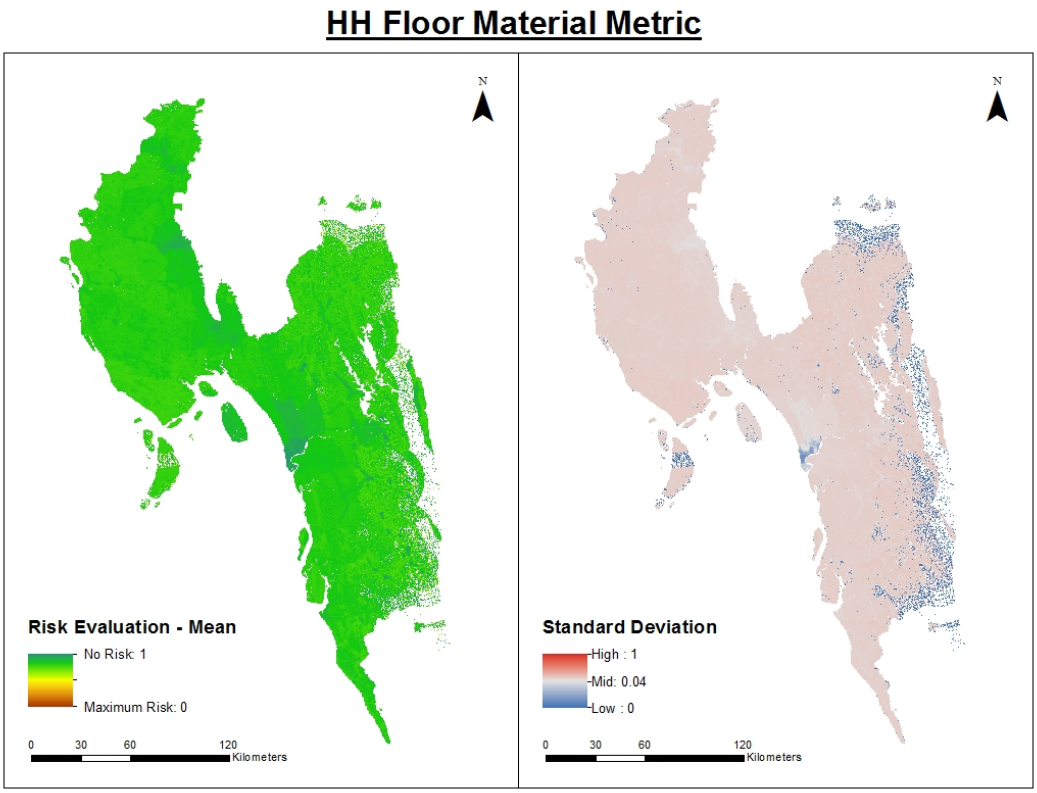
Logic: Faruque et al. (1994) found that individuals that live in home with a mud floor to be statistically significant with cholera with severe dehydration, opposed to a cement floor.

Emch (1999) found that there was no association between household construction material, a socioeconomic variable, and cholera incidence.

Rabbi & Dey (2013) found that floor material (measured in binary of concrete v. other) was statistically significant in predicting hand washing practices. Recall that Sasaki et al. (2008) found that hand washing with soap plays a protective role in cholera prevention.

Answers of "Finished" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, ½⁰). "Finished" floor answers are grouped from "parquet or polished wood," "vinyl or asphalt strips," "ceramic tiles," "cement," and "carpet." Answers of "Natural" are given a minimum value of 0.4 (slight risk) and a maximum value of 0.9 (minimal risk). "Natural" answers are grouped from "wood planks" and "palm/bamboo." Answers of "Rudimentary" are given a minimum value of 0.1 (high risk) and a maximum value of 0.3 (medium risk). "Rudimentary" answers are grouped from "earth/sand" and "dung." Maps will range from high risk to no risk.

Example realization metric map



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Faruque, A. S. G., Mahalanabis, D., Islam, A., & Hoque, S. S. 1994. Severity of cholera during concurrent infections with other enteric pathogens. *Journal of diarrhoeal diseases research*, 214-218.

Rabbi, S. E., & Dey, N. C. 2013. Exploring the gap between hand washing knowledge and practices in Bangladesh: a cross-sectional comparative study. *BMC public health*, *13*(1), 89.

Sasaki, S., Suzuki, H., Igarashi, K., Tambatamba, B., & Mulenga, P. 2008. Spatial analysis of risk factor of cholera outbreak for 2003–2004 in a peri-urban area of Lusaka, Zambia. *The American journal of tropical medicine and hygiene*, *79*(3), 414-421.

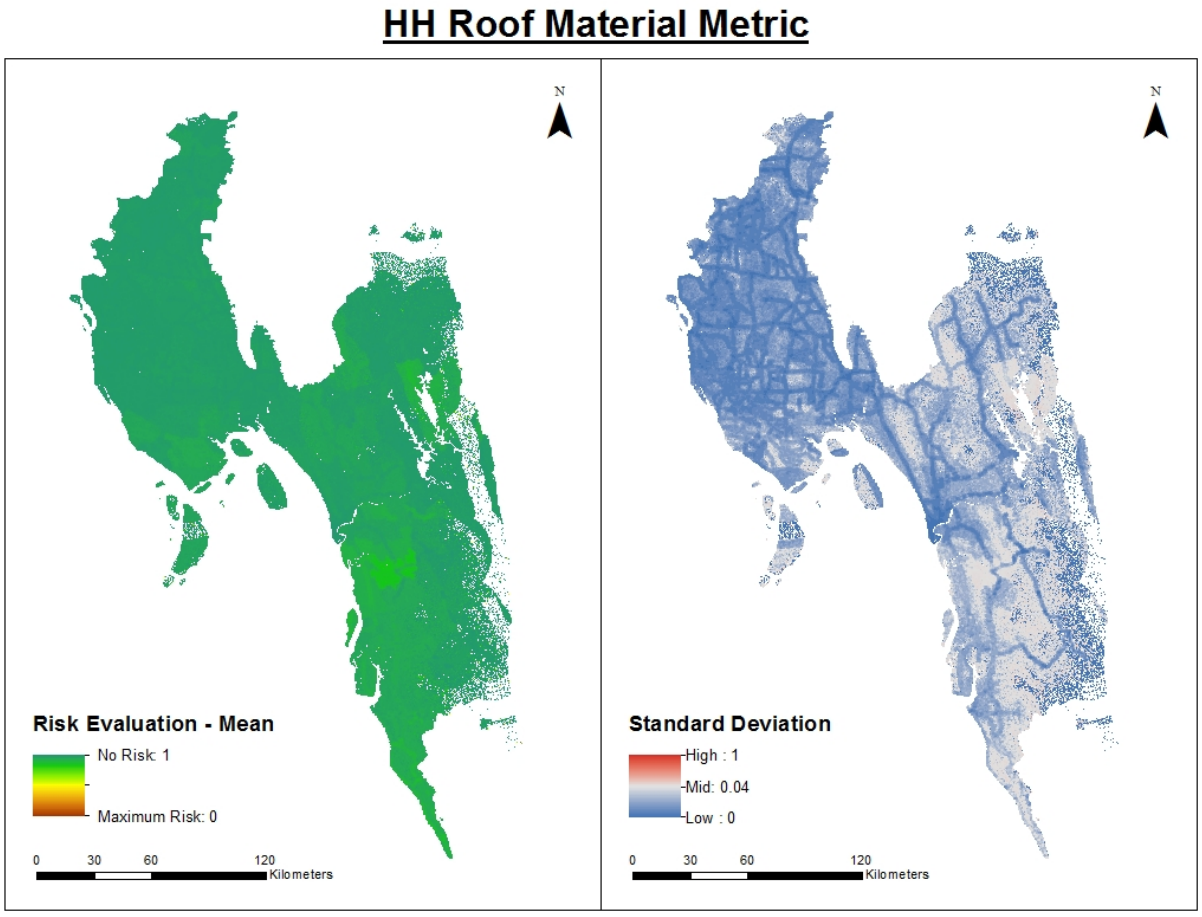
Semba, R. D., Kraemer, K., Sun, K., de Pee, S., Akhter, N., Moench-Pfanner, R., & Bloem, M. W. 2011. Relationship of the presence of a household improved latrine with diarrhea and under-five child mortality in Indonesia. *The American journal of tropical medicine and hygiene*, *84*(3), 443-450.

Metric: Household Roof Material

Indicator:	Dangerous Housing
Factor:	Substandard Conditions
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	Finished (min: 1.0, max: 1.0) Natural (min: 0.1, max: 0.5) Rudimentary (min: 0.4, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Emch et al. (2010); Hashizume et al. (2008); Rabbi & Dey (2013); Sasaki et al. (2008)
Logic:	Hashizume et al. (2008) found that in the flood period, risk of cholera was significantly higher for people living in a household with a non-concrete roof in Bangladesh. Rabbi & Dey (2013) found that roof material (measured in binary of concrete v. other) was positively related to predicting improved hand washing practices. Recall that Sasaki et al. (2008) found that hand washing with soap plays a protective role in cholera prevention. Emch et al. (2010) intended to use roof material as an independent variable, but excluded it after finding that most residents have a tin roof. Answers of "Finished" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, ½⁰). "Finished answers" are grouped from "metal," "wood," "calamine/cement fiber," "ceramic tiles," "cement," and "roofing shingles." Answers of

"Natural" are given a minimum value of 0.1 (high risk) and a maximum value of 0.5 (slight risk). "Natural" answers are grouped from "no roof," "thatch/palm leaf," and "sod." Answers of "Rudimentary" are given a minimum value of 0.4 (slight risk) and a maximum value of 0.9 (minimal risk). "Rudimentary" answers are grouped from "rustic mat," "palm/bamboo," "wood planks," "cardboard." Maps will range from high risk to no risk.

Example realization metric map



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Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

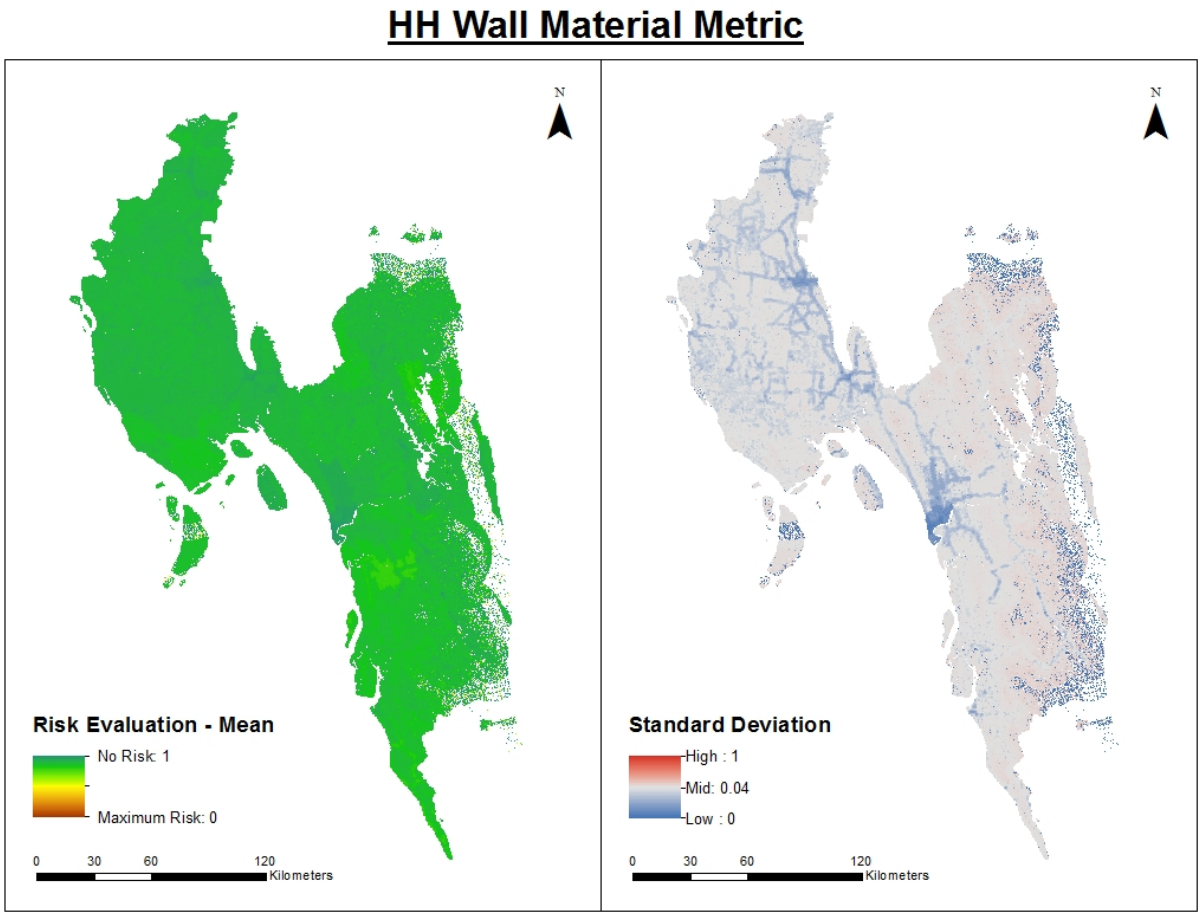
Rabbi, S. E., & Dey, N. C. 2013. Exploring the gap between hand washing knowledge and practices in Bangladesh: a cross-sectional comparative study. *BMC public health*, *13*(1), 89.

Sasaki, S., Suzuki, H., Igarashi, K., Tambatamba, B., & Mulenga, P. 2008. Spatial analysis of risk factor of cholera outbreak for 2003–2004 in a peri-urban area of Lusaka, Zambia. *The American journal of tropical medicine and hygiene*, *79*(3), 414-421.

Metric: Household External Wall Material

Indicator:	Dangerous Housing
Factor:	Substandard Conditions
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	Finished (min: 1.0, max: 1.0) Natural (min: 0.1, max: 0.5) Rudimentary (min: 0.4, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Emch et al. (2010); Rabbi & Dey (2013); Root et al. (2013); Sasaki et al. (2008)
Logic:	Rabbi & Dey (2013) found that wall material (measured in binary of concrete v. other) was unrelated to predicting hand washing practices. Recall that Sasaki et al. (2008) found that hand washing with soap plays a protective role in cholera prevention. Emch et al. (2010) used household wall material as a predictor for socioeconomic status and is ranked as follows: 1. Pucca 2. Tin Wall 3. Tin 4. Wood 5. Bamboo 6. Other 7. No Dwelling. Emch et al. (2010) goes on to find that socioeconomic status is negatively associated and statistically significant. This means that in higher socioeconomic baris, there is less cholera. Root et al. (2013) uses wall material as an indicator for socioeconomic status. Wall material is ranked as follows, from best to worst: 5. Pucca/cement 4. Tin 3. Tin and other materials 2. Bamboo and/or wood 1. Other material. This metric consists of answers to the question concerning observation of household exterior wall material. “Finished answers” are grouped from “cement,” “stone with lime/cement,” “bricks,” “cement blocks,” “covered adobe,” and “wood planks/shingles.” These answers are given both a minimum and maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). “Rudimentary” answers are grouped from “bamboo with mud,” “stone with mud,” “uncovered adobe,” “plywood,” “cardboard,” and “reused wood.” These answers are given a minimum value of 0.4 (slight risk) and a maximum value of 0.9 (minimal risk). “Natural” answers are grouped from “no walls,” “cane/palm/trunks,” and “dirt.” These answers are given a minimum value of 0.1 (high risk) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Maps will range from high risk to no risk.

Example realization metric map



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Rabbi, S. E., & Dey, N. C. 2013. Exploring the gap between hand washing knowledge and practices in Bangladesh: a cross-sectional comparative study. *BMC public health*, *13*(1), 89.

Root, E. D., Rodd, J., Yunus, M., & Emch, M. 2013. The role of socioeconomic status in longitudinal trends of cholera in Matlab, Bangladesh, 1993–2007. *PLoS Negl Trop Dis*, *7*(1), e1997.

Sasaki, S., Suzuki, H., Igarashi, K., Tambatamba, B., & Mulenga, P. 2008. Spatial analysis of risk factor of cholera outbreak for 2003–2004 in a peri-urban area of Lusaka, Zambia. *The American journal of tropical medicine and hygiene*, *79*(3), 414-421.

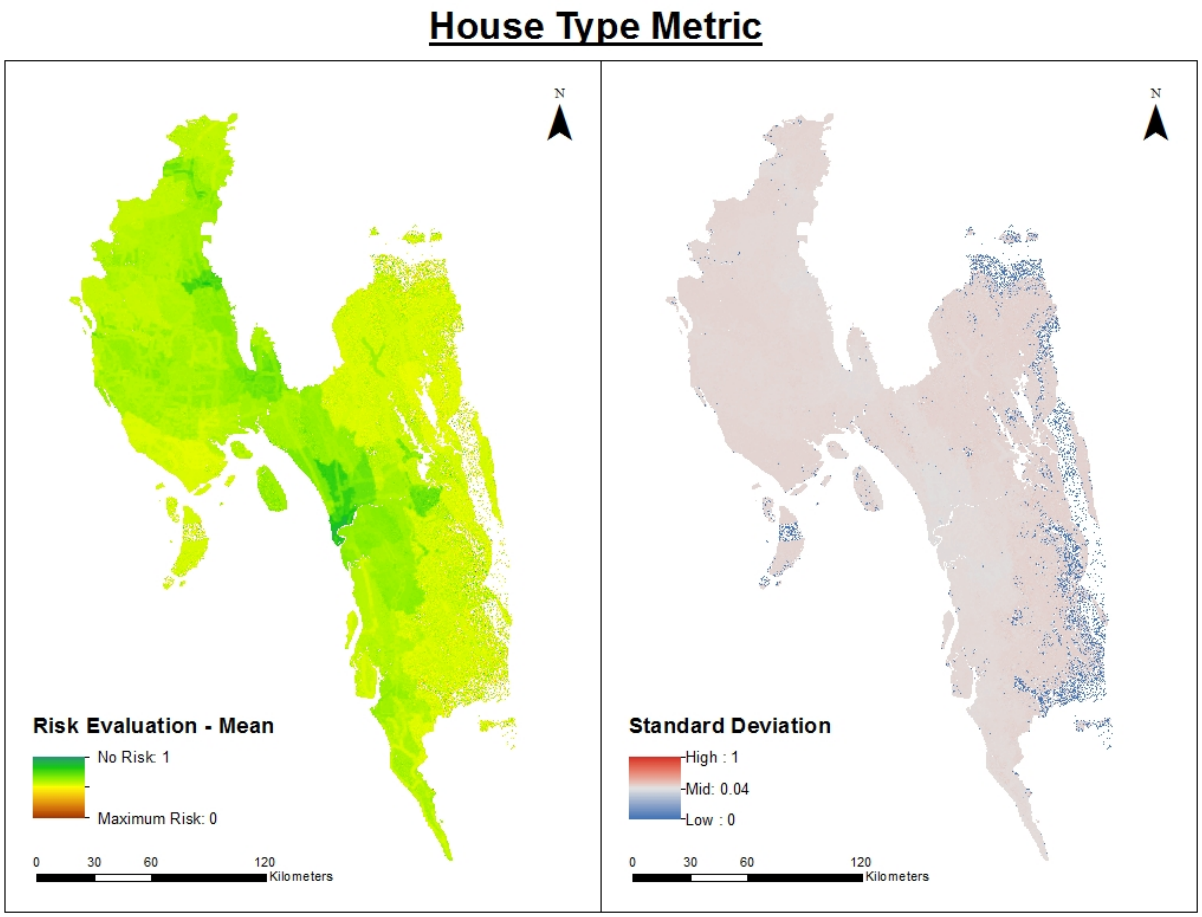
Metric: House Type

Indicator:	Dangerous Housing
Factor:	Substandard Conditions
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	Pucka (min: 1.0, max: 1.0) Semi-Pucka (min: 0.4, max: 1.0) Kutcha (min: 0.125, max: 0.5) Jhupri (min: 0.0625, max: 0.25)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	Dasgupta et al. (2015); Emch et al. (2010); Rabbi & Dey (2013); Root et al. (2013); Sasaki et al. (2008); Sheuya (2008)
Logic:	The types of house are defined as, "Jhupri structures are temporary houses made of such removable materials as grass, thatch, bamboo, and wood. Kutcha houses have walls and roofs made of unburnt brick, bamboo, mud, reed, thatch, or loosely packed stones. Semi-pucca houses have fixed walls made of pucca materials, with non-pucca such materials as (Dasgupta et al., 2015)". Rabbi & Dey (2013) found that wall material (measured in binary of concrete v. other) was unrelated to predicting hand washing practices. Recall that Sasaki et al. (2008) found that hand washing with soap plays a protective role in cholera prevention. Emch et al. (2010) used household wall material as a predictor for socioeconomic status and is ranked as follows, from best to worst: 1. Pucca 2. Tin Wall 3. Tin 4. Wood 5. Bamboo 6. Other 7. No Dwelling. Emch et al. (2010) goes on to find that socioeconomic status is negatively associated and statistically significant. This means that in higher socioeconomic baris, there is less cholera. Root et al. (2013) uses wall material as an indicator for socioeconomic status. Wall material is ranked as follows, from best to worst: 5. Pucca/cement 4. Tin 3. Tin and other materials 2. Bamboo and/or wood 1. Other material. Pucka, or pucca, homes are built with permanent and more durable materials such as brick, timber, stone, and concrete. These homes are often found in more urban areas. This answer receives both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Semi-pucka houses have some elements of pucka homes (i.e. concrete foundation with a roof of organic materials). This answer is given a minimum value of 0.4 for those homes with straw walls or roof (slight risk) and a maximum value of 1.0 for those semi-pucka homes with solid wood instead of straw. Kutcha, or kacca, homes are more temporary and built with earthen and organic materials. This answer is given a minimum value of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Jhupri structures are shacks, made of jute sticks, tree leaves, jute sacks, and often are indicative of informal settlements. This answer

receives a minimum value of 0.0625 (extreme risk, $1/2^4$) and a maximum value of 0.125 (high risk, $1/2^3$).

Maps will range from extreme risk to no risk.

Example realization metric map



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Emch, M., Yunus, M., Escamilla, V., Feldacker, C., & Ali, M. 2010. Local population and regional environmental drivers of cholera in Bangladesh. *Environmental Health*, *9*(1), 1.

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A.3.2.3 Indicator: Polluted and disease-bearing environment

The Polluted and Disease-Bearing Environment indicator accounts for illnesses and risk of contracting illnesses at the household and neighborhood levels. PACOM specifies that metrics should include: "the number of reported cases of waterborne illnesses per capita of:

- Malaria
- Amebiasis
- **Cholera**
- Dengue fever
- Hepatitis A
- …and other waterborne illnesses"

The HC framework also specifies the inclusion of other diseases such as tetanus, E. coli, ebola, etc.

As this framework aims to predict risk to cholera outbreaks, metrics should include data on illnesses or medicinal consumptions related to cholera and diarrheal disease. At the household level, this can account for elements that lead to a dangerous living environment. This indicator is essential to identifying areas that are especially susceptible to cholera risk.

Metric weighting logic

As the Stool Disposal metric (where the youngest child's stools are disposed in the household) is potentially the most determinant of the household disease environment, it is the most constraining on the indicator, and is given both a minimum and maximum weight of 1.0.

Metric	Weight Minimum Value	Weight Maximum Value
Illness - Diarrhea	0.8	1.0
Vaccinated	0.7	0.9
Stool Disposal	1.0	1.0

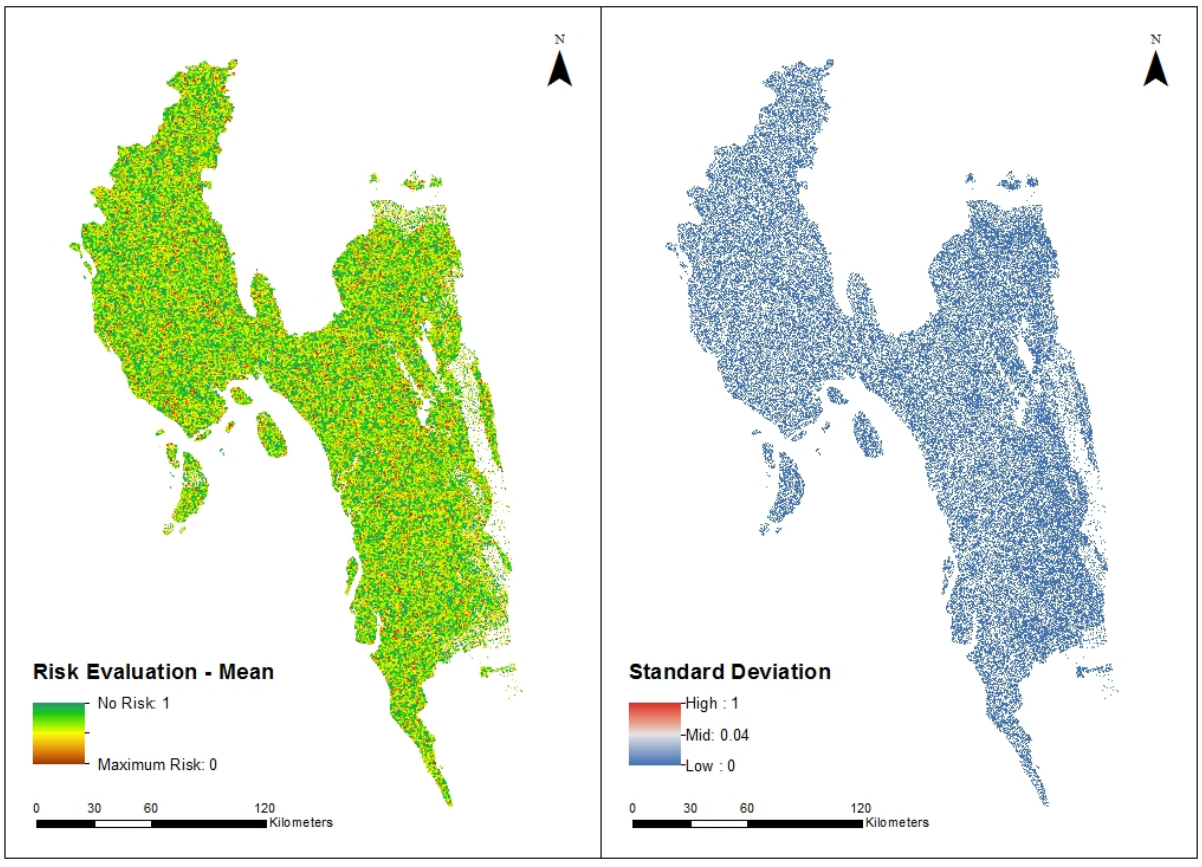
Uncertainty values

The low uncertainty values are due to the robust data collection on household materials and types by both DHS & IPUMS. Adding more data on the local environments and pollution levels, especially in terms of cholera risks, could decrease the uncertainty values.

Indicator Uncertainty Min:	0.15
Indicator Uncertainty Max:	0.25

Example outcome

Polluted Disease Environment Indicator

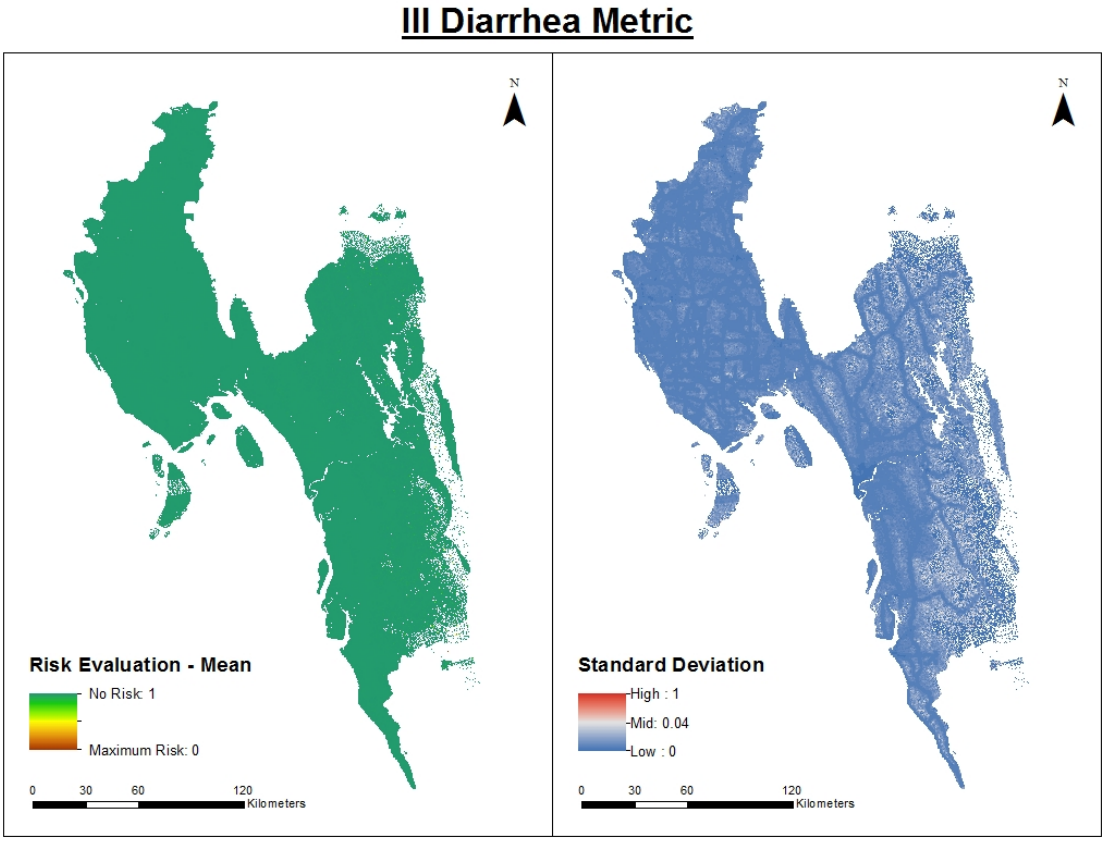


Metric: Illness – Diarrhea

Indicator:	Polluted and Disease-Bearing Environment
Factor:	Substandard Conditions
Condition:	Human Behavioral Impact

Framework:	Cholera
Metric Assigned Values:	Yes (min: 0.125, max: 0.9) No (min: 1.0, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Emch (1999); Hashizume et al. (2008); Sack et al. (2003)
Logic:	Sack et al. (2003) studied Vibrio cholera in four rural areas of Bangladesh over four years. 14% of patients for acute diarrhea had cholera. Emch's (1999) study of diarrheal disease in Bangladesh from 1992-1994 saw 6,257 patients of which 20% were cholera cases. Hashizume et al. (2008) studied the diarrheal disease that followed the 1998 flooding of Dhaka, Bangladesh which affected 4 million people – almost 40% of the population. The flood period was defined as the river level exceeding the danger level of 6 meters (which maxed at 7 m) and lasted 8 weeks. The post-flood period was the following six months. During the flood period, 41.5% of diarrheal patients had cholera, opposed to post-flood patients of which 28.6% of patients had cholera. This metric consists of answers to the question if a child has had diarrhea within the last 2 weeks from the women's portion of the DHS survey. Answers of "Yes" are given a minimum value of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.9 (minimal risk). Answers of "No" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from high risk to no risk. It should be noted that, as this version of the framework was constructed as a proof of research concept, only the results pertaining to the first child for whom answers were provided were used to create this metric. For questions under section 2 (Reproduction) of the women's portion of the DHS Bangladesh survey, answers were allowed for up to 12 children. Results from these questions will only contain answers for the eldest child. For questions under Sections 4 (Pregnancy and Postnatal Care) and 5 (Child Immunization, Health, and Nutrition), answers were allowed for children from the last birth, the next-to-last birth, and the second next-to-last birth (i.e. the youngest three children of the female respondent). Results from these questions will only contain answers for the youngest child.

Example realization metric map



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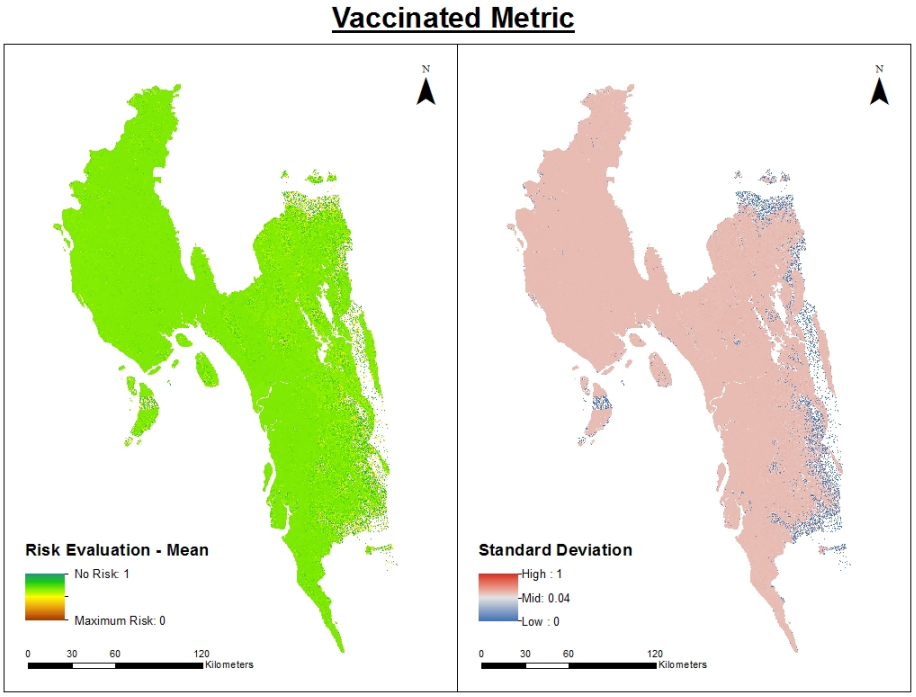
Sack, R. B., Siddique, A. K., Longini, I. M., Nizam, A., Yunus, M., Islam, M. S., & Qadri, F. 2003. A 4-year study of the epidemiology of Vibrio cholerae in four rural areas of Bangladesh. *Journal of Infectious Diseases*, *187*(1), 96-101.

Metric: Vaccinated

Indicator:	Polluted and Disease-Bearing Environment
Factor:	Substandard Conditions
Condition:	Human Behavioral Impact
Framework:	Cholera

Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.0625, max: 0.9)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Deen et al. (2008); Wahed et al. (2013)
Logic:	This metric acts as a proxy for access to vaccinations. Wahed et al. (2013) conducted an analysis of preventive practices related to cholera and oral cholera vaccine in Dhaka, Bangladesh. Results included, "Of 2,830 families included in the final analysis, 23% could recognize cholera as acute watery diarrhea and 16% had ever heard of oral cholera vaccine. About 54% of the respondents had poor knowledge about cholera-related issues while 97% had a positive attitude toward cholera and oral cholera vaccine. One-third showed poor practice relating to the prevention of cholera." Deen et al. (2008) concluded that "Incidence of cholera is important when considering where and among whom interventions such as vaccination would be most beneficial." Access to an oral cholera vaccination is an immediate to medium-term strategy against cholera until improved water supply and sanitation can be achieved. This metric consists of answers to the question asking respondents if they have ever been vaccinated. Answers of "No" are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.9 (minimal risk). Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$).

Example realization metric map



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Metric: Stool Disposal

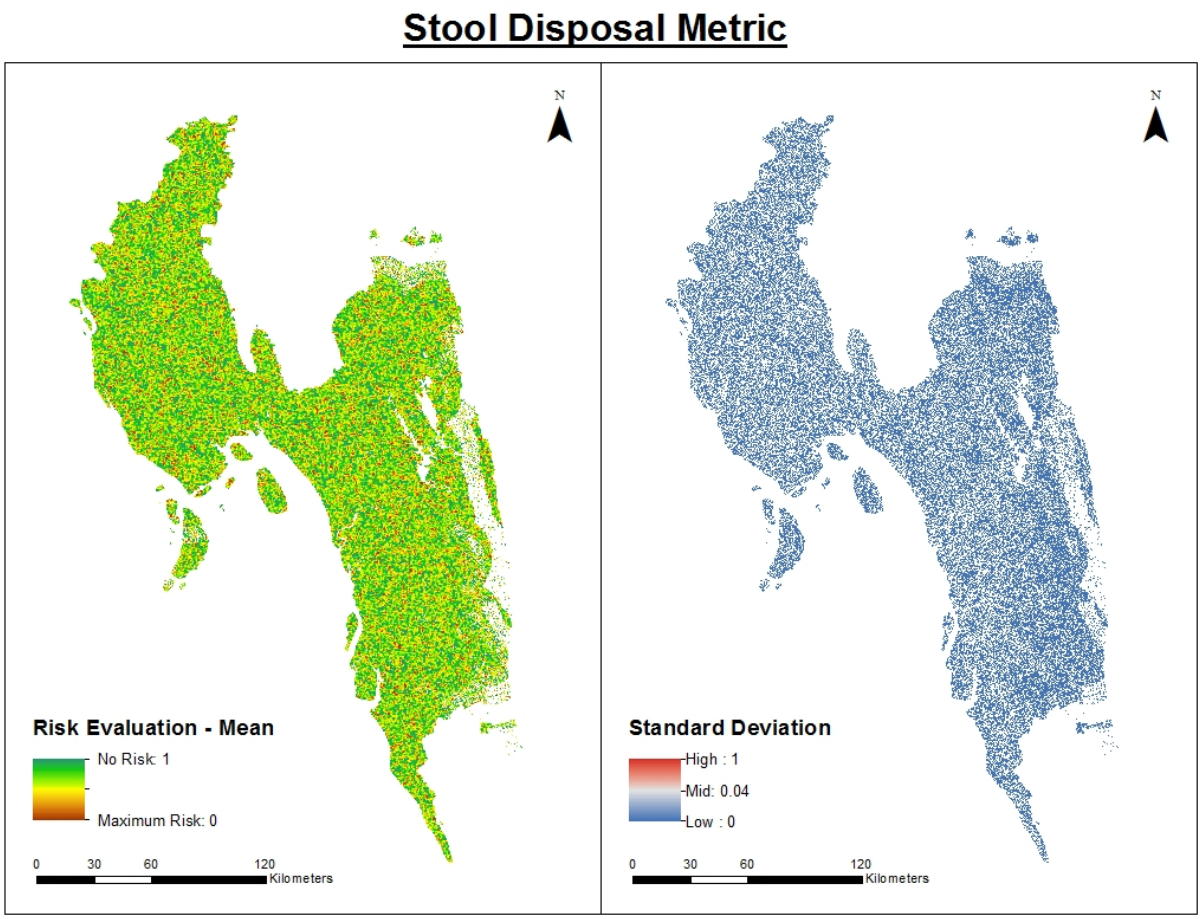
Indicator:	Polluted and Disease-Bearing Environment		
Factor:	Substandard Conditions		
Condition:	Human Behavioral Impact		
Framework:	Cholera		
Metric Assigned Values:	1 Used Toilet Latrine	Min: 1.000	Max:
	2 Put Rinsed In Toilet Latrine	Min: 1.000	Max:
	3Put Rinsed Into Drain Or Ditch	Min: 0.125	Max:
	4 Throw Into Garbage	Min: 0.250	Max:
	5 Buried	Min: 0.250	Max:
	6 Rinse Away	Min: 0.250	Max:
	7 Use Disposable Diapers	Min: 0.500	Max:
	8 Use Washable Diapers	Min: 0.500	Max:
	9 Left In Open – Not Disposed	Min: 0.125	Max:
	96 Other	Min: 0.125	Max:
Survey:	DHS - Women		
Survey Date:	2011		
Other Data Sources:	Curtis, Cairncross, & Yonli (2000); Sasaki et al. (2008); Water and Sanitation Program (2015)		
Logic:	This metric consists of answers to the question concerning the location of the youngest child's stool disposal from the women's portion of the DHS survey. Water and Sanitation Program (2015) found that "In most countries analyzed, over 50% of households with children under age three reported that the feces of their children were unsafely disposed." They define "safe disposal" as the child using "a toilet or latrine or, for very young children, to put or rinse their feces into a toilet or latrine. For the purposes of this brief, these disposal methods are referred to as "safe," whether the feces is deposited into an unimproved or an improved toilet or latrine. Other methods are considered "unsafe." When a child's feces are put or rinsed into an "improved" toilet or latrine, this is termed "improved child feces disposal."" They report that almost 80% of children in Bangladesh have unsafe feces disposal.		

Curtis, Cairncross, & Yonli (2000) identify safe stool disposal as a primary barrier to disease transmission and may be more important that hand washing before eating. The state that ways to keep infections organisms from the environment is “the disposal of stools in such a way that they are isolated from all future human contact (by the use of latrines, sewers, burying, etc.).”

Sasaki et al. (2008) found “the lack of access to latrines has also been identified as a risk factor for cholera in informal settlement areas.”

Answers of “1 Used Toilet Latrine” and “2Put Rinsed In Toilet Latrine” are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of “7 Use Disposable Diapers,” and “8 Use Washable Diapers” are given an overall value of minimal risk with a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of “4 Throw Into Garbage,” “5 Buried,” and “6 Rinse Away” are given a minimum value 0.25 (medium risk, $½^2$) and a maximum value of 0.5 (slight risk, $½^1$). Answers of “3Put Rinsed Into Drain Or Ditch” and “9 Left In Open – Not Disposed” are both given a minimum of 0.125 (high risk, $½^3$) and a maximum value of 0.5 (slight risk, $½^1$). Answers of “96 Other” are given a minimum value of the lowest minimum value (0.125) and a maximum value of the highest possible value (1.0).

Example realization metric map



References

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Water and Sanitation Program. 2015. "Management of Child Feces: Current Disposal Practices" https://www.wsp.org/sites/wsp.org/files/publications/WSP-CFD-Summary-Brief.pdf.

A.3.3 Household civil infrastructure failure factor overview

This factor focuses on infrastructure at the micro-level as this framework targets households. It is these indicators and metrics that most represent how the environment can impact an individual's predisposition to contracting cholera.

The HC framework includes Civil Infrastructure Failure as an indicator to the Substandard Conditions factor. In the cholera framework, as Civil Infrastructure plays an essential role at keeping cholera outbreaks at bay, the authors felt it prudent to make Civil Infrastructure its own factor. PACOM specifies that metrics should include: number of incidents involving failure of dams and levees (compared with historical data); number of incidents involving failure of bridges; percentage of bridges assessed as structurally unstable; percentage of buildings assessed as structurally unstable; and percentage of roads assessed as impassable or dangerous.

As the number of incidents regarding dams, bridges, and roads is extremely difficult to assess with public survey results, the authors took it upon themselves to best inform the risk to cholera with the available data. As cholera is highly correlated to the absence of tap water, unsanitary latrines (Gerolomo and Penna, 2000; Giebultowicz et al., 2011)

Indicator weighting logic

Both "Household Water Infrastructure" and "Household Toilet" indicators within the Household Civil Infrastructure Failure factor are given both a minimum and a maximum value of 1.0. This is because each indicator is equally as constraining on the factor. The indicator "Household Electricity" is weighted lower, as electricity is not as important in predicting cholera risk compared to the other indicators in the factor.

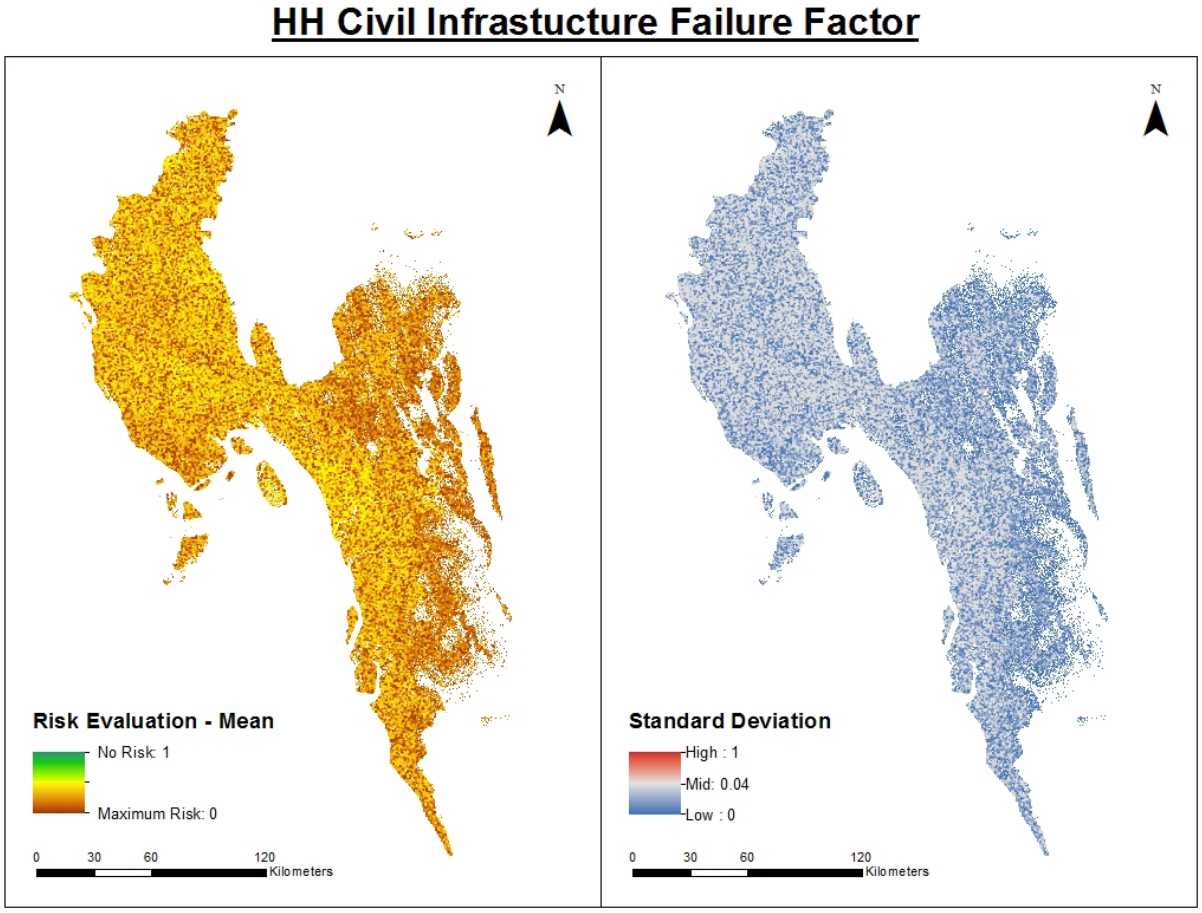
Indicator	Weight Minimum Value	Weight Maximum Value
Household Water Infrastructure	1.0	1.0
Household Toilet	1.0	1.0
Household Electricity	0.4	0.6

Uncertainty values

This factor is given a range of uncertainty values from 0.1 to 0.3 because of the perceived ability of the existing indicators to fully address the themes of the factor. The addition of more metrics informing these indicators could further decrease the uncertainty values.

Factor Uncertainty Min:	0.1
Factor Uncertainty Max:	0.3

Example outcome



References

Gerolomo, M. & Penna, M.L. 2000. Cholera and living conditions. *Brazil Rev. Saude Publica,* 34, 342-347.

Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. 2011. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2: 490-497.

A.3.3.1 Indicator: Household water infrastructure

The Household Water Infrastructure indicator accounts for water infrastructure at the household and neighborhood levels. Metrics should include data on drinking water source and treatment of water and its impact on cholera risk. At the household level, this can account for elements that lead to a dangerous living environment. This indicator is essential to identifying areas that are especially susceptible to cholera risk.

Metric weighting logic

The metric weighted the most on this indicator is "Household Source of Drinking Water" and was given a minimum weight of 0.4 and a maximum weight of 0.6 as it is the most specific and indicative of a household's water source. "Iodized Salt" is the least constraining and is given a weight minimum of 0.1 and maximum of 0.3 as there is only one source supporting it as an effective method of preventing cholera risk.

Currently, each metric is treated as a variable independent of the others, due to the constraints of the computational logic behind the framework construction. However, with a greater understanding of the relationship between certain metrics, and subsequent alterations to the framework, a more comprehensive suitability function could be defined. For example, if a household has a drinking water source of "piped into dwelling," then the "Drinking Water Treated" and "Iodized Salt" metrics should be weighted much less, if accounted for at all.

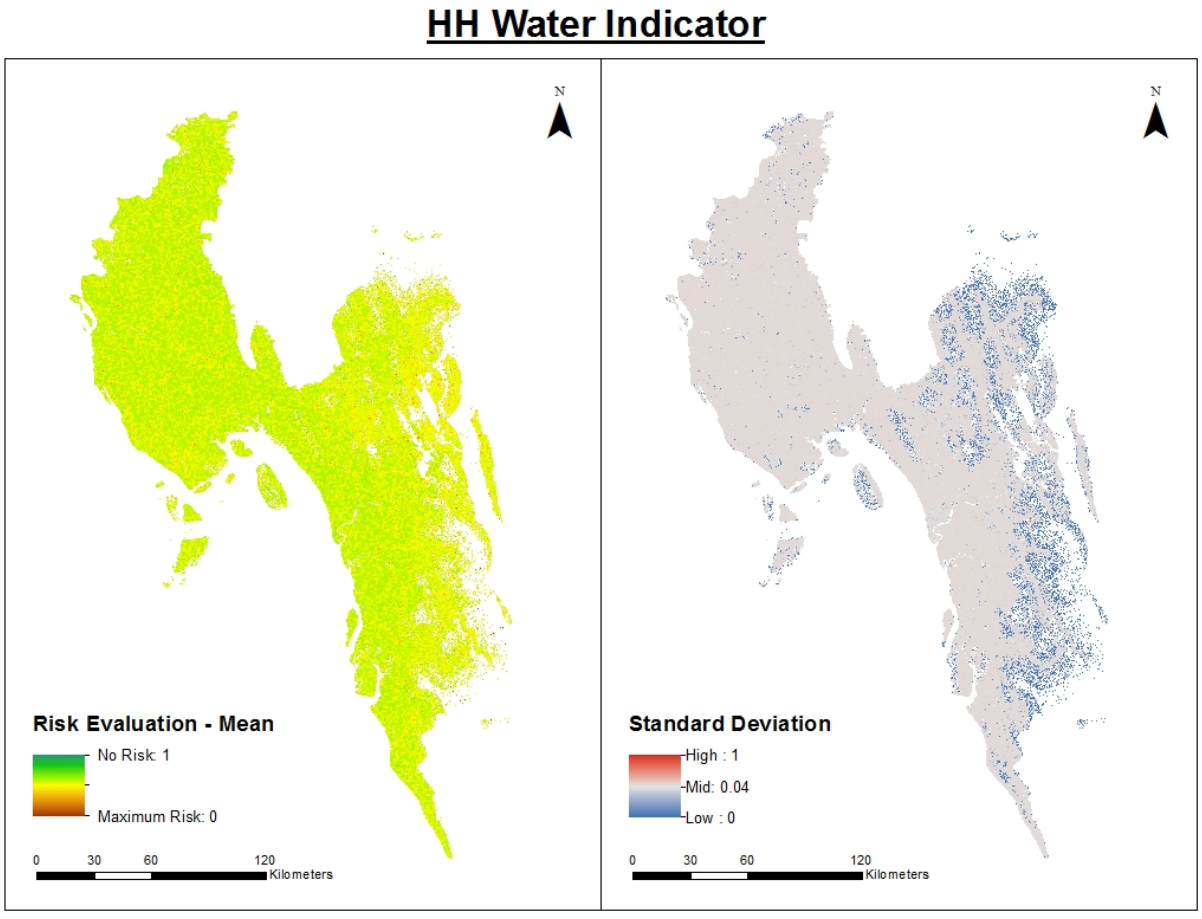
Metric	Weight Minimum Value	Weight Maximum Value
Household Drinking Water Source	0.3	0.5
Iodized Salt	0.1	0.3
Household Water Access Location	0.3	0.5
Household Source of Drinking Water	0.4	0.6
Drinking Water Treated	0.3	0.5

Uncertainty values

The low uncertainty values are due to the robust data collection on household materials and types by both DHS & IPUMS. Adding more data on the local environments and pollution levels, especially in terms of cholera risks, could decrease the uncertainty values.

Indicator Uncertainty Min:	0.15
Indicator Uncertainty Max:	0.25

Example outcome



Metric: Household Drinking Water Source

Indicator:	Household Water Infrastructure
Factor:	Household Civil Infrastructure Failure
Condition:	Human Behavioral Impact

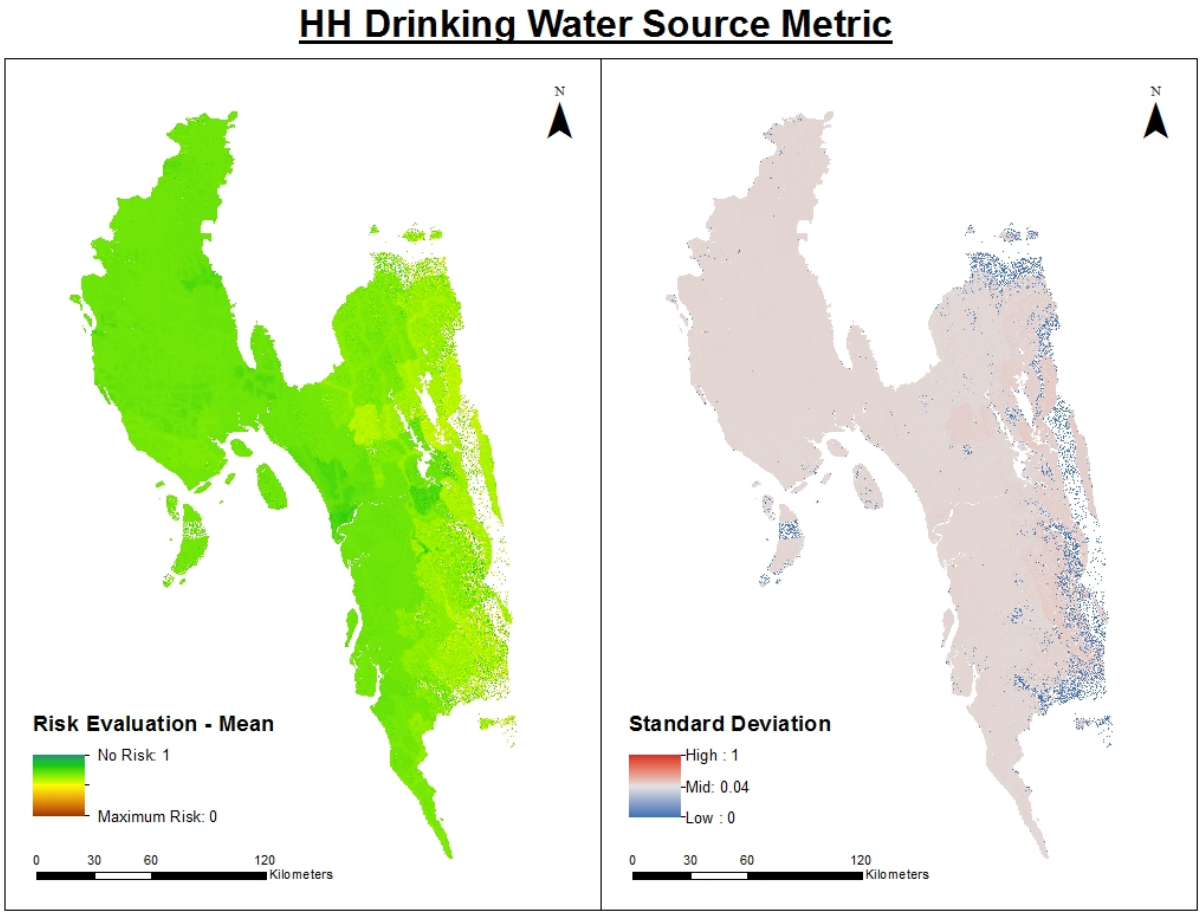
Framework:	Cholera
Metric Assigned Values:	Tap (min: 0.5, max: 1.0) Tubewell (min: 0.4, max: 0.8) Other (min: 0.0625, max: 0.7)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 2); Emch (1999); Gerolomo, M. & Penna, M.L. (2000); Giebultowicz et al. (2011); Haque et al. (2013); Hashizume et al. (2008); Jutla et al. (2013); de Magny et al. (2008); Perez-Saez et al. (2016); USAID (2016); WHO. (n.d.).
Logic:	This metric consists of observations from the surveyor based on the water source for the surveyed household. Ali et al. (2002, 2) states that while all households in Matlab can access a tubewell, surface water is compelling to people due to the excessive iron content. Surface water is also extensively used for cooking, bathing, and washing as iron content extends cooking time and stains clothes. Emch (1999) found that "tubewell or other" to be statistically significant in predicting the relative risk of cholera. Gerolomo and Penna (2000) found "that the proportion of households without tap water was the variable that contributed the most to the increasing fluctuation of cholera incidence rates" in Brazil during the 1992 outbreak. They went on to conclude "that having an adequate tap water supply is of maximum priority for cholera prevention." Haque et al. (2013) found that outbreaks in urban Bangladesh in 2011 occurred from tap water, likely contaminated from the visible leakages in the pipes. Hashizume et al. (2008) studied the effects of drinking water source on cholera outbreaks during and after the 1998 flood in Dhaka, Bangladesh. They found that 69% of cholera patients got their drinking water from tap. During the post-flood period, 62% of cholera patients got their drinking water from tube well. The DHS stat compiler for the 2011 survey breaks down households using improved water sources by rural/urban residence and wealth quintile. Households using water piped into dwelling is 5.7%. 21% of urban households and 0.5% of rural households used water piped into dwelling in 2011. Across wealth: 0%, 0%, 0%, 1.1%, & 28.3% of households used water piped into dwelling in 2011. Households using a public tap/standpipe is 2.1%. 7% of urban households and 0.5% of rural households using a public tap/standpipe. Across wealth: 0.5%, 0.7%, 0.8%, 2.9%, & 6.0% of households using a public tap/standpipe. Households using a tubewell/borehole is 85.5%. 54.6% of urban households and 95.8% of rural households used a tubewell/borehole in 2011. Across wealth: 95.9%, 96.6%, 95.9%, 87.5%, & 49.5% of households used a tubewell/borehole in 2011. Thus residence and wealth are key indicators for all sources of water (USAID, 2016). Jutla et al. (2013) determines that the United States rarely experiences cholera outbreak due to its robust water and sanitation infrastructure as effective prevention methods for the spread of cholera (p.602). De Magny et al. (2008) also states that "Because

good sanitation is practiced and safe drinking water is available to the populations of [regions where V. cholerae is naturally occurring], cholera epidemics no longer occur." Perez-Saez et al. (2016) reiterate that inadequate water infrastructure exposes the population to cholera.

In Grundy, Wright, & Conroy's review of household water quality in developing countries, ponds, tubewells, standpipes, shallow wells, taps, open wells, and surface water are all associated cholera. Deb et al. (1982), Spira et al. (1980) and Sengupta et al. (1995) found that tubewells are associated with cholera in both Urban and Rural areas for all ages.

Answers of "Other" are a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.7 (minimal risk). Answers of "Tap" are given an overall value of minimal risk with a minimum value of 0.5 (slight risk, $\frac{1}{2}^1$) and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "Tubewell" are given a minimum value of 0.4 (slight risk) and a maximum value of 0.8 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map



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Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2 (2011): 490-497.

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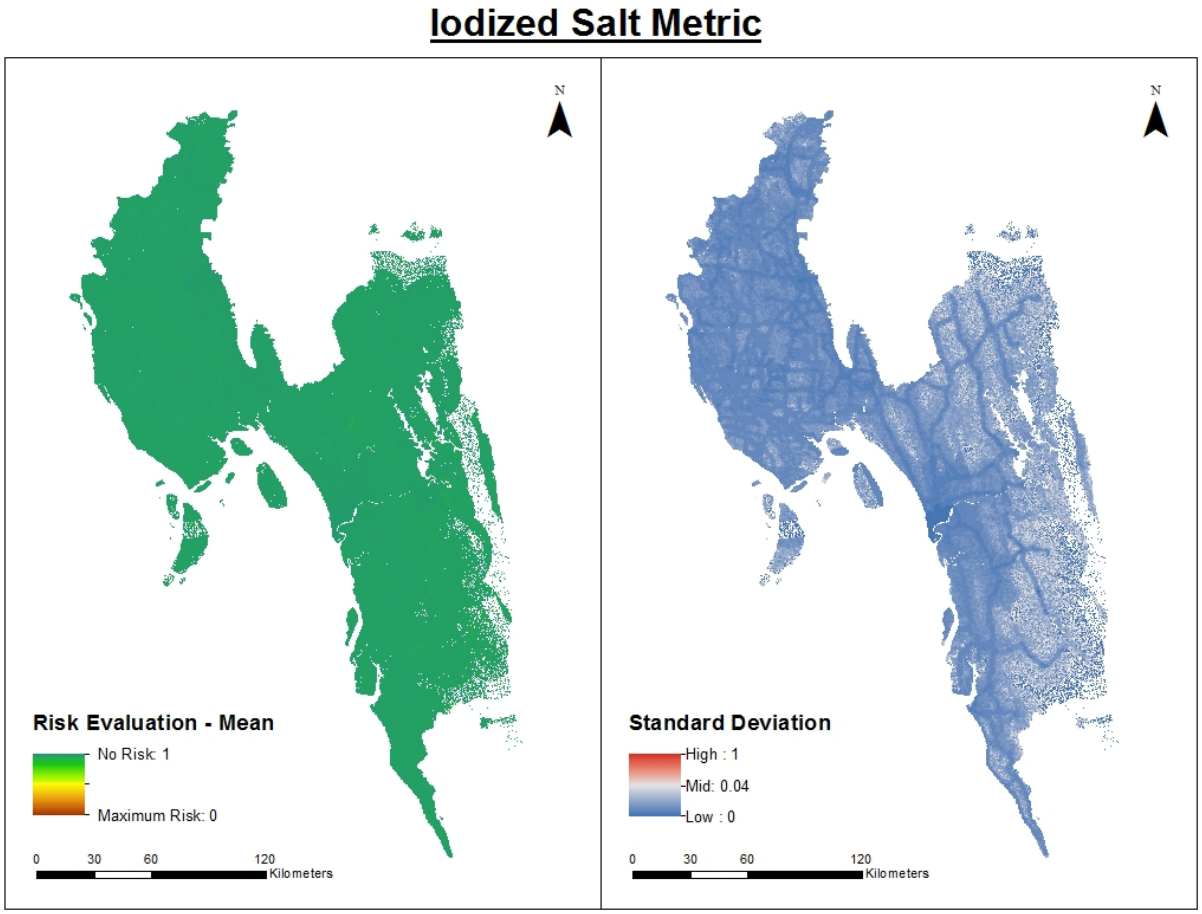
USAID 2016. StatCompiler – The DHS Program. Retrieved from http://statcompiler.com/en/.

Metric: Iodized Salt

Indicator:	Household Water Infrastructure
Factor:	Household Civil Infrastructure Failure
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	Iodine Present (min: 1.0, max: 1.0) No Iodine (min: 0.75, max: 0.9) No Salt (min: 0.25, max: 0.75)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	Semba et al. (2011)
Logic:	This metric consists of observations by the surveyor of whether or not there is iodized salt, iodine, or salt present in the household. Semba et al. (2011) is the first study to show a relationship between lack of adequately iodized salt and child diarrhea. Answers of "Iodine Present" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "No Iodine" are given a minimum value of 0.75 (minimal risk) and a maximum value of 0.9 (minimal risk). Answers of "No Salt" are given a minimum value of 0.25 (medium risk, $½^2$) and a maximum value of 0.75 (minimal risk). Maps will range from medium risk to no risk.

Example realization metric map



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Metric: Household Water Access Location

Indicator:	Household Water Infrastructure
Factor:	Household Civil Infrastructure Failure
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	In Own Dwelling (min: 1.0, max: 1.0) In Own Yard Plot (min: 0.5, max: 0.9) Elsewhere (min: 0.0625, max: 0.9)

Survey: IPUMS

Survey Date: 2011

Other Data Sources: Ali et al. (2002, 2); Deb et al. (1982); Emch (1999); Gerolomo, M. & Penna, M.L. (2000); Giebultowicz et al. (2011); Gundry, Wright & Conroy (2004); Hashizume et al. (2008); Hughes et al. (1982); Jutla et al. (2013); de Magny et al. (2008); Perez-Saez et al. (2016); Sengupta et al. (1995); Spira et al. (1980); USAID (2016)

Logic: This metric consists of answers to the question concerning the location of the household water access source from the IPUMS survey.

Ali et al. (2002, 2) states that while all households in Matlab can access a tubewell, surface water is compelling to people due to the excessive iron content. Surface water is also extensively used for cooking, bathing, and washing as iron content extends cooking time and stains clothes.

Emch (1999) Giebultowicz et al. (2011) finds that "unsanitary latrines are responsible for surface water contamination." Gerolomo and Penna (2000) found "that the proportion of households without tap water was the variable that contributed the most to the increasing fluctuation of cholera incidence rates" in Brazil during the 1992 outbreak. They went on to conclude "that having an adequate tap water supply is of maximum priority for cholera prevention."

The DHS stat compiler for the 2011 survey breaks down households using improved water sources by rural/urban residence and wealth quintile. Households using water piped into dwelling is 5.7%. 21% of urban households and 0.5% of rural households used water piped into dwelling in 2011. Across wealth: 0%, 0%, 0%, 1.1%, & 28.3% of households used water piped into dwelling in 2011. Households using a public tap/standpipe is 2.1%. 7% of urban households and 0.5% of rural households using a public tap/standpipe. Across wealth: 0.5%, 0.7%, 0.8%, 2.9%, & 6.0% of households using a public tap/standpipe. Households using a tubewell/borehole is 85.5%. 54.6% of urban households and 95.8% of rural households used a tubewell/borehole in 2011. Across wealth: 95.9%, 96.6%, 95.9%, 87.5%, & 49.5% of households used a tubewell/borehole in 2011. Thus residence and wealth are key indicators for all sources of water (USAID, 2016).

Jutla et al. (2013) determines that the United States rarely experiences cholera outbreak due to its robust water and sanitation infrastructure as effective prevention methods for the spread of cholera (p.602). De Magny et al. (2008) also states that "Because good sanitation is practiced and safe drinking water is available to the populations of [regions where V. cholerae is naturally occurring], cholera epidemics no longer occur."

Perez-Saez et al. (2016) reiterate that inadequate water infrastructure exposes the population to cholera. Hashizume et al. (2008) studied the effects of drinking water source on cholera outbreaks during and after the 1998 flood in Dhaka, Bangladesh. They found that during the flood, 65% of cholera patients' distance to water source was more than 5 meters. This number jumps to 72% in the post-flood period.

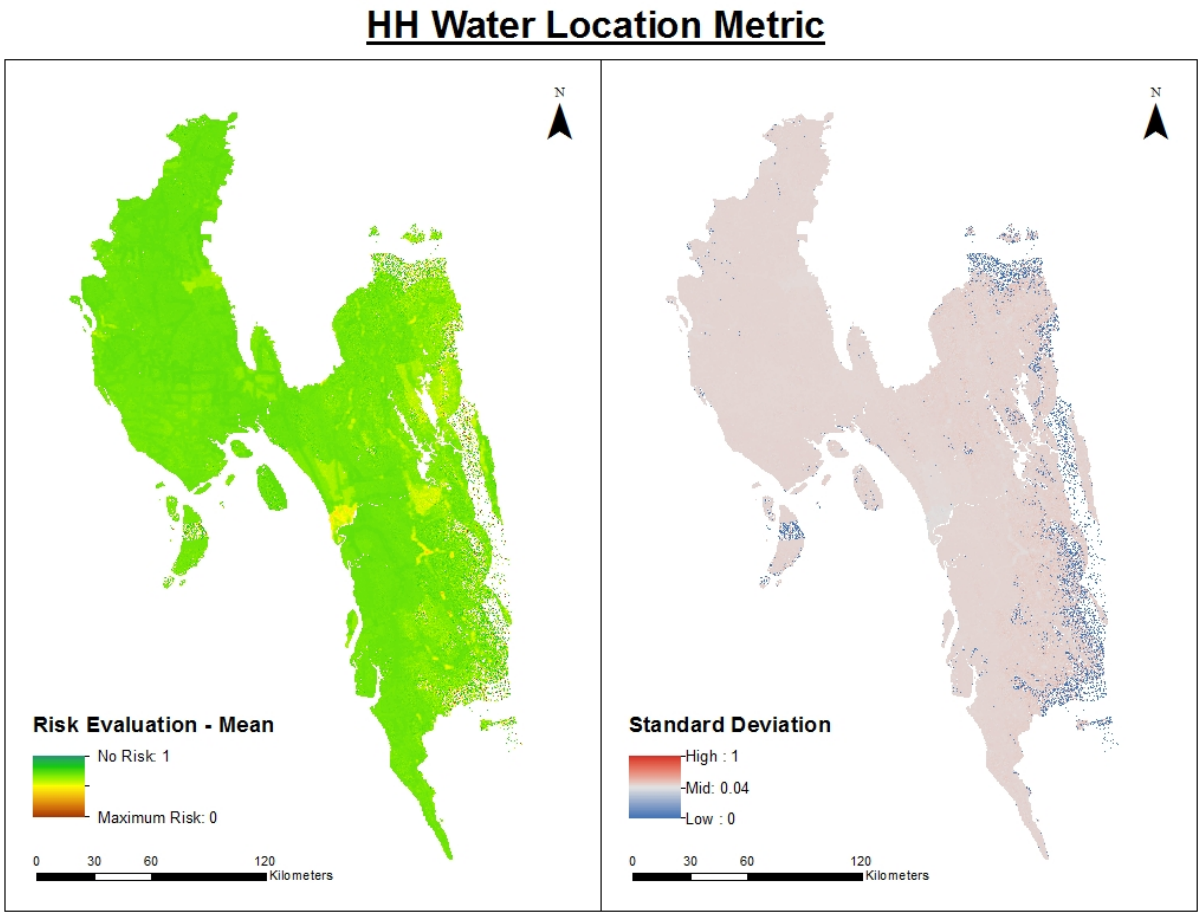
In Grundy, Wright, & Conroy's review of household water quality in developing countries, ponds, tubewells, standpipes, shallow wells, taps, open wells, and surface water are all associated cholera. Deb et

al. (1982), Spira et al. (1980) and Sengupta et al. (1995) found that tubewells are associated with cholera in both Urban and Rural areas for all ages.

Hughes et al. (1982) found that in neighborhoods with cholera infection, 44% of surface water sources were positive for cholera, opposed to 2% of surface water source in control areas. Canals, rivers, and tanks were most frequently positive. Families that used the water for drinking, cooking, or bathing were more at risk.

Answers of "In Own Dwelling" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "In Own Yard Plot" are given a minimum value of 0.5 (slight risk, $\frac{1}{2}^1$) and a maximum value of 0.9 (minimal risk). Answers of "Elsewhere" are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value 0.9. Maps will range from extreme risk to no risk.

Example realization metric map



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USAID 2016. StatCompiler – The DHS Program. http://statcompiler.com/en/.

Metric: Household Source of Drinking Water

Indicator:	Household Water Infrastructure
Factor:	Household Civil Infrastructure Failure
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	Piped Into Dwelling (min: 1.0, max: 1.0) Piped Into Yard Plot (min: 0.5, max: 0.9) Public Tap Standpipe (min: 0.5, max: 0.8) Tubewell Borhole (min: 0.5, max: 0.8) Protected Well (min: 0.5, max: 1.0) Unprotected Well (min: 0.0625, max: 0.5) Protecting Spring (min: 0.5, max: 1.0) Unprotected Spring (min: 0.0625, max: 0.5) Rainwater (min: 0.0625, max: 0.5) Tanker Truck (min: 0.5, max: 0.9) Cart with Small Tank (min: 0.5, max: 0.9) Surface Water (min: 0.0625, max: 0.5) Bottled Water (min: 1.0, max: 1.0) Other (min: 1.0, max: 1.0)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Gerolomo and Penna (2000); Gundry, Wright, & Conroy (2004); Hughes et al. (1982); Jutla et al. (2013); Perez-Saez et al. (2016); USAID (2016); WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation
Logic:	The metric consists of answers to the question of where households obtain their water from the household portion of the DHS survey. The DHS stat compiler for the 2011 survey breaks down households using improved water sources in Bangladesh by rural/urban residence and wealth quintile. Households using water piped into dwelling (1) is 5.7%. 21% of urban households and 0.5% of rural households used water piped into dwelling in 2011. Across wealth: 0%, 0%, 0%, 1.1%, & 28.3% of households used water piped into dwelling in 2011. Households using water piped into yard/plot (2) is 4.5%. 16.2% of urban households and 0.7% of rural households used water piped into yard/plot in 2011. Across wealth: 0.2%, 0.4%, 1.2%, 6.9%, & 15% of households used water piped into yard/plot in 2011. Households using a public tap/standpipe (3) is 2.1%. 7% of urban households and 0.5% of rural households using a public tap/standpipe. Across wealth: 0.5%, 0.7%, 0.8%, 2.9%, & 6.0% of households using a public tap/standpipe. Households using a tubewell/borehole (4) is 85.5%. 54.6% of urban households and 95.8% of rural households used a tubewell/borehole in 2011. Across wealth: 95.9%, 96.6%, 95.9%, 87.5%, & 49.5% of households used a tubewell/borehole in 2011. Households using a protected well (5) is 0.2%. 0.1% of urban households and 0.2% of rural households used

a protected well in 2011. Across wealth: 0.3%, 0.2%, 0.1%, 0.1%, & 0% of households used a protected well in 2011. Households using an unprotected well (6) is 0.2%. 0.0% of urban households and 0.3% of rural households used an unprotected well in 2011. Across wealth: 0.6%, 0.2%, 0.1%, 0.1%, & 0.1% of households used an unprotected well in 2011. Households using a protected spring (7) is 0.0%. 0.0% of urban households and 0.0% of rural households used a protected spring in 2011. Across wealth: 0.1%, 0.0%, 0.0%, 0.0%, & 0.0% of households used a protected spring in 2011. Data on unprotected spring (8) is not available. Households using a rainwater (9) is 0.4%. 0.3% of urban households and 0.5% of rural households used rainwater in 2011. Across wealth: 0.5%, 0.5%, 0.5%, 0.5%, & 0.1% of households used rainwater in 2011. Households using tanker truck (10) is negligible except for 0.1% of the wealthiest households. Households using cart with tank (11) is negligible except for 0.1% of urban residents and 0.1% the wealthiest households. Households using a surface water (12) is 1.2%. 0.4% of urban households and 1.4% of rural households used surface water in 2011. Across wealth: 1.7%, 1.3%, 1.4%, 0.9%, & 0.4% of households used surface water in 2011. Households using a bottled water (13) is 0.1%. 0.3% of urban households and 0.0% of rural households used bottled water in 2011. Across wealth: 0.0%, 0.0%, 0.0%, 0.0%, & 0.4% of households used bottled water in 2011. Households using "other" source for water (14) is negligible except for 0.1% of rural residents. Thus residence and wealth are key indicators for all sources of water.

Gerolomo and Penna (2000) found "that the proportion of households without tap water was the variable that contributed the most to the increasing fluctuation of cholera incidence rates" in Brazil during the 1992 outbreak. Jutla et al. (2013) determines that the United States rarely experiences cholera outbreak due to its robust water and sanitation infrastructure as effective prevention methods for the spread of cholera (p.602). Perez-Saez et al. (2016) reiterate that inadequate water infrastructure exposes the population to cholera. In Grundy, Wright, & Conroy's review of household water quality in developing countries, ponds, tubewells, standpipes, shallow wells, taps, open wells, and surface water are all associated cholera. Deb et al. (1982), Spira et al. (1980) and Sengupta et al. (1995) found that tubewells are associated with cholera in both Urban and Rural areas for all ages. Hughes et al. (1982) found that in neighborhoods with cholera infection, 44% of surface water sources were positive for cholera, opposed to 2% of surface water source in control areas. Canals, rivers, and tanks were most frequently positive. Families that used the water for drinking, cooking, or bathing were more at risk.

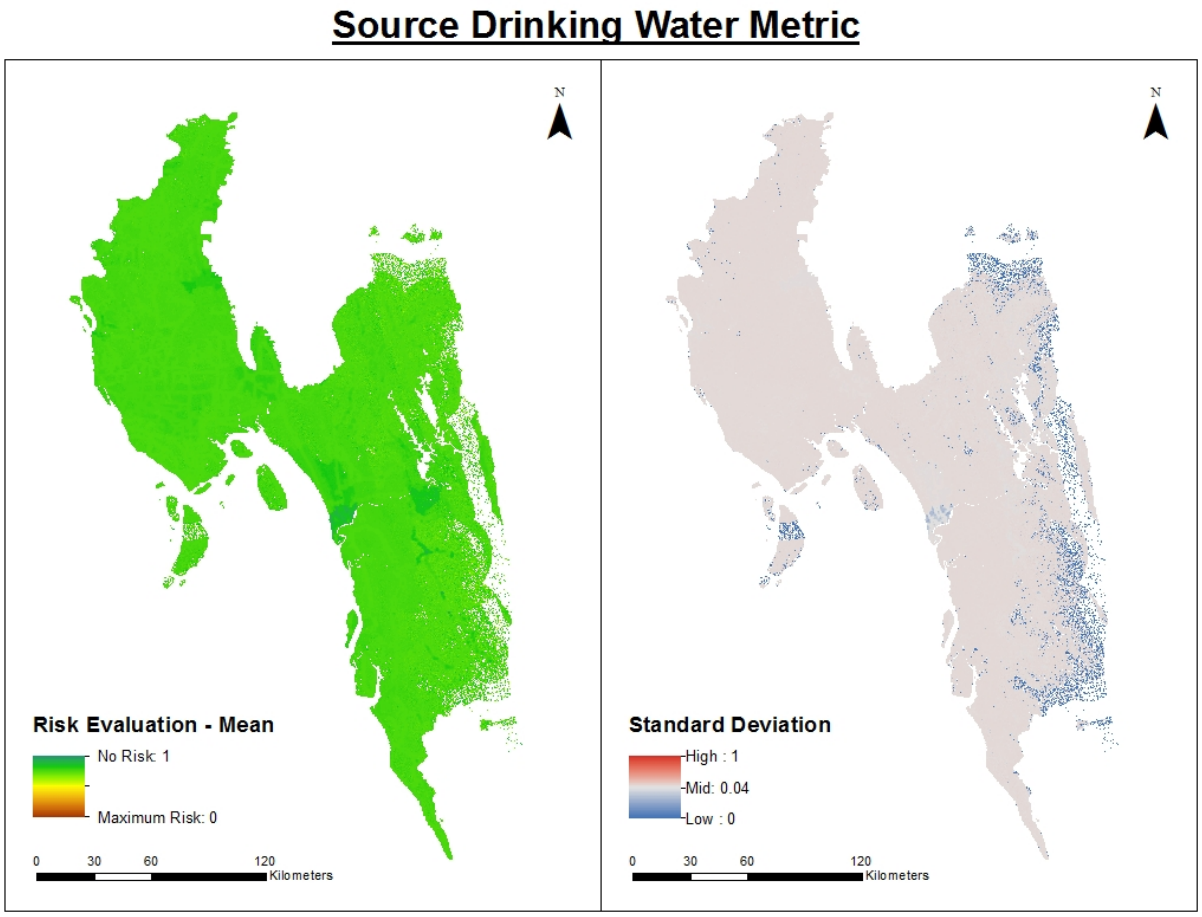
Answers of "Piped Into Dwelling," "Bottled Water," and "Other" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "Public Tap Standpipe" and "Tube Well Borehole" are given a mnimum value of 0.5 (slight risk, $½^1$) and a maximum value of 0.8 (minimal risk). Answers of "Piped int Yard Plot," "Tanker Truck," and "Cart with Small Tank" are given a minimum value of 0.5 and a maximum value of 0.9 (minimal risk). Answers of "Protected Well" and "Protected Spring" are given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0. Answers of "Unprotected Well," "Unprotected Spring," "Rainwater," and "Surface Water" are given a minimum of 0.0625 (extreme risk,

½4) and a maximum value of 0.5 (slight risk, ½1). Maps will range from extreme risk to no risk.

The WHO states that the following are “improved” and “unimproved” forms:

"Improved" sources of drinking water:	"Unimproved" sources of drinking water:
Piped water into dwelling [v]	Unprotected spring [v]
Piped water to yard/plot [v]	Unprotected dug well [v]
Public tap or standpipe [v]	Cart with small tank/drum [v]
Tubewell or borehole [v]	Tanker truck [v]
Protected dug well [v]	Surface water [v]
Protected spring [v]	Bottled water [v]
Rainwater [v]	

Example realization metric map



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Perez-Saez et al., 2016. Climate-driven endemic cholera is modulated by human mobility in a megacity. *Advances in Water Resources*. http://dx.doi.org/10.1016/j.advwatres.2016.11.013.

USAID 2016. StatCompiler – The DHS Program. http://statcompiler.com/en/.

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Metric: Treatment of Drinking Water

Indicator:	Household Water Infrastructure
Factor:	Household Civil Infrastructure Failure
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	Unknown (min: 0.0625, max: 1.0) No (min: 0.0625, max: 1.0) Yes – Water boiled (1) (min: 1.0, max: 1.0) Yes – Water bleached/chlorine added (2) (min: 0.5, max: 1.0) Yes – Water strained (3) (min: 0.0625, max: 0.5) Yes – Water filter used (4) (min: 0.5, max: 1.0) Yes – Water solar disinfected (5) (min: 0.5, max: 1.0) Yes – Let water stand and settle (6) (min: 0.0625, max: 0.5) Yes – Water treated – other (7) (min: 0.25, max: 1.0) Yes – Unknown water treatment (8) (min: 0.0625, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Colwell et al. (2003); Gundry, Wright, & Conroy (2004); Perez-Saez et al. (2016); Rosa & Clasen (2010); USAID (2016); WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation

Logic:

This metric consists of answers to the question of whether or not a household treats their drinking water, and if "yes" what method they use for treatment.

The WHO's JMP outlines that boil, bleach, filter, or solar disinfection methods have been shown to be microbiologically effective, but strain or settle are "inadequate."

The DHS stat compiler for the 2011 survey breaks down households treating water in Bangladesh by rural/urban residence and wealth quintile. Households that do not treat water is 89.3%. 68.7% of urban households and 96.2% of rural households did not treat water in 2011. Across wealth: 97.6%, 97.3%, 96.9%, 92.3%, & 60.7% of households did not treat water in 2011. Households that treat water by boiling is 6.3%. 23.4% of urban households and 0.4% of rural households treat water by boiling in 2011. Across wealth: 0.3%, 0.6%, 0.7%, 3.9%, & 27.1% of households treat water by boiling in 2011. Households adding bleach/chlorine to water (2) is 0.3%. 0.4% of urban households and 0.3% of rural households adding bleach/chlorine to water in 2011. Across wealth: 0.4%, 0.3%, 0.2%, 0.3%, & 0.4% of households adding bleach/chlorine to water in 2011. Households straining water (3) is 0.5%. 1% of urban households and 0.3% of rural households strained water. Across wealth: 0.2%, 0.5%, 0.2%, 0.3%, & 1.2% of households strained water. Households using a filter (4) is 4.4%. 10.8% of urban households and 2.3% of rural households used a filter in 2011. Across wealth: 0.7%, 0.8%, 1.5%, 3.2%, & 16.6% of households used a filter in 2011. Households using another method to treat water (7) is 0.6%. 0.4% of urban households and 0.6% of rural households using another method to treat water in 2011. Across wealth: 0.9%, 0.7%, 0.6%, 0.3%, & 0.3% of households using another method to treat water in 2011. Thus residence and wealth are key indicators for treatment of water.

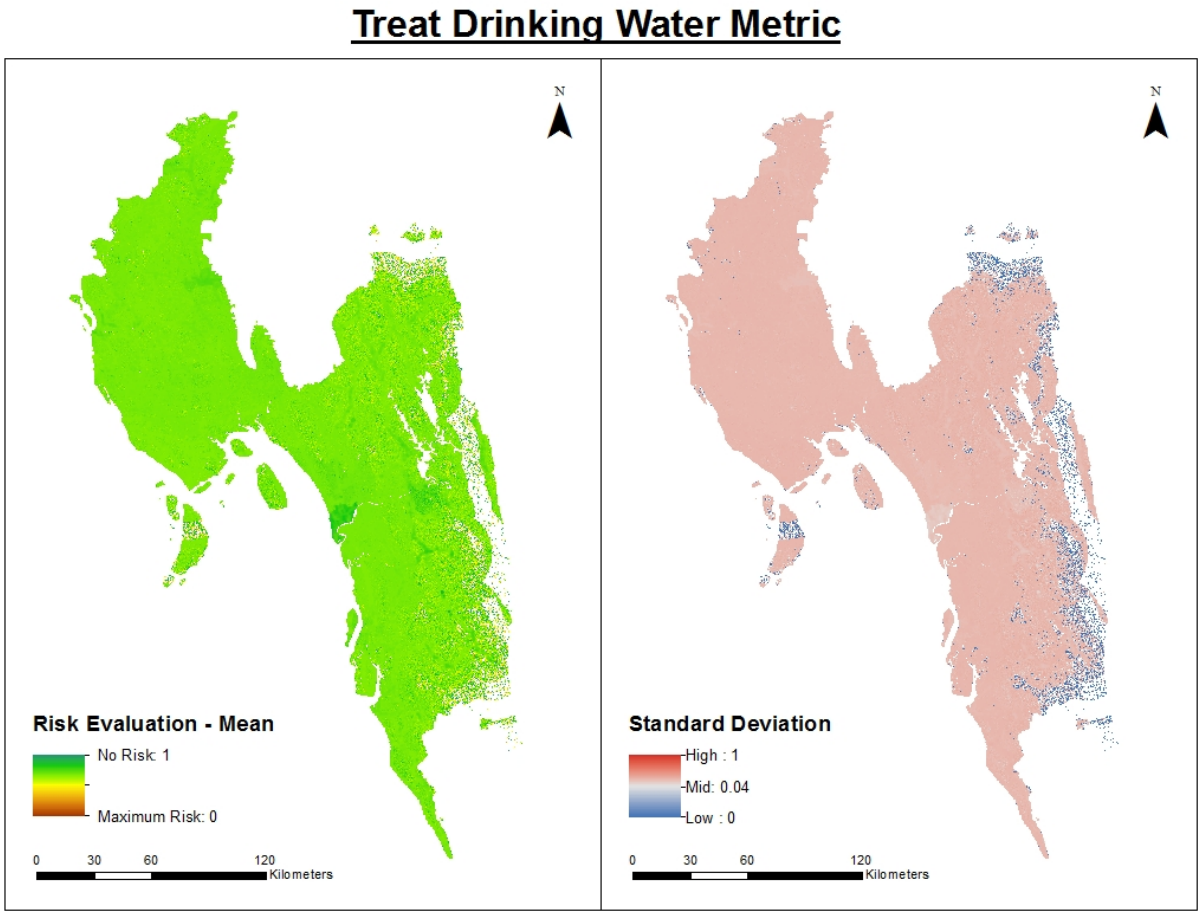
Colwell et al. (2003) used, "a simple filtration procedure was developed whereby zooplankton, most phytoplankton, and particulates >20 μm were removed from water before use. Effective deployment of this filtration procedure, from September 1999 through July 2002 in 65 villages of rural Bangladesh, of which the total population for the entire study comprised [of] 133,000 individuals, yielded a 48% reduction in cholera ($P < 0.005$) compared with the control." Thus, filtration has the ability to greatly reduce cholera outbreaks.

Perez-Saez et al. (2016) reiterate that inadequate water infrastructure exposes the population to cholera. In Grundy, Wright, & Conroy's review of household water quality in developing countries, ponds, tubewells, standpipes, shallow wells, taps, open wells, and surface water are all associated cholera. Rosa & Clasen (2010) estimate the scope of household water treatment in low-income countries. They find that 1% of people in Southeast Asia use chlorine or bleach whereas close to 10% of households use filters. Close to 7% of household strain in Southeast Asia.

Answers of "Unknown" and "No" are given a minimum value of 0.0625 (extreme risk, $½^4$) and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "Yes – Water boiled (1)" are given both a minimum and maximum value of 1.0. Answers of "Yes – Water bleached/chlorine added (2)", "Yes – Water filter used (4)", and "Yes – Water solar disinfected (5)" are given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0. Answers of "Yes – Water treated – other (7)" are given a minimum of 0.25 (medium risk, $½^2$) and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$).

Answers of "Yes – Water strained (3)" and "Yes – Let water stand and settle (6)" are given a minimum of 0.0625 and a maximum value of 0.5. Answers of "Yes – Unknown water treatment (8)" are given a minimum value of 0.0625 and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map



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A.3.3.2 Indicator: Household toilet infrastructure

The Household Toilet Infrastructure indicator accounts for toilet infrastructure at the household and neighborhood levels. Metrics should include data on type of toilet/human waste disposal. At the household level, this can account for elements that lead to a dangerous living environment. This indicator is essential to identifying areas that are especially susceptible to cholera risk. For example, Jutla et al. (2013) finds that poor sanitation yields a higher likelihood of a cholera epidemic. They determine that the United States rarely experiences cholera outbreak due to its robust water and sanitation infrastructure as effective prevention methods for the spread of cholera (p.602).

Metric weighting logic

As the metric "Household Toilet Type" from the DHS survey is more detailed in answer enumerations from the same question in the IPUMS survey, it is weighted the highest for the indicator.

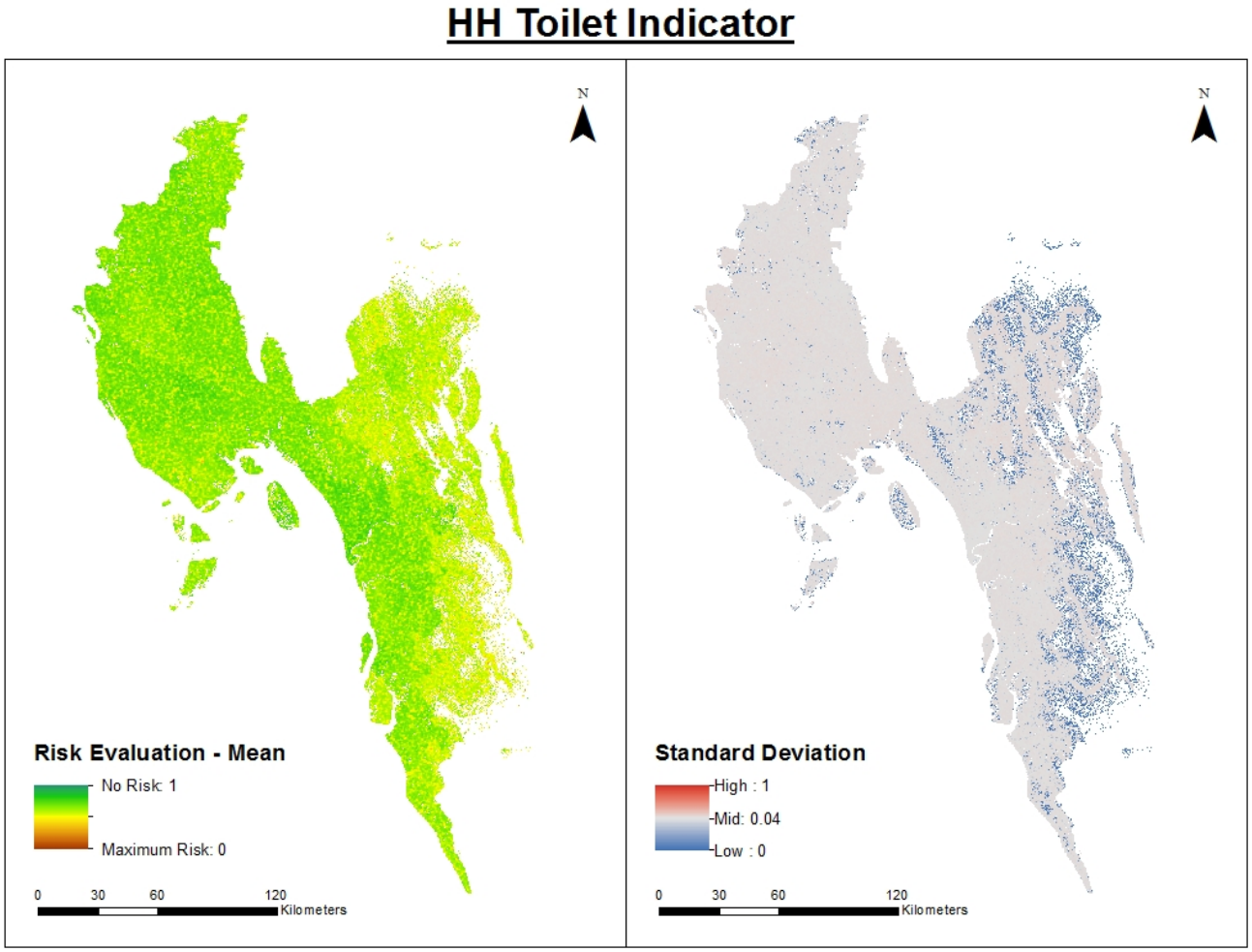
Metric	Weight Minimum Value	Weight Maximum Value
Household Toilet Type (IPUMS)	0.4	0.6
Household Toilet Type (DHS)	0.5	0.7
Shared Toilet	0.2	0.5

Uncertainty values

The low uncertainty values are due to the robust data collection on household materials and types by both DHS & IPUMS. Adding more data on the local environments and pollution levels, especially in terms of cholera risks, could decrease the uncertainty values.

Indicator Uncertainty Min:	0.15
Indicator Uncertainty Max:	0.25

Example outcome



References

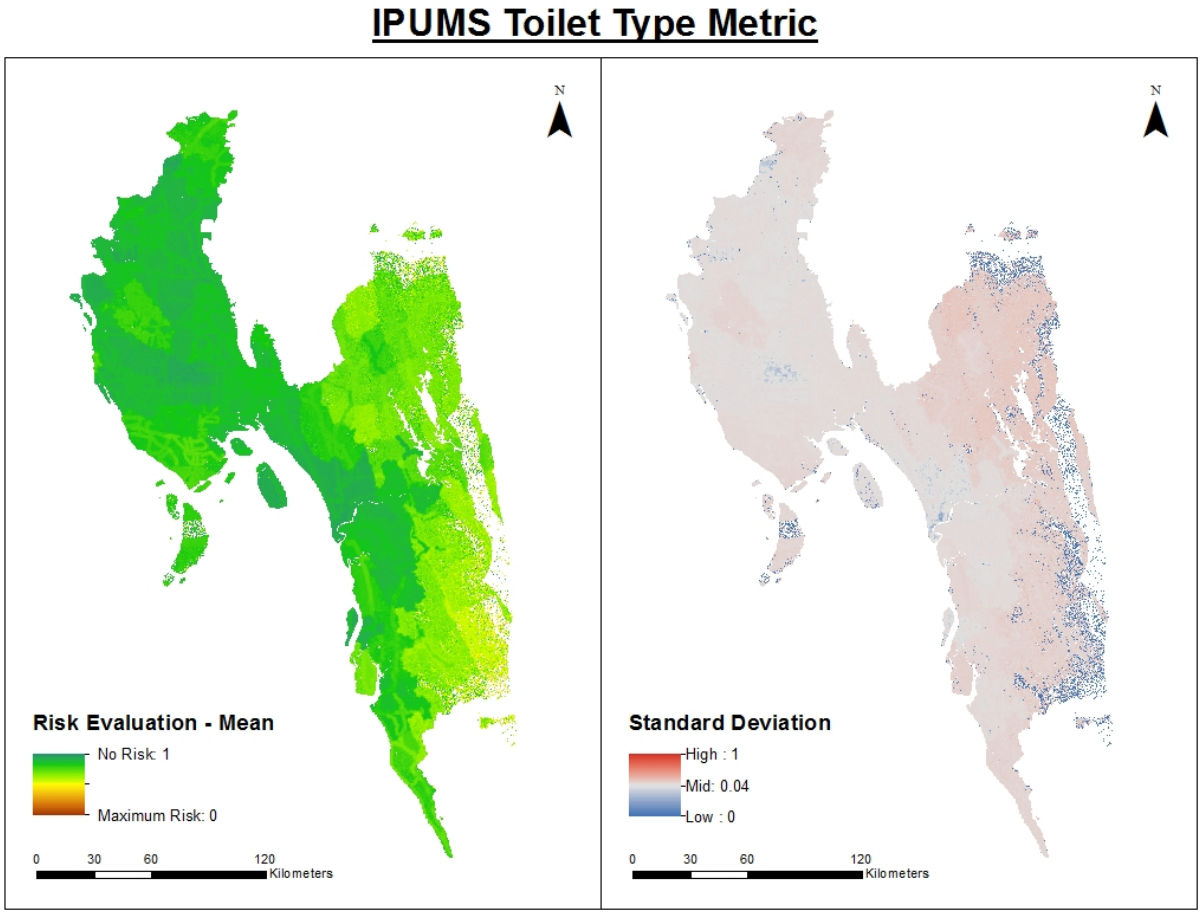
Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A.,... & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Metric: Household Toilet Type (IPUMS)

Indicator:	Household Toilet Infrastructure
Factor:	Household Civil Infrastructure Failure
Condition:	Human Behavioral Impact
Framework:	Cholera

Metric Assigned Values:	Sanitary with water seal (min: 1.0, max: 1.0) Sanitary without seal (min: 0.75, max: 1.0) Non-Sanitary (min: 0.0625, max: 0.8) None (min: 0.0625, max: 0.5)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 2); Emch (1999); Giebultowicz et al. (2011); Hashizume et al. (2008); Jutla et al. (2013); Perez-Saez et al. (2016); Root et al. (2013); WHO (n.d.)
Logic:	The interviewer Instructions for this question from the IPUMS survey states: "The toilet which is pit latrine with water sealed facility is called sanitary (water sealed). The latrine which is pit latrine but having no water sealed facility is called sanitary (Non-water sealed). The toilet which may be pucca, semi-pucca or kutch but having no facility to cover the discharge waste is called Non-sanitary. Such type of toilet is not free from water and environment pollution. None means there is no toilet for the household usually uses to go bush, jungle or open space as and when necessary." Ali et al. (2002, 2) clarifies sanitation data by unsafe and safe latrines. An unsafe latrine is open, thus feces can spread to contaminate nearby surface water, especially in the rainy season (Jul-Sept). Emch (1999) Giebultowicz et al. (2011) finds that "unsanitary latrines are responsible for surface water contamination." Jutla et al. (2013) finds that poor sanitation yields a higher likelihood of a cholera epidemic. They determine that the United States rarely experiences cholera outbreak due to its robust water and sanitation infrastructure as effective prevention methods for the spread of cholera (p.602). Perez-Saez et al. (2016) reiterate that inadequate sanitation infrastructure exposes the population to cholera. Hashizume et al. (2008) found that cholera risk is higher for those using unsanitary toilets and drinking tubewell water. Root et al. (2013) uses latrine facility as an indicator for socioeconomic status. Latrine facility is ranked as follows: 4. Septic tank/modern toilet 3. Water sealed/slab latrine 2. Open latrine or open place 1. No latrine. Answers of "Sanitary with water seal" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "Sanitary w/o seal" are given an overall value of minimal risk with a minimum value of 0.75 (minimal risk) and a maximum value of 1.0. Answers of "Non-Sanitary" are given a minimum of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.8 (minimal risk). Answers of "None" are given a minimum of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Maps will range from extreme risk to no risk.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

Emch, Michael. "Diarrheal disease risk in Matlab, Bangladesh." *Social science & medicine* 49, no. 4 (1999): 519-530.

Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2 (2011): 490-497.

Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Perez-Saez et al., 2016. Climate-driven endemic cholera is modulated by human mobility in a megacity. *Advances in Water Resources*. http://dx.doi.org/10.1016/j.advwatres.2016.11.013.

Root, E. D., Rodd, J., Yunus, M., & Emch, M. 2013. The role of socioeconomic status in longitudinal trends of cholera in Matlab, Bangladesh, 1993–2007. *PLoS Negl Trop Dis*, *7*(1), e1997.

WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation. "Improved and unimproved water sources and sanitation facilities." http://www.wssinfo.org/definitions-methods/watsan-categories/.

Metric: Household Toilet Type (DHS)

Indicator: Household Toilet

Factor: Household Civil Infrastructure Failure

Condition: Human Behavioral Impact

Framework: Cholera

Metric Assigned Values:

Toilet Type	Min	M
Flush Toilet (I)	1.000	1.
Flush To Piped Sewer System (I)	1.000	1.
Flush To Septic Tank (I)	0.750	1.
Flush To Pit Latrine (I)	0.750	1.
Flush To Somewhere Else (U)	0.125	0.
Flush Do Not Know Where (U)	0.0625	0.
Pit Toilet Latrine (B)	0.125	1.
Ventilated Improved Pit Latrine (I)	0.25	1.
Pit Latrine With Slab (I)	0.25	1.
Pit Latrine Without Slab Open Pit (U)	0.0625	0.
No Facility (U)	0.0625	0.
No Facility Bush Field (U)	0.0625	0.
Composting Toilet (I)	0.750	1.
Bucket Toilet (U)	0.125	0.
Hanging Toilet Latrine (U)	0.0625	0.

Survey: DHS - Household

Survey Date: 2011

Other Data Sources: Ali et al. (2002, 2); Emch (1999); Giebultowicz et al. (2011); Hashizume et al. (2008); Jutla et al. (2013); Perez-Saez et al. (2016); WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation

Logic: This metric consists of answers to the question about the household toilet type from the DHS survey. Answers are organized by "improved" (I), "unimproved" (U), or "both" (B).

Ali et al. (2002, 2) clarifies sanitation data by unsafe and safe latrines. An unsafe latrine is open, thus feces can spread to contaminate nearby surface water, especially in the rainy season (Jul-Sept). Giebultowicz et al. (2011) finds that "unsanitary latrines are responsible for surface water contamination." Jutla et al. (2013) finds that poor sanitation yields a higher likelihood of a cholera epidemic. They determine that the United States rarely experiences cholera outbreak due to its robust water and sanitation infrastructure as effective prevention methods for the spread of cholera (p.602). Perez-Saez et al. (2016) reiterate that inadequate sanitation infrastructure exposes the population to cholera. Hashizume et al. (2008) found that cholera risk is higher for those using unsanitary toilets and drinking tubewell water.

Root et al. (2013) uses latrine facility as an indicator for socioeconomic status. Latrine facility is ranked as follows: 4. Septic tank/modern toilet 3. Water sealed/slab latrine 2. Open latrine or open place 1. No latrine.

Answers of "Flush Toilet (I)" and "Flush To Piped Sewer System (I)" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "Flush To Septic Tank (I)", " Flush To Pit Latrine (I)", and "Composting Toilet (I)" are given an overall value of minimal risk with a minimum value of 0.75 (minimal risk) and a maximum value of 1.0. Answers of "Ventilated Improved Pit Latrine (I)" and "Pit Latrine With Slab (I)" are given a minimum of 0.25 (medium risk, $½^2$) and a maximum value of 1.0. Answers of "Pit Toilet Latrine (B)" are given a minimum of 0.125 (high risk, $½^3$) and a maximum value of 1.0. Answers of "Flush To Somewhere Else (U)" and "Bucket Toilet (U)" are given a minimum of 0.125 (high risk, $½^3$) and a maximum value of 0.75 (minimal risk). Answers of "Flush Do Not Know Where (U)", "Pit Latrine Without Slab Open Pit (U)", "No Facility (U)", "No Facility Bush Field (U)", and "Hanging Toilet Latrine (U)" are given a minimum of 0.0625 (extreme risk, $½^4$)and a maximum value of 0.75. Maps will range from extreme risk to no risk.

The WHO states the following as forms of "improved" and "unimproved" sanitation.

"Improved" sanitation:

Flush toilet [v]

Piped sewer system [v]

Septic tank [v]

Flush/pour flush to pit latrine [v]

Ventilated improved pit latrine (VIP) [v]

Pit latrine with slab [v]

Composting toilet [v]

Special case [v]

"Unimproved" sanitation:

Flush/pour flush to elsewhere [v]

Pit latrine without slab [v]

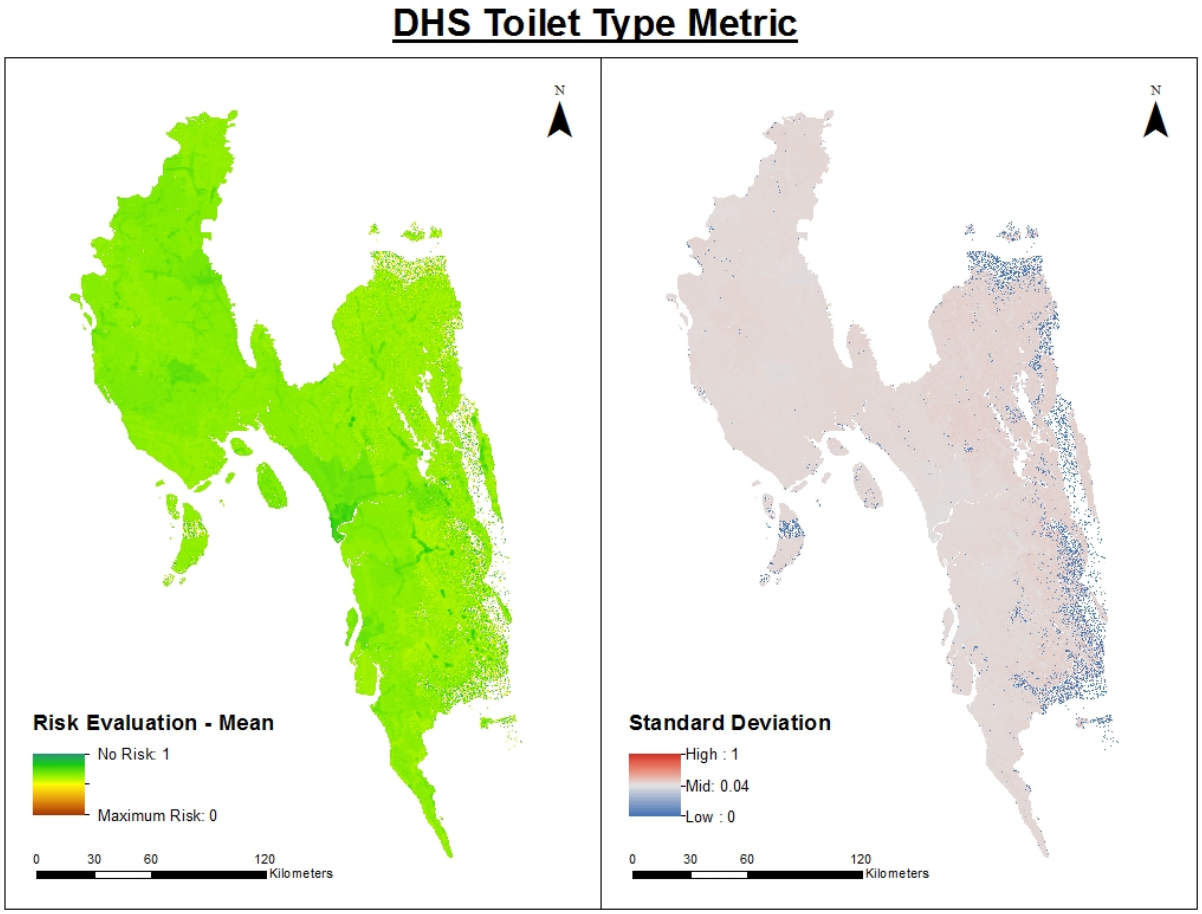
Bucket [v]

Hanging toilet or hanging latrine [v]

Shared sanitation [v]

No facilities or bush or field [v]

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

Emch, Michael. "Diarrheal disease risk in Matlab, Bangladesh." *Social science & medicine* 49, no. 4 (1999): 519-530.

Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2 (2011): 490-497.

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Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Perez-Saez et al., 2016. Climate-driven endemic cholera is modulated by human mobility in a megacity. *Advances in Water Resources*. http://dx.doi.org/10.1016/j.advwatres.2016.11.013.

WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation. "Improved and unimproved water sources and sanitation facilities." http://www.wssinfo.org/definitions-methods/watsan-categories/.

Metric: Sharing Toilet with Other Households

Indicator: Household Toilet

Factor: Household Civil Infrastructure Failure

Condition: Human Behavioral Impact

Framework: Cholera

Metric Assigned Values:

Toilet Type	Min	Max
ShareToiletWOtherHhld, No	1.0	1.000
SharingToilet, No	1.0	1.000
1Hhld	0.7	1.000
2Hhlds	0.5	1.000
3Hhlds	0.25	1.000
4Hhlds	0.125	1.000
5Hhlds	0.0625	1.000
6Hhlds	0.0625	0.500
7Hhlds	0.0625	0.500
8Hhlds	0.0625	0.500
9Hhlds	0.0625	0.500
10plusHhlds	0.0625	0.250
Unknown	0.0625	1.000

Survey: DHS - Household

Survey Date: 2011

Other Data Sources: Ali et al. (2002, 2); Emch (1999); Fuller et al. (2014); Giebultowicz et al. (2011); Hashizume et al. (2008); Jutla et al. (2013); Kanungo et al. (2012); Perez-Saez et al. (2016); WHO (n.d.)

Logic: Ali et al. (2002, 2) clarifies sanitation data by unsafe and safe latrines. An unsafe latrine is open, thus feces can spread to contaminate nearby surface water, especially in the rainy season (Jul-Sept). Giebultowicz et al. (2011) finds that "unsanitary latrines are responsible for surface water contamination." Emch (1999) found the number of households using a latrine to be statistically significant to the relative risk of cholera.

Jutla et al. (2013) finds that poor sanitation yields a higher likelihood of a cholera epidemic. They determine that the United States rarely experiences cholera outbreak due to its robust water and sanitation infrastructure as effective prevention methods for the spread of cholera (p.602).

Perez-Saez et al. (2016) reiterate that inadequate sanitation infrastructure exposes the population to cholera. Hashizume et al. (2008) found that cholera risk is higher for those using unsanitary toilets and drinking tubewell water.

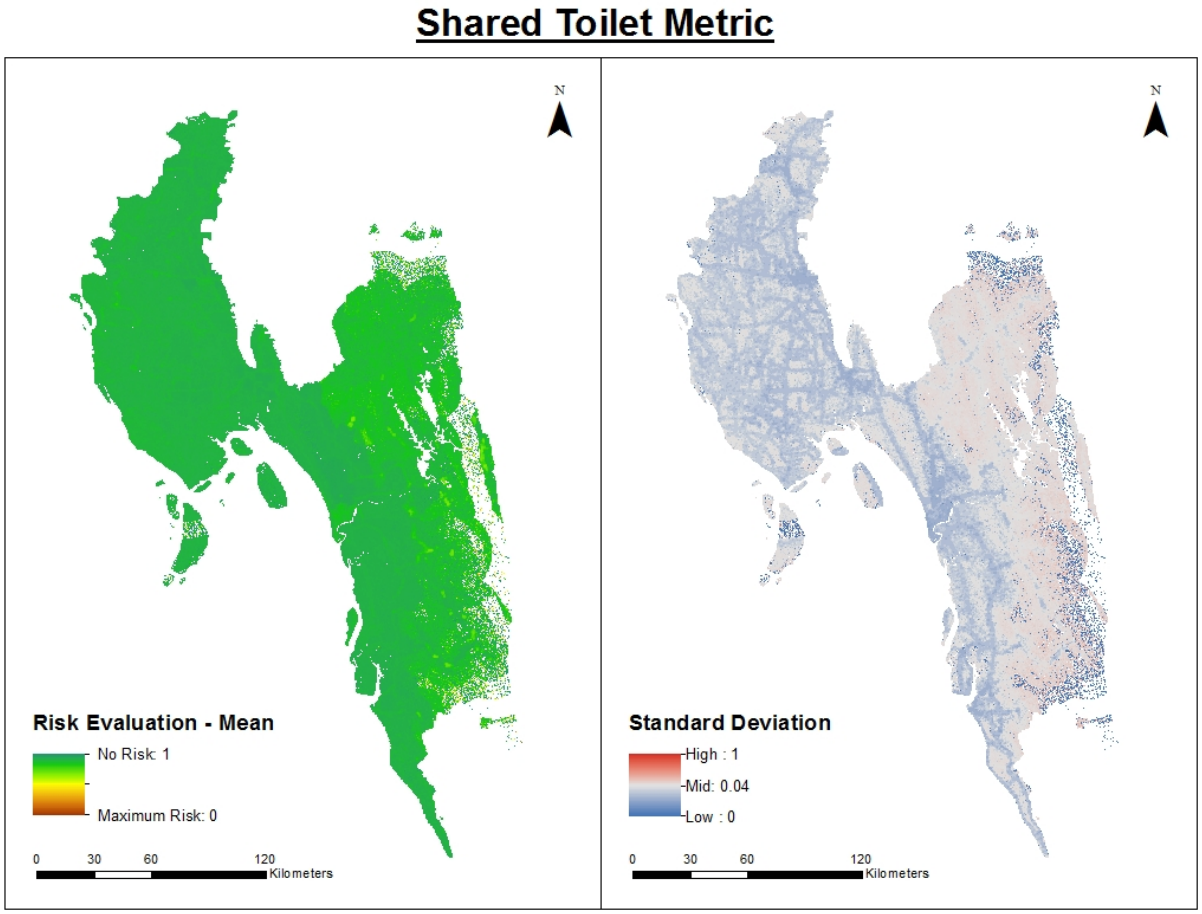
Kanungo et al. (2012) found that in high population density Kolkata, residents live in tightly packed in homes with sewage-littered streets and share toilets and drinking water. The study reveals an average of 12 individuals in a household using safe toilet, or non-shared flush toilet, and was found to be statistically significant as a predictor of risk of cholera.

In the Kampala slums of Uganda, access to improved sanitation is a key preventive measure against diarrhea. 68% of the sample shared toilets, 11% used public toilets, and less than 1% used open defecation.

Fuller et al (2014) found that "Shared sanitation appears to be a risk factor for diarrhea although differences in socioeconomic status are important." In Bangladesh, the prevalence of diarrhea is 10.1% from the 2011 DHS with 8.6% not having access to a toilet, 37.6% use an improved toilet, 45.1% use a shared toilet facility, and 11.2% share a toilet with over five households.

Answers of "ShareToiletWOtherHhld, No" and "SharingToilet, No" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "1Hhld" are given a minimum of 0.7 (minimal risk) and a maximum value of 1.0. Answers of "2Hhlds" are given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0. Answers of "3Hhlds" are given a minimum of 0.25 (medium risk, $½^2$) and a maximum value of 1.0. Answers of "4Hhlds" are given a minimum of 0.125 (high risk, $½^3$) and a maximum value of 1.0. Answers of "5Hhlds" are given a minimum value 0.0625 (extreme risk, $½^4$) and a maximum value of 1.0. Answers of "6Hhlds," "7Hhlds," "8Hhlds," and "9Hhlds" are given a minimum value 0.0625 (extreme risk, $½^4$) and a maximum value of 0.5 (slight risk, $½^1$). Answers of "10plusHhlds" are given a minimum value 0.0625 and a maximum value of 0.25. Answers of "Unknown" are given a minimum value of 0.0625 and a maximum value of 1.0. Maps will range from extreme risk to no risk.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

Emch, Michael. "Diarrheal disease risk in Matlab, Bangladesh." *Social science & medicine* 49, no. 4 (1999): 519-530.

Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2 (2011): 490-497.

Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

Fuller, J. A., Clasen, T., Heijnen, M., & Eisenberg, J. N. 2014. Shared sanitation and the prevalence of diarrhea in young children: evidence from 51 countries, 2001–2011. *The American journal of tropical medicine and hygiene*, *91*(1), 173-180.

Kanungo, S., Sur, D., Ali, M., You, Y. A., Pal, D., Manna, B., & Nair, G. B. 2012. Clinical, epidemiological, and spatial characteristics of Vibrio parahaemolyticus diarrhea and cholera in the urban slums of Kolkata, India. *BMC public health*, *12*(1), 830.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Perez-Saez et al., 2016. Climate-driven endemic cholera is modulated by human mobility in a megacity. *Advances in Water Resources*. http://dx.doi.org/10.1016/j.advwatres.2016.11.013.

WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation. "Improved and unimproved water sources and sanitation facilities." http://www.wssinfo.org/definitions-methods/watsan-categories/.

A.3.3.3 Indicator: Household access to electricity

The HC framework's "Energy Deficits" indicator under the "Utilities Disruption" has a list of 14 recommended metrics. The only the metric "Household Access to Electricity" is an available metric at the household level that overlaps as a predictor to cholera incidence.

Metric weighting logic

The metrics are very similar and in order to prevent overlapping of the two metrics, they have been weighted equally with minimum and maximum values of 0.5.

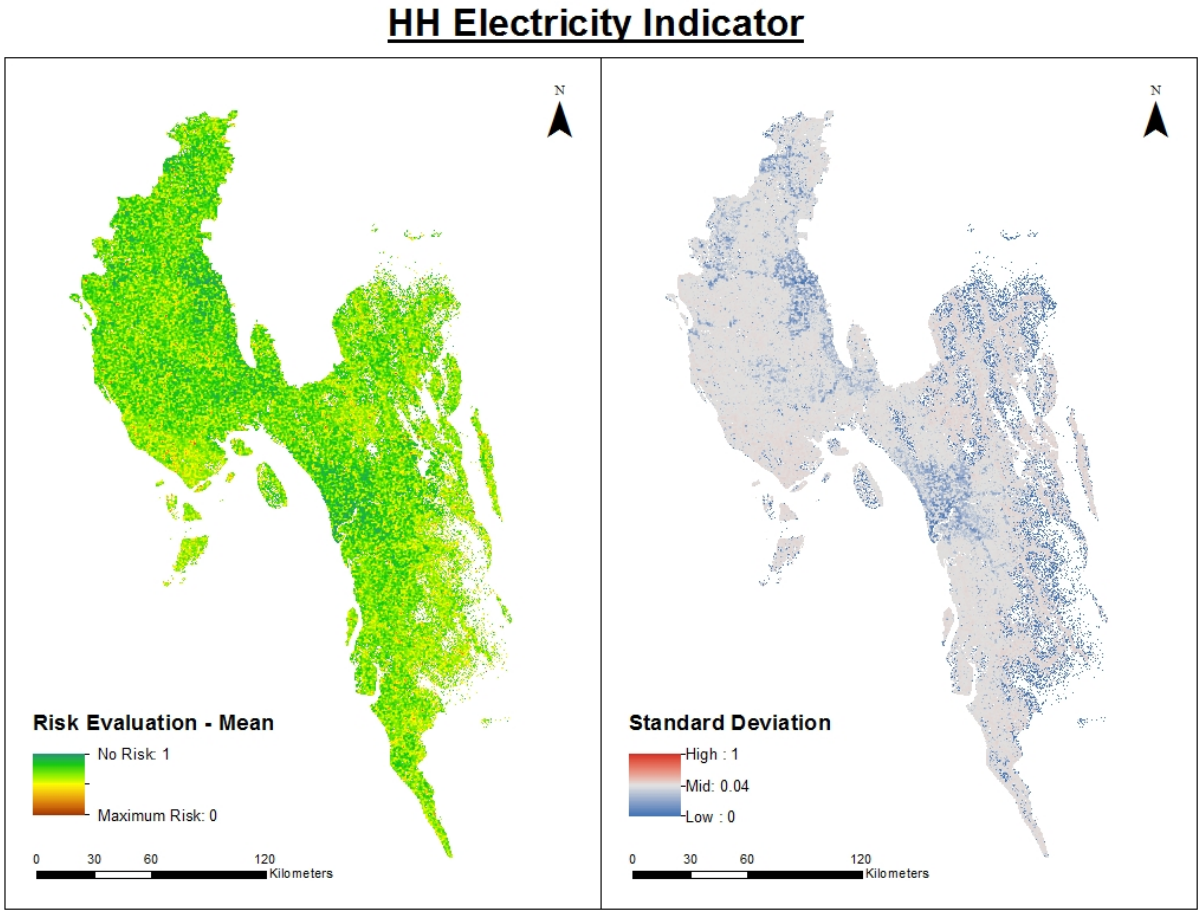
Metric	Weight Minimum Value	Weight Maximum Value
Household Access to Electricity (IPUMS)	0.5	0.5
Household Access to Electricity (DHS)	0.5	0.5

Uncertainty values

Adding more data on the interaction of work and factors that increase risk to cholera incidence could decrease the uncertainty values.

Indicator Uncertainty Min:	0.3
Indicator Uncertainty Max:	0.5

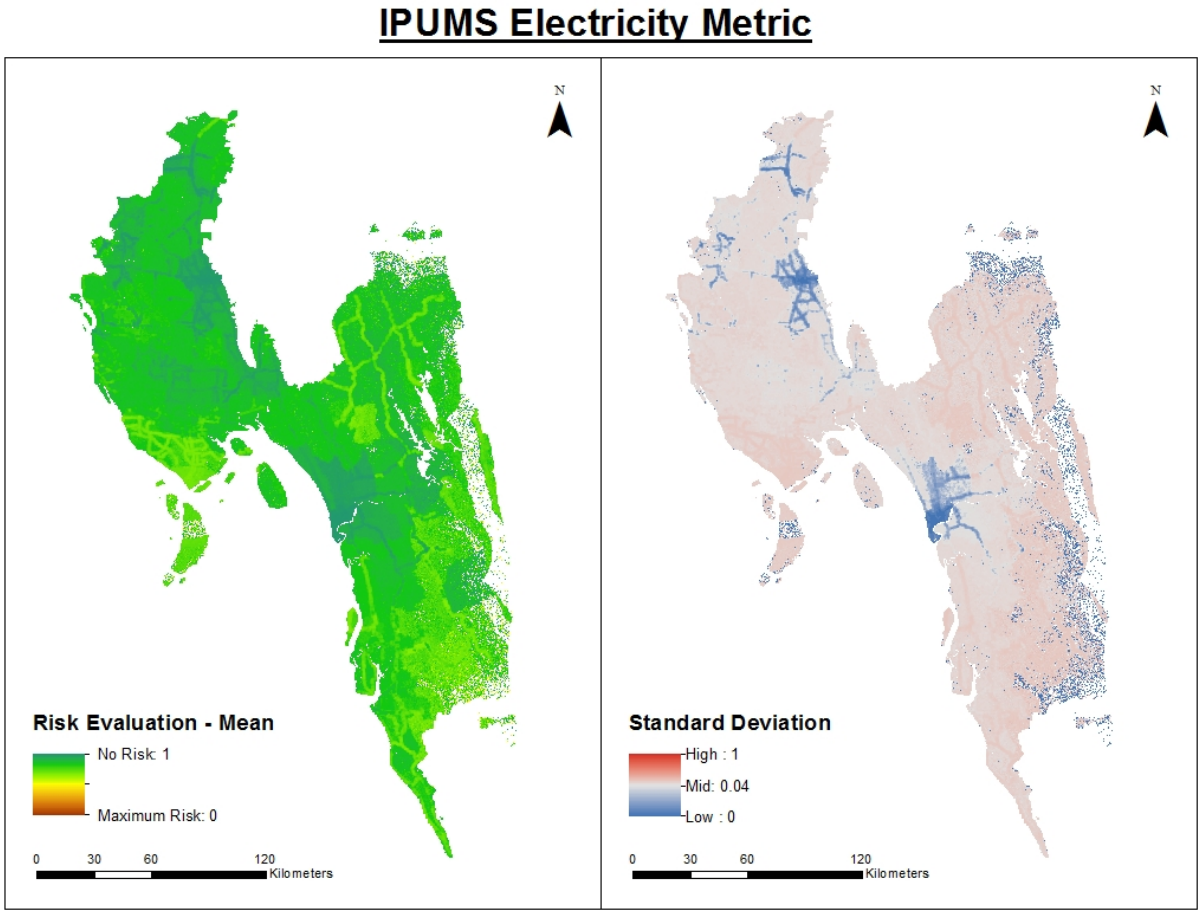
Example outcome



Metric: Household Access to Electricity (IPUMS)

Indicator:	Household Electricity
Factor:	Household Civil Infrastructure
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.2, max: 0.8)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	Luby et al. (2011); Nketiah-Amponsah et al. (2009); Oparaku, O. U. (2002); USAID (2016)
Logic:	This metric consists of answers to the question whether or not a household has access to electricity. Luby et al. (2011) found that households who owned items that required electricity was statistically significant in observing less diarrhea among children under 5. Oparaku, O. U. (2002) found that electrification benefited a village in Nigeria by guaranteeing water supply and an improved standard of living. Nketiah-Amponsah et al. (2009) found that electricity was statistically significant for all regressions of types of drinking water, including, piped into residence, public outdoor tap, protected well, and unprotected source. Regarding residence as an indicator for electricity, Nketiah-Amponsah et al. (2009) found that rural dwellers are 9 and 30% less likely to have access to piped water in residence and public outdoor tap respectively as compared to boreholes. "Yes" answers are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). "No" answers are given a minimum value of 0.2 (medium risk) and a maximum value of 0.8 (minimal risk). Maps will range from medium risk to no risk.

Example realization metric map



References

Luby, S. P., Halder, A. K., Huda, T., Unicomb, L., & Johnston, R. B. 2011. The effect of handwashing at recommended times with water alone and with soap on child diarrhea in rural Bangladesh: an observational study. *PLoS Med*, *8*(6), e1001052.

Nketiah-Amponsah, E., Aidam, P. W., & Senadza, B. (2009, October). Socio-economic determinants of sources of drinking water: Some insight from Ghana. In *Conference on International Research on Food Security, Natural Resource Management and Rural Development, University of Hamburg*.

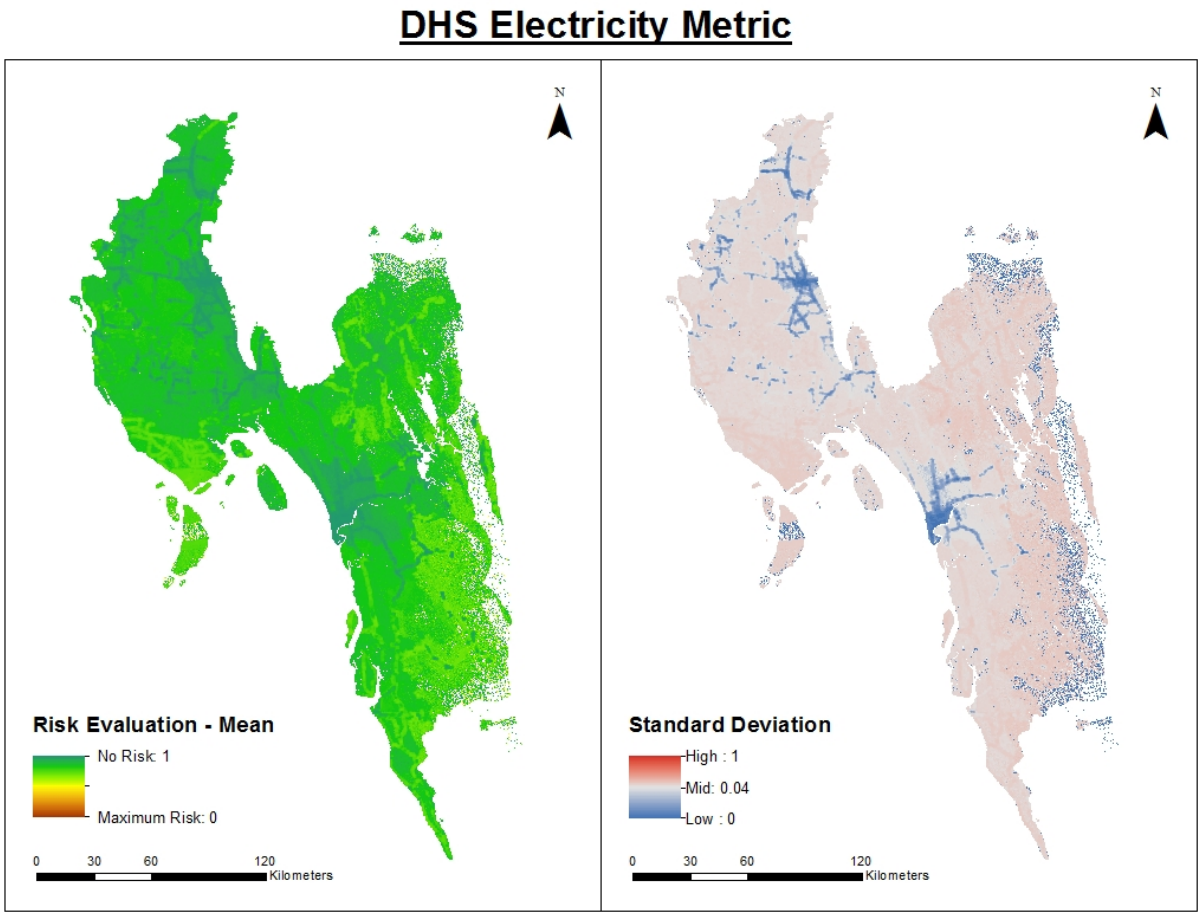
Oparaku, O. U. 2002. Photovoltaic systems for distributed power supply in Nigeria. *Renewable energy*, *25*(1), 31-40.

USAID 2016. StatCompiler – The DHS Program. http://statcompiler.com/en/.

Metric: Household Access to Electricity (DHS)

Indicator:	Household Electricity
Factor:	Household Civil Infrastructure
Condition:	Human Behavioral Impact
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.2, max: 0.8)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	USAID (2016); Luby et al. (2011); Oparaku, O. U. (2002); Nketiah-Amponsah et al. (2009)
Logic:	This metric consists of answers to the question whether or not a household has access to electricity. The DHS stat compiler for the 2011 survey breaks down households with electricity by rural/urban residence. Households with electricity is 59.6%. 90.2% of urban households have electricity opposed to 49.3% of rural households who have electricity. Thus residence is the main indicators for electricity is residence location. Luby et al. (2011) found that households who owned items that required electricity was statistically significant in observing less diarrhea among children under 5. Oparaku, O. U. (2002) found that electrification benefited a village in Nigeria by guaranteeing water supply and an improved standard of living. Nketiah-Amponsah et al. (2009) found that electricity was statistically significant for all regressions of types of drinking water, including, piped into residence, public outdoor tap, protected well, and unprotected source. Regarding residence as an indicator for electricity, Nketiah-Amponsah et al. (2009) found that rural dwellers are 9 and 30% less likely to have access to piped water in residence and public outdoor tap respectively as compared to boreholes. "Yes" answers are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, ½^0). "No" answers are given a minimum value of 0.2 (medium risk) and a maximum value of 0.8 (minimal risk). Maps will range from medium risk to no risk.

Example realization metric map



References

Luby, S. P., Halder, A. K., Huda, T., Unicomb, L., & Johnston, R. B. 2011. The effect of handwashing at recommended times with water alone and with soap on child diarrhea in rural Bangladesh: an observational study. *PLoS Med*, *8*(6), e1001052.

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Oparaku, O. U. 2002. Photovoltaic systems for distributed power supply in Nigeria. *Renewable energy*, *25*(1), 31-40.

USAID 2016. StatCompiler – The DHS Program. http://statcompiler.com/en/.

A.4 Service failure condition overview

This condition focuses on the potential impacts that service failures, specifically targeted toward medical service failures and utility failures, could have on local living and working conditions. It is these factors, indicators, and metrics that most represent how the local environment can affect an individual's risk to contract cholera.

Factors within this condition include Health & Medical Service Insufficiencies (6.1) and Utility Disruption (6.2).

Factor weighting logic

Both factors are extremely important in the field of cholera. Utility Disruption is weighted much higher than Health & Medical Service Insufficiencies as half of the latter is reactionary to any potential cholera risk. Utility Disruption plays a larger role in predicting if any outbreak were to occur, and is therefore more constraining on the condition as a whole.

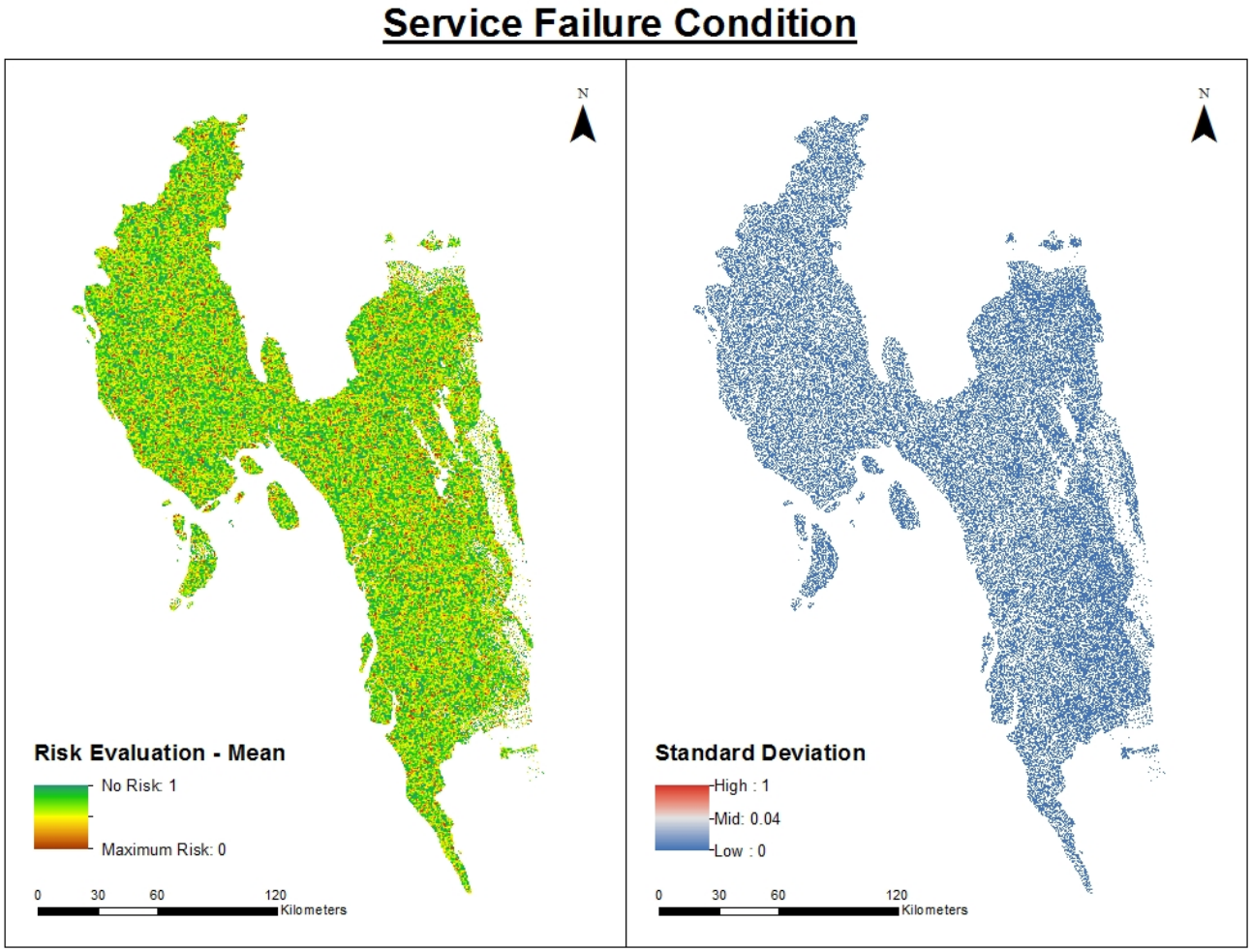
Factor	Weight Minimum Value	Weight Maximum Value
Health & Medical Service Insufficiencies	0.25	0.5
Utility Disruption	0.75	1.0

Uncertainty values

This condition is given a range of uncertainty values from 0.1 to 0.3 because of the perceived ability of the existing factors to fully address the themes of the condition. The factors address many issues regarding the human environment and potential risk-avoiding behavior regarding water infrastructure integrity and medical preparation that could prevent local and regional risk to waterborne disease outbreaks. The addition of other factors, indicators, and metrics which measure quality of life, such as transportation, could further decrease the uncertainty values.

Condition Uncertainty Min:	0.1
Condition Uncertainty Max:	0.3

Example outcome



A.4.1 Health & medical service insufficiencies factor overview

This factor accounts for service failures in the health and medical sectors within the study area. The efficacy of medical services during typical day-to-day operations will suggest their effectiveness in adapting to a crisis situation. "Medical Services" is one of 28 indicators in the World Risk Index under the heading of "coping capacity" (Welle and Birkmann 2015). In other words, coping capacities point to the function of governance, disaster preparedness and early warning, medical services, and social and economic security.

Indicators within this factor include Doctor and Access to Primary Care, Hospitals/Clinics & Secondary Care, Household Health Practices, and Treatment for Diarrhea.

Indicator weighting logic

All four indicators within the Health & Medical Service Insufficiencies factor are given both a minimum and a maximum value of 0.25. This is because each indicator is equally as constraining on and contributing to the factor.

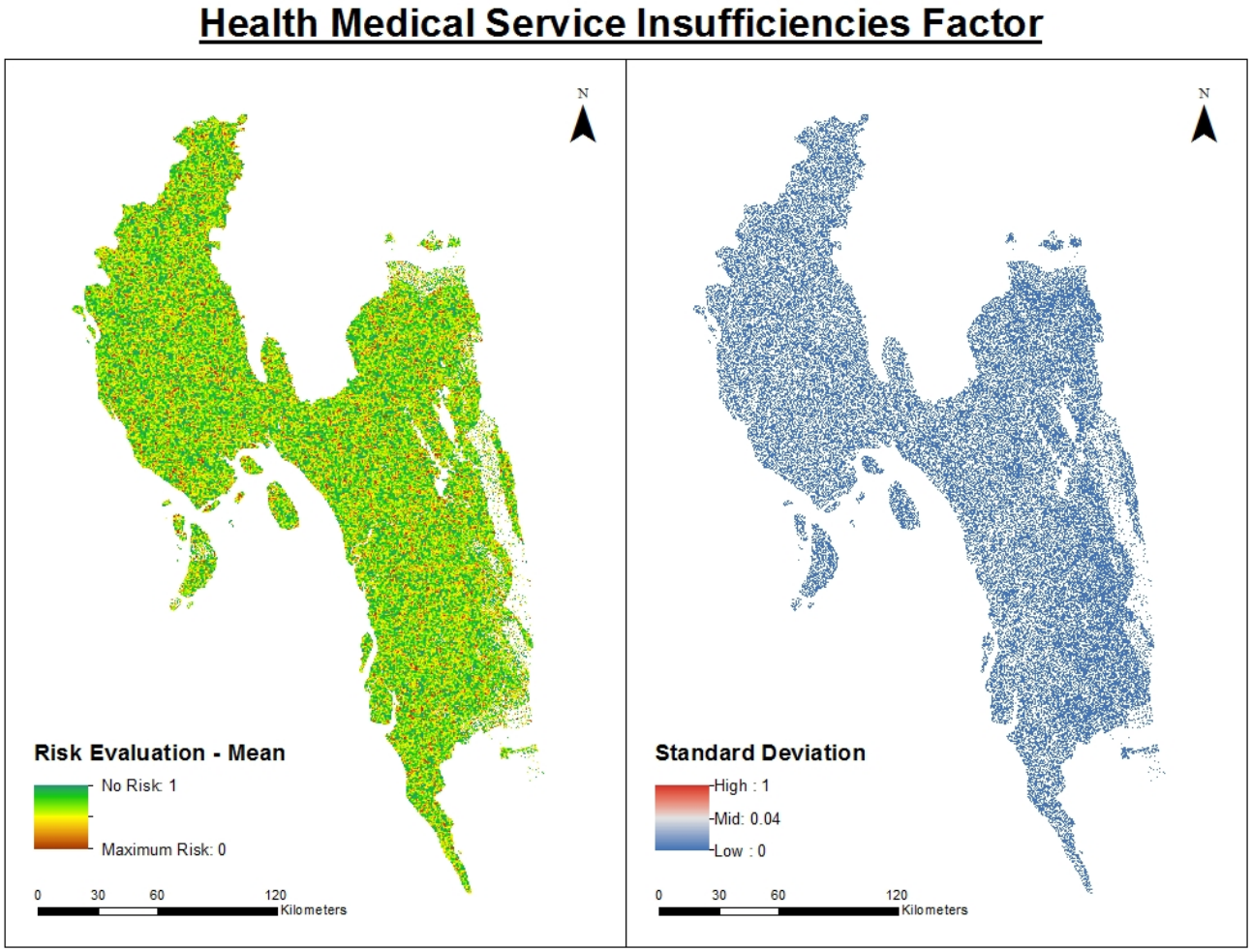
Indicator	Weight Minimum Value	Weight Maximum Value
Doctor & Access to Primary Care	0.25	0.25
Hospitals/Clinics & Secondary Care	0.25	0.25
Household Health Practices	0.25	0.25
Treatment for Diarrhea	0.25	0.25

Uncertainty values

This factor is given a range of uncertainty values from 0.1 to 0.2 because of the perceived ability of the existing indicators to fully address the themes of the factor. The addition of other indicators and metrics which measure quality of life, such as transportation, could further decrease the uncertainty values.

Factor Uncertainty Min:	0.1
Factor Uncertainty Max:	0.2

Example outcome



References

Welle, Torsten and Joern Birkmann 2015. "The World Risk Index – An Approach to Assess Risk and Vulnerability on a Global Scale." J Extreme Events, Vol. 2, No. 1 (2015) 1550003 (34 pages).

A.4.1.1 Indicator: Doctor and access to primary care

This indicator predicts ability to access healthcare. The survey questions used to predict this are all taken from the DHS Woman's Survey. This indicator reflects the ability of the framework to recover from a cholera outbreak. For those who purely wish to predict cholera outbreak, this indicator can be removed.

Metric weighting logic

As "Perceived Distance to Healthcare" contributes the most to an understanding of access to doctors and primary care compared to other metrics within this indicator, it is the most constraining and is weighted the highest.

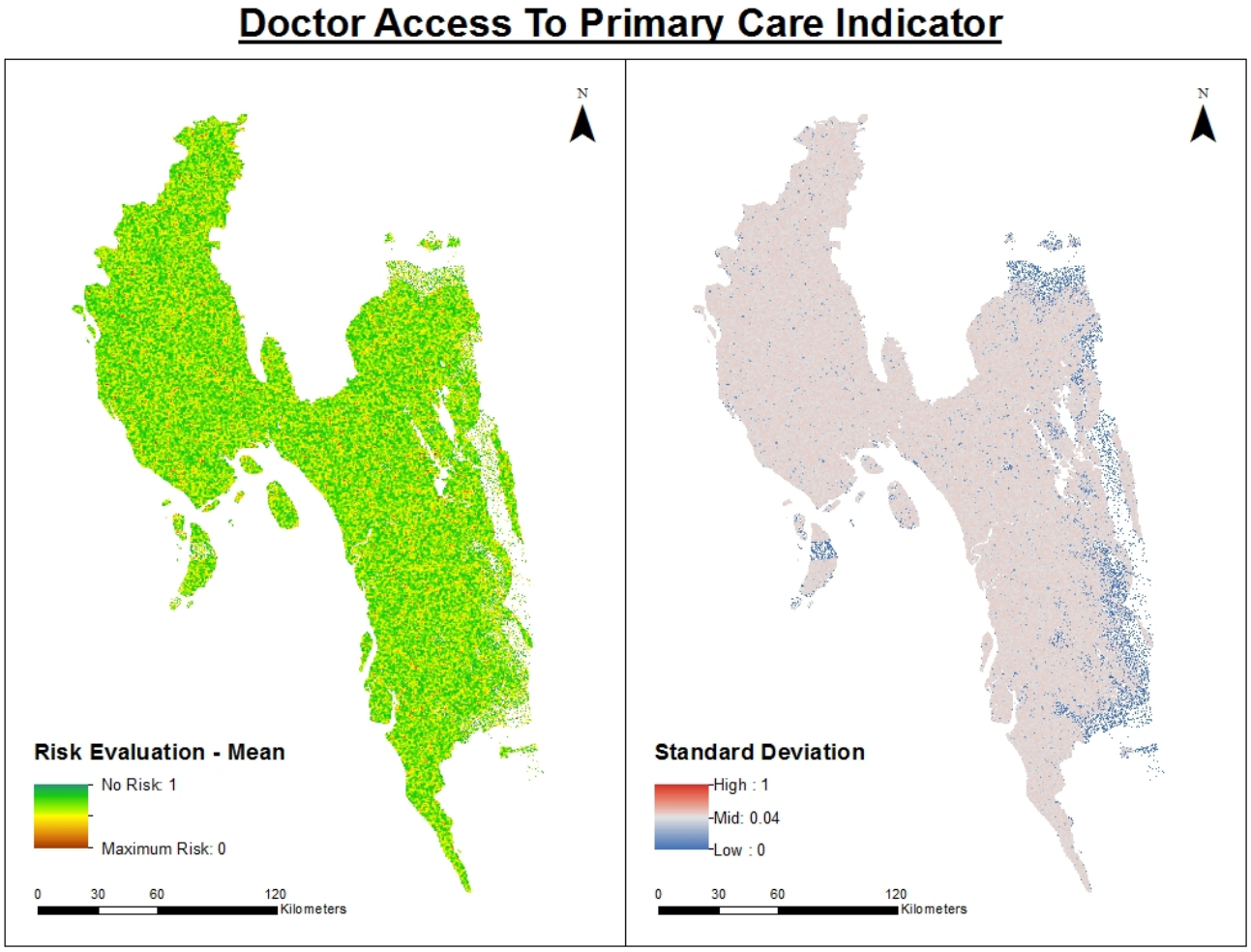
Metric	Weight Minimum Value	Weight Maximum Value
Does woman need permission to get medical care?	0.1	0.4
Perceived distance to healthcare	0.3	0.6
Issue getting money for treatment?	0.2	0.5
Know where to get treatment?	0.1	0.4
Concern for lack of provider	0.1	0.4
Who makes healthcare decisions?	0.1	0.4
Covered by health insurance?	0.2	0.5

Uncertainty values

Adding more data on large infrastructure failures or structural issues at the marco-level (i.e. road conditions) could decrease the uncertainty values as this could increase or decrease ease of access to healthcare.

Indicator Uncertainty Min:	0.4
Indicator Uncertainty Max:	0.6

Example outcome



Metric: Getting Permission to Get Medical Care

Indicator:	Doctor & Access to Primary Care
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	Big Problem (min: 0.125, max: 0.5) Not a big problem (min: 0.5, max: 0.9) No problem (min: 1.0, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Harris et al. (2008)

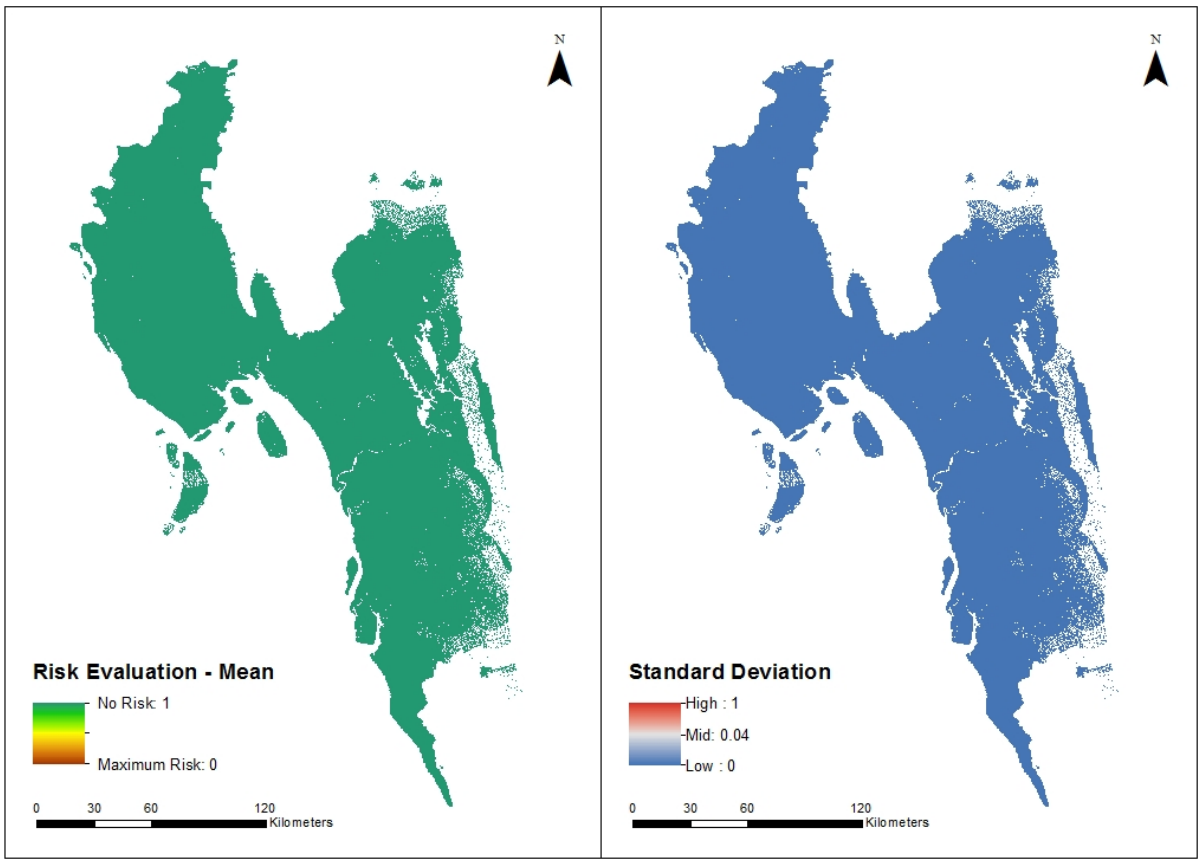
Logic:

This metric consists of answers to the question on how difficult it is for a woman to get permission to get medical care from the women's portion of the DHS survey.

Harris et al. (2008) stated that "Our data from the 2007 floods show that *V. cholerae* 01 is still the most commonly identified pathogen causing diarrhea requiring hospitalization during flood-related diarrheal epidemics in Dhaka, Bangladesh… Another major observation from this study was that the severity of dehydration in hospitalized patients has been increasing over the last decade… However, it can be argued that awareness of treatment of diarrhea with oral rehydration therapy or antibiotics is widespread in Bangladesh so that only those with severe life-threatening disease now seek care at health facilities." Thus access to medical care is important in fighting off cholera

Answers of "Big Problem" were given a minimum value of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "Not a big problem" were given a minimum value of 0.5 and a maximum value of 0.9 (minimal risk). Answers of "No problem" were given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from high risk to no risk.

Example realization metric map



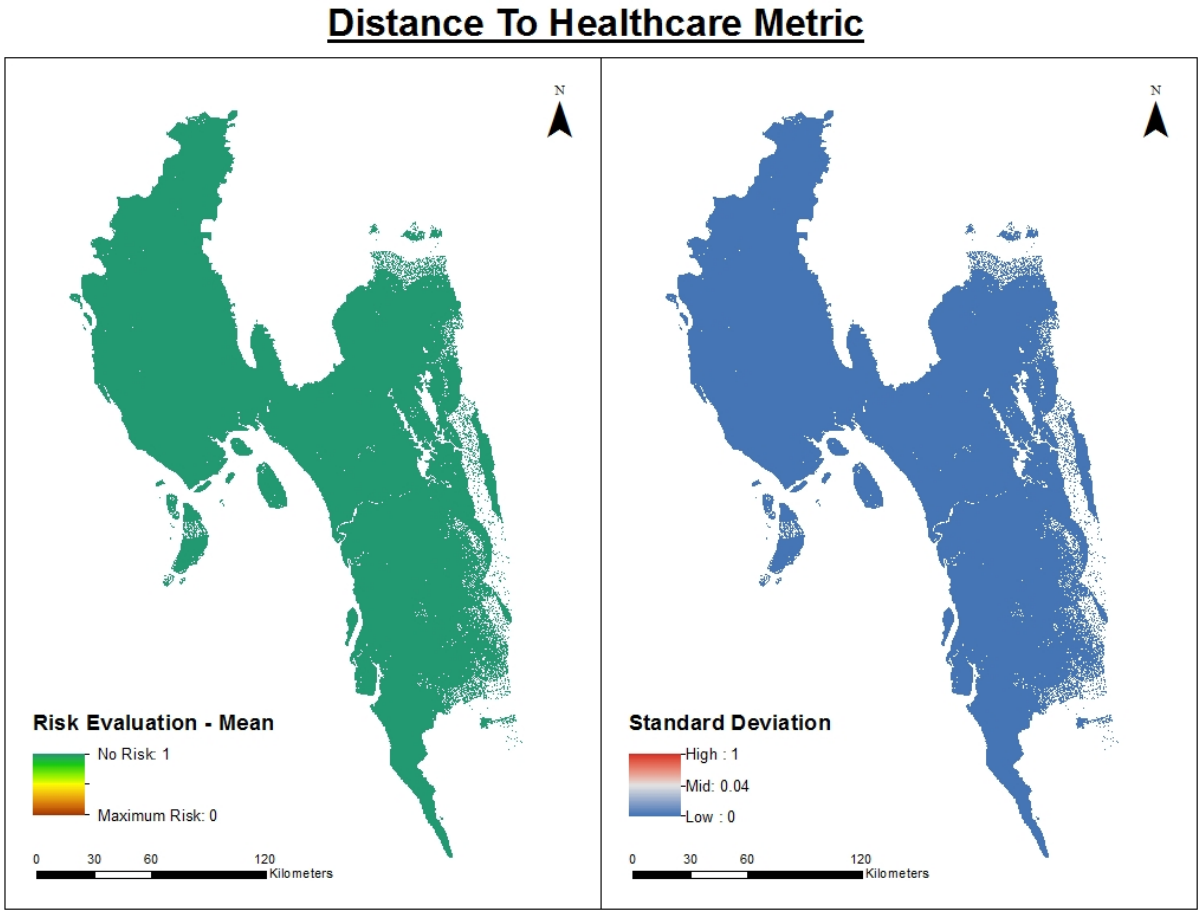
References

Harris, A. M., Chowdhury, F., Begum, Y. A., Khan, A. I., Faruque, A. S., Svennerholm, A. M., & Qadri, F. 2008. Shifting prevalence of major diarrheal pathogens in patients seeking hospital care during floods in 1998, 2004, and 2007 in Dhaka, Bangladesh. *The American journal of tropical medicine and hygiene*, *79*(5), 708-714.

Metric: Perceived Distance to Healthcare

Indicator:	Doctor & Access to Primary Care
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	Big Problem (min: 0.125, max: 0.5) Not a big problem (min: 0.5, max: 0.9) No problem (min: 1.0, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 1); Haque et al. (2013)
Logic:	This metric consists of answers to the question on how difficult it is for a woman to access medical care based on distance from the women's portion of the DHS survey. Haque et al. (2013) state that "The close proximity of the affected areas to hospitals and the majority of the case-patients seeking health care from hospital practitioners likely facilitated prompt and appropriate management. This assisted the recovery of cholera affected patients and resulted in no associated mortality." Thus while this metric may not play a role in risk of contracting cholera, it plays a key role in the prevention of cholera caused mortality. This is why the metric is weighted moderately. Interestingly, Ali et al. (2002, 1) stated that, "Educational level is hypothesized to be an indicator of mortality because it indirectly determines healthcare seeking behavior." If future studies consider actual access to healthcare, improvements in predicting the ability to recover from cholera may be seen. Answers of "Big Problem" were given a minimum value of 0.125 (high risk, $½^3$) and a maximum value of 0.5 (slight risk, $½^1$). Answers of "Not a big problem" were given a minimum value of 0.5 and a maximum value of 0.9 (minimal risk). Answers of "No problem" were given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Maps will range from high risk to no risk.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 1). The spatial epidemiology of cholera in an endemic area of Bangladesh. *Social science & medicine*, *55*(6), 1015-1024.

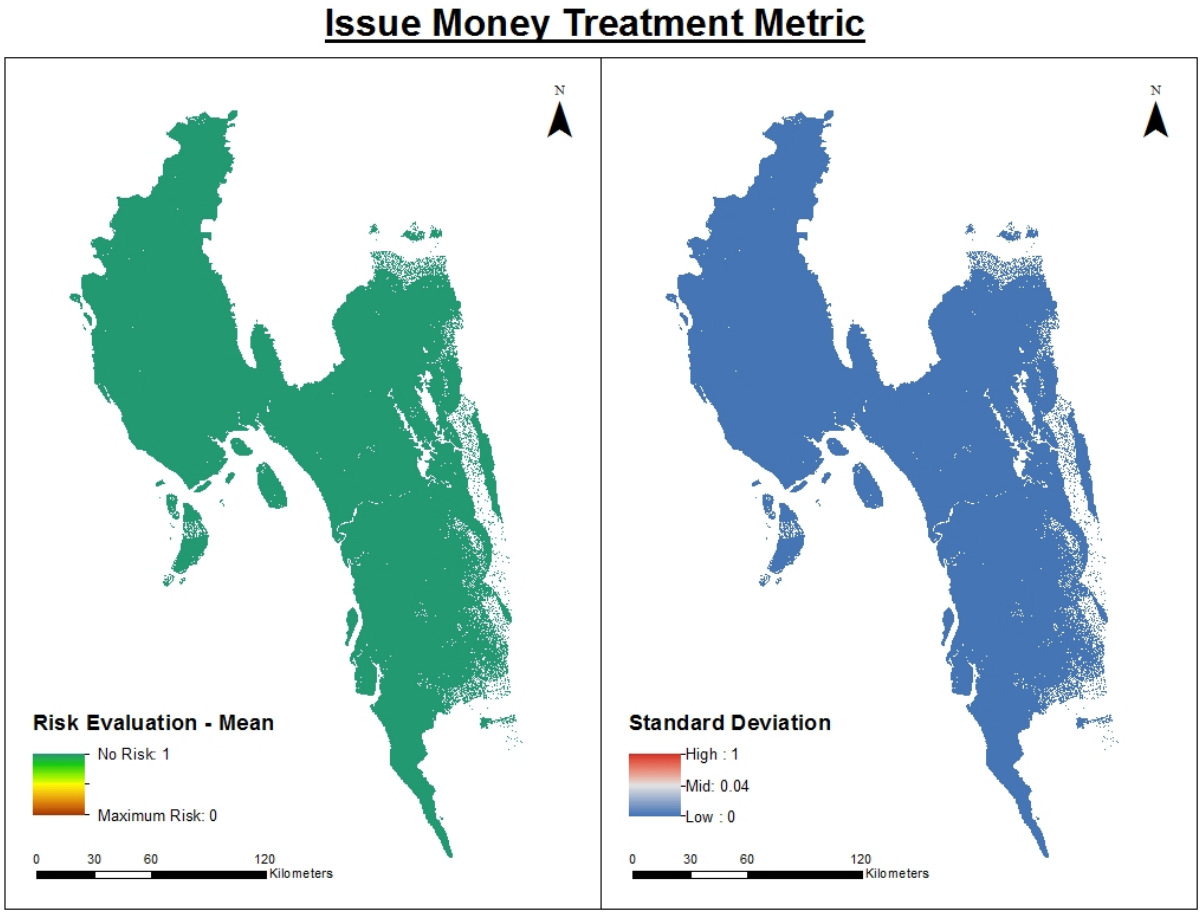
Haque, F., Hossain, M. J., Kundu, S. K., Naser, A. M., Rahman, M., & Luby, S. P. 2013. Cholera outbreaks in urban Bangladesh in 2011. *Epidemiology (Sunnyvale, Calif.)*, *3*.

Metric: Perceived Issue Getting Money for Healthcare

Indicator:	Doctor & Access to Primary Care
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera

Metric Assigned Values:	Big Problem (min: 0.125, max: 0.5) Not a big problem (min: 0.5, max: 0.9) No problem (min: 1.0, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 1); Chen, Huq, & d'Souza (1981); Stanton & Clemens (1989)
Logic:	This metric consists of answers to the question on how difficult it is for a woman to get money to access medical care from the women's portion of the DHS survey. Stanton & Clemens (1989) state "We note evidence that the existing government health care system appears already to be providing care to two of the most medically vulnerable groups in Bangladesh, the poor and women, and provide evidence that such fees may seriously interfere with maintaining this patient profile." Thus getting money for treatment can play a big role in potentially recovering from cholera. Chen, Huq, & d'Souza (1981) found that male children are 66% more likely to receive diarrheal treatment than female children in 5-14 year olds. Interestingly, Ali et al. (2002, 1) stated that, "Educational level is hypothesized to be an indicator of mortality because it indirectly determines healthcare seeking behavior." If future studies consider actual access to healthcare, improvements in predicting the ability to recover from cholera may be seen. Answers of "Big Problem" were given a minimum value of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "Not a big problem" were given a minimum value of 0.5 and a maximum value of 0.9 (minimal risk). Answers of "No problem" were given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from high risk to no risk.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 1). The spatial epidemiology of cholera in an endemic area of Bangladesh. *Social science & medicine*, *55*(6), 1015-1024.

Chen, L. C., Huq, E., & d'Souza, S. 1981. Sex bias in the family allocation of food and health care in rural Bangladesh. *Population and development review*, 55-70.

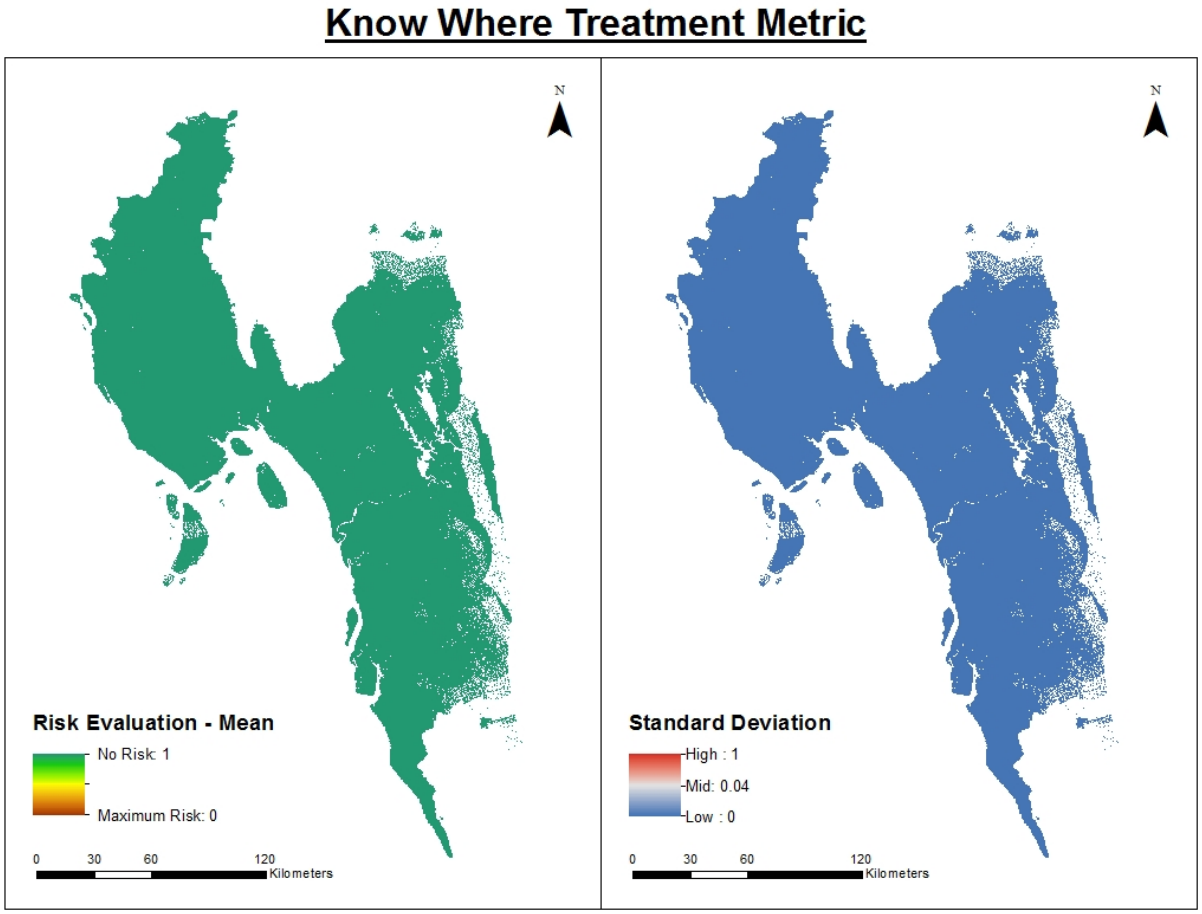
Stanton, B., & Clemens, J. 1989. User fees for health care in developing countries: a case study of Bangladesh. *Social science & medicine*, *29*(10), 1199-1205.

Metric: Problem of knowing where to get Healthcare

Indicator:	Doctor & Access to Primary Care
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera

Metric Assigned Values:	Big Problem (min: 0.125, max: 0.5) Not a big problem (min: 0.5, max: 0.9) No problem (min: 1.0, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 1); Harris et al. (2008)
Logic:	This metric consists of answers to the question on how difficult it is for a woman to get access to medical care based on their knowledge from the women's portion of the DHS survey. Harris et al. (2008) stated that "Our data from the 2007 floods show that *V. cholerae* 01 is still the most commonly identified pathogen causing diarrhea requiring hospitalization during flood-related diarrheal epidemics in Dhaka, Bangladesh… Another major observation from this study was that the severity of dehydration in hospitalized patients has been increasing over the last decade… However, it can be argued that awareness of treatment of diarrhea with oral rehydration therapy or antibiotics is widespread in Bangladesh so that only those with severe life-threatening disease now seek care at health facilities." Thus knowing where to access to medical care is important in fighting off cholera. Interestingly, Ali et al. (2002, 1) stated that, "Educational level is hypothesized to be an indicator of mortality because it indirectly determines healthcare seeking behavior." If future studies consider actual access to healthcare, improvements in predicting the ability to recover from cholera may be seen. Answers of "Big Problem" were given a minimum value of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "Not a big problem" were given a minimum value of 0.5 and a maximum value of 0.9 (minimal risk). Answers of "No problem" were given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from high risk to no risk.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 1). The spatial epidemiology of cholera in an endemic area of Bangladesh. *Social science & medicine*, *55*(6), 1015-1024.

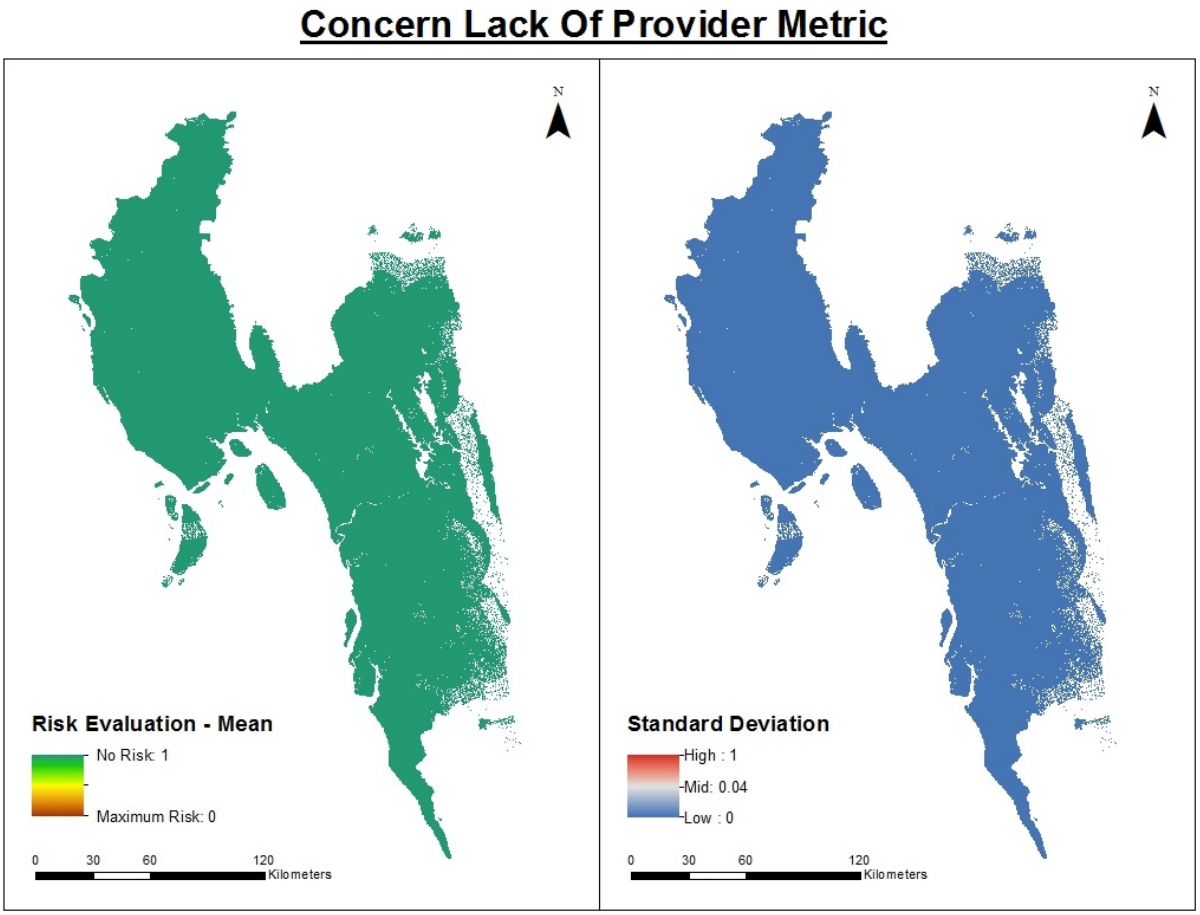
Harris, A. M., Chowdhury, F., Begum, Y. A., Khan, A. I., Faruque, A. S., Svennerholm, A. M., & Qadri, F. 2008. Shifting prevalence of major diarrheal pathogens in patients seeking hospital care during floods in 1998, 2004, and 2007 in Dhaka, Bangladesh. *The American journal of tropical medicine and hygiene*, *79*(5), 708-714.

Metric: Perceived concern of an available healthcare provider

Indicator:	Doctor & Access to Primary Care
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera

Metric Assigned Values:	Big Problem (min: 0.125, max: 0.5) Not a big problem (min: 0.5, max: 0.9) No problem (min: 1.0, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 1); Harris et al. (2008)
Logic:	This metric consists of answers to the question on women's perception of the availability of healthcare from the DHS survey. Siddique et al (1992) found during the 1991 diarrhea epidemic, only 23% of patients had access to treatment by qualified physicians. Harris et al. (2008) stated that "Our data from the 2007 floods show that *V. cholerae* 01 is still the most commonly identified pathogen causing diarrhea requiring hospitalization during flood-related diarrheal epidemics in Dhaka, Bangladesh… Another major observation from this study was that the severity of dehydration in hospitalized patients has been increasing over the last decade… However, it can be argued that awareness of treatment of diarrhea with oral rehydration therapy or antibiotics is widespread in Bangladesh so that only those with severe life-threatening disease now seek care at health facilities." Thus access to medical care is important in fighting off cholera. Interestingly, Ali et al. (2002, 1) stated that, "Educational level is hypothesized to be an indicator of mortality because it indirectly determines healthcare seeking behavior." If future studies consider actual access to healthcare, improvements in predicting the ability to recover from cholera may be seen. Answers of "Big Problem" were given a minimum value of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "Not a big problem" were given a minimum value of 0.5 and a maximum value of 0.9 (minimal risk). Answers of "No problem" were given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Maps will range from high risk to no risk.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 1). The spatial epidemiology of cholera in an endemic area of Bangladesh. *Social science & medicine*, *55*(6), 1015-1024.

Harris, A. M., Chowdhury, F., Begum, Y. A., Khan, A. I., Faruque, A. S., Svennerholm, A. M., & Qadri, F. 2008. Shifting prevalence of major diarrheal pathogens in patients seeking hospital care during floods in 1998, 2004, and 2007 in Dhaka, Bangladesh. *The American journal of tropical medicine and hygiene*, *79*(5), 708-714.

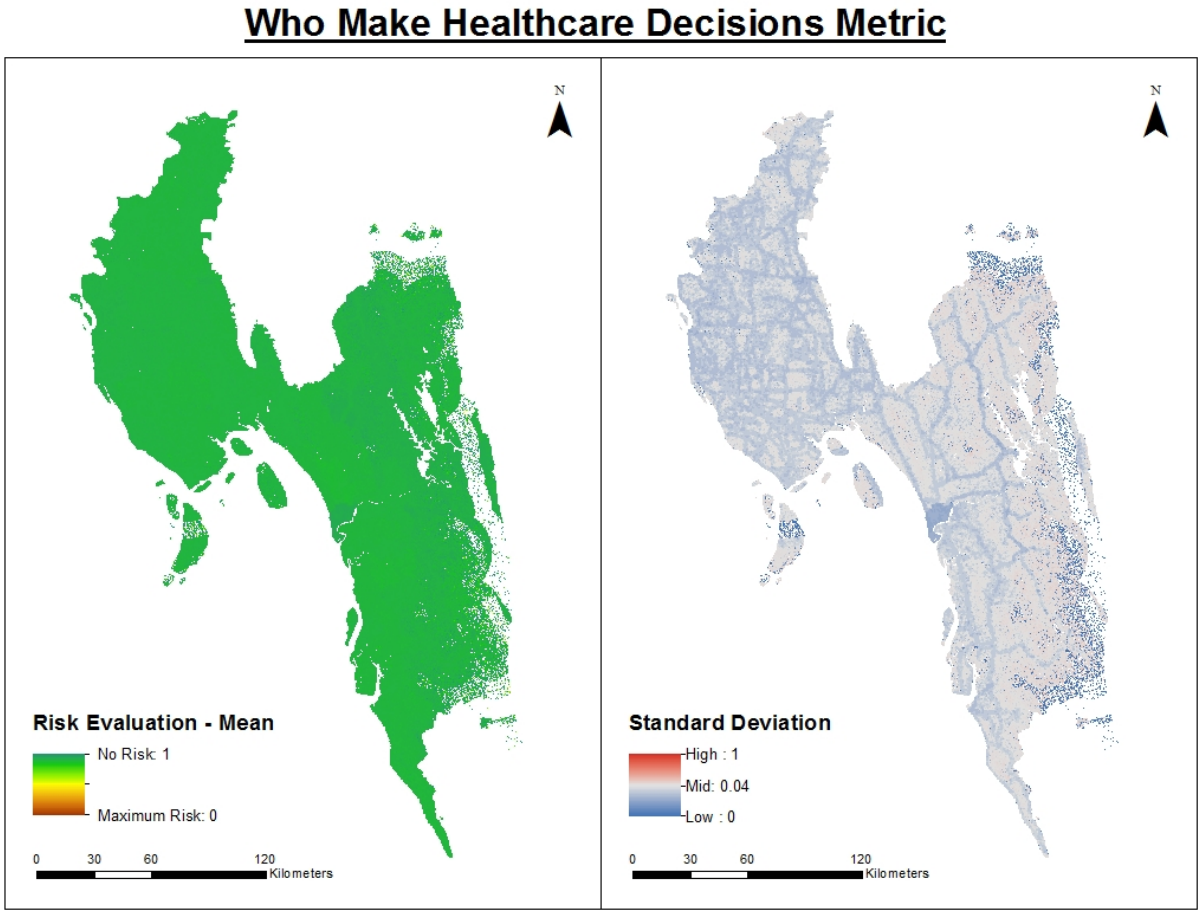
Siddique, A. K., Zaman, K., Baqui, A. H., Akram, K., Mutsuddy, P., Eusof, A., & Sack, R. B. 1992. Cholera epidemics in Bangladesh: 1985-1991.*Journal of diarrhoeal diseases research*, 79-86.

Metric: Who makes decisions regarding healthcare

Indicator: Doctor & Access to Primary Care

Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	1RespondentAlone (min: 1.0, max: 1.0) 2RespondentAndSpousePartner (min: 1.0, max: 1.0) 3RespondentAndOther (min: 0.5, max: 1.0) 4SpousePartnerAlone (min: 0.5, max: 0.8) 5SomeoneElse (min: 0.125, max: 0.7)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	USAID (2016)
Logic:	This metric consists of answers to the question of who makes decision about healthcare from the women's portion of the DHS survey. The DHS stat compiler for the 2011 survey reported that 63% of married women indicated that they have the final say in own health care – the combination of mainly wife and wife and husband jointly. 30.6% of health care decisions are made by husbands only. Answers of "1RespondentAlone" and "2RespondentandSpousePartner" were given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "3RespondentAndOther" were given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0. Answers of "4SpousePartnerAlone" were given a minimum value of 0.5 and a maximum value of 0.8 (minimal risk). Answers of "5SomeoneElse" are given a minimum value of 0.125 and a maximum value of 0.7 (minimal risk). Maps will range from high risk to no risk.

Example realization metric map



References

USAID 2016. StatCompiler – The DHS Program. http://statcompiler.com/en/.

Metric: Health insurance coverage?

Indicator:	Doctor & Access to Primary Care
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.125, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 1)

Logic:

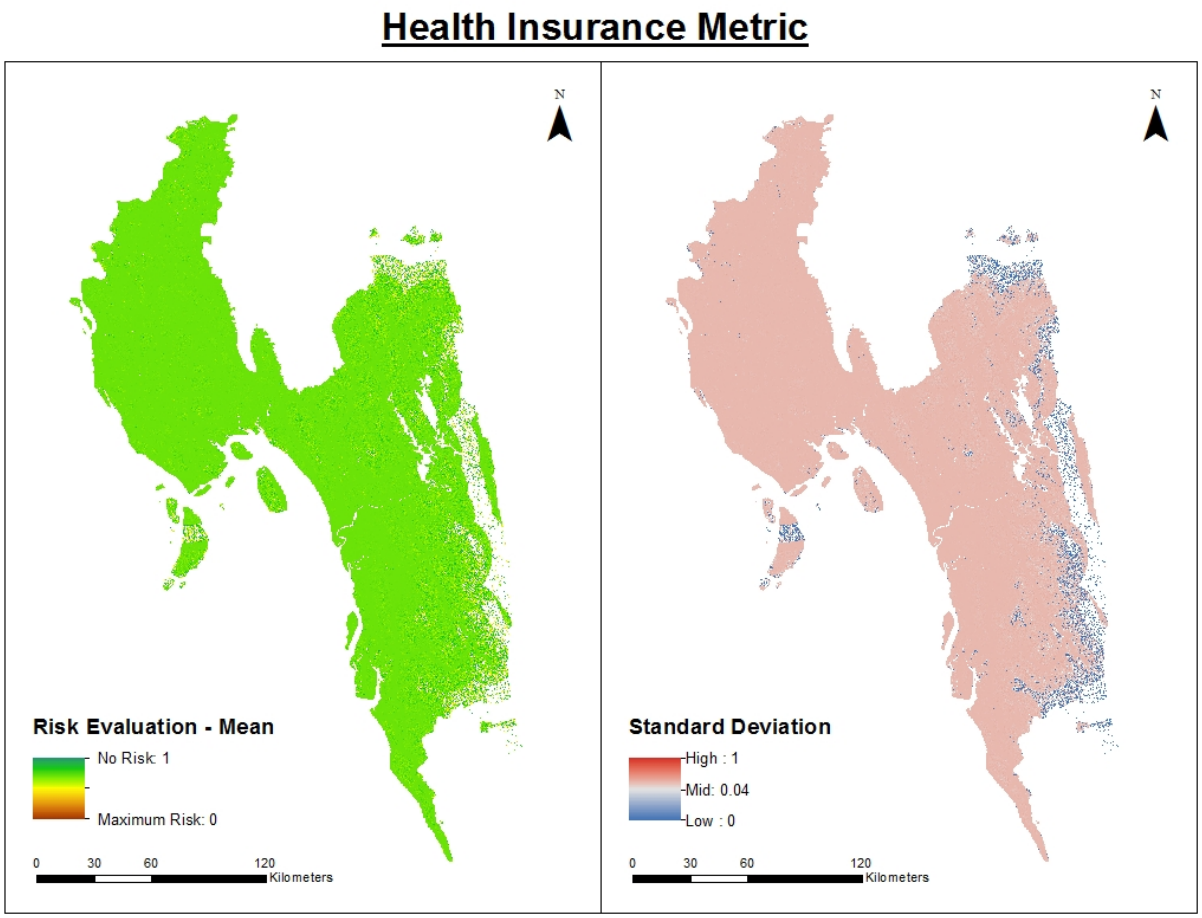
This metric consists of answers to the question of whether or not the respondent is covered by health insurance from the DHS survey.

Few papers discuss the availability of insurance coverage in Bangladesh.

Interestingly, Ali et al. (2002, 1) stated that, "Educational level is hypothesized to be an indicator of mortality because it indirectly determines healthcare seeking behavior." If future studies consider actual access to healthcare, improvements in predicting the ability to recover from cholera may be seen.

Answers of "No" were given a minimum value of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "Yes" were given both a minimum and a maximum value of 1.0.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 1). The spatial epidemiology of cholera in an endemic area of Bangladesh. *Social science & medicine*, *55*(6), 1015-1024.

Siddique, A. K., Zaman, K., Baqui, A. H., Akram, K., Mutsuddy, P., Eusof, A., & Sack, R. B. 1992. Cholera epidemics in Bangladesh: 1985-1991.*Journal of diarrhoeal diseases research*, 79-86.

A.4.1.2 Indicator: Hospitals/clinics and secondary care

This indicator predicts ease of access to healthcare, specifically secondary care related to diarrheal treatment. The survey questions used to predict this are all taken from the DHS Woman's Survey. This indicator reflects the ability of the framework to recover from a cholera outbreak. For those who purely wish to predict cholera outbreak, this indicator can be removed.

Metric weighting logic

As each of these metrics contributes to an understanding of the indicator, they are equally constraining and are all weighted equally.

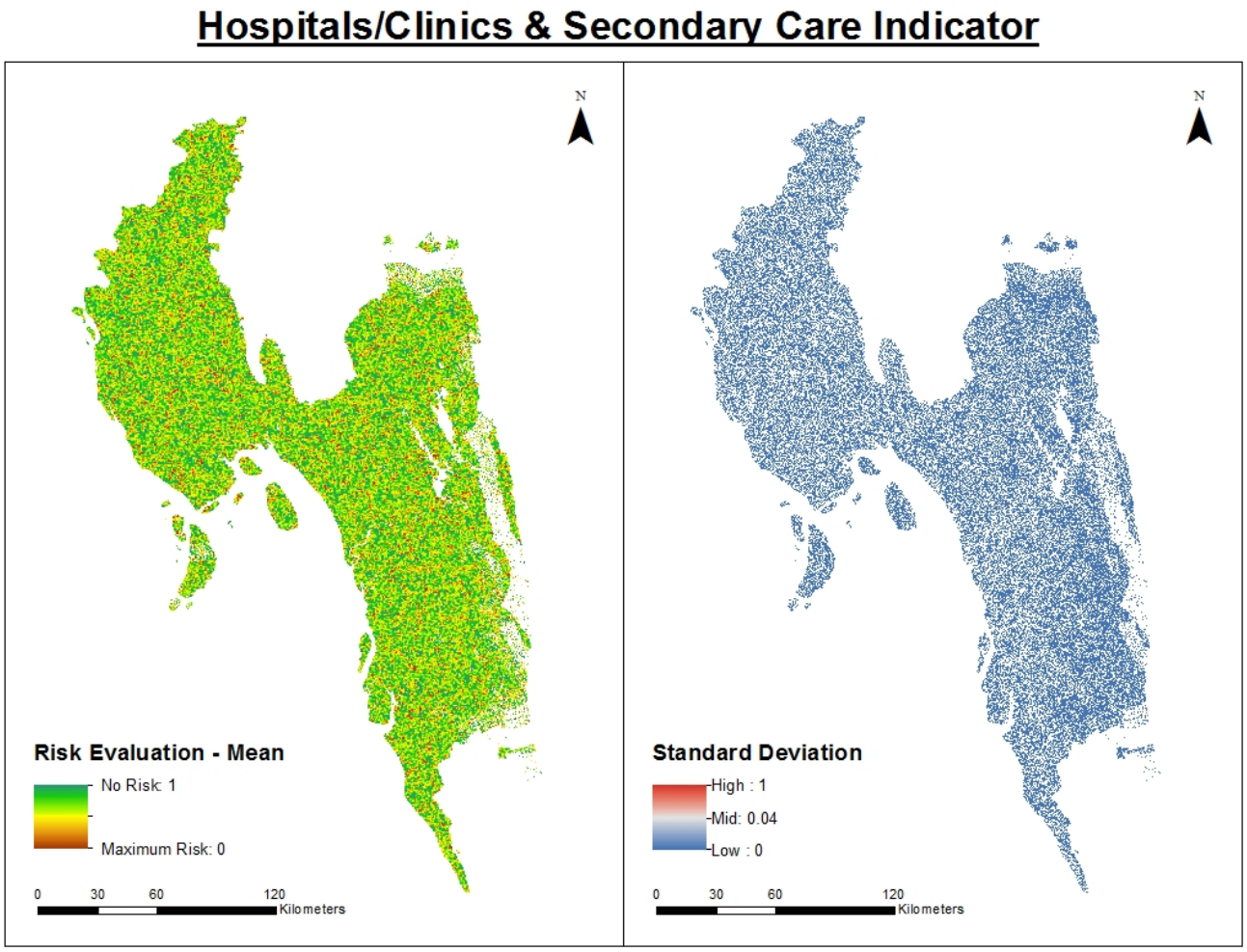
Metric	Weight Minimum Value	Weight Maximum Value
First Source Medical Care Diarrhea	0.4	0.6
Diarrhea Treatment Location	0.4	0.6
Where did you first seek care for diarrhea?	0.4	0.6

Uncertainty values

Adding more data on availability and accessibility of non-general physicians, clinics, hospitals would decrease the uncertainty levels.

Indicator Uncertainty Min:	0.5
Indicator Uncertainty Max:	0.6

Example outcome



Metric: First Source Medical Care Diarrhea

Indicator:	Hospitals/Clinic and Secondary Care
Factor:	Health and Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	Public Sector (min: 0.5, max: 1.0) Private Medical Sector (min: 0.5, max: 1.0) Other (min: 0.4, max: 0.9)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	

Logic:

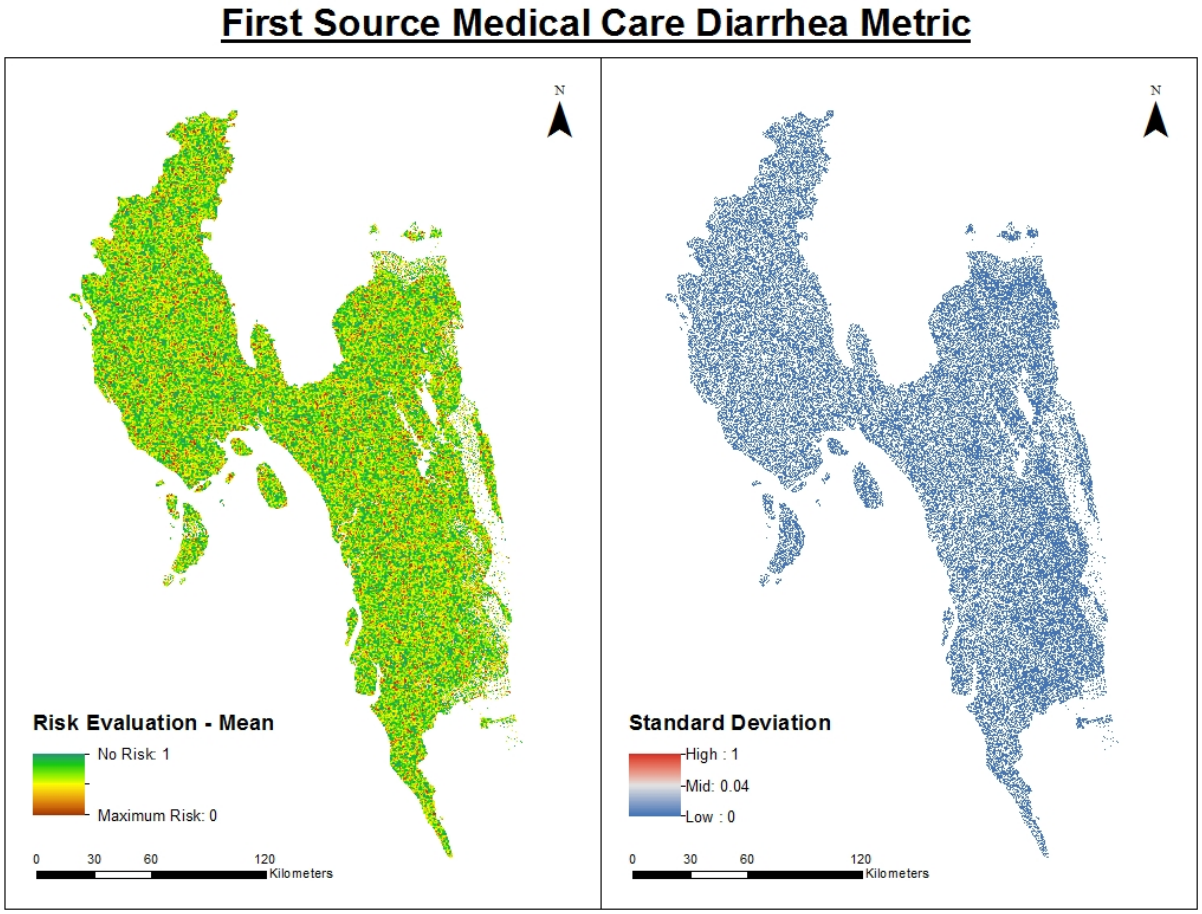
This metric consists of answers to the question “Where do you first seek medical advice or treatment?” concerning cases of diarrhea in children from the DHS survey.

Answers of “Public Sector” and “Private Medical Sector” are given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of “Other” are given a minimum value of 0.4 (slight risk) and a maximum value of 0.9 (minimal risk). Maps will range from slight risk to no risk.

Assigned metric values would be better informed with rankings of geographically proximate medical facilities, rather than the existing micro-survey categorizations of medical facilities by ownership and management. In this way, the map would be represent the quality of specific facilities.

It should be noted that, as this version of the framework was constructed as a proof of research concept, only the results pertaining to the first child for whom answers were provided were used to create this metric. For questions under section 2 (Reproduction) of the women’s portion of the DHS Bangladesh survey, answers were allowed for up to 12 children. Results from these questions will only contain answers for the eldest child. For questions under Sections 4 (Pregnancy and Postnatal Care) and 5 (Child Immunization, Health, and Nutrition), answers were allowed for children from the last birth, the next-to-last birth, and the second next-to-last birth (i.e. the youngest three children of the female respondent). Results from these questions will only contain answers for the youngest child.

Example realization metric map



Metric: Diarrhea Treatment Location

Indicator:	Hospitals/Clinic and Secondary Care
Factor:	Health and Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	Government Hospital (min: 0.5, max: 1.0) Private Hospital (min: 0.5, max: 1.0) Private Pharmacy (min: 0.5, max: 1.0) Private Doctor (min: 0.5, max: 1.0) Other (min: 0.125, max: 1.0) Not Sought (min: 0.0625, max: 0.5)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	

Logic:

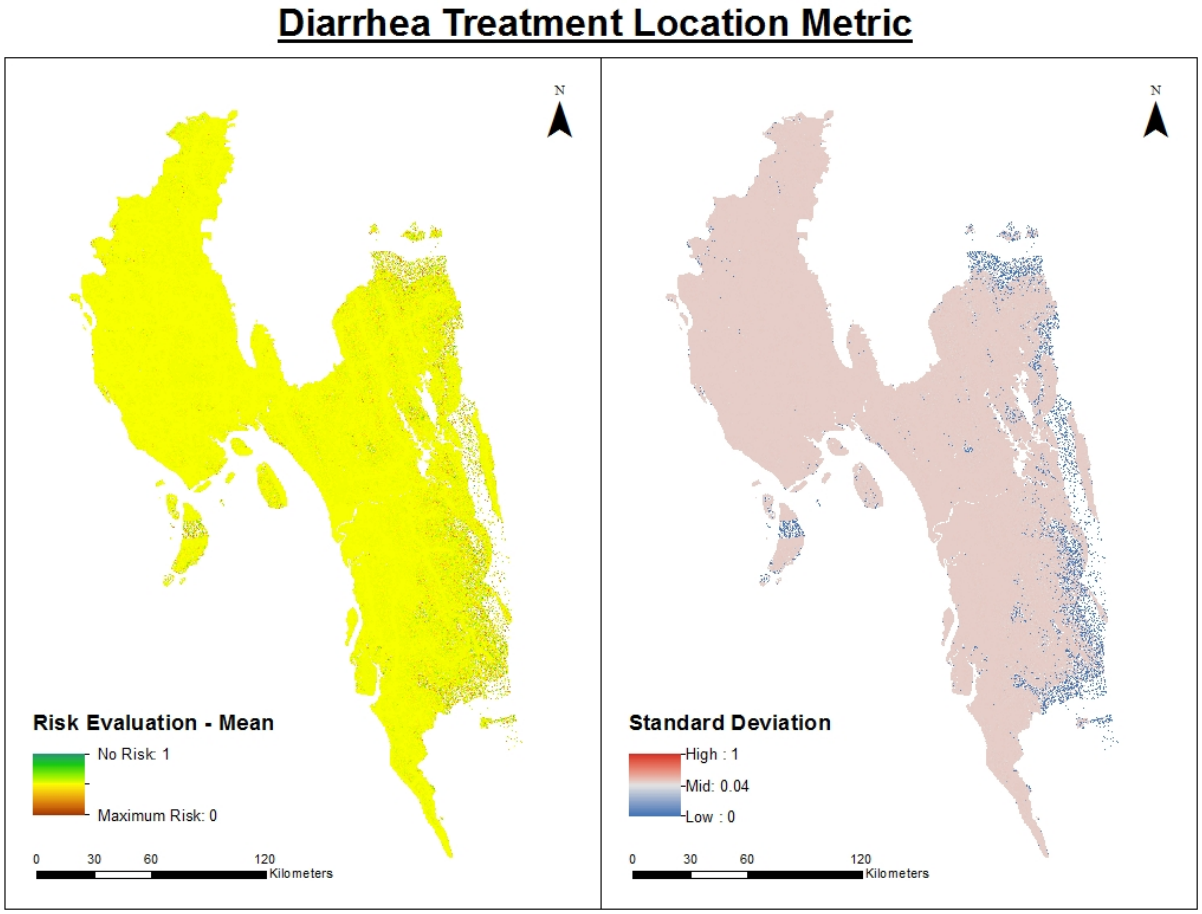
This metric consists of answers to the question "Where was diarrhea treated?" concerning cases of diarrhea in children from the DHS survey.

Answers of "Government Hospital," "Private Hospital," "Private Pharmacy," and "Private Doctor" are given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "Other" were given a minimum value of 0.125 (high risk, $½^3$) and a maximum value of 1.0. Answers of "Not Sought" were given a minimum value 0.0625 (extreme risk, $½^4$) and a maximum value of 0.5. Maps will range from high risk to no risk.

Assigned metric values would be better informed with rankings of geographically proximate medical facilities, rather than the existing micro-survey categorizations of medical facilities by ownership and management. In this way, the map would be represent the quality of specific facilities.

It should be noted that, as this version of the framework was constructed as a proof of research concept, only the results pertaining to the first child for whom answers were provided were used to create this metric. For questions under section 2 (Reproduction) of the women's portion of the DHS Bangladesh survey, answers were allowed for up to 12 children. Results from these questions will only contain answers for the eldest child. For questions under Sections 4 (Pregnancy and Postnatal Care) and 5 (Child Immunization, Health, and Nutrition), answers were allowed for children from the last birth, the next-to-last birth, and the second next-to-last birth (i.e. the youngest three children of the female respondent). Results from these questions will only contain answers for the youngest child.

Example realization metric map



Metric: Where did you first seek care for diarrhea?

Indicator:	Hospitals/Clinic and Secondary Care
Factor:	Health and Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	10AllPublicSector (min: 0.5, max: 1.0) 11GovernmentHospital (min: 0.5, max: 1.0) 12CSPublic (min: 0.5, max: 1.0) 20AllPrivateSector (min: 0.5, max: 1.0) 21PrivateHospitalClinic (min: 0.5, max: 1.0) 22Pharmacy (min: 0.5, max: 1.0) 23PrivateDoctor (min: 0.5, max: 1.0) 24CSPrivate (min: 0.5, max: 1.0) 30AllOther (min: 0.125, max: 0.9) 31CSOther (min: 0.125, max: 0.9)

960ther (min: 0.125, max: 0.9)

Survey: DHS - Women

Survey Date: 2011

Other Data Sources:

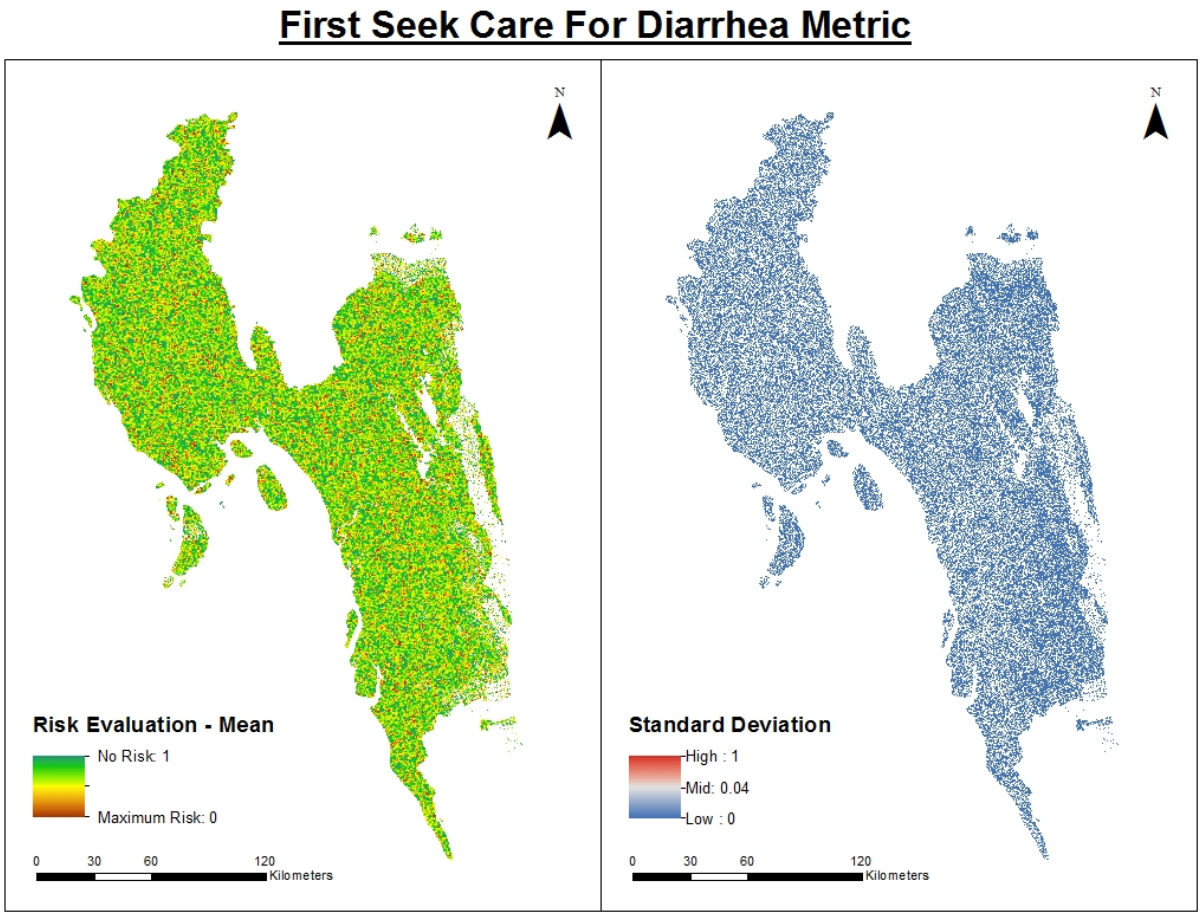
Logic: This metric consists of answers to the question "Place first sought treatment for diarrhea" concerning cases of diarrhea in children from the DHS survey.

Answers of "10AllPublicSector," "11GovernmentHospital," "12CSPublic," "20AllPrivateSector," "21PrivateHospitalClinic," "22Pharmacy," "23PrivateDoctor," and "24CSPrivate" are given a minimum value of 0.5 (slight risk, $\frac{1}{2}^1$) and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "30AllOther," "31CSOther," and "96Other" were given a minimum value of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.9 (minimal risk). Maps will range from high risk to no risk.

Assigned metric values would be better informed with rankings of geographically proximate medical facilities, rather than the existing micro-survey categorizations of medical facilities by ownership and management. In this way, the map would be represent the quality of specific facilities.

It should be noted that, as this version of the framework was constructed as a proof of research concept, only the results pertaining to the first child for whom answers were provided were used to create this metric. For questions under section 2 (Reproduction) of the women's portion of the DHS Bangladesh survey, answers were allowed for up to 12 children. Results from these questions will only contain answers for the eldest child. For questions under Sections 4 (Pregnancy and Postnatal Care) and 5 (Child Immunization, Health, and Nutrition), answers were allowed for children from the last birth, the next-to-last birth, and the second next-to-last birth (i.e. the youngest three children of the female respondent). Results from these questions will only contain answers for the youngest child.

Example realization metric map



A.4.1.3 Indicator: Household health practices

The HC framework does not include this explicitly as an indicator, but this framework aims to anticipate cholera outbreaks. As household health practices play a key role in areas that are prone to cholera outbreaks, the authors felt it necessary to include it as its own indicator.

Metric weighting logic

The metrics within the "Household Health Practices" are focused primarily on hand washing and partially on food preparation. The metrics "Water Available at Handwashing Place" and "Cleaning Agent Available at Handwashing Place" are weighted more heavily as there is more support in the literature that water and soap decrease cholera risk. For example, hand washing with soap has been found to play a protective role in cholera prevention (Sasaki et al., 2008).

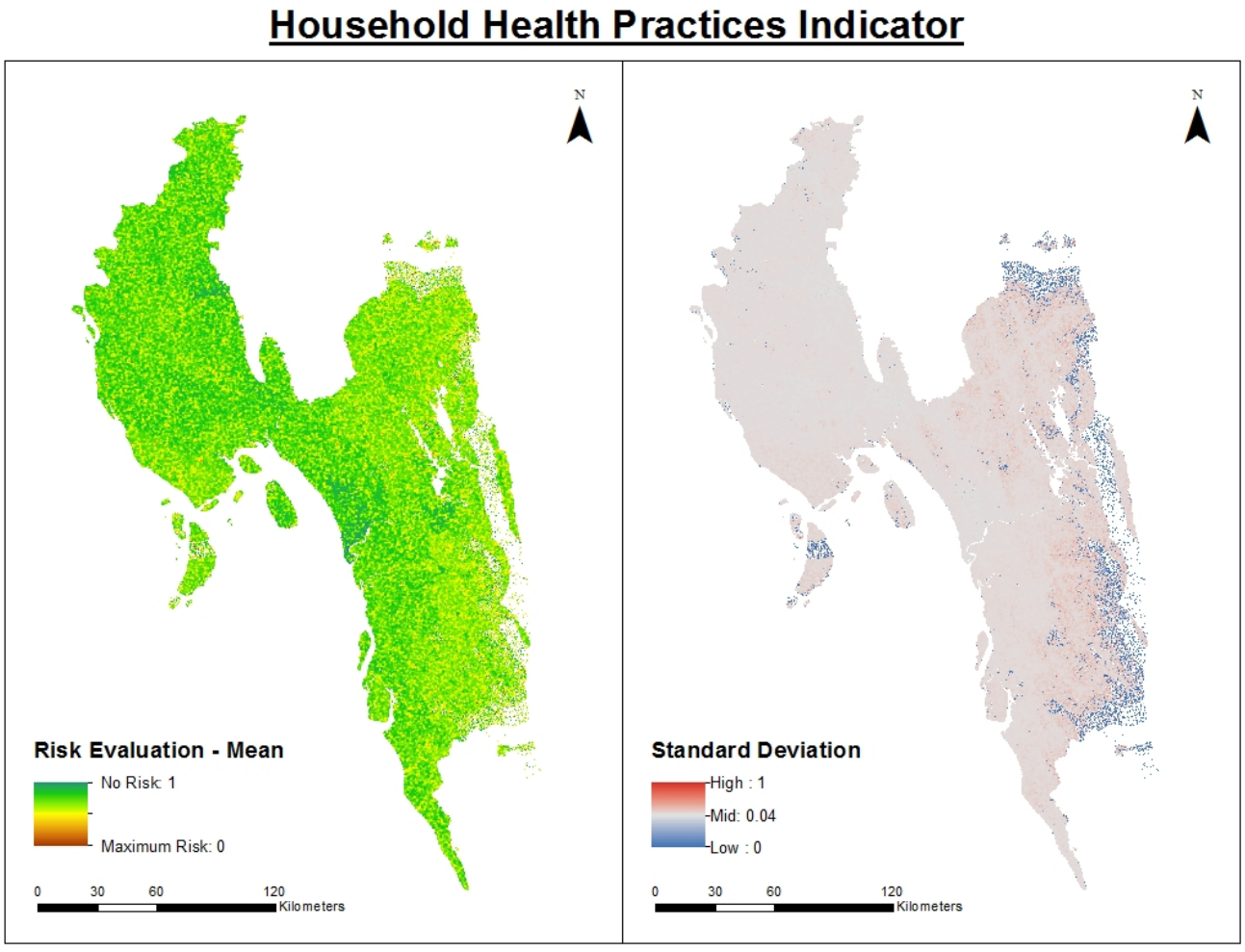
Metric	Weight Minimum Value	Weight Maximum Value
If Surveyor Observed Handwashing Place	0.2	0.5
Water Available at Handwashing Place	0.3	0.6
Cleaning Agent Available at Handwashing Place	0.3	0.6
Location Where Food Is Cooked	0.2	0.5

Uncertainty values

Adding more data and supporting literature regarding household practices and preventing diarrheal disease could decrease the uncertainty values.

Indicator Uncertainty Min:	0.2
Indicator Uncertainty Max:	0.4

Example outcome



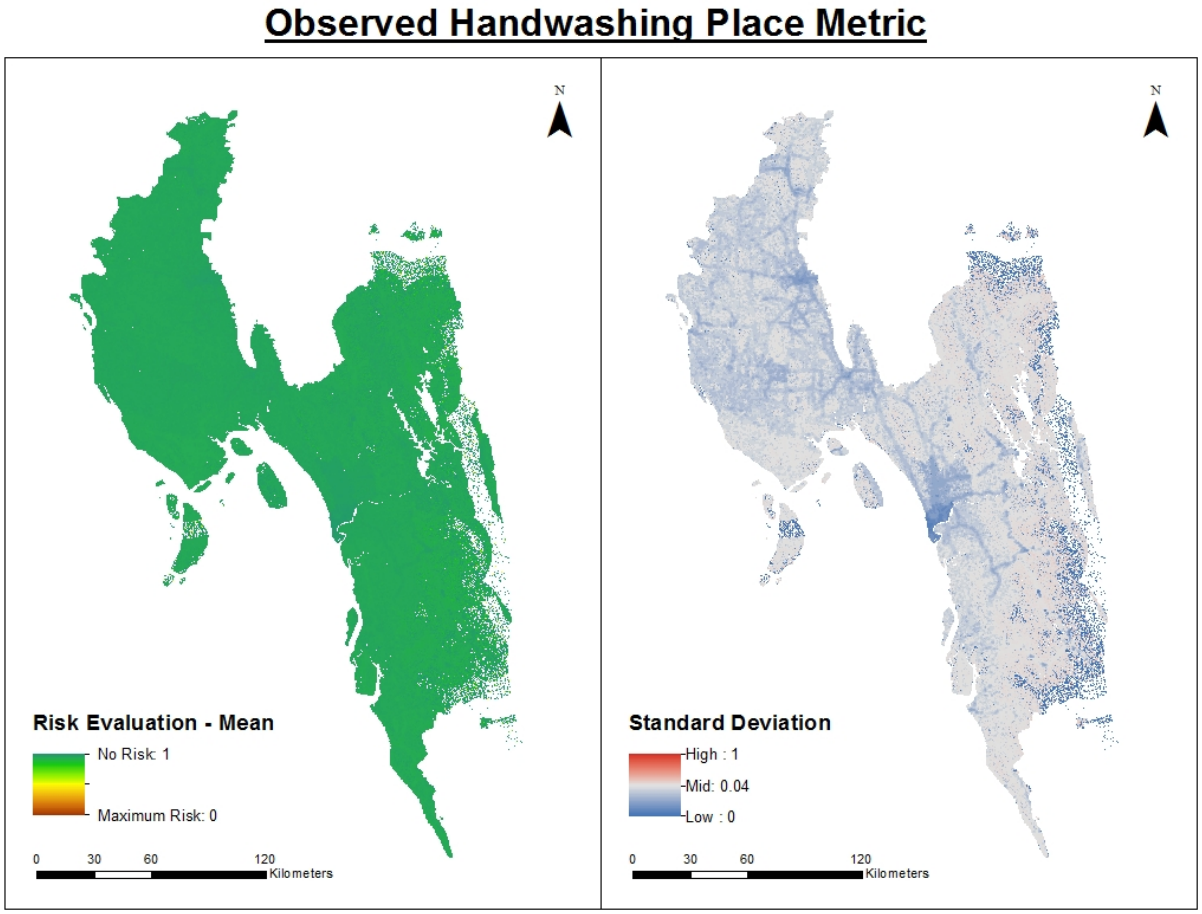
References

Sasaki, S., Suzuki, H., Igarashi, K., Tambatamba, B., & Mulenga, P. 2008. Spatial analysis of risk factor of cholera outbreak for 2003–2004 in a peri-urban area of Lusaka, Zambia. *The American journal of tropical medicine and hygiene*, *79*(3), 414-421.

Metric: If Surveyor Observed Handwashing Place

Indicator:	Household Health Practices
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	Observed (min: 1.0, max: 1.0) Unobserved (min: 0.0625, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Curtis, Cairncross, & Yonli (2000); Luby et al. (2011); Rabbi & Dey (2013); Sasaki et al. (2008); USAID (2016)
Logic:	This metric consists of observations by the surveyor on whether or not a place for washing hands in the household was observed. The DHS stat compiler for the 2011 Bangladesh survey breaks down households that surveyor observes handwashing place by rural/urban residence and wealth quintile. Households with observed handwashing place 86%. 92.8% of urban households and 83.7% of rural households with observed handwashing place in 2011. Across wealth: 76.2%, 81.5%, 85.3%, 90.8%, & 97.8% of households with observed handwashing place in 2011. Curtis, Cairncross, & Yonli (2000) recommend that "hygiene promotion programmes should give priority to the safe disposal of faecal material and the adequate washing of hands after contact with adult and child stools." Luby et al. (2011) found "that handwashing before preparing food is a particularly important opportunity to prevent childhood diarrhea, and that handwashing with water alone can significantly reduce childhood diarrhea." Rabbi & Dey (2013) conduct a study to evaluate the effectiveness of a sanitation and hygiene program in Bangladesh. The baseline returned 8% washed their hands with soap. At the conclusion of the program, 22% reported washing their hands with soap 5 years later. Sasaki et al. (2008) found that hand washing with soap plays a protective role in cholera prevention. Answers of "Observed" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "Unobserved" were given a minimum value 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map



References

Curtis, V., Cairncross, S., & Yonli, R. 2000. Review: Domestic hygiene and diarrhoea–pinpointing the problem. *Tropical medicine & international health*, *5*(1), 22-32.

Luby, S. P., Halder, A. K., Huda, T., Unicomb, L., & Johnston, R. B. 2011. The effect of handwashing at recommended times with water alone and with soap on child diarrhea in rural Bangladesh: an observational study. *PLoS Med*, *8*(6), e1001052.

Rabbi, S. E., & Dey, N. C. 2013. Exploring the gap between hand washing knowledge and practices in Bangladesh: a cross-sectional comparative study. *BMC public health*, *13*(1), 89.

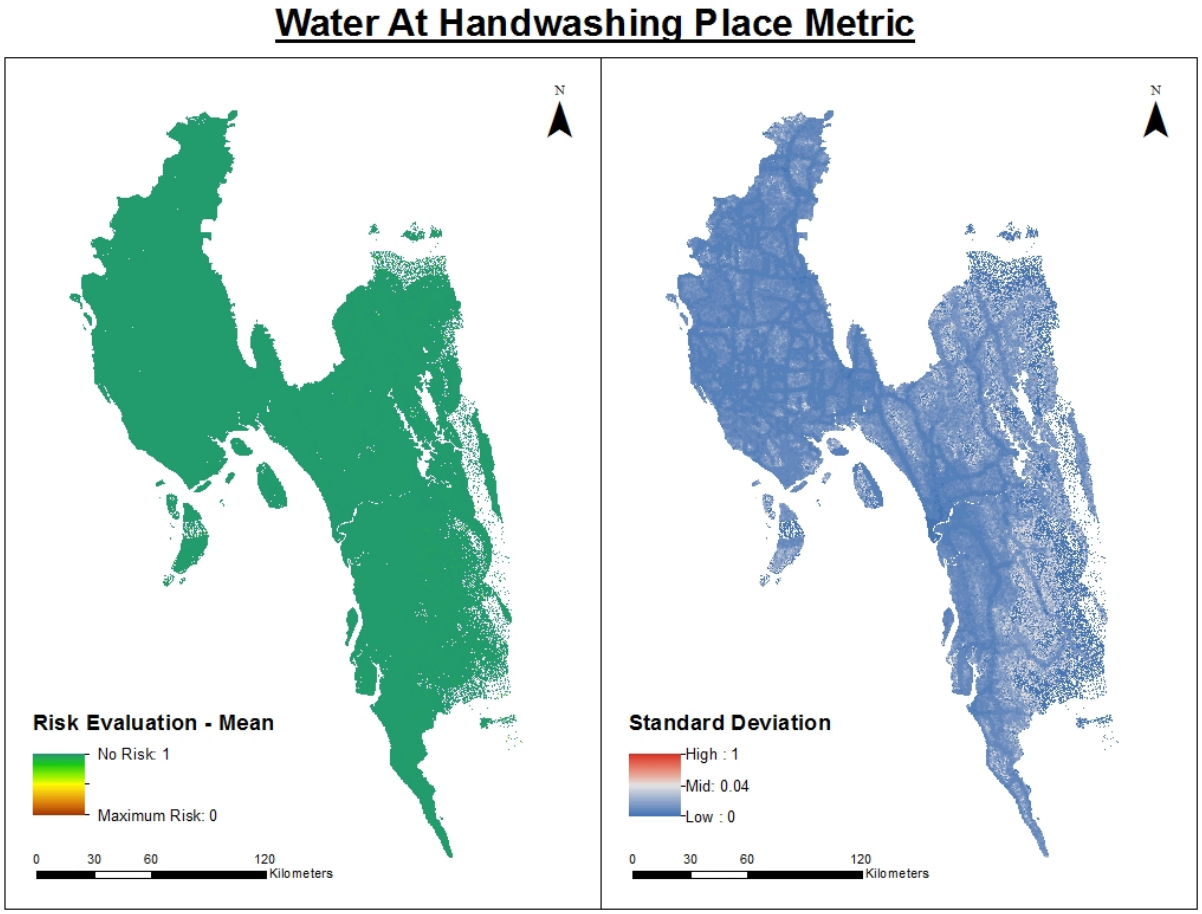
Sasaki, S., Suzuki, H., Igarashi, K., Tambatamba, B., & Mulenga, P. 2008. Spatial analysis of risk factor of cholera outbreak for 2003–2004 in a peri-urban area of Lusaka, Zambia. *The American journal of tropical medicine and hygiene*, *79*(3), 414-421.

USAID 2016. StatCompiler – The DHS Program. http://statcompiler.com/en/.

Metric: Water Available at Handwashing Place

Indicator:	Household Health Practices
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	Water Available (min: 1.0, max: 1.0) Water Not Available (min: 0.25, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Curtis, Cairncross, & Yonli (2000); Luby et al. (2011); Rabbi & Dey (2013); Sasaki et al. (2008); USAID (2016)
Logic:	This metric consists of observations by the surveyor on whether or not there is water available at the handwashing place within the surveyed household. The DHS stat compiler for the 2011 Bangladesh survey breaks down households that surveyor observes handwashing place with water only by rural/urban residence and wealth quintile. Households with observed handwashing place with water only 66.5%. 48.7% of urban households and 73.1% of rural households with observed handwashing place with water only in 2011. Across wealth: 84.9%, 79.3%, 77.7%, 64.6%, & 30.7% of households with observed handwashing place with water only in 2011. Thus residence and wealth are key indicators for household health practices. Curtis, Cairncross, & Yonli (2000) recommend that "hygiene promotion programmes should give priority to the safe disposal of faecal material and the adequate washing of hands after contact with adult and child stools." Luby et al. (2011) found "that handwashing before preparing food is a particularly important opportunity to prevent childhood diarrhea, and that handwashing with water alone can significantly reduce childhood diarrhea." Rabbi & Dey (2013) conduct a study to evaluate the effectiveness of a sanitation and hygiene program in Bangladesh. The baseline returned 8% washed their hands with soap. At the conclusion of the program, 22% reported washing their hands with soap 5 years later. Sasaki et al. (2008) found that hand washing with soap plays a protective role in cholera prevention. Answers of "Water Available" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "Water Not Available" are given an overall value of slight risk with a minimum of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.9 (minimal risk). Maps will range from medium risk to no risk.

Example realization metric map



References

Curtis, V., Cairncross, S., & Yonli, R. 2000. Review: Domestic hygiene and diarrhoea–pinpointing the problem. *Tropical medicine & international health*, *5*(1), 22-32.

Luby, S. P., Halder, A. K., Huda, T., Unicomb, L., & Johnston, R. B. 2011. The effect of handwashing at recommended times with water alone and with soap on child diarrhea in rural Bangladesh: an observational study. *PLoS Med*, *8*(6), e1001052.

Rabbi, S. E., & Dey, N. C. 2013. Exploring the gap between hand washing knowledge and practices in Bangladesh: a cross-sectional comparative study. *BMC public health*, *13*(1), 89.

Sasaki, S., Suzuki, H., Igarashi, K., Tambatamba, B., & Mulenga, P. 2008. Spatial analysis of risk factor of cholera outbreak for 2003–2004 in a peri-urban area of Lusaka, Zambia. *The American journal of tropical medicine and hygiene*, *79*(3), 414-421.

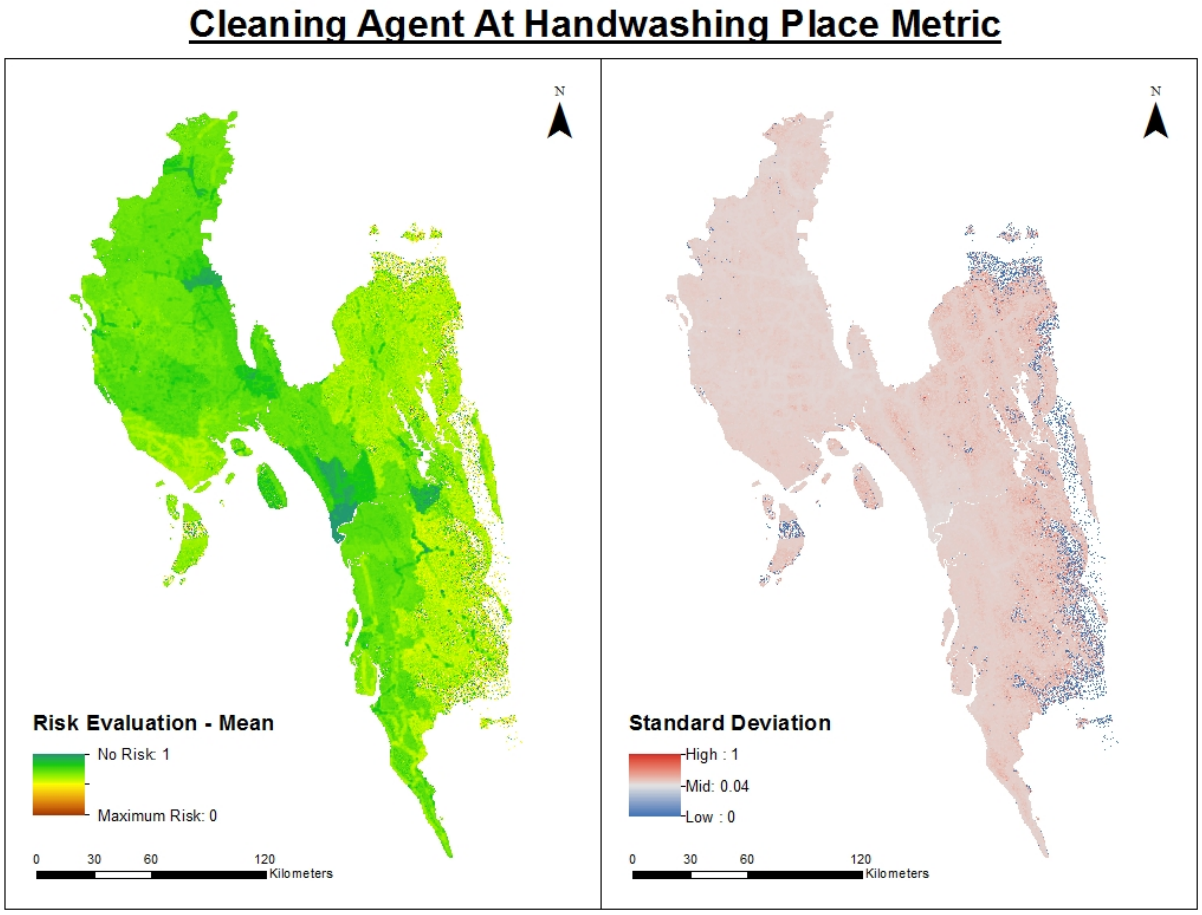
USAID 2016. StatCompiler – The DHS Program. http://statcompiler.com/en/.

Metric: Cleaning Agent Available at Handwashing Place

Indicator:	Household Health Practices
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	Soap or Detergent (min: 1.0, max: 1.0) Ash, Mud, or Sand (min: 0.5, max: 0.75) Other Cleaning Agent (min: 0.5, max: 0.75) None (min: 0.125, max: 0.5)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Curtis, Cairncross, & Yonli (2000); Luby et al. (2011); Rabbi & Dey (2013); Sasaki et al. (2008); USAID (2016)
Logic:	This metric consists of observations by the surveyor on whether or not a cleaning agent is present at the handwashing place within the surveyed household. The DHS stat compiler for the 2011 Bangladesh survey breaks down households that surveyor observes handwashing place with water only by rural/urban residence and wealth quintile. Households with observed handwashing place with water only 66.5%. 48.7% of urban households and 73.1% of rural households with observed handwashing place with water only in 2011. Across wealth: 84.9%, 79.3%, 77.7%, 64.6%, & 30.7% of households with observed handwashing place with water only in 2011. Households with soap and water is 24.9%. 46.3% of urban households and 17% of rural households have both soap and water available at handwashing place. Across wealth: 3.8%, 8.5%, 12.7%, 27.5%, & 66.5% of households had both soap and water available. Households with another cleansing agent and water is 6%. 3.5% of urban households and 6.9% of rural households have another cleansing agent and water available at handwashing place. Across wealth: 6.8%, 7.9%, 6.9%, 6.5%, & 2.2% of households had another cleansing agent and water available. Thus residence and wealth are key indicators for household health practices. Curtis, Cairncross, & Yonli (2000) recommend that “hygiene promotion programmes should give priority to the safe disposal of faecal material and the adequate washing of hands after contact with adult and child stools.” Luby et al. (2011) found “that handwashing before preparing food is a particularly important opportunity to prevent childhood diarrhea, and that handwashing with water alone can significantly reduce childhood diarrhea.” Rabbi & Dey (2013) conduct a study to evaluate the effectiveness of a sanitation and hygiene program in Bangladesh. The baseline returned 8% washed their hands with soap. At the conclusion of the program, 22% reported washing their hands with soap 5 years later. Sasaki et al. (2008) found that hand washing with soap plays a protective role in cholera prevention.

Answers of “Soap or Detergent” are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of “Ash, Mud or Sand” and “Other Cleaning Agent” are given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 0.75. Answers of “None” are given a minimum value of 0.125 (high risk, $½^3$) and a maximum value of 0.5. Maps will range from high risk to no risk.

Example realization metric map



References

Curtis, V., Cairncross, S., & Yonli, R. 2000. Review: Domestic hygiene and diarrhoea–pinpointing the problem. *Tropical medicine & international health*, *5*(1), 22-32.

Luby, S. P., Halder, A. K., Huda, T., Unicomb, L., & Johnston, R. B. 2011. The effect of handwashing at recommended times with water alone and with soap on child diarrhea in rural Bangladesh: an observational study. *PLoS Med*, *8*(6), e1001052.

Rabbi, S. E., & Dey, N. C. 2013. Exploring the gap between hand washing knowledge and practices in Bangladesh: a cross-sectional comparative study. *BMC public health*, *13*(1), 89.

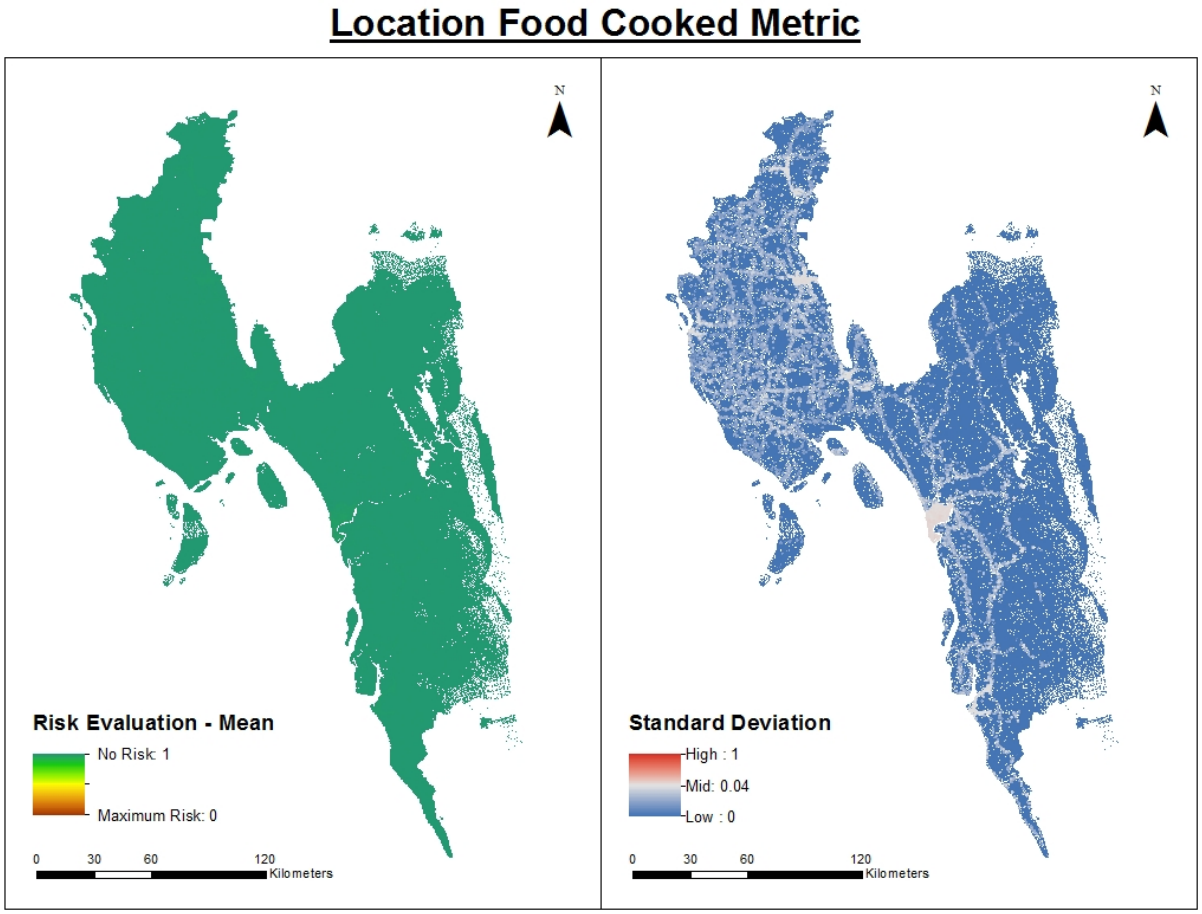
Sasaki, S., Suzuki, H., Igarashi, K., Tambatamba, B., & Mulenga, P. 2008. Spatial analysis of risk factor of cholera outbreak for 2003–2004 in a peri-urban area of Lusaka, Zambia. *The American journal of tropical medicine and hygiene*, *79*(3), 414-421.

USAID 2016. StatCompiler – The DHS Program. http://statcompiler.com/en/.

Metric: Location where food is cooked

Indicator:	Household Health Practices
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	InTheHouse (min: 1.0, max: 1.0) InASeparateBuilding (min: 0.5, max: 1.0) Outdoors (min: 0.25, max: 1.0) Other (min: 0.125, max: 1.0)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Hughes et al. (1982); Khan et al. (1981); USAID (2016)
Logic:	This metric consists of answers to the question concerning the location of where the food is cooked in the household. The DHS stat compiler for the 2011 Bangladesh survey breaks down households that surveyor observes 12.3% households cooking in the house, 64.3% of households cooking in a separate building, 23.3% of households cooking outdoors, and 0.1% of households cooking in other places. The numbers change slightly when broken out by urban/rural status. 22.8% of urban households cook in the house opposed to 8.8% of rural households. The numbers for cooking a separate building is fairly similar for both urban and rural households. Cooking outdoors is observed for 26.4% of rural households and 13.9% for urban households. Thus residence is a key indicator for household health practices. Many papers in the literature note the water used for cooking to be highly associated with cholera infection (e.g. Hughes et al., 1982; Khan et al., 1981), but none have been found stating that cooking location is imperative to predicting cholera risk. Answers of "In The House" are given both a minimum and maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "In A Separate Building" are given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0. Answers of "Outdoors" are given a minimum value of 0.25 (medium risk, $½^2$) and a maximum value of 1.0. Answers of "Other" are given a minimum of 0.125 (high risk, $½^3$) and a maximum value of 1.0. Maps will range from high risk to no risk.

Example realization metric map



References

Hughes, J. M., Boyce, J. M., Levine, R. J., Khan, M., Aziz, K. M. A., Huq, M. I., & Curlin, G. T. 1982. Epidemiology of eltor cholera in rural Bangladesh: importance of surface water in transmission. *Bulletin of the World Health Organization*, *60*(3), 395.

Khan, M. U., Mosley, W. H., Chakraborty, J., Sarder, A. M., & Khan, M. R. 1981. The relationship of cholera to water source and use in rural Bangladesh. *International journal of epidemiology*, *10*(1), 23-26.

USAID 2016. StatCompiler – The DHS Program. http://statcompiler.com/en/.

A.4.1.4 Indicator: Treatment for diarrhea

The HC framework does not include this explicitly as an indicator, but as this framework aims to anticipate cholera outbreaks. As diarrhea is a main symptom of cholera, it plays a key role in areas that are prone to cholera outbreaks that people are able to receive treatment for the disease and

identify cholera outbreaks when they occur. The authors felt it necessary to include "Treatment for Diarrhea" as its own indicator. This indicator reflects the ability of the framework to recover from a cholera outbreak. For those who purely wish to predict cholera outbreak, this indicator can be removed.

Metric weighting logic

The metrics within the "Treatment for Diarrhea" are focused on children's treatment. "Treatment given to children for diarrhea" is the most constraining on this indicator, and is given the higher minimum value than the other metrics since it addresses the ability to recover from cholera.

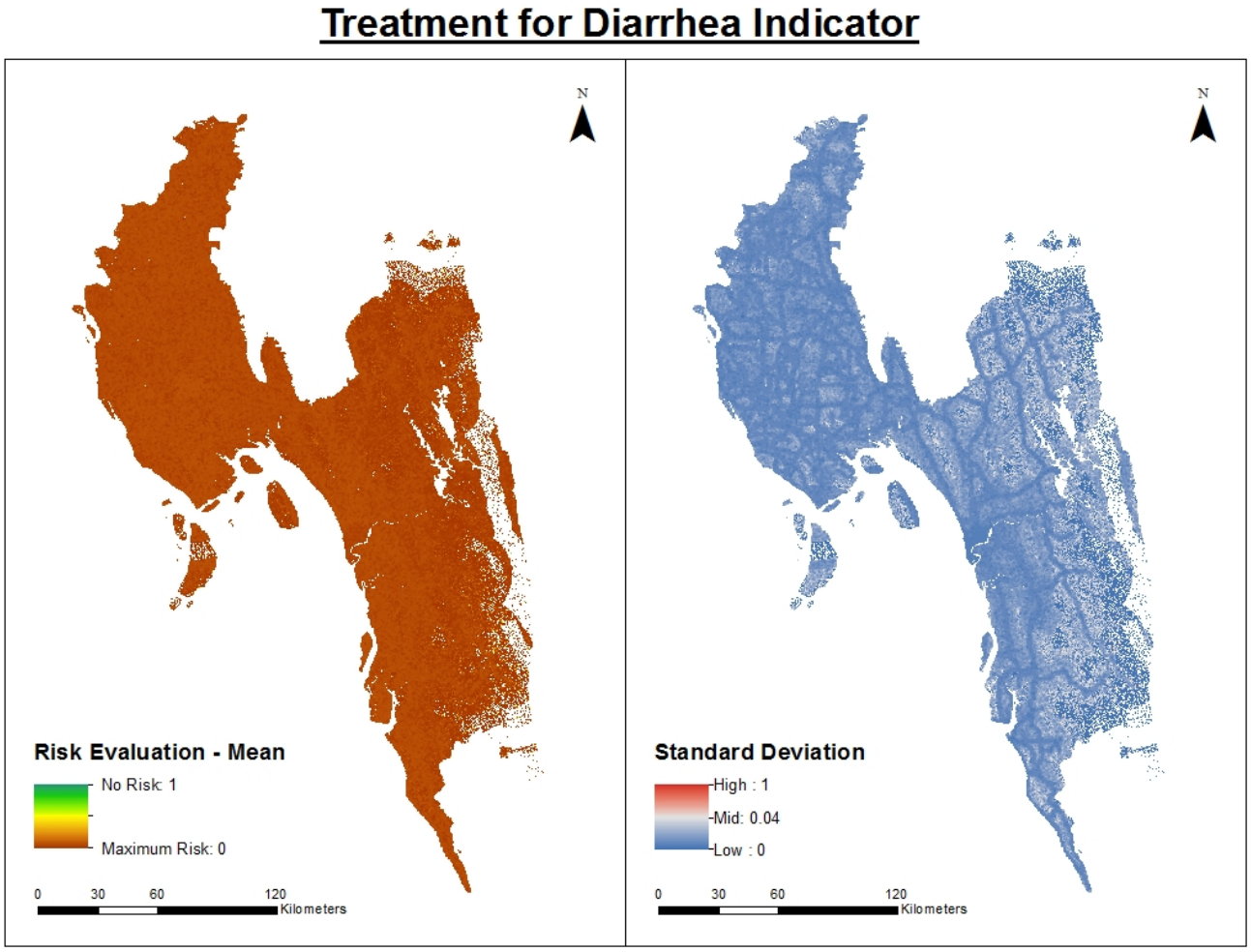
Metric	Weight Minimum Value	Weight Maximum Value
Treatment given to children for diarrhea	0.6	0.9
Child had diarrhea in last 2 weeks: amount offered to drink	0.2	0.5
Child had diarrhea in last 2 weeks: amount offered to eat	0.2	0.5

Uncertainty values

Adding more data on access to treatment for diarrhea could decrease the uncertainty values.

Indicator Uncertainty Min:	0.1
Indicator Uncertainty Max:	0.3

Example outcome



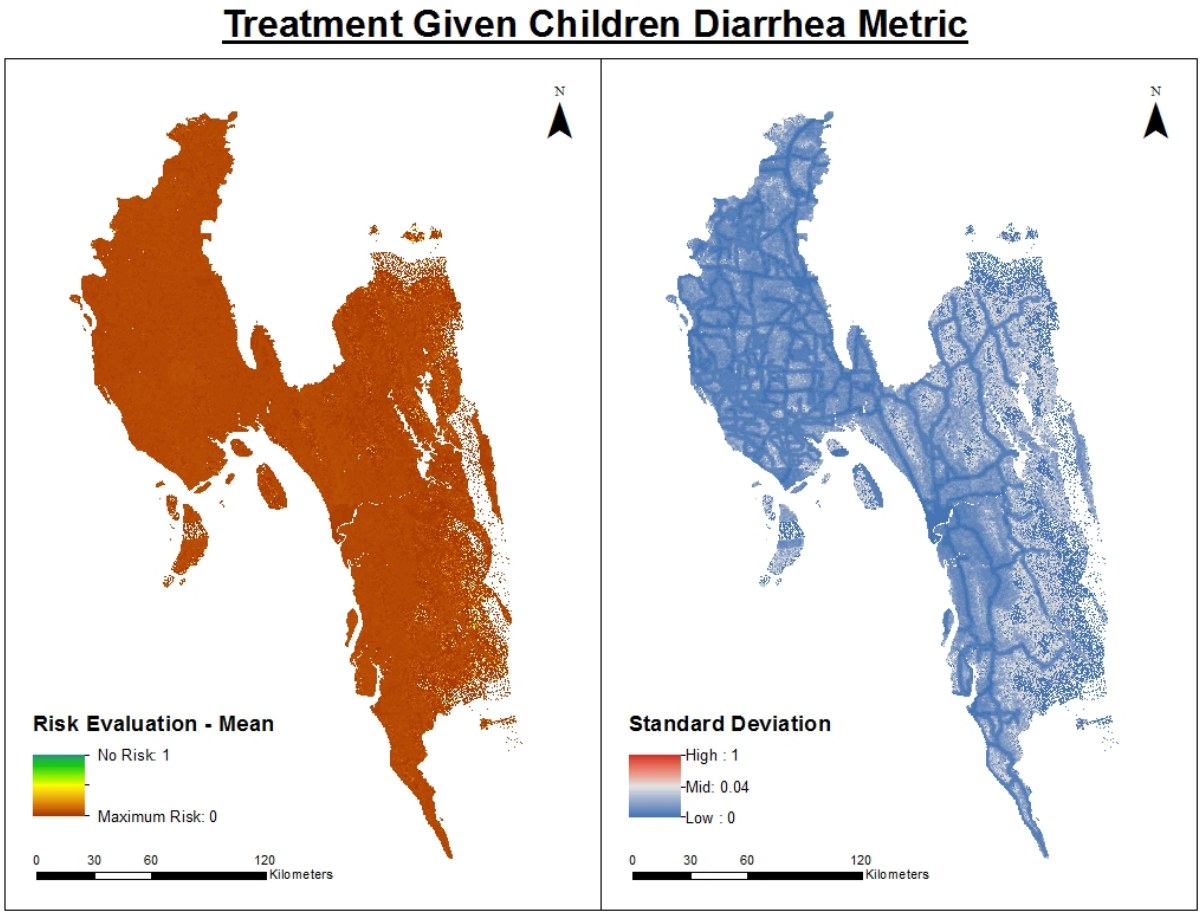
Metric: Treatment Given to Children for Diarrhea

Indicator:	Treatment for Diarrhea
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	(1) Oral Rehydration (min: 1.0, max: 1.0) (2) Prepackaged ORS (min: 0.5, max: 1.0) (3) Home Solution (min: 0.5, max: 1.0) (4) Oral Antibiotics (min: 0.5, max: 1.0) (5) Antimotility (min: 0.5, max: 1.0) (6) Antibiotic Injections (min: 0.5, max: 1.0) (7) Intravenous (min: 1.0, max: 1.0) (8) Home Remedy (min: 0.5, max: 1.0) (9) Zinc (min: 0.5, max: 1.0) (10) Other (min: 0.5, max: 1.0) (11) Non-antibiotic Inj. (min: 0.5, max: 1.0) (12) Other Treatment (min: 0.5, max: 1.0) (13) No Treatment (min: 0.0625, max: 0.5) (14) Any Treatment (min: 0.5, max: 1.0)

Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Center for Disease Control (CDC) (2016); Jutla et al. (2013); USAID (2016)
Logic:	This metric consists of answers to the question of what kind of treatment a child was given for diarrhea from the women's portion of the DHS survey. The DHS stat compiler for the 2011 Bangladesh survey breaks down households that surveyor observes treatment for diarrhea in the three years preceding the survey (from 2008-2011). For use of (1,2) ORS, 81% of male children and 67.8% of female children, 83.8% of urban children and 73.3% of rural children, 80.7% of the two lowest wealth quintiles, 66.5% of middle quintile, 64.9% of the fourth, and 79.7% of the highest quintile children. Those that receive NO ORS, RHF or increased fluids, while 20.5% on average, 14.2% of males & 28.7% of females did not receive ORS, RHF, or increased fluids. This reiterates the gendered risk to contracting cholera. Urban children (14.1%) are more likely to receive treatment opposed to rural children where 22% do not receive treatment. Interestingly, the middle and second highest wealth quintiles are least likely to receive treatment at 27% opposed to the lowest, second lowest, and highest around 17%. There is no data from USAID (2016) on the treatment of diarrhea via (4) antibiotics, (5) antimotility drugs, (9) zinc supplements, (7) intravenous solution, (6) injection, (3) home remedy – other, and (13) no treatment. The CDC stated "Cholera can be simply and successfully treated by immediate replacement of the fluid and salts lost through diarrhea. Patients can be treated with oral rehydration solution, a prepackaged mixture of sugar and salts to be mixed with water and drunk in large amounts. This solution is used throughout the world to treat diarrhea. Severe cases also require intravenous fluid replacement. With prompt rehydration, less than 1% of cholera patients die. Antibiotics shorten the course and diminish the severity of the illness, but they are not as important as receiving rehydration. Persons who develop severe diarrhea and vomiting in countries where cholera occurs should seek medical attention promptly." Jutla et al. (2013) calls for a robust cholera prediction model coupled with a risk map that allows for allocation of oral hydration therapy. Based on the information given by the CDC, any treatment is given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "Oral Rehydration" and "Intravenous," being the most effective treatments, are given both a minimum and maximum value of 1.0. Answers of "No Treatment" are given a minimum value of 0.0625 (extreme risk, $½^4$) and a maximum value of 0.5. Maps will range from extreme risk to no risk. It should be noted that, as this version of the framework was constructed as a proof of research concept, only the results pertaining to the first child for whom answers were provided were used to create this metric. For questions under section 2 (Reproduction) of the

women's portion of the DHS Bangladesh survey, answers were allowed for up to 12 children. Results from these questions will only contain answers for the eldest child. For questions under Sections 4 (Pregnancy and Postnatal Care) and 5 (Child Immunization, Health, and Nutrition), answers were allowed for children from the last birth, the next-to-last birth, and the second next-to-last birth (i.e. the youngest three children of the female respondent). Results from these questions will only contain answers for the youngest child.

Example realization metric map



References

Center for Disease Control (CDC) 2016. "Cholera - *Vibrio cholerae* infection" 9 Nov. 2016. https://www.cdc.gov/cholera/general/.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A.,... & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

USAID 2016. StatCompiler – The DHS Program. http://statcompiler.com/en/.

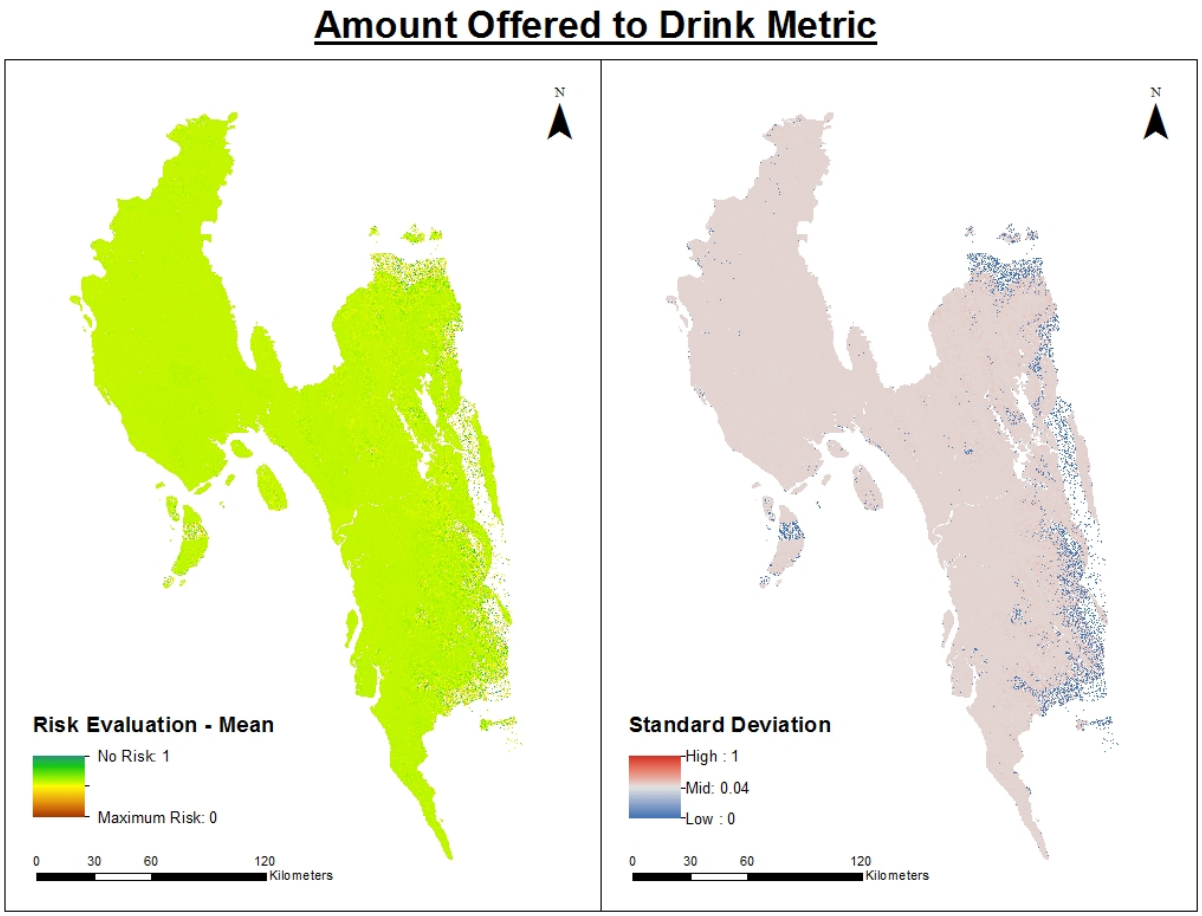
Metric: Child had diarrhea in last 2 weeks: amount offered to drink

Indicator:	Treatment for Diarrhea
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	Nothing to Drink (min: 0.0625, max: 0.5) 2MuchLess (min: 0.125, max: 0.75) 3SomewhatLess (min: 0.25, max: 0.75) 4AboutSame (min: 0.75, max: 1.0) 5More (min: 1.0, max: 1.0) Unknown (min: 0.0625, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Center for Disease Control (CDC) (2016); USAID (2016)
Logic:	This metric consists of answers to the question on the amount offered to drink to a child with diarrhea in the past 2 weeks compared to the amount they normally drink from the women's portion of the DHS survey. The DHS stat compiler for the 2011 Bangladesh survey breaks down households that surveyor observes treatment for diarrhea in the three years preceding the survey (from 2008-2011). For children under 5, only 22.4% received [5] increased fluids as treatment of diarrhea. Reiterating the gendered risk to contracting cholera, 25.3% of male children and 18.6% of female children received increased fluids as treatment. 19.9% of urban children and 23% of rural children received increased fluids as treatment. Only 13.1% of the poorest compared to 27.8% of the poorer, 24.1% of the middle, 31.3% of richer, and 22.5% of the richest quintiles increased fluid consumption. 50.5% of all children under 5 consumed the same amount of fluids [4]. 23.2% consumed somewhat less fluids, 3.4% consumed much less fluids, and 0.5% stopped fluids completely. The CDC stated "Cholera can be simply and successfully treated by immediate replacement of the fluid and salts lost through diarrhea. Patients can be treated with oral rehydration solution, a prepackaged mixture of sugar and salts to be mixed with water and drunk in large amounts. This solution is used throughout the world to treat diarrhea. Severe cases also require intravenous fluid replacement. With prompt rehydration, less than 1% of cholera patients die. Antibiotics shorten the course and diminish the severity of the illness, but they are not as important as receiving rehydration. Persons who develop severe diarrhea and vomiting in countries where cholera occurs should seek medical attention promptly." Answers of "Nothing To Drink" are given a minimum of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "2 Much Less" given a minimum of 0.125 (high risk, $\frac{1}{2}^3$)

and a maximum value of 0.75 (minimal risk). Answers of "3 Somewhat Less" are given a minimum of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.75. Answers of "4 About Same" are given an overall value of minimal risk with a minimum value of 0.75 and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "5 More" are given both a minimum value and a maximum value of 1.0. Answers of "Unknown" are given both a minimum value of 0.0625 and a maximum value of 1.0. Maps will range from extreme risk to no risk.

It should be noted that, as this version of the framework was constructed as a proof of research concept, only the results pertaining to the first child for whom answers were provided were used to create this metric. For questions under section 2 (Reproduction) of the women's portion of the DHS Bangladesh survey, answers were allowed for up to 12 children. Results from these questions will only contain answers for the eldest child. For questions under Sections 4 (Pregnancy and Postnatal Care) and 5 (Child Immunization, Health, and Nutrition), answers were allowed for children from the last birth, the next-to-last birth, and the second next-to-last birth (i.e. the youngest three children of the female respondent). Results from these questions will only contain answers for the youngest child.

Example realization metric map



References

Center for Disease Control (CDC) 2016. "Cholera - *Vibrio cholerae* infection" 9 Nov. 2016. https://www.cdc.gov/cholera/general/.

USAID 2016. StatCompiler – The DHS Program. http://statcompiler.com/en/.

Metric: Child had diarrhea in last 2 weeks: amount offered to eat

Indicator:	Treatment for Diarrhea
Factor:	Health & Medical Service Insufficiencies
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	0StoppedFood (min: 0.0625, max: 0.25) 1NeverGaveFood (min: 0.0625, max: 0.25) 2MuchLess (min: 0.125, max: 0.25) 3SomewhatLess (min: 0.25, max: 0.5)

4AboutSame (min: 0.5, max: 0.9)
5More (min: 1.0, max: 1.0)
Unknown (min: 0.0625, max: 1.0)

Survey: DHS - Women

Survey Date: 2011

Other Data Sources: Center for Disease Control (CDC) (2016); Emch (1999); USAID (2016)

Logic: This metric consists of answers to the question on the amount offered to eat to a child with diarrhea in the past 2 weeks compared to the amount they normally drink from the women's portion of the DHS survey.

The DHS stat compiler for the 2011 Bangladesh survey breaks down households that surveyor observes treatment for diarrhea in the three years preceding the survey (from 2008-2011). For children under 5, 12% received [5] increased food amount as a response to diarrhea. Interestingly, 8.9% of male children and 16% of female increased food amount. 51.5% of all children under 5 consumed the same amount of food [4]. 24.2% consumed somewhat less food [3], 6.1% consumed much less food [2], 3.4% never gave food [1], and 2.9% stopped fluids completely [0].

The CDC stated "Cholera can be simply and successfully treated by immediate replacement of the fluid and salts lost through diarrhea. Patients can be treated with oral rehydration solution, a prepackaged mixture of sugar and salts to be mixed with water and drunk in large amounts. This solution is used throughout the world to treat diarrhea. Severe cases also require intravenous fluid replacement. With prompt rehydration, less than 1% of cholera patients die. Antibiotics shorten the course and diminish the severity of the illness, but they are not as important as receiving rehydration. Persons who develop severe diarrhea and vomiting in countries where cholera occurs should seek medical attention promptly."

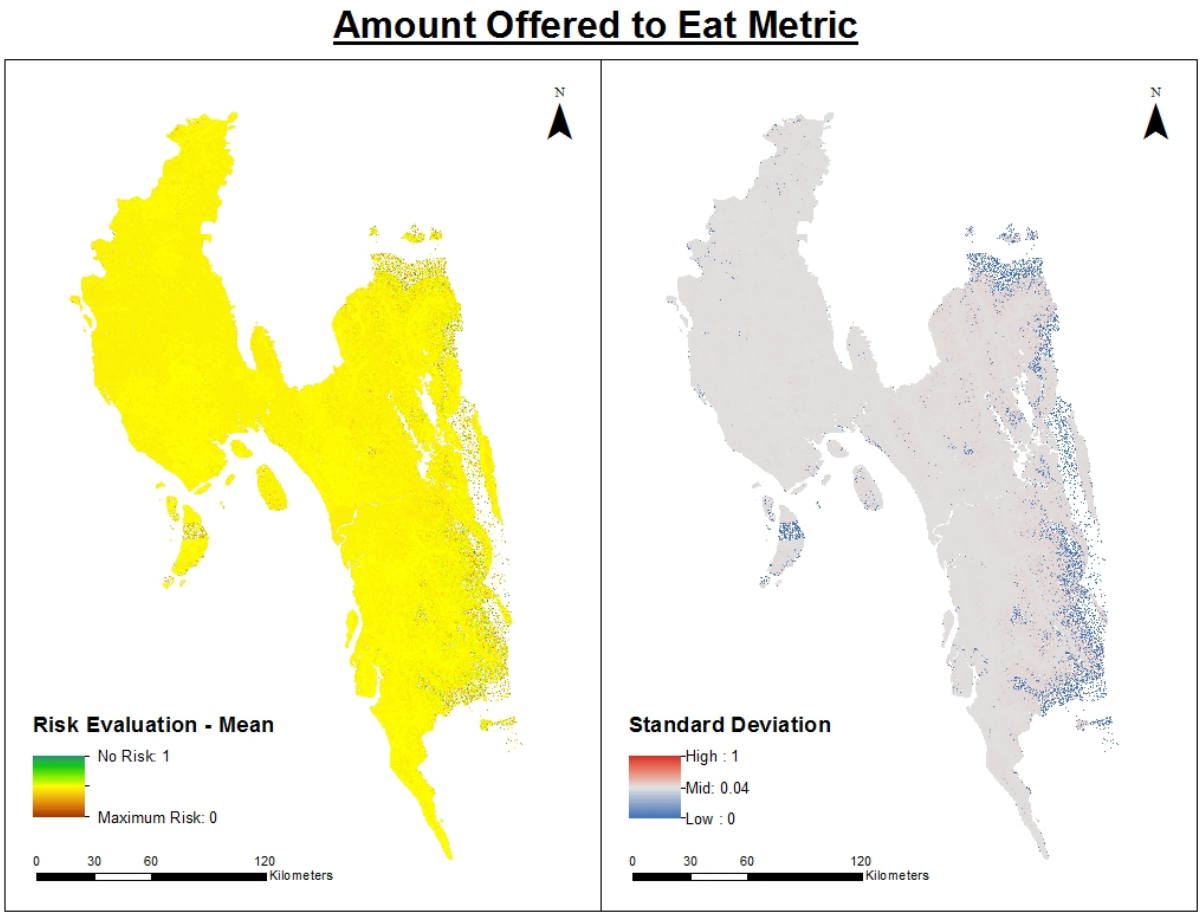
"Stanton and Clemens (1986) found the longstanding belief that malnutrition was associated with cholera not to be true" (Emch, 1999).

Answers of "0 Stopped Food" and "1 Never Gave Food" are given a minimum of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.25 (medium risk, $\frac{1}{2}^2$). Answers of "2 Much Less" given a minimum of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.25. Answers of "3 Somewhat Less" are given a minimum of 0.25 and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "4 About Same" are given an overall value of minimal risk with a minimum value of 0.5 and a maximum value of 0.9 (minimal risk). Answers of "5 More" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "Unknown" are given both a minimum value of 0.0625 and a maximum value of 1.0. Maps will range from extreme risk to no risk. Maps will range from extreme risk to no risk.

It should be noted that, as this version of the framework was constructed as a proof of research concept, only the results

pertaining to the first child for whom answers were provided were used to create this metric. For questions under section 2 (Reproduction) of the women's portion of the DHS Bangladesh survey, answers were allowed for up to 12 children. Results from these questions will only contain answers for the eldest child. For questions under Sections 4 (Pregnancy and Postnatal Care) and 5 (Child Immunization, Health, and Nutrition), answers were allowed for children from the last birth, the next-to-last birth, and the second next-to-last birth (i.e. the youngest three children of the female respondent). Results from these questions will only contain answers for the youngest child.

Example realization metric map



References

Center for Disease Control (CDC) 2016. "Cholera - *Vibrio cholerae* infection" 9 Nov. 2016. https://www.cdc.gov/cholera/general/.

Emch, Michael. "Diarrheal disease risk in Matlab, Bangladesh." *Social science & medicine* 49, no. 4 (1999): 519-530.

USAID 2016. StatCompiler – The DHS Program. http://statcompiler.com/en/.

A.4.2 Utilities disruption factor overview

This factor emphasizes the more conventional aspect of "service" failures, in terms of public infrastructure services often provided by a local, regional, or national government. These include sanitation, clean water, communications infrastructure (i.e. cell-phone and radio towers, broadband, etc.), and power/energy. Urban and rural patterns in if and how utilities are provided should be taken into account in both determining metrics and weighting indicators.

Indicators within this factor include Inadequate Sanitation, Water Shortfalls, and Energy Deficits.

Indicator weighting logic

"Inadequate Sanitation" and "Water Shortfalls" were given a minimum value of 0.5 and a maximum value of 1.0. This is because these indicators are key in predicting cholera risk. "Energy Deficits" is given both a minimum and maximum value of 0.333, as it is less important in predicting cholera risk.

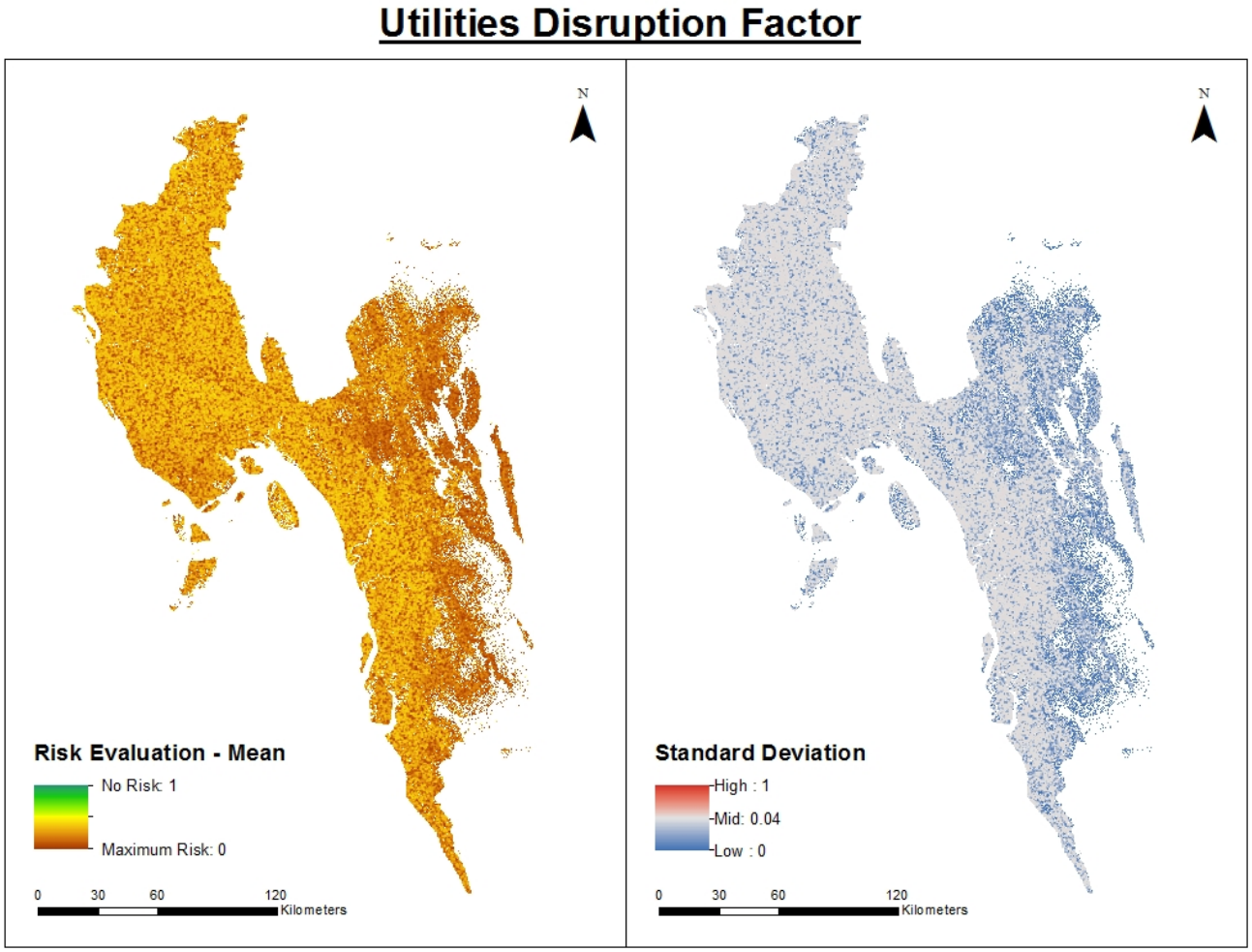
Indicator	Weight Minimum Value	Weight Maximum Value
Sanitation Infrastructure	0.5	1.0
Water Shortfalls	0.5	1.0
Energy Deficits	0.333	0.333

Uncertainty values

This factor is given a range of uncertainty values from 0.1 to 0.3 because all of the aspects named in the factor overview are addressed.

Factor Uncertainty Min:	0.1
Factor Uncertainty Max:	0.3

Example outcome



A.4.2.1 Indicator: Sanitation infrastructure

According to the World Health Organization:

> Sanitation generally refers to the provision of facilities and services for the safe disposal of human urine and feces. Inadequate sanitation is a major cause of disease world-wide and improving sanitation is known to have a significant beneficial impact on health both in households and across communities. The word 'sanitation' also refers to the maintenance of hygienic conditions, through services such as garbage collection and wastewater disposal (“Sanitation” 2017).

Household-level infrastructure measures, as demonstrated in the metrics currently included in this indicator, can inform maps of civil-level infrastructure. Due to the ubiquitousness of the USAID survey microdata used to inform the metrics, this approach is perhaps a better methodology than using state- or city-level infrastructure datasets.

PACOM specifies that metrics should include: percentage of sanitation facilities damaged; percentage of population with access to sanitation (compared with historical data); and satisfaction with access to sanitation. In regards to the cholera framework, sanitation infrastructure is key in preventing cholera outbreaks. We focus on toilet infrastructure at the household level. The literature is very supportive as Jutla et al. (2013) finds that poor sanitation yields a higher likelihood of a cholera epidemic and Giebultowicz et al. (2011) finds that "unsanitary latrines are responsible for surface water contamination."

Metric weighting logic

The two "HH Type Toilet" (household toilet type from the IPUMS and DHS surveys) are the most constraining metric, and are therefore weighted both a minimum value of 0.4 and maximum value of 0.7. The "Toilet Shared" metric asks if a household shares a toilet with other households. While important, the levels of sanitation of a household's toilet is more important. For this reason, it is weighted the lowest of the three metrics.

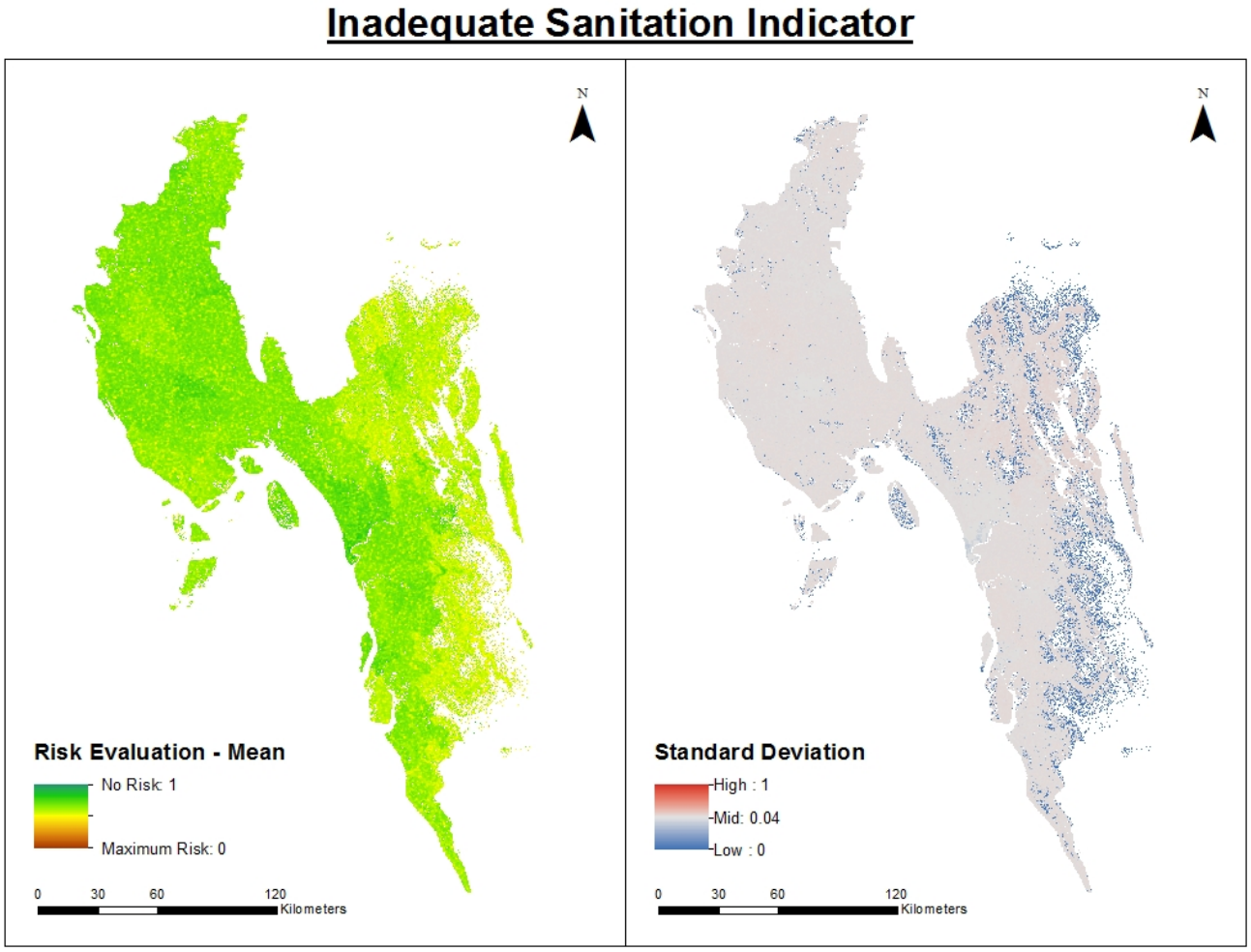
Metric	Weight Minimum Value	Weight Maximum Value
HH Type Toilet (IPUMS)	0.4	0.7
HH Type Toilet (DHS)	0.4	0.7
Toilet Shared	0.2	0.5

Uncertainty values

The addition of data on city-wide sanitation system provisions and larger urban sanitation issues could further decrease the uncertainty values.

Indicator Uncertainty Min:	0.10
Indicator Uncertainty Max:	0.15

Example outcome



References

Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2 (2011): 490-497.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

World Health Organization (WHO) 2017. "Sanitation." 2017. http://www.who.int/topics/sanitation/en/.

Metric: Household Toilet Type (IPUMS)

Indicator: Inadequate Sanitation

Factor:	Utilities Disruption
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	Sanitary with water seal (min: 1.0, max: 1.0) Sanitary without seal (min: 0.75, max: 1.0) Non-Sanitary (min: 0.0625, max: 0.8) None (min: 0.0625, max: 0.5)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	Ali et al. (2002, 2); Giebultowicz et al. (2011); Hashizume et al. (2008); Jutla et al. (2013); Perez-Saez et al. (2016); WHO (n.d.)

Logic:

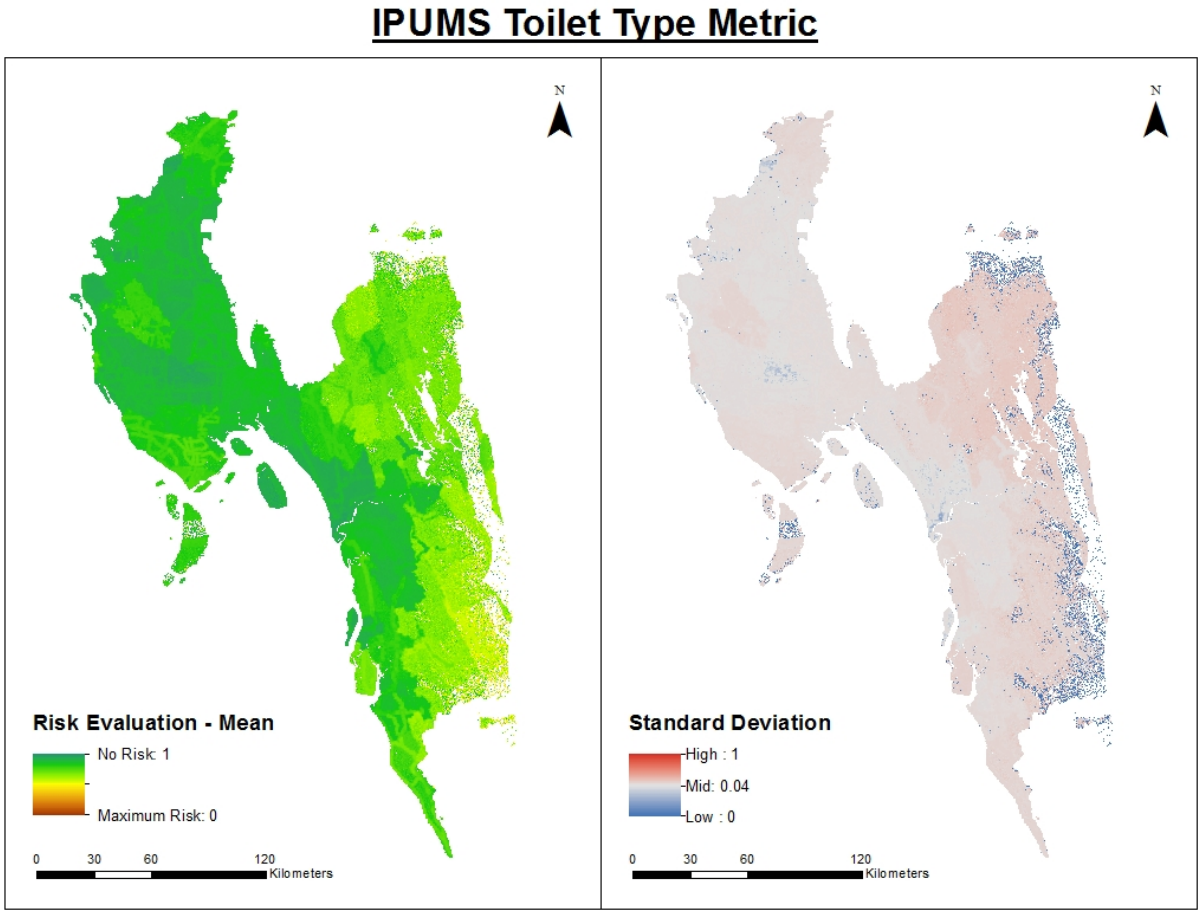
The interviewer Instructions for the IPUMS states:

"The toilet which is pit latrine with water sealed facility is called sanitary (water sealed). The latrine which is pit latrine but having no water sealed facility is called sanitary (Non-water sealed). The toilet which may be pucca, semi-pucca or kutcha but having no facility to cover the discharge waste is called Non-sanitary. Such type of toilet is not free from water and environment pollution. None means there is no toilet for the household usually uses to go bush, jungle or open space as and when necessary."

Ali et al. (2002, 2) clarifies sanitation data by unsafe and safe latrines. An unsafe latrine is open, thus feces can spread to contaminate nearby surface water, especially in the rainy season (Jul-Sept). Giebultowicz et al. (2011) finds that "unsanitary latrines are responsible for surface water contamination." Jutla et al. (2013) finds that poor sanitation yields a higher likelihood of a cholera epidemic. They determine that the United States rarely experiences cholera outbreak due to its robust water and sanitation infrastructure as effective prevention methods for the spread of cholera (p.602). Perez-Saez et al. (2016) reiterate that inadequate sanitation infrastructure exposes the population to cholera. Hashizume et al. (2008) found that cholera risk is higher for those using unsanitary toilets and drinking tubewell water.

Answers of "Sanitary with water seal" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "Sanitary w/o seal" are given an overall value of minimal risk with a minimum value of 0.75 (minimal risk) and a maximum value of 1.0. Answers of "Non-Sanitary" are given a minimum of 0.0625 (extreme risk, $½^4$) and a maximum value of 0.8 (minimal risk). Answers of "None" are given a minimum of 0.0625 (extreme risk, $½^4$) and a maximum value of 0.5 (slight risk, $½^1$). Maps will range from extreme risk to no risk.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2 (2011): 490-497.

Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A.,... & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Perez-Saez et al., 2016. Climate-driven endemic cholera is modulated by human mobility in a megacity. *Advances in Water Resources*. http://dx.doi.org/10.1016/j.advwatres.2016.11.013.

WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation. "Improved and unimproved water sources and sanitation facilities." http://www.wssinfo.org/definitions-methods/watsan-categories/.

Metric: Household Toilet Type (DHS)

Indicator: Household Toilet

Factor: Utilities Disruption

Condition: Service Failure

Framework: Cholera

Metric Assigned Values:

Toilet Type	Min
Flush Toilet (I)	0.5
Flush To Piped Sewer System (I)	1.0
Flush To Septic Tank (I)	0.75
Flush To Pit Latrine (I)	0.75
Flush To Somewhere Else (U)	0.5
Flush Do Not Know Where (U)	0.5
Pit Toilet Latrine (B)	0.0625
Ventilated Improved Pit Latrine (I)	0.25
Pit Latrine With Slab (I)	0.25
Pit Latrine Without Slab Open Pit (U)	0.0625
No Facility (U)	0.0625
No Facility Bush Field (U)	0.0625
Composting Toilet (I)	0.75
Bucket Toilet (U)	0.125
Hanging Toilet Latrine (U)	0.125

Survey: DHS - Household

Survey Date: 2011

Other Data Sources: Ali et al. (2002, 2); Giebultowicz et al. (2011); Hashizume et al. (2008); Jutla et al. (2013); Perez-Saez et al. (2016); WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation

Logic: This metric consists of answers to the question about the household toilet type from the DHS survey. Answers are organized by "improved" (I), "unimproved" (U), or "both" (B). Ali et al. (2002, 2) clarifies sanitation data by unsafe and safe latrines. An unsafe latrine is open, thus feces can spread to contaminate nearby surface water, especially in the rainy season (Jul-Sept). Giebultowicz et al. (2011) finds that "unsanitary latrines are responsible for surface water

contamination." Jutla et al. (2013) finds that poor sanitation yields a higher likelihood of a cholera epidemic. They determine that the United States rarely experiences cholera outbreak due to its robust water and sanitation infrastructure as effective prevention methods for the spread of cholera (p.602). Perez-Saez et al. (2016) reiterate that inadequate sanitation infrastructure exposes the population to cholera. Hashizume et al. (2008) found that cholera risk is higher for those using unsanitary toilets and drinking tubewell water.

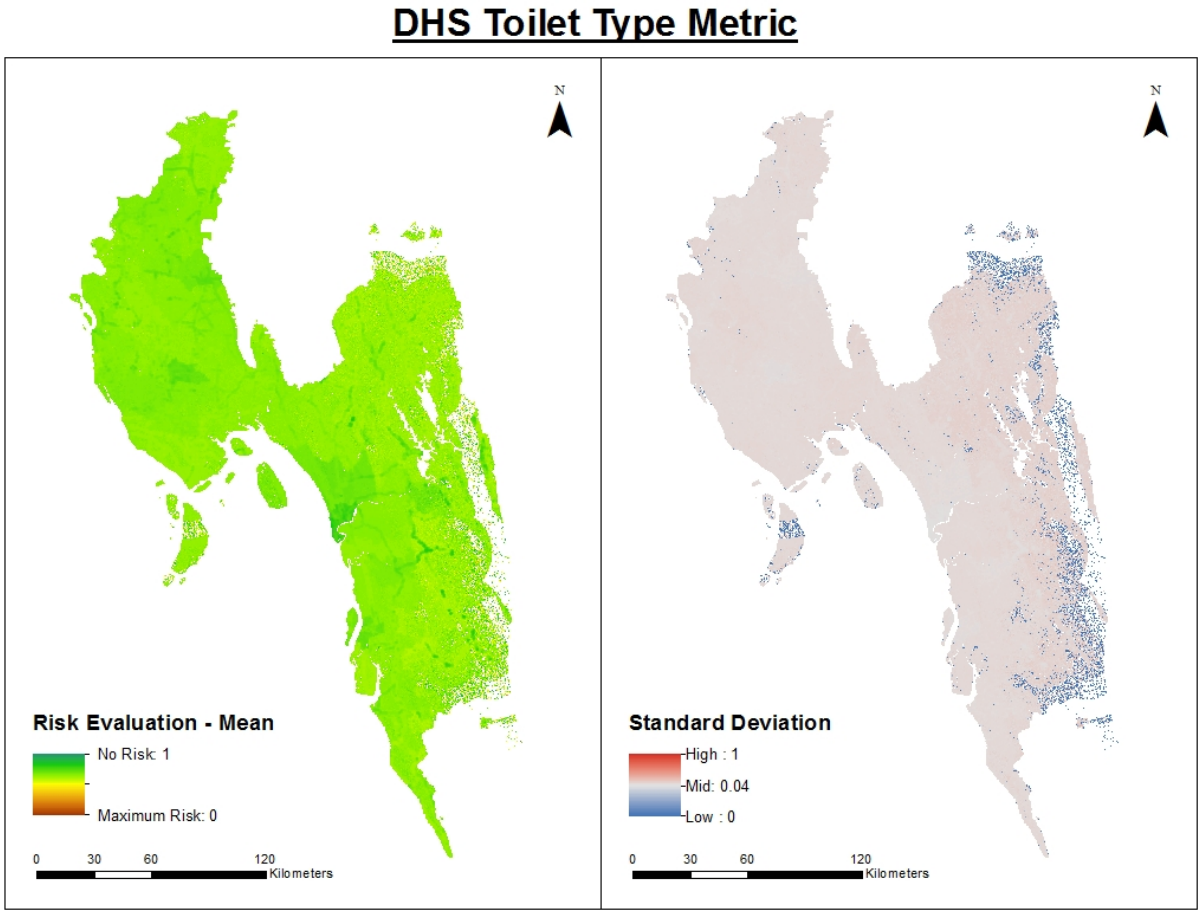
Answers of "Flush Toilet (I)" and "Flush Do Not Know Where (U)" are given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "Flush To Piped Sewer System (I)" are given both a minimum and a maximum value of 1.0. Answers of "Flush To Septic Tank (I)" are given a minimum value of 0.75 (minimal risk) and a maximum value of 1.0. Answers of "Flush To Pit Latrine (I)", and "Composting Toilet (I)" are given a minimum value of 0.75 and a maximum value of 0.9 (minimal risk). Answers of "Ventilated Improved Pit Latrine (I)" and "Pit Latrine With Slab (I)" are given a minimum of 0.25 (medium risk, $½^2$) and a maximum value of 0.8. Answers of "Pit Toilet Latrine (B)" are given a minimum of 0.0625 (extreme risk, $½^4$) and a maximum value of 1.0. Answers of "Flush To Somewhere Else (U)" are given a minimum value of 0.5 and a maximum value of 0.75. Answers of "Hanging Toilet Latrine (U)" and "Bucket Toilet (U)" are given a minimum of 0.125 (high risk, $½^3$) and a maximum value of 0.75 (minimal risk). Answers of "Pit Latrine Without Slab Open Pit (U)" are given a minimum value of 0.0625 and a maximum value of 0.75. Answers of "No Facility (U)" and "No Facility Bush Field (U)" are given a minimum of 0.0625 and a maximum value of 0.5. Maps will range from extreme risk to no risk.

The WHO states the following as forms of "improved" and "unimproved" sanitation.

"Improved" sanitation:
Flush toilet [v]
Piped sewer system [v]
Septic tank [v]
Flush/pour flush to pit latrine [v]
Ventilated improved pit latrine (VIP) [v]
Pit latrine with slab [v]
Composting toilet [v]
Special case [v]

"Unimproved" sanitation:
Flush/pour flush to elsewhere [v]
Pit latrine without slab [v]
Bucket [v]
Hanging toilet or hanging latrine [v]
Shared sanitation [v]
No facilities or bush or field [v]

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2 (2011): 490-497.

Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Perez-Saez et al., 2016. Climate-driven endemic cholera is modulated by human mobility in a megacity. *Advances in Water Resources*. http://dx.doi.org/10.1016/j.advwatres.2016.11.013.

WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation. "Improved and unimproved water sources and sanitation facilities." http://www.wssinfo.org/definitions-methods/watsan-categories/.

Metric: Sharing Toilet with Other Households

Indicator: Household Toilet

Factor: Utilities Disruption

Condition: Service Failure

Framework: Cholera

Metric Assigned Values:

Toilet Type	Min	Max
ShareToiletWOtherHhld, No	1.0	1.000
SharingToilet, No	1.0	1.000
1Hhld	0.7	1.000
2Hhlds	0.5	1.000
3Hhlds	0.25	1.000
4Hhlds	0.125	1.000
5Hhlds	0.0625	1.000
6Hhlds	0.0625	0.500
7Hhlds	0.0625	0.500
8Hhlds	0.0625	0.500
9Hhlds	0.0625	0.500
10plusHhlds	0.0625	0.250
Unknown	0.0625	1.000

Survey: DHS – Household

Survey Date: 2011

Other Data Sources: Ali et al. (2002, 2); Emch (1999); Giebultowicz et al. (2011); Hashizume et al. (2008); Jutla et al. (2013); Perez-Saez et al. (2016); WHO (n.d.); Kanungo et al. (2012); Fuller et al. (2014)

Logic: Ali et al. (2002, 2) clarifies sanitation data by unsafe and safe latrines. An unsafe latrine is open, thus feces can spread to contaminate nearby surface water, especially in the rainy season (Jul-Sept). Giebultowicz et al. (2011) finds that "unsanitary latrines are responsible for surface water contamination." Jutla et al. (2013) finds that poor sanitation yields a higher likelihood of a cholera epidemic. They determine that the United States rarely experiences cholera outbreak due to its robust water and sanitation infrastructure as effective prevention methods for the spread of cholera (p.602). Perez-Saez et al. (2016) reiterate that inadequate sanitation infrastructure exposes the population to cholera. Hashizume et al. (2008) found that cholera risk is higher for those using unsanitary toilets and drinking tubewell water. Kanungo et al. (2012) found that in

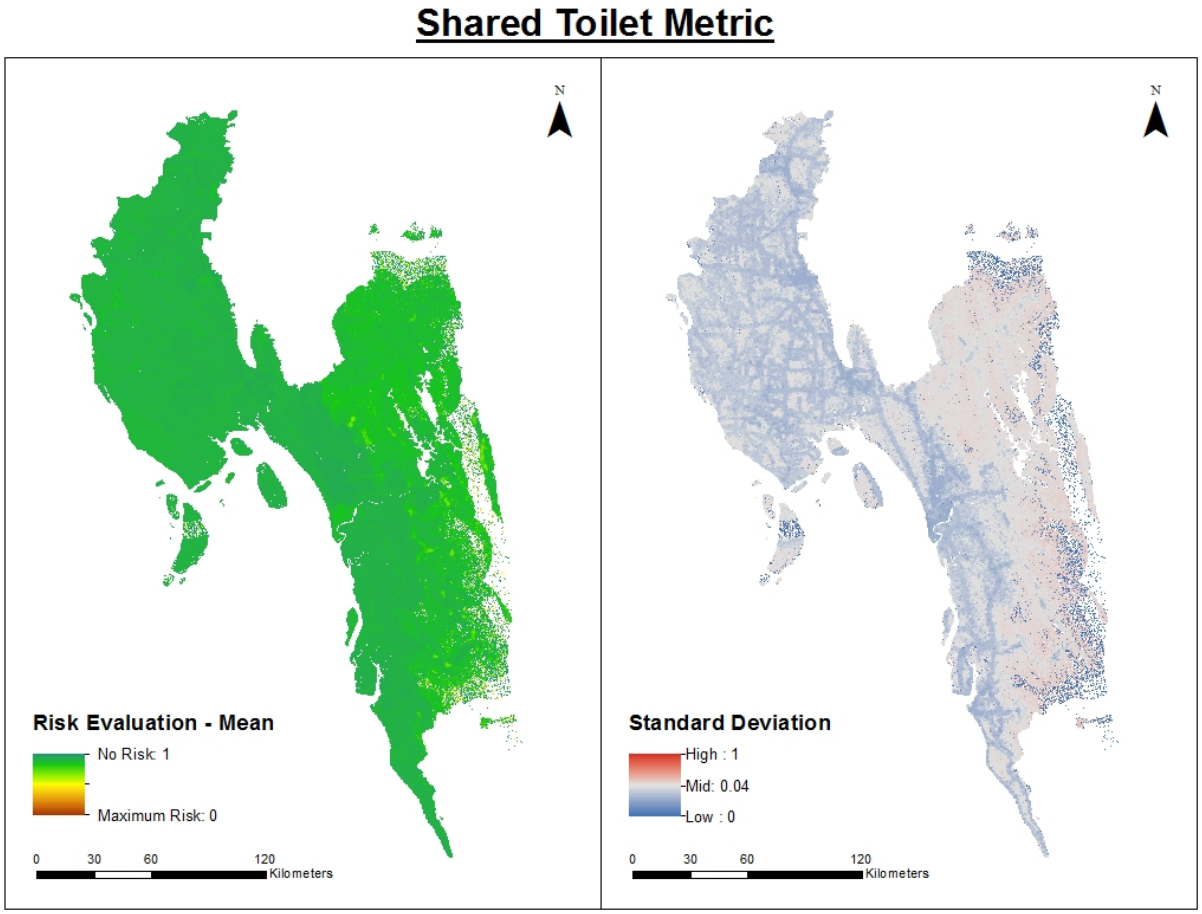
high population density Kolkata, residents live in tightly packed in homes with sewage-littered streets and share toilets and drinking water. The study reveals an average of 12 individuals in a household using safe toilet, or non-shared flush toilet, and was found to be statistically significant as a predictor of risk of cholera.

In the Kampala slums of Uganda, access to improved sanitation is a key preventive measure against diarrhea. 68% of the sample shared toilets, 11% used public toilets, and less than 1% used open defecation.

Fuller et al (2014) found that "Shared sanitation appears to be a risk factor for diarrhea although differences in socioeconomic status are important." In Bangladesh, the prevalence of diarrhea is 10.1% from the 2011 DHS with 8.6% not having access to a toilet, 37.6% use an improved toilet, 45.1% use a shared toilet facility, and 11.2% share a toilet with over five households.

Answers of "ShareToiletWOtherHhld, No" are given a minimum of 0.8 (minimal risk) and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "SharingToilet, No" are given a minimum of 0.8 (minimal risk) and a maximum value of 1.0. Answers of "1Hhld" are given a minimum of 0.7 (minimal risk) and a maximum value of 1.0. Answers of "2Hhlds" are given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 1.0. Answers of "3Hhlds" are given a minimum of 0.25 (medium risk, $½^2$) and a maximum value of 1.0. Answers of "4Hhlds" are given a minimum of 0.125 (high risk, $½^3$) and a maximum value of 1.0. Answers of "5Hhlds" are given a minimum value 0.0625 (extreme risk, $½^4$) and a maximum value of 1.0. Answers of "6Hhlds," "7Hhlds," "8Hhlds," and "9Hhlds" are given a minimum value 0.0625 (extreme risk, $½^4$) and a maximum value of 0.5 (slight risk, $½^1$). Answers of "10plusHhlds" are given a minimum value 0.0625 and a maximum value of 0.25. Answers of "Unknown" are given a minimum value of 0.0625 and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Maps will range from extreme risk to no risk.

Example realization metric map



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

Giebultowicz, Sophia, Mohammad Ali, Mohammad Yunus, and Michael Emch. "A comparison of spatial and social clustering of cholera in Matlab, Bangladesh." Health & place 17, no. 2 (2011): 490-497.

Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

Jutla, A., Whitcombe, E., Hasan, N., Haley, B., Akanda, A., Huq, A., & Colwell, R. 2013. Environmental factors influencing epidemic cholera. *The American journal of tropical medicine and hygiene*, *89*(3), 597-607.

Perez-Saez et al., 2016. Climate-driven endemic cholera is modulated by human mobility in a megacity. *Advances in Water Resources*. http://dx.doi.org/10.1016/j.advwatres.2016.11.013.

WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation. "Improved and unimproved water sources and sanitation facilities." http://www.wssinfo.org/definitions-methods/watsan-categories/.

A.4.2.2 Indicator: Water shortfalls

The HC framework calls for several metrics to quantify this indicator. The framework focuses on access to and sufficient supply of potable water. Available metrics at the household level that overlap to help predict cholera incidence are included in this indicator.

Metrics within this indicator include source of drinking water from IPUMS, where is the water source located in relation to the dwelling, additive for drinking water, and time to get to water source.

Metric weighting logic

The metrics within "Water Shortfalls" are all very important to determining access and supply of potable water and thus have high weights. Source of drinking water is the most important to water access and supply and thus the most constraining on the indicator, with a minimum and maximum of 1.0.

Metric	Weight Minimum Value	Weight Maximum Value
Source of drinking water – IPUMS	1.0	1.0
Where is water source located?	0.7	0.9
Additive for drinking water	0.5	0.75
How long does it take to get to water source?	0.5	0.75

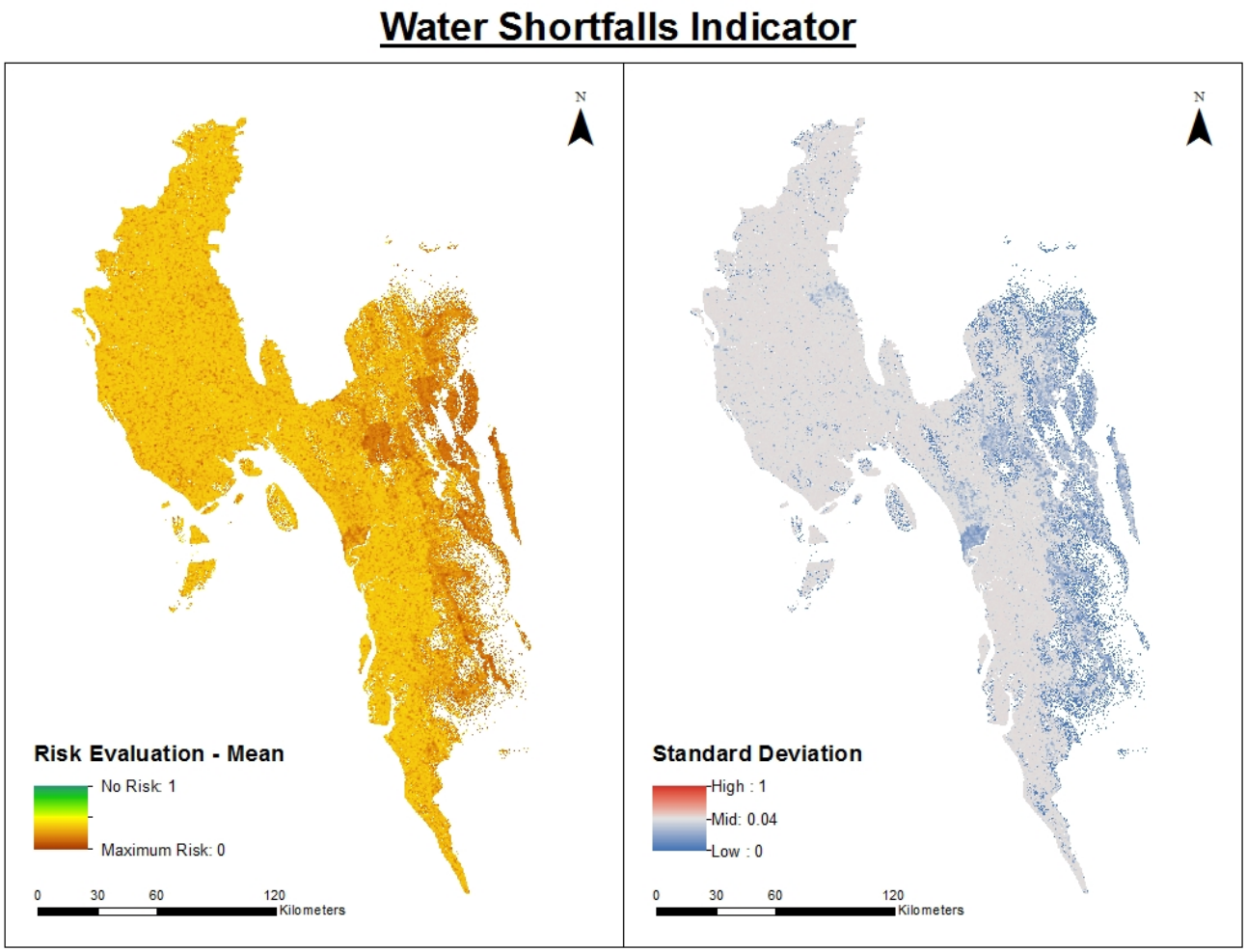
Uncertainty values

The authors believe the metrics included provide an exhaustive list of publicly available metrics that serve the indicator, but the indicator uncertainty values remain non-zero to allow for the capturing of future studies and research. We believe the amount of available quantitative data we have is exhaustive, but the addition of qualitative data could further decrease the uncertainty. Examples of additional qualitative metrics could be a question encompassing opinions on access to clean water or if any local

organizations are active in water issues. Examples of additional quantitative metrics that could decrease uncertainty are questions about different kinds of water shortfalls such as source of cooking/bathing water.

Indicator Uncertainty Min:	0.1
Indicator Uncertainty Max:	0.2

Example outcome

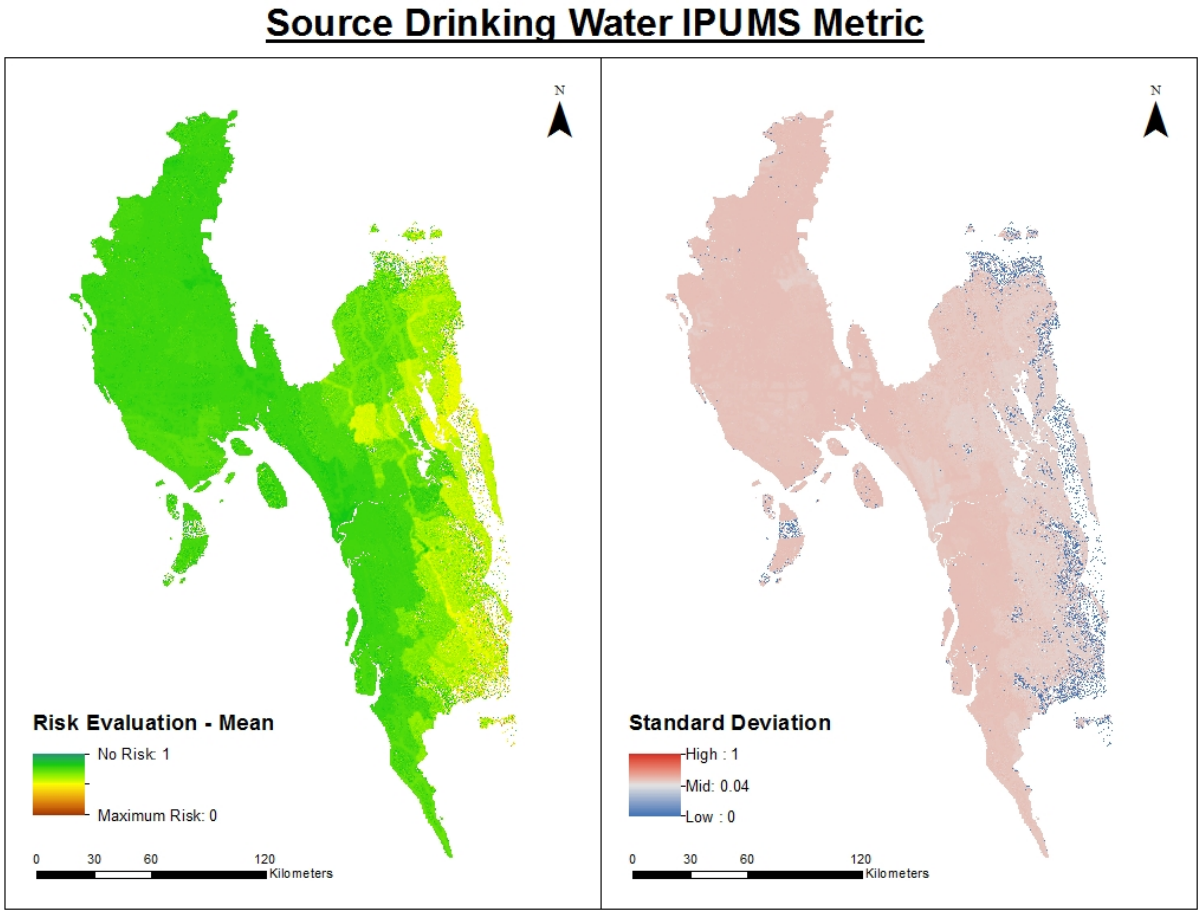


Metric: Source of Drinking Water?

Indicator:	Water Shortfalls
Factor:	Utilities Disruption
Condition:	Service Failure
Framework:	Cholera

Metric Assigned Values:	Tap (min: 0.5, max: 1.0) Tubewell (min: 0.25, max: 1.0) Other (min: 0.0625, max: 0.5)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	Jutla et al. (2013); USAID (2016)
Logic:	This metric consists of observations from the surveyor based on the water source for the surveyed household. The DHS stat compiler for the 2011 survey breaks down households using improved water sources by rural/urban residence and wealth quintile. Households using water piped into dwelling is 5.7%. 21% of urban households and 0.5% of rural households used water piped into dwelling in 2011. Across wealth: 0%, 0%, 0%, 1.1%, & 28.3% of households used water piped into dwelling in 2011. Households using a public tap/standpipe is 2.1%. 7% of urban households and 0.5% of rural households using a public tap/standpipe. Across wealth: 0.5%, 0.7%, 0.8%, 2.9%, & 6.0% of households using a public tap/standpipe. Households using a tubewell/borehole is 85.5%. 54.6% of urban households and 95.8% of rural households used a tubewell/borehole in 2011. Across wealth: 95.9%, 96.6%, 95.9%, 87.5%, & 49.5% of households used a tubewell/borehole in 2011. Thus residence and wealth are key indicators for all sources of water. Jutla et al. (2013) credits the United States' lack of cholera outbreaks to the robust water and sanitation infrastructure. This is opposed to countries around the world at risk of post-flood outbreaks such as Haiti, Pakistan, and India. Haque et al. (2013) found that outbreaks in urban Bangladesh in 2011 occurred from tap water, likely contaminated from the visible leakages in the pipes. In Grundy, Wright, & Conroy's review of household water quality in developing countries, ponds, tubewells, standpipes, shallow wells, taps, open wells, and surface water are all associated cholera. Deb et al. (1982), Spira et al. (1980) and Sengupta et al. (1995) found that tubewells are associated with cholera in both Urban and Rural areas for all ages. Answers of "Tap" are given a minimum value of 0.5 (slight risk, $\frac{1}{2}^1$) and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "Tubewell" are given a minimum value of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 1.0. Answers of "Other" are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5. Maps will range from extreme risk to no risk.

Example realization metric map



References

Deb, B. C., Sircar, B. K., Sengupta, P. G., Sen, D., Saha, M. R., & Pal, S. C. 1982. Intra-familial transmission of Vibrio cholerae biotype El Tor in Calcutta slums. *Indian journal of medical research*, *76*, 814-819.

Gundry, S., Wright, J., & Conroy, R. 2004. A systematic review of the health outcomes related to household water quality in developing countries. *Journal of water and Health*, *2*(1), 1-13.

Haque, F., Hossain, M. J., Kundu, S. K., Naser, A. M., Rahman, M., & Luby, S. P. 2013. Cholera outbreaks in urban Bangladesh in 2011. *Epidemiology (Sunnyvale, Calif.)*, *3*.

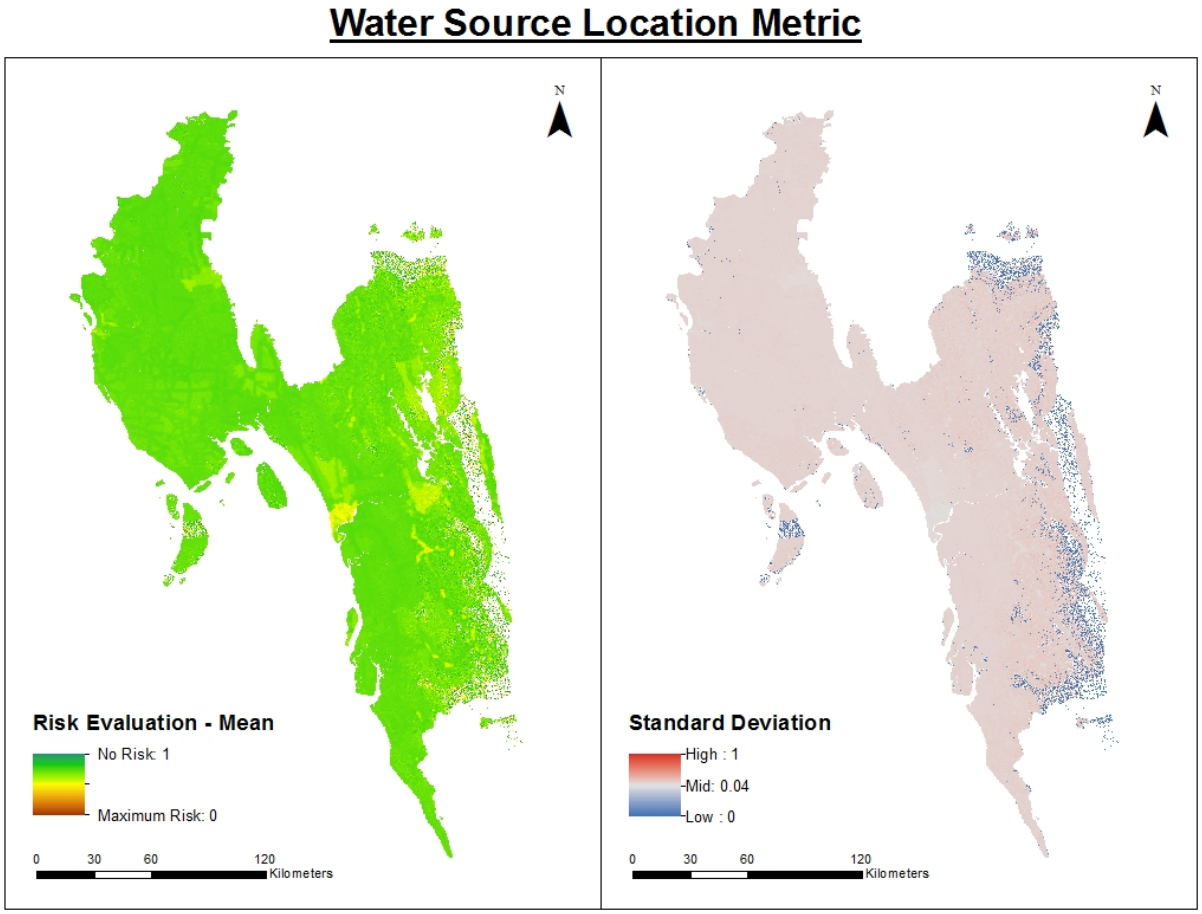
Sengupta, P. G., Sircar, B. K., Mandal, S. K., Mukhopadhyay, A. K., Nair, G. B., Gupta, D. N., & Manna, B. 1995. Epidemiology of Vibrio cholerae 0139 with special reference to intrafamilial transmission in Calcutta. *Journal of Infection*, *31*(1), 45-47.

Spira, W. M., Khan, M. U., Saeed, Y. A., & Sattar, M. A. 1980. Microbiological surveillance of intra-neighbourhood El Tor cholera transmission in rural Bangaldesh. *Bulletin of the World Health Organization*, *58*(5), 731.

Metric: Where is the water source located?

Indicator:	Water Shortfalls
Factor:	Utilities Disruption
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	In Own Dwelling (min: 1.0, max: 1.0) In Own Yard Plot (min: 0.5, max: 0.9) Elsewhere (min: 0.0625, max: 0.9)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	Jutla et al. (2013); Nsagha et al. (2015); Penrose et al. (2010); USAID (2016)
Logic:	This metric consists of answers to the question concerning the location of the household water access source from the IPUMS survey. Gundy et al. (2004) stated that, "In many developing countries, potable water is collected from communal sources which are either unimproved (e.g. unprotected wells, unprotected springs, and rivers) or improved (e.g. protected wells, boreholes and public standpipes)." Hughes et al. (1982) found that in neighborhoods with cholera infection, 44% of surface water sources were positive for cholera, opposed to 2% of surface water source in control areas. Canals, rivers, and tanks were most frequently positive. Families that used the water for drinking, cooking, or bathing were more at risk. Answers of "In Own Dwelling" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "In Own Yard Plot" are given a minimum value of 0.5 (slight risk, $½^1$) and a maximum value of 0.9 (minimal risk). Answers of "Elsewhere" are given a minimum value of 0.0625 (extreme risk, $½^4$) and a maximum value 0.9. Maps will range from extreme risk to no risk.

Example realization metric map



References

Gundry, S., Wright, J., & Conroy, R. 2004. A systematic review of the health outcomes related to household water quality in developing countries. *Journal of water and Health*, *2*(1), 1-13.

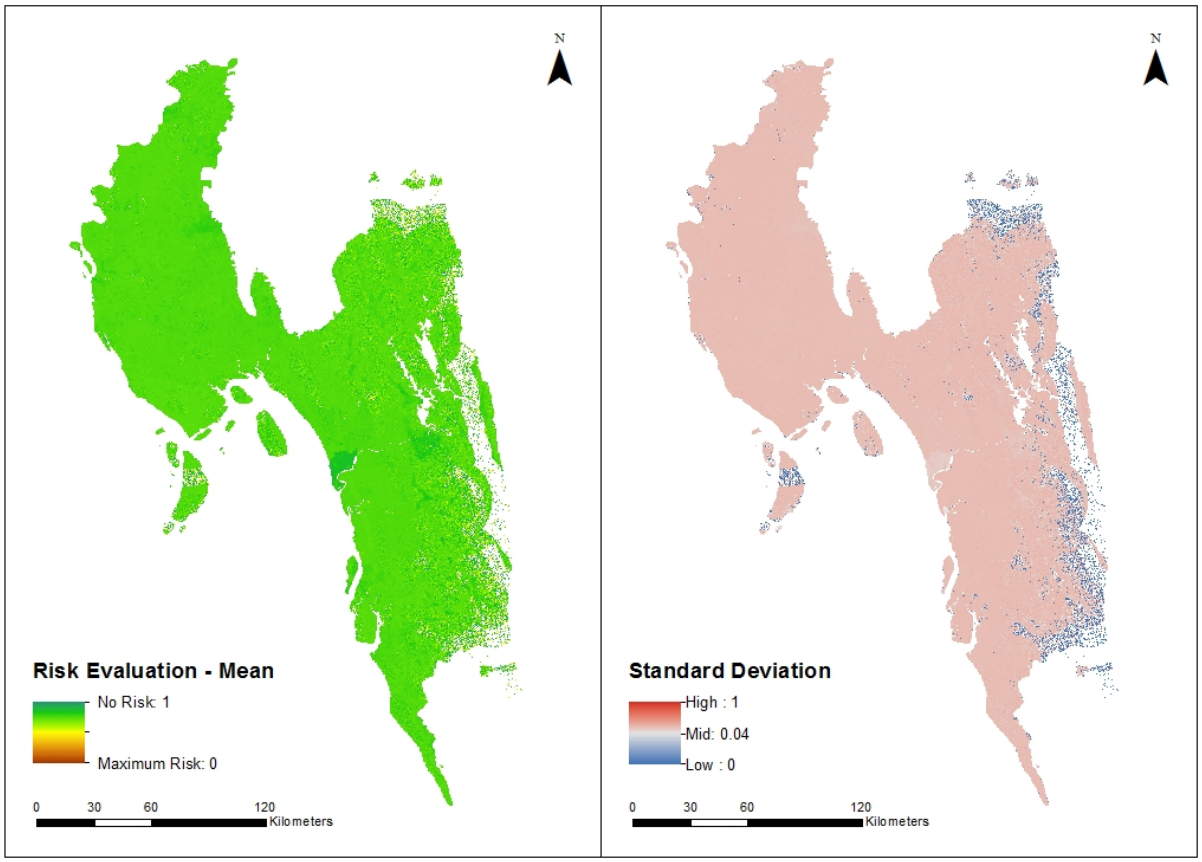
Hughes, J. M., Boyce, J. M., Levine, R. J., Khan, M., Aziz, K. M. A., Huq, M. I., & Curlin, G. T. 1982. Epidemiology of eltor cholera in rural Bangladesh: importance of surface water in transmission. *Bulletin of the World Health Organization*, *60*(3), 395.

Metric: Additive for Drinking Water

Indicator:	Water Shortfalls
Factor:	Utilities Disruption
Condition:	Service Failure
Framework:	Cholera

Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.0625, max: 1.0)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	
Logic:	Grundy et al. (2004) found that home water treatment and storage interventions reduced cholera. Mintz et al. (2001) found that sodium hypochlorite was the most effective point-of-use disinfectant as its use can reduce diarrheal illness by up to 85%. Solar disinfection is also an effective way to improve water quality inexpensively. This question consists of the question “Do you do anything to the water to make it safe to drink?” from the DHS survey. Answers of “Yes” are given both a minimum and maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of “No” are given a minimum value of 0.0625 (extreme risk, $½^4$) and a maximum value of 1.0. Maps will range from extreme risk to no risk.

Drinking Water Treated Metric



References

Gundry, S., Wright, J., & Conroy, R. 2004. A systematic review of the health outcomes related to household water quality in developing countries. *Journal of water and Health*, *2*(1), 1-13.

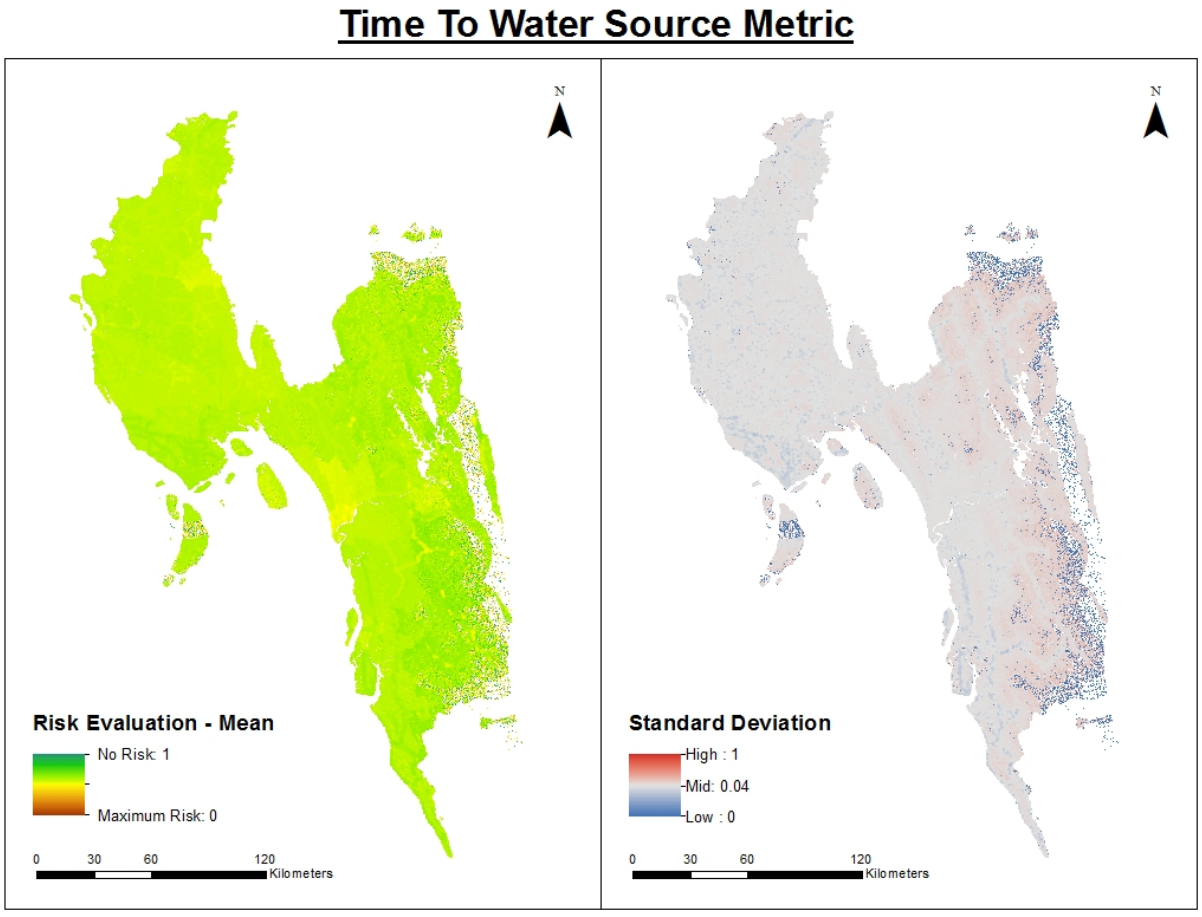
Mintz, E., Bartram, J., Lochery, P., & Wegelin, M. 2001. Not just a drop in the bucket: expanding access to point-of-use water treatment systems. *American journal of public health*, *91*(10), 1565-1570.

Metric: How Long Does it Take to Get to Water Source?

Indicator:	Water Shortfalls	
Factor:	Utilities Disruption	
Condition:	Service Failure	
Framework:	Cholera	
Metric Assigned Values:	1-7 minutes (min: 1.0, max: 1.0) 8-12 minutes (min: 0.9, max: 1.0) 13-17 minutes (min: 0.8, max: 1.0) 18-22 minutes (min: 0.75, max: 0.9)	23-32 minutes (min: 0.5, max: 0.7) 33-60 minutes (min: 0.125, max: 0.5) 61 + minutes (min: 0.0625, max: 0.25) Unknown (min: 0.0625, max: 1.0)
Survey:	IPUMS	
Survey Date:	2011	
Other Data Sources:	USAID (2016)	
Logic:	The DHS stat compiler for the 2011 Bangladesh survey breaks down households that must travel to obtain water by rural/urban residence and wealth quintile. Households without water on the premises 28.6%. 17.5% of urban households and 32.4% of rural households without water on the premises in 2011. Across wealth: 44.5%, 36.2%, 30.4%, 19.1%, & 10.4% of households without water on the premises in 2011. Households with water less than 30 minutes away round trip 24.8%. 15.6% of urban households and 27.9% of rural households with water less than 30 minutes away round trip. Across wealth: 37.2%, 31.6%, 26.5%, 17.3%, & 9.2% of households with water less than 30 minutes away round trip. Households with water more than 30 minutes away round trip is 3.7%. 1.8% of urban households and 4.4% of rural households with water more than 30 minutes away round trip in 2011. Across wealth: 7.1%, 4.4%, 3.7%, 1.9%, & 1.1% of households with water more than 30 minutes away round trip in 2011. Thus residence and wealth are key indicators for water accessibility. Answers of 1-7 minutes are given both a minimum and maximum value of 1.0 (minimal risk with no impact on risk, ½⁰). Answers of 8-12 minutes are given a minimum value of 0.9 (minimal risk) and a maximum value of 1.0. Answers of 13-17 minutes are given a minimum value of 0.8 (minimal risk) and a maximum value of 1.0.	

Answers of 18-22 minutes are given a minimum value of 0.75 (minimal risk) and a maximum value of 0.9 Answers of 23-32 minutes are given a minimum value of 0.5 (slight risk, $\frac{1}{2}^1$) and a maximum value of 0.7 (minimal risk). Answers of 33-60 minutes are given a minimum value of 0.125 (high risk, $\frac{1}{2}^3$) and a maximum value of 0.5. Answers of 61+ minutes are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.25 (medium risk, $\frac{1}{2}^2$). Answers of "Unknown" are given a minimum value of 0.0625 and a maximum value of 1.0. Maps will range from extreme risk to no risk.

Example realization metric map



A.4.2.3 Indicator: Energy deficits

The HC framework has a list of 14 recommended metrics for the "Energy Deficits" indicator, but only "Household Access to Electricity" (asked in both the IPUMS and DHS surveys) are available metrics at the household level that overlap as a predictor to cholera incidence.

Metric weighting logic

As both metrics essentially ask the same question from different surveys, they equally as effective on the indicator.

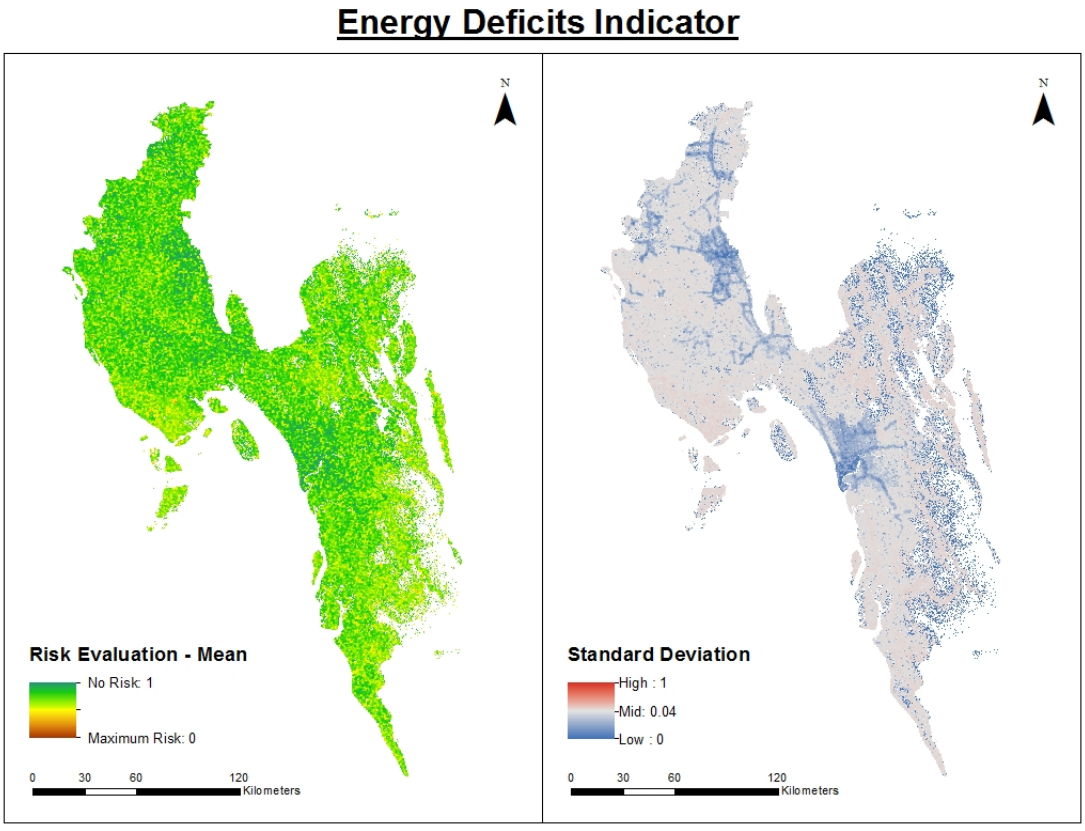
Metric	Weight Minimum Value	Weight Maximum Value
Electrical connection (IPUMS)	0.5	0.5
Has electricity? (DHS)	0.5	0.5

Uncertainty values

This indicator is given an uncertainty minimum value of 0.25 and an uncertainty maximum value of 0.35. Adding more data on the interaction of work and factors that increase risk to cholera incidence could decrease the uncertainty values.

Indicator Uncertainty Min:	0.25
Indicator Uncertainty Max:	0.35

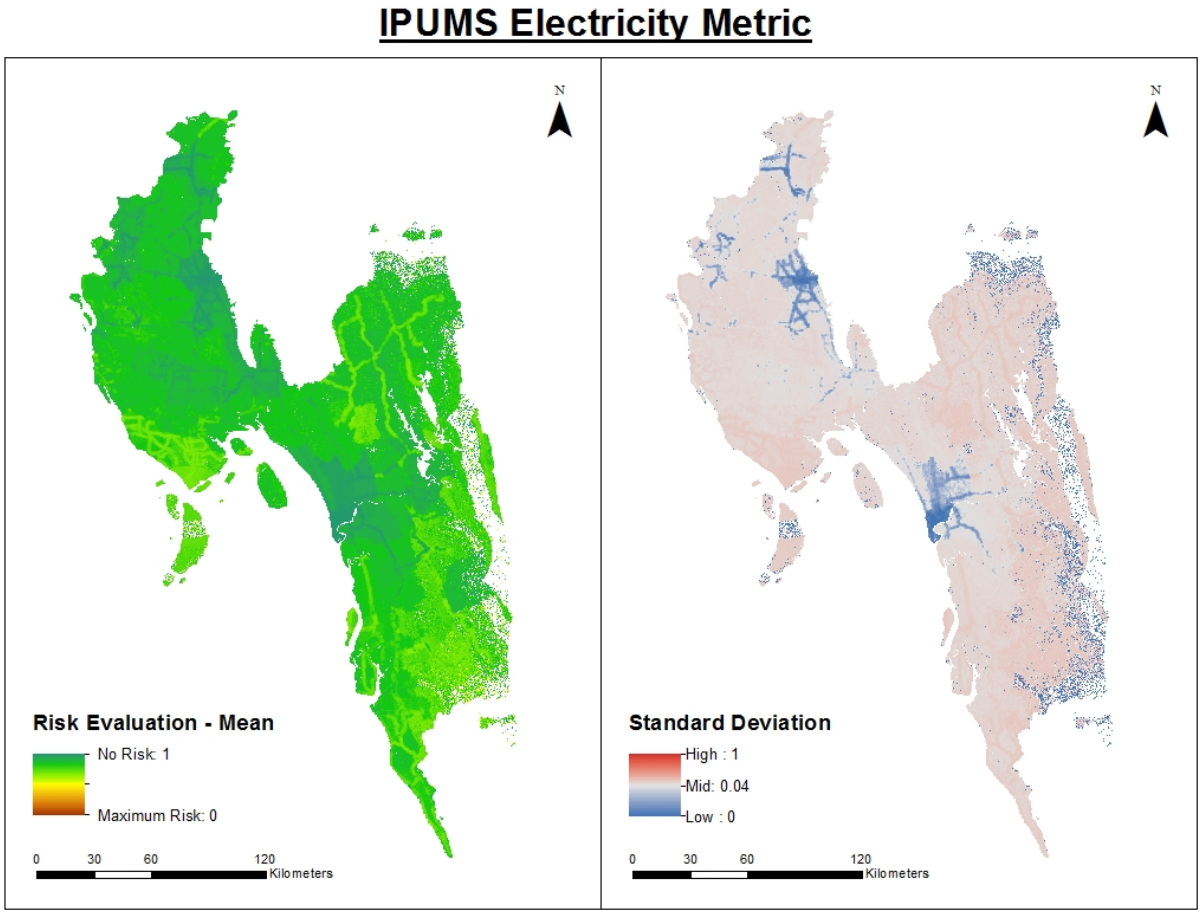
Example outcome



Metric: Household Access to Electricity (IPUMS)

Indicator:	Energy Deficits
Factor:	Utilities Disruption
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.2, max: 0.8)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	USAID (2016); Luby et al. (2011); Oparaku, O. U. (2002); Nketiah-Amponsah et al. (2009)
Logic:	The DHS stat compiler for the 2011 survey breaks down households with electricity by rural/urban residence. Households with electricity is 59.6%. 90.2% of urban households have electricity opposed to 49.3% of rural households who have electricity. Thus residence is the main indicators for electricity is residence location. Luby et al. (2011) found that households who owned items that required electricity was statistically significant in observing less diarrhea among children under 5. Oparaku, O. U. (2002) found that electrification benefited a village in Nigeria by guaranteeing water supply and an improved standard of living. Nketiah-Amponsah et al. (2009) found that electricity was statistically significant for all regressions of types of drinking water, including, piped into residence, public outdoor tap, protected well, and unprotected source. Regarding residence as an indicator for electricity, Nketiah-Amponsah et al. (2009) found that rural dwellers are 9 and 30% less likely to have access to piped water in residence and public outdoor tap respectively as compared to boreholes. This metric consists of answers to the question of whether or not there is an electrical connection within the household. “Yes” answers are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, ½^0). “No” answers are given a minimum value of 0.2 (medium risk) and a maximum value of 0.8 (minimal risk). Maps will range from medium risk to no risk.

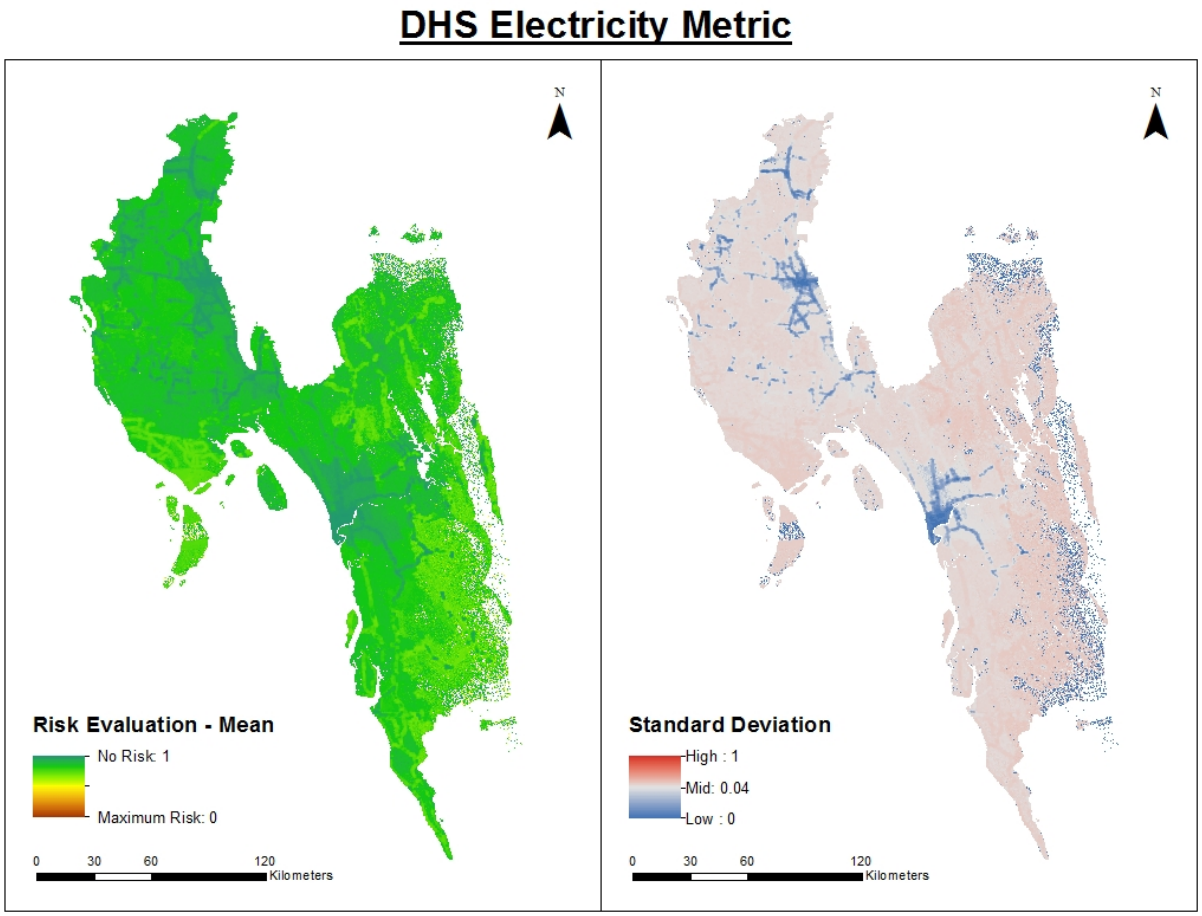
Example realization metric map



Metric: Household Access to Electricity (DHS)

Indicator:	Energy Deficits
Factor:	Utilities Disruption
Condition:	Service Failure
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.2, max: 0.8)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	USAID (2016); Luby et al. (2011); Oparaku, O. U. (2002); Nketiah-Amponsah et al. (2009)
Logic:	The DHS stat compiler for the 2011 survey breaks down households with electricity by rural/urban residence. Households with electricity is 59.6%. 90.2% of urban households have electricity opposed to 49.3% of rural households who have electricity. Thus residence is the main indicators for electricity is residence location. Luby et al. (2011) found that households who owned items that required electricity was statistically significant in observing less diarrhea among children under 5. Oparaku, O. U. (2002) found that electrification benefited a village in Nigeria by guaranteeing water supply and an improved standard of living. Nketiah-Amponsah et al. (2009) found that electricity was statistically significant for all regressions of types of drinking water, including, piped into residence, public outdoor tap, protected well, and unprotected source. Regarding residence as an indicator for electricity, Nketiah-Amponsah et al. (2009) found that rural dwellers are 9 and 30% less likely to have access to piped water in residence and public outdoor tap respectively as compared to boreholes. This metric consists of answers to the question of whether or not there is an electrical connection within the household. “Yes” answers are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). “No” answers are given a minimum value of 0.2 (medium risk) and a maximum value of 0.8 (minimal risk). Maps will range from medium risk to no risk.

Example realization metric map



A.5 Resilience deficiencies condition overview

According to the United Nations, "resilience" is defined as:

> The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.
>
> Comment: Resilience means the ability to "resile from" or "spring back from" a shock. The resilience of a community in respect to potential hazard events is determined by the degree to which the community has the necessary resources and is capable of organizing itself both prior to and during times of need." (UNISDR 2009, pg 8)

The HC framework condition accounts for the existence or lack of those resources and capabilities at both the preventive and response stages, but emphasizes the post-disaster stage (phases 4 and 5). The factors within the HC framework condition focus on three key aspects of resilience: financial investment (Insufficient Investment/Assistance), commerce and trade (Malfunctioning Commerce/Services), and infrastructure (Inadequate Construction/Reconstruction). As adjusted to the cholera framework, this condition focus on one key aspect of resilience: financial investment (Household Economic Resilience). An extensive literature review showed no evidence of other HC factors effecting cholera risk.

It should be noted that while the name implies that it measures the lack of resilience, it actually does the opposite; and still is evaluated on the 0-1 risk scale with 0 being total risk and 1 being no risk. A better name would be "Resilience Capacities" or "Resilience Capabilities."

Factor weighting logic

As there is only one factor within this condition, it is automatically the most constraining and is weighted both a minimum and maximum value of 1.0.

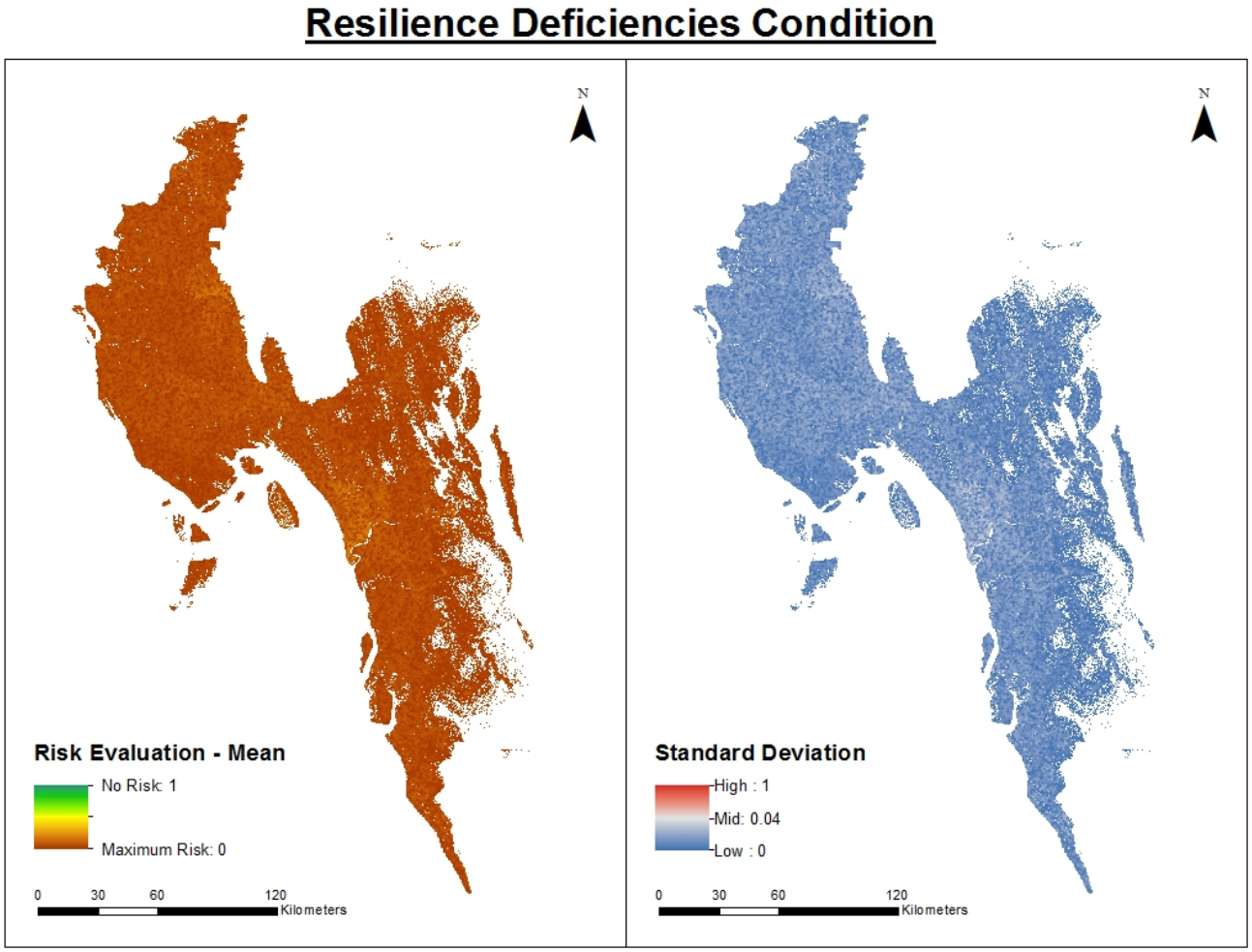
Factor	Weight Minimum Value	Weight Maximum Value
Household Economic Resilience	1.0	1.0

Uncertainty values

While the factors do encompass multiple aspects of resilience failures, these low uncertainty values reflect the potential for additional factors to be added to increase accuracy.

Condition Uncertainty Min:	0.1
Condition Uncertainty Max:	0.3

Example outcome



References

United Nations International Strategy for Disaster Reduction (UNISDR) 2009. *2009 UNISDR Terminology on Disaster Risk Reduction*. Geneva, Switzerland. May 2009.

A.5.1 Household economic resilience factor overview

This factor focuses on households' socioeconomic status as it has been found in the literature to be a key variable in predicting cholera risk (e.g. Hashizume et al., 2008; Emch et al., 2010; Emch, 1999; Ali et al., 2002 (2)). The American Psychological Association defines socioeconomic status as, "Socioeconomic status is the social standing or class of an individual or group. It is often measured as a combination of education, income and occupation. Examinations of socioeconomic status often reveal inequities in

access to resources, plus issues related to privilege, power and control" (American Psychological Association, 2017).

As education is already an indicator in the framework, it is not included in this factor.

The authors developed this factor as the HC framework does not address the socioeconomic indicators that are considered key to predicting cholera risk. These metrics represent how socioeconomic status and household ownership impact the individual's resilience.

The indicators within this factor that applies to resilience to cholera risk from a socioeconomic standpoint is Socioeconomic Status and Household Ownership.

Indicator weighting logic

The indicator Socioeconomic Status is given a minimum value of 0.75 and a maximum value of 1.0 as it is the most applicable to predict the factor and is therefore the most constraining.

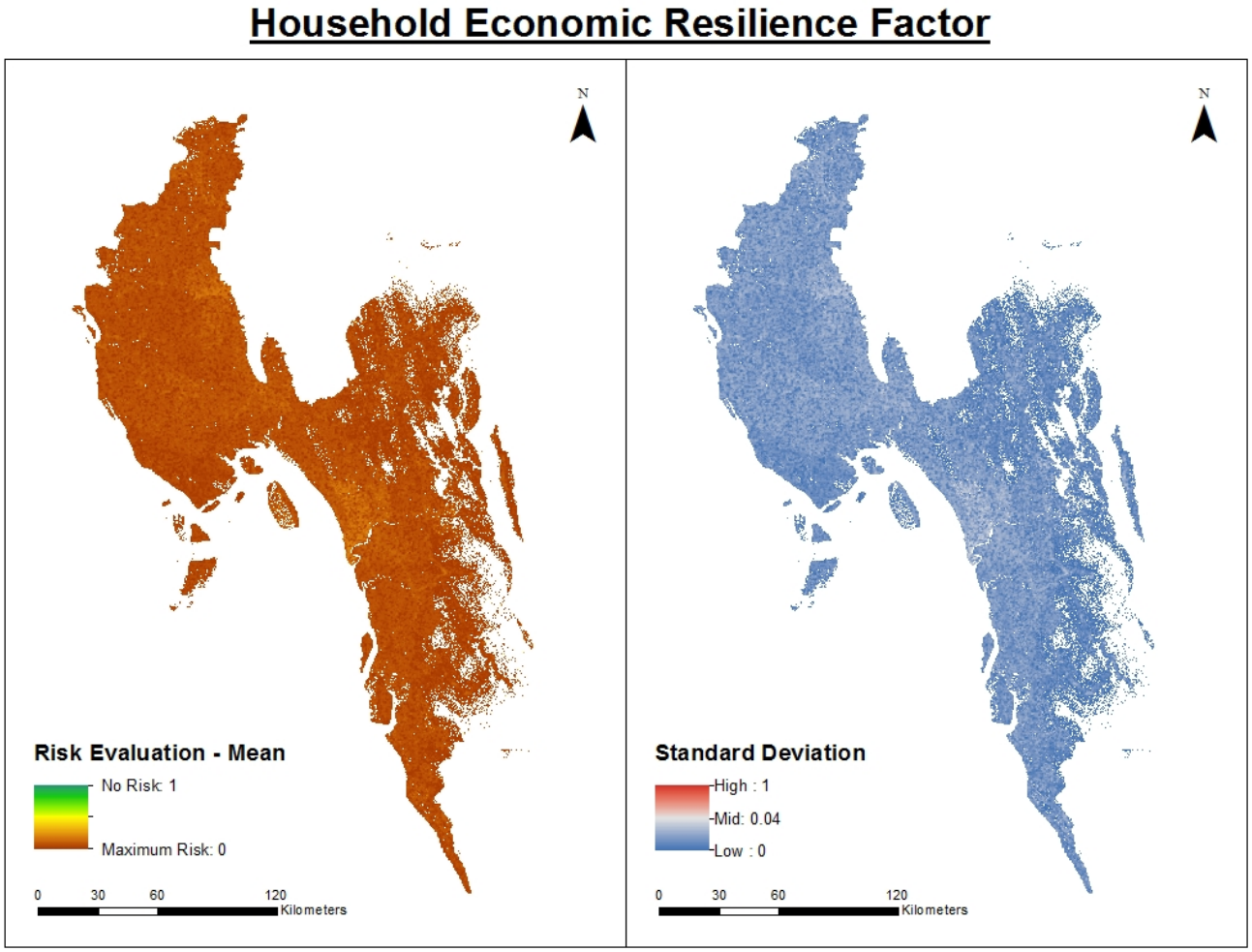
Indicator	Weight Minimum Value	Weight Maximum Value
Socioeconomic Status	0.75	1.0
Household Ownership	0.25	0.5

Uncertainty values

This factor is given a range of uncertainty values from 0.1 to 0.3 because of the ability of the existing indicators to fully address the themes of the factor.

Factor Uncertainty Min:	0.1
Factor Uncertainty Max:	0.3

Example outcome



References

Ali, M., Emch, M., Donnay, J. P., Yunus, M., & Sack, R. B. (2002, 2). Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & place*, *8*(3), 201-210.

American Psychological Association 2017. Socioeconomic Status. http://www.apa.org/topics/socioeconomic-status/.

Emch, M., Yunus, M., Escamilla, V., Feldacker, C., & Ali, M. 2010. Local population and regional environmental drivers of cholera in Bangladesh. *Environmental Health*, *9*(1), 1.

Emch, Michael. "Diarrheal disease risk in Matlab, Bangladesh." *Social science & medicine* 49, no. 4 (1999): 519-530.

Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

A.5.1.1 Indicator: Socioeconomic status

Socioeconomic status measurements can include household assets, which are encompassed in the socioeconomic status indicator. Socioeconomic status measurement can be arbitrary in the literature. Note that Emch et al. (2010) includes wall material but excludes roof material as most residents have tin roofs in the study area (Matlab, BD) whereas Hasizume et al. (2008) defined socioeconomic status as education level and roof structure for the study area of Dhaka, BD.

Metric weighting logic

The metrics within "Socioeconomic Status" (SES) are focused on reported wealth and ownership of items. The metric measuring if a household member has a bank account best represents household SES, and is therefore weighted the highest. Both the "Men Reported Wealth Index" and "Women Reported Wealth Index" metrics also provide viable information on household SES, and are weighted the second highest. Together, these metrics are the most constraining on the indicator.

It should be noted that metric maps, once produced, should be observed for quality control of weights.

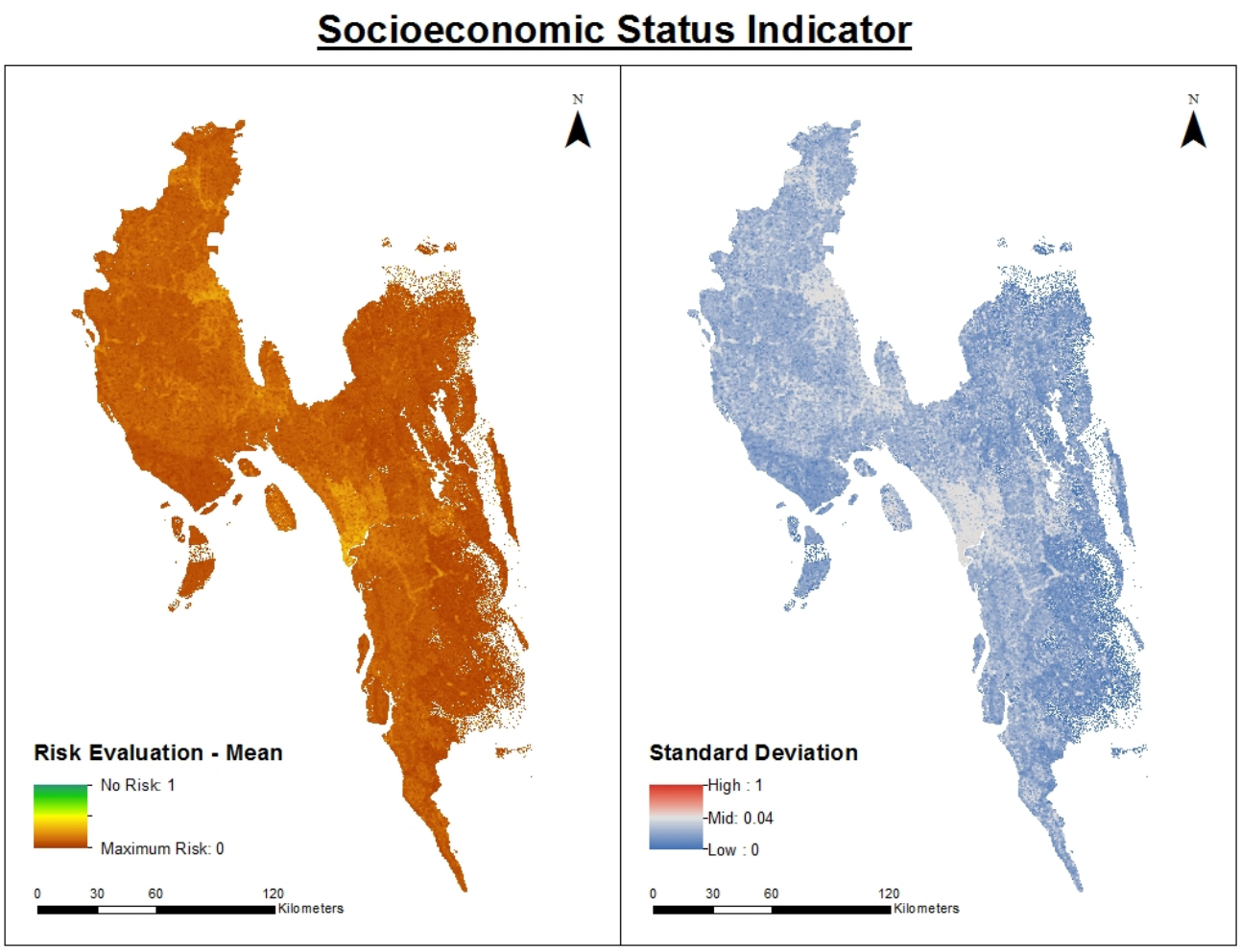
Metric	Weight Minimum Value	Weight Maximum Value
Men Reported Wealth Index	0.4	0.8
Women Reported Wealth Index	0.4	0.8
Has a Bank Account?	0.7	0.9
Owns a Radio?	0.4	0.6
Owns a TV?	0.4	0.6
Owns a Refrigerator?	0.4	0.6
Owns a Bicycle?	0.2	0.4
Owns a Motorcycle Scooter?	0.4	0.6
Owns a Telephone (Non-mobile)?	0.4	0.6
Owns a Mobile Telephone?	0.4	0.6
Owns a Watch?	0.2	0.4

Uncertainty values

This indicator is given an uncertainty minimum value of 0.1 and an uncertainty maximum value of 0.3. Adding more data on the interaction of SES and access to infrastructure at the macro-level (i.e. water quality, sanitation) could decrease the uncertainty values.

Indicator Uncertainty Min:	0.1
Indicator Uncertainty Max:	0.3

Example outcome



References

Emch, M., Yunus, M., Escamilla, V., Feldacker, C., & Ali, M. 2010. Local population and regional environmental drivers of cholera in Bangladesh. *Environmental Health*, *9*(1), 1.

Emch, Michael. "Diarrheal disease risk in Matlab, Bangladesh." *Social science & medicine* 49, no. 4 (1999): 519-530.

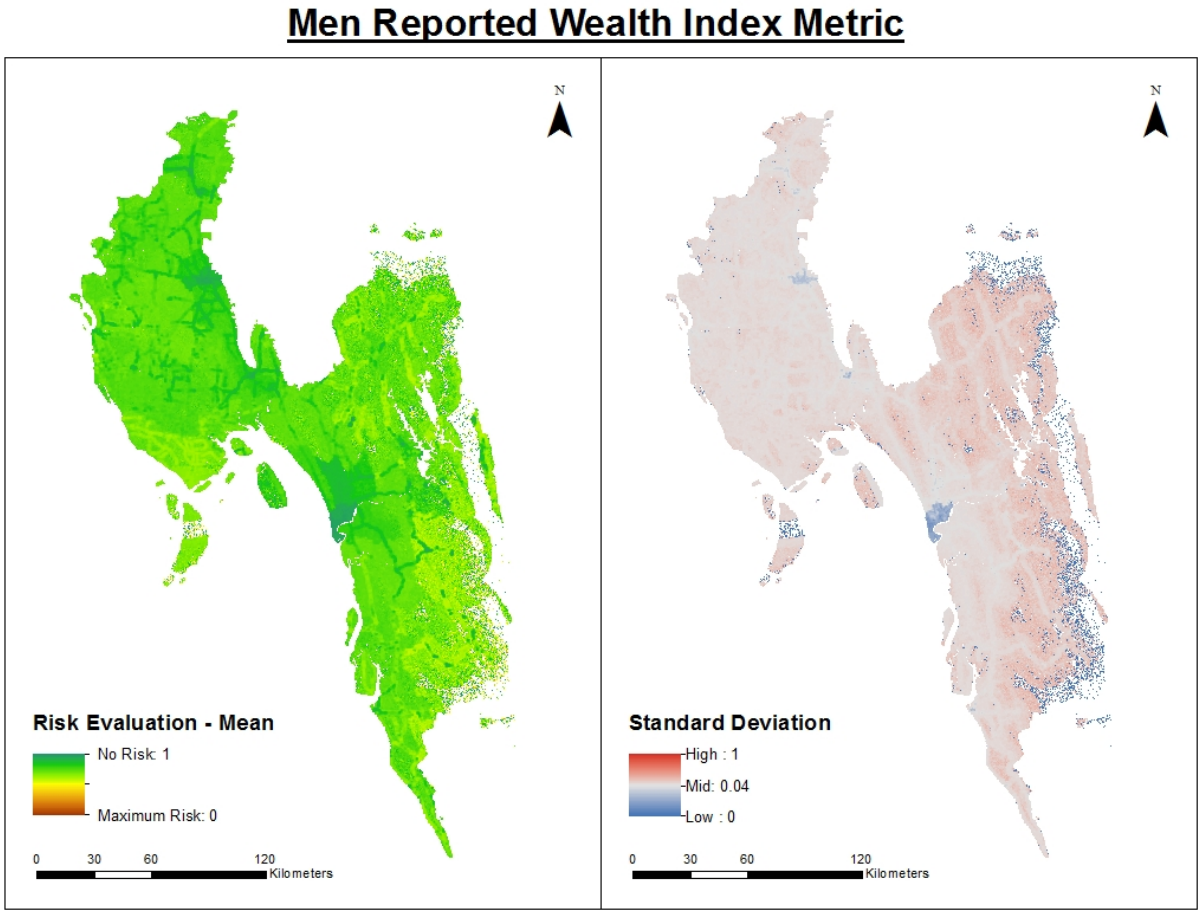
Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of Water and Health*, *6*(3), 323-332.

Metric: Men Reported Wealth Index

Indicator:	Socioeconomic Status
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	1 Poorest (min: 0.0625, max: 0.5) 2 Poorer (min: 0.25, max: 0.75) 3 Middle (min: 0.5, max: 1.0) 4 Richer (min: 0.75, max: 1.0) 5 Richest (min: 1.0, max: 1.0)
Survey:	DHS - Men
Survey Date:	2011
Other Data Sources:	Ackers et al. (1998); Gerolomo, M. & Penna, M.L. (2000); USAID (2016)
Logic:	DHS stat compiler for the 2011 survey results from Bangladesh breaks down variable aggregates by wealth quintile. It reports that in 2011, the under-five mortality rate was 78,78, 58, 58, & 38 respectively. Regarding treatment for diarrhea via either ORS or RHF, from 2008-2011, interestingly, 82.3% of the poorest people, 80.7% of poorer people, 69.1% of middle people, 72.8% of richer people, and 81% of richest people were treated. In 2011, only 13.6% of the poorest women had a secondary education or higher compared to 27.3% of poorer women, 41.3% of middle women, 52.5% of richer women, and 72% of richest women. Furthermore, for women who are literate 35.7% of the lowest were, 51.6% of poorer women were literate, 51% of middle women, 66.4% of richer women, and 80.4% of the richest women were literate in 2011. Ackers et al (1998) found that in Latin America, "the gross national product per capita (above US $2000) was weakly and negatively correlated with cholera cumulative incidence rates." Gerolomo and Penna (2000) found that for the 1992 cholera outbreak in Brazil, "the proportion of households with an income of less than or equal to the minimum wage revealed a positive association with cholera incidence rates with statistically significant regression coefficients." Respondents within the lowest quintile ("Poorest") are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Respondents within the fourth quintile ("Poorer") are given a minimum value of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.75 (minimal risk). Respondents within the third quintile ("Middle") are given a minimum value of 0.5 and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Respondents within the

second quintile (“Richer”) are given a minimum value of 0.75 and a maximum value of 1.0. Respondents within the first quintile (“Richest”) are given both a minimum and maximum value of 1.0. Maps will range from extreme risk to no risk.

Example realization metric map

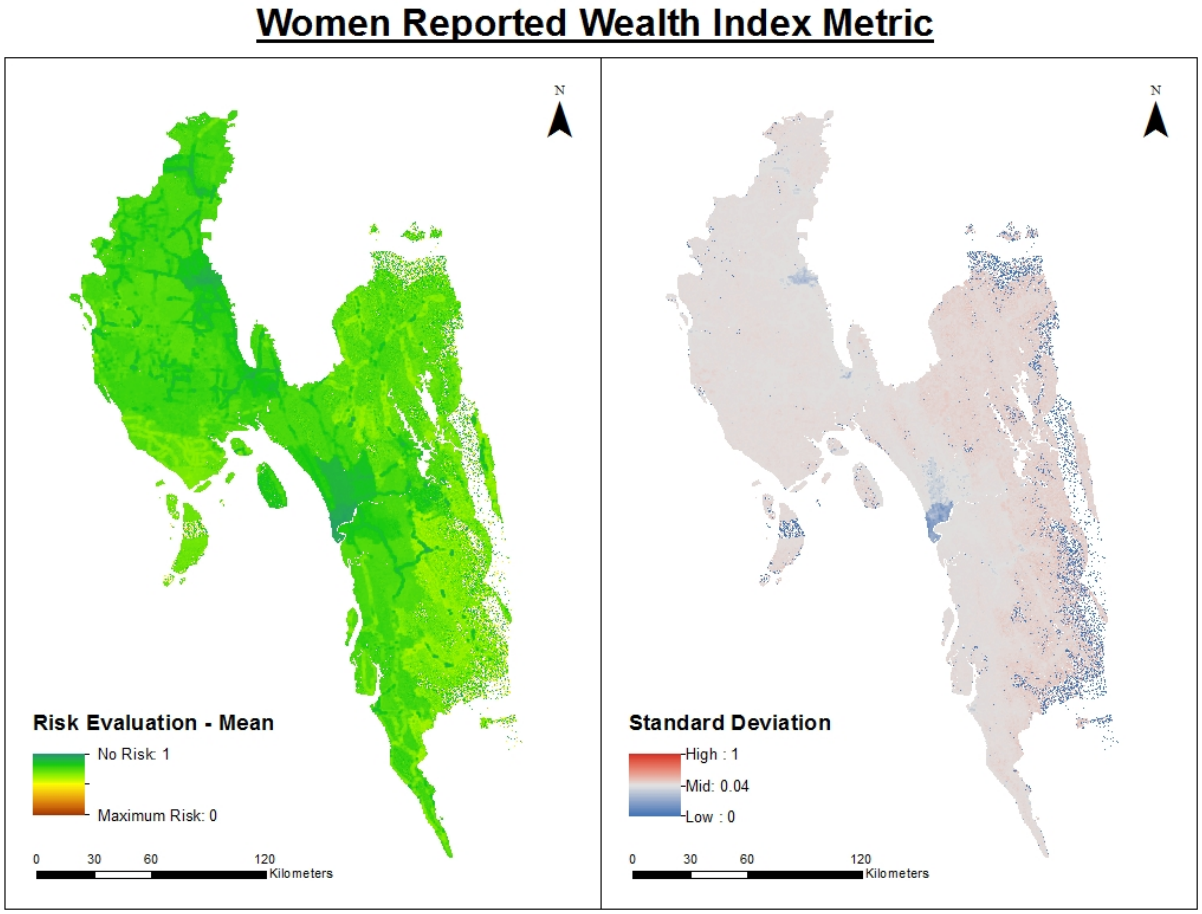


Metric: Women Reported Wealth Index

Indicator:	Socioeconomic Status
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	1 Poorest (min: 0.0625, max: 0.5) 2 Poorer (min: 0.25, max: 0.75) 3 Middle (min: 0.5, max: 1.0) 4 Richer (min: 0.75, max: 1.0) 5 Richest (min: 1.0, max: 1.0)

Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	Ackers et al. (1998); Gerolomo, M. & Penna, M.L. (2000); USAID (2016)
Logic:	DHS stat compiler for the 2011 survey results from Bangladesh breaks down variable aggregates by wealth quintile. It reports that in 2011, the under-five mortality rate was 78,78, 58, 58, & 38 respectively. Regarding treatment for diarrhea via either ORS or RHF, from 2008-2011, interestingly, 82.3% of the poorest people, 80.7% of poorer people, 69.1% of middle people, 72.8% of richer people, and 81% of richest people were treated. In 2011, only 13.6% of the poorest women had a secondary education or higher compared to 27.3% of poorer women, 41.3% of middle women, 52.5% of richer women, and 72% of richest women. Furthermore, for women who are literate 35.7% of the lowest were, 51.6% of poorer women were literate, 51% of middle women, 66.4% of richer women, and 80.4% of the richest women were literate in 2011. Ackers et al (1998) found that in Latin America, "the gross national product per capita (above US $2000) was weakly and negatively correlated with cholera cumulative incidence rates." Gerolomo and Penna (2000) found that for the 1992 cholera outbreak in Brazil, "the proportion of households with an income of less than or equal to the minimum wage revealed a positive association with cholera incidence rates with statistically significant regression coefficients." Respondents within the lowest quintile ("Poorest") are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Respondents within the fourth quintile ("Poorer") are given a minimum value of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.75 (minimal risk). Respondents within the third quintile ("Middle") are given a minimum value of 0.5 and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Respondents within the second quintile ("Richer") are given a minimum value of 0.75 and a maximum value of 1.0. Respondents within the first quintile ("Richest") are given both a minimum and maximum value of 1.0. Maps will range from extreme risk to no risk.

Example realization metric map



Metric: Has a Bank Account?

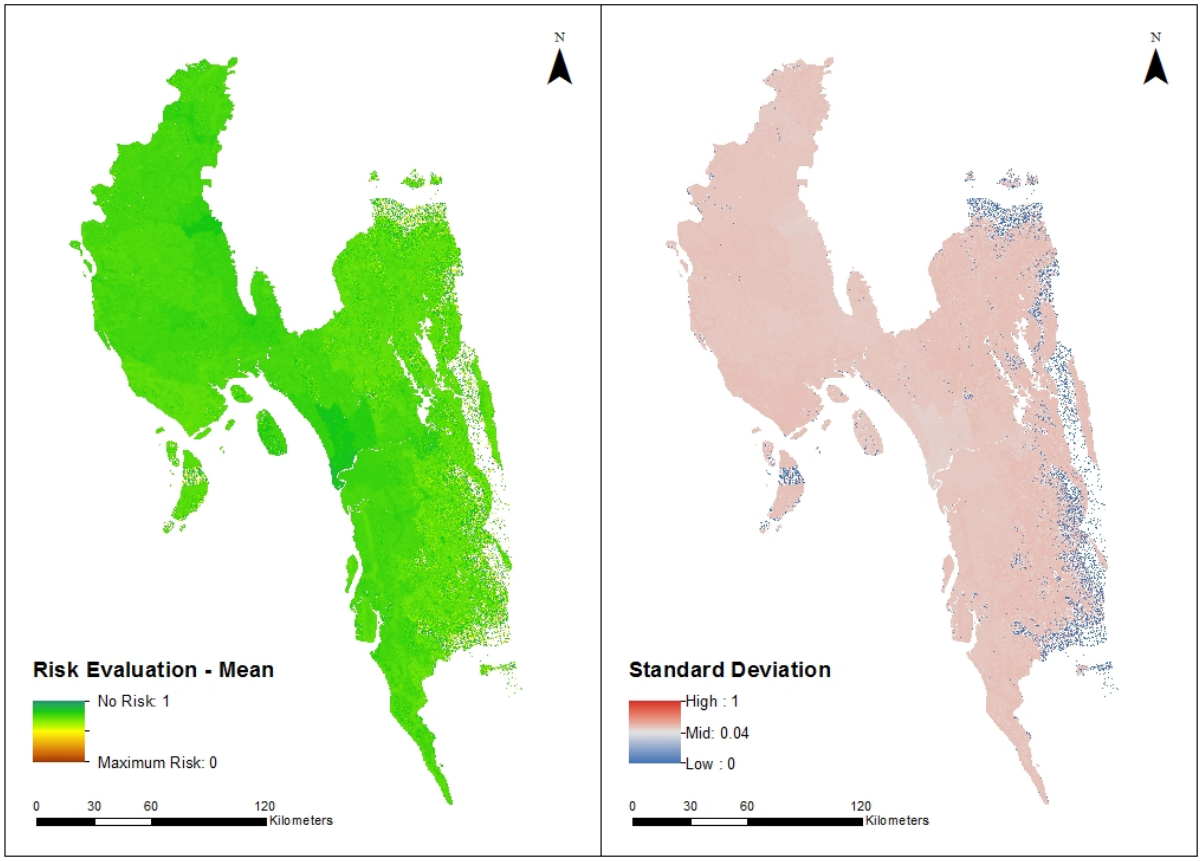
Indicator:	Socioeconomic Status
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.0625, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Psaki et al (2014)
Logic:	This question consists of asking respondents whether or not any household member has a bank account.

Psaki et al (2014) studied how various SES indicators in multiple countries (including Bangladesh, for which they used Dhaka as a study region) affected stunted growth in children, and found household possession of a bank account to be the second most important variable in predicting height-for-age Z-score, based on the random forests approach. Children with stunted growth could be at higher risk for contracting cholera.

Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "No" are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map

Has Bank Account Metric

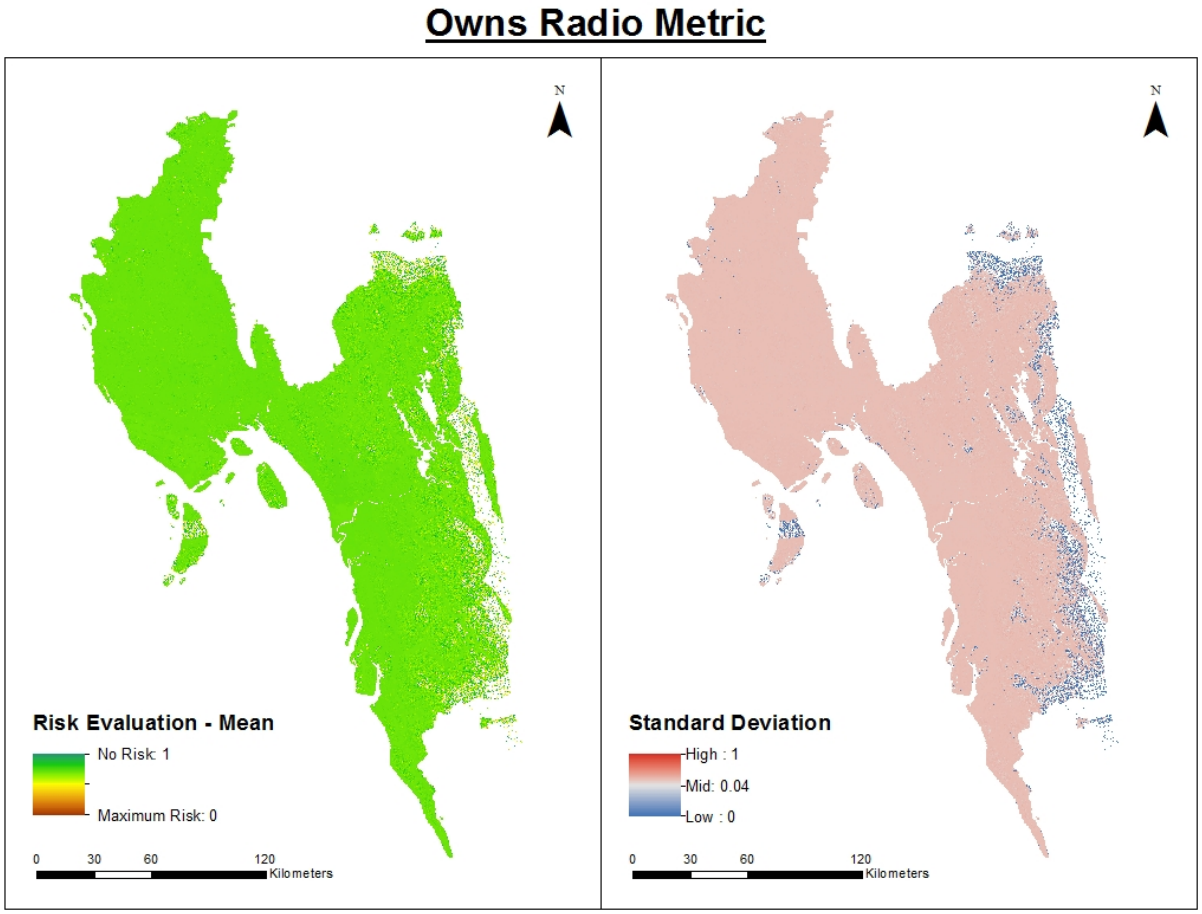


Metric: Own Radio?

Indicator:	Socioeconomic Status
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera

Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.0625, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Penrose et al. (2010); USAID (2016)
Logic:	DHS stat compiler for the 2011 survey results from Bangladesh breaks down socioeconomic indicators such as radio ownership by urban/rural residence. 8.2% of households owned a radio in 2011. 6.9% of urban households possessed a radio, while 8.7% of rural households possessed a radio in 2011. Penrose et al. (2010)'s model suggests that there is "close to a fifty percent decrease in cholera incidence in wards where informal residents had minimally improved income levels, as measured by ownership of a radio or CD player on average, in comparison to wards where informal residents did not own any items about which they were asked." Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "No" are given a minimum value of 0.0625 (extreme risk, $½^4$) and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map



Metric: Own TV?

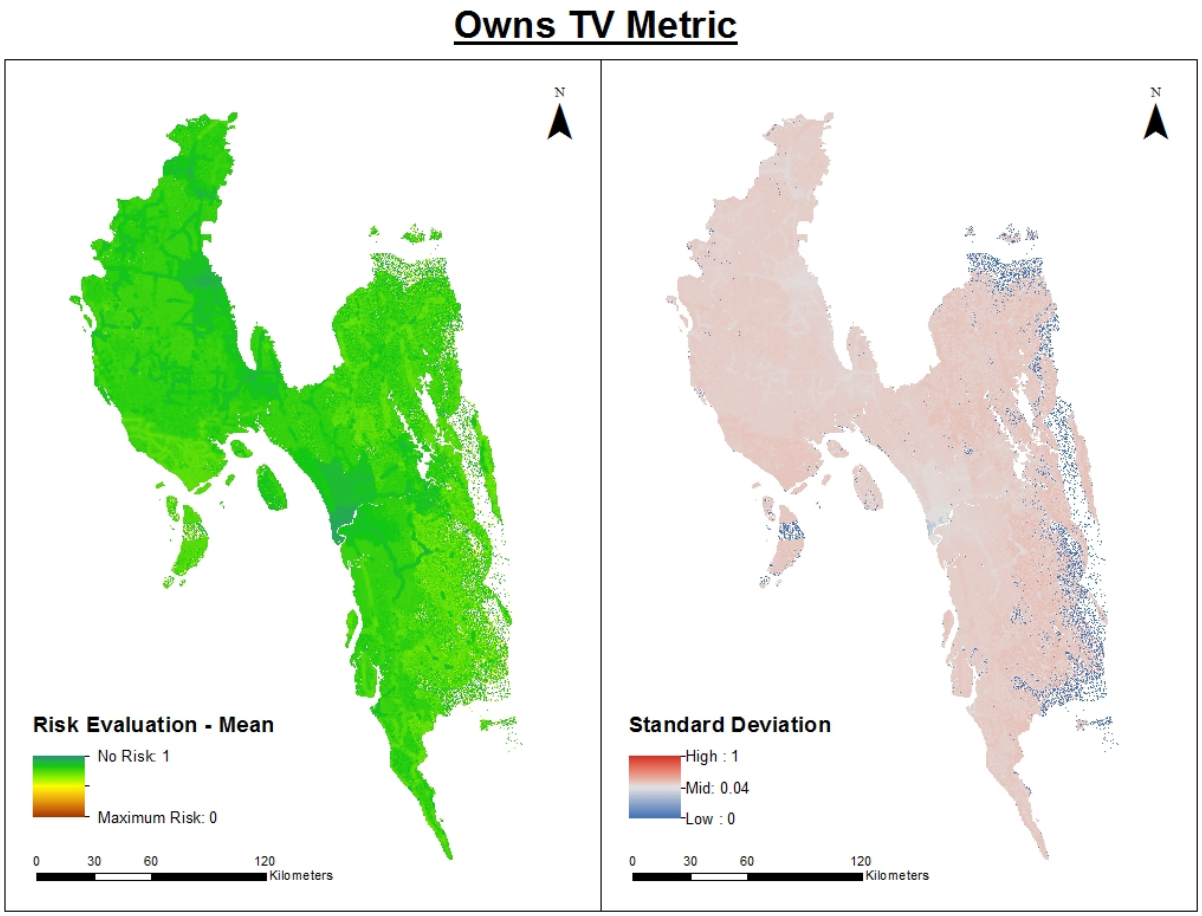
Indicator:	Socioeconomic Status
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.0625, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Penrose et al. (2010); USAID (2016)
Logic:	DHS stat compiler for the 2011 survey results from Bangladesh breaks down socioeconomic indicators such as TV ownership by urban/rural residence. 39.9% of households owned a TV in 2011. 70.2% of urban

households possessed a TV, while 29.8% of rural households possessed a TV in 2011.

Penrose et al. (2010)'s model suggests that there is "close to a fifty percent decrease in cholera incidence in wards where informal residents had minimally improved income levels, as measured by ownership of a radio or CD player on average, in comparison to wards where informal residents did not own any items about which they were asked."

Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "No" are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map

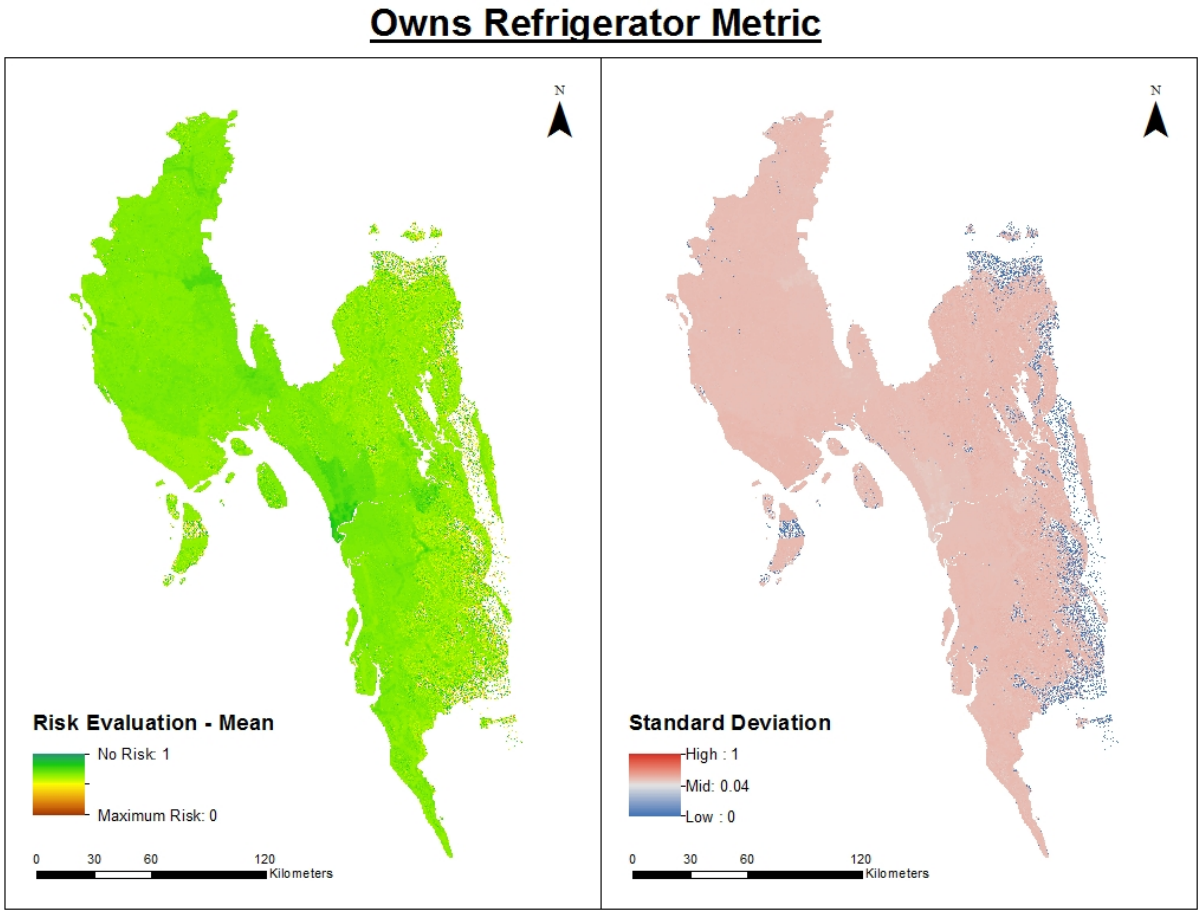


Metric: Own Refrigerator?

Indicator:	Socioeconomic Status
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera

Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.0625, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Penrose et al. (2010); USAID (2016); Psaki et al (2014)
Logic:	DHS stat compiler for the 2011 survey results from Bangladesh breaks down socioeconomic indicators such as refrigerator ownership by urban/rural residence. 13.5% of households owned a refrigerator in 2011. 35.6% of urban households possessed a refrigerator, while 6.2% of rural households possessed a refrigerator in 2011. Penrose et al. (2010)'s model suggests that there is "close to a fifty percent decrease in cholera incidence in wards where informal residents had minimally improved income levels, as measured by ownership of a radio or CD player on average, in comparison to wards where informal residents did not own any items about which they were asked." Psaki et al (2014) found that owning a refrigerator was the fourth most important variable in predicting height-for-age Z-score, based on the random forests approach. Children with stunted growth could be at higher risk for contracting cholera. Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "No" are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map



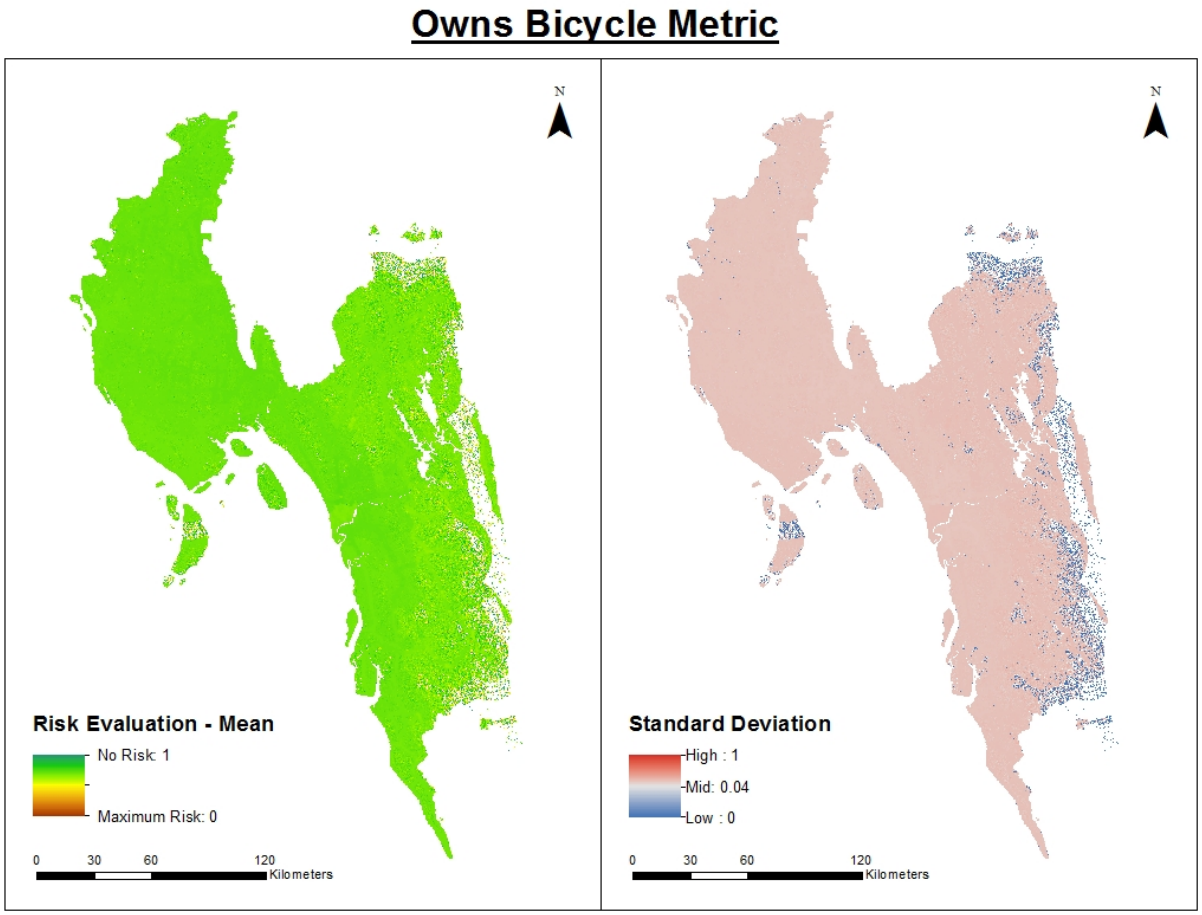
Metric: Own Bicycle?

Indicator:	Socioeconomic Status
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.0625, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Penrose et al. (2010)
Logic:	Penrose et al. (2010)'s model suggests that there is "close to a fifty percent decrease in cholera incidence in wards where informal residents had minimally improved income levels, as measured by ownership of a

radio or CD player on average, in comparison to wards where informal residents did not own any items about which they were asked."

Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "No" are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map

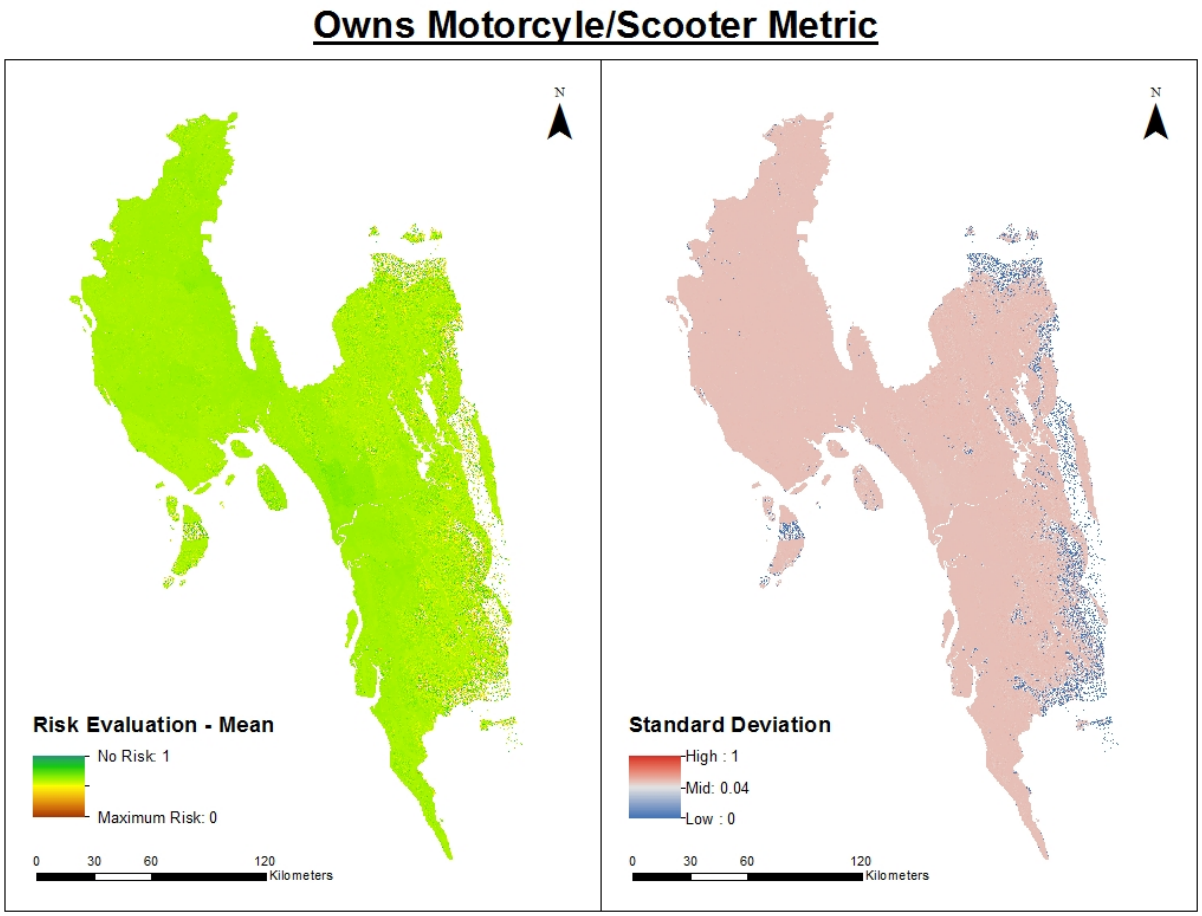


Metric: Own Motorcycle Scooter?

Indicator:	Socioeconomic Status
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.0625, max: 1.0)

Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Penrose et al. (2010);
Logic:	Penrose et al. (2010)'s model suggests that there is "close to a fifty percent decrease in cholera incidence in wards where informal residents had minimally improved income levels, as measured by ownership of a radio or CD player on average, in comparison to wards where informal residents did not own any items about which they were asked." Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "No" are given a minimum value of 0.0625 (extreme risk, $½^4$) and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

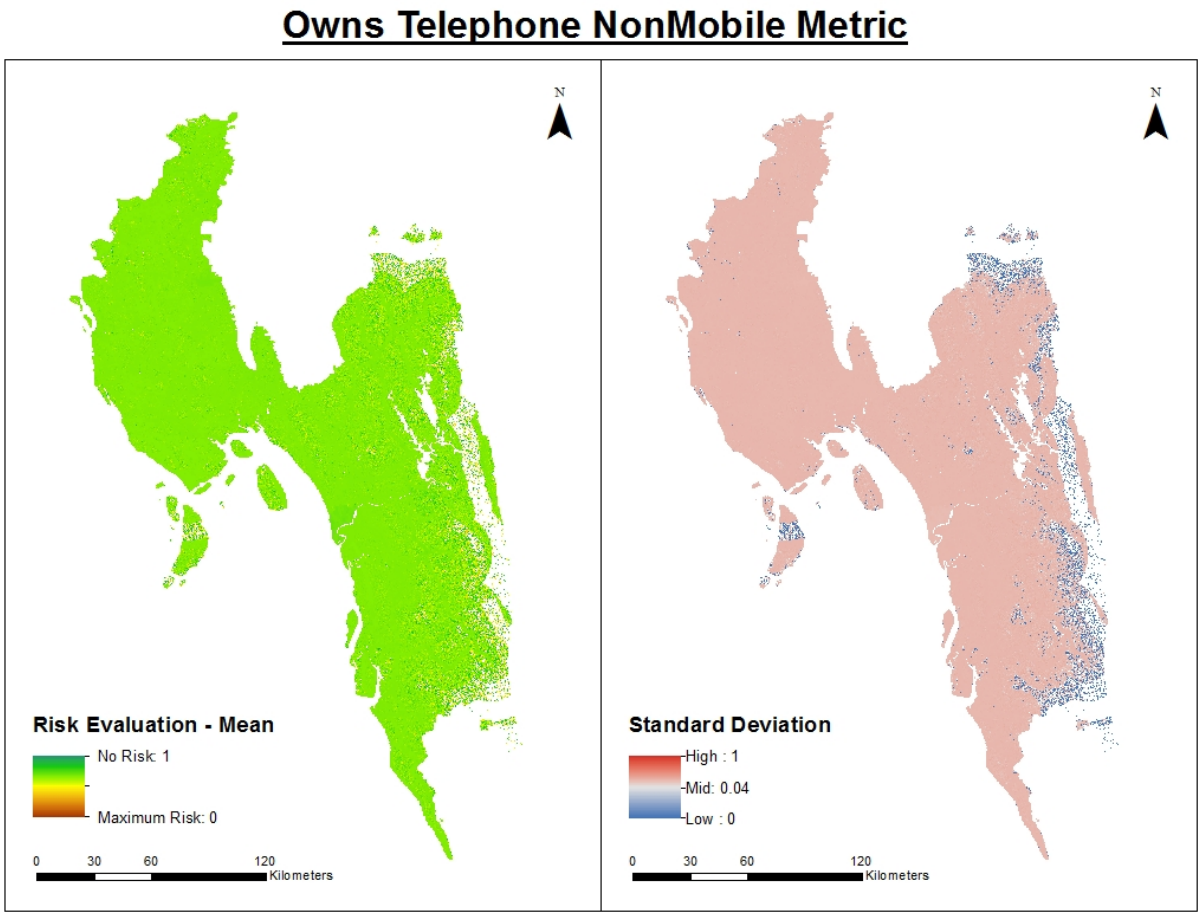
Example realization metric map



Metric: Own Telephone – Non-mobile?

Indicator:	Socioeconomic Status
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.0625, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Penrose et al. (2010); USAID (2016)
Logic:	DHS stat compiler for the 2011 survey results from Bangladesh breaks down socioeconomic indicators such as telephone ownership by urban/rural residence. 2.1% of households owned a telephone in 2011. 7.6% of urban households possessed a telephone, while 0.3% of rural households possessed a telephone in 2011. The model by Penrose et al. (2010) suggests that there is "close to a fifty percent decrease in cholera incidence in wards where informal residents had minimally improved income levels, as measured by ownership of a radio or CD player on average, in comparison to wards where informal residents did not own any items about which they were asked." Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of "No" are given a minimum value of 0.0625 (extreme risk, $½^4$) and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map



Metric: Own Mobile Telephone?

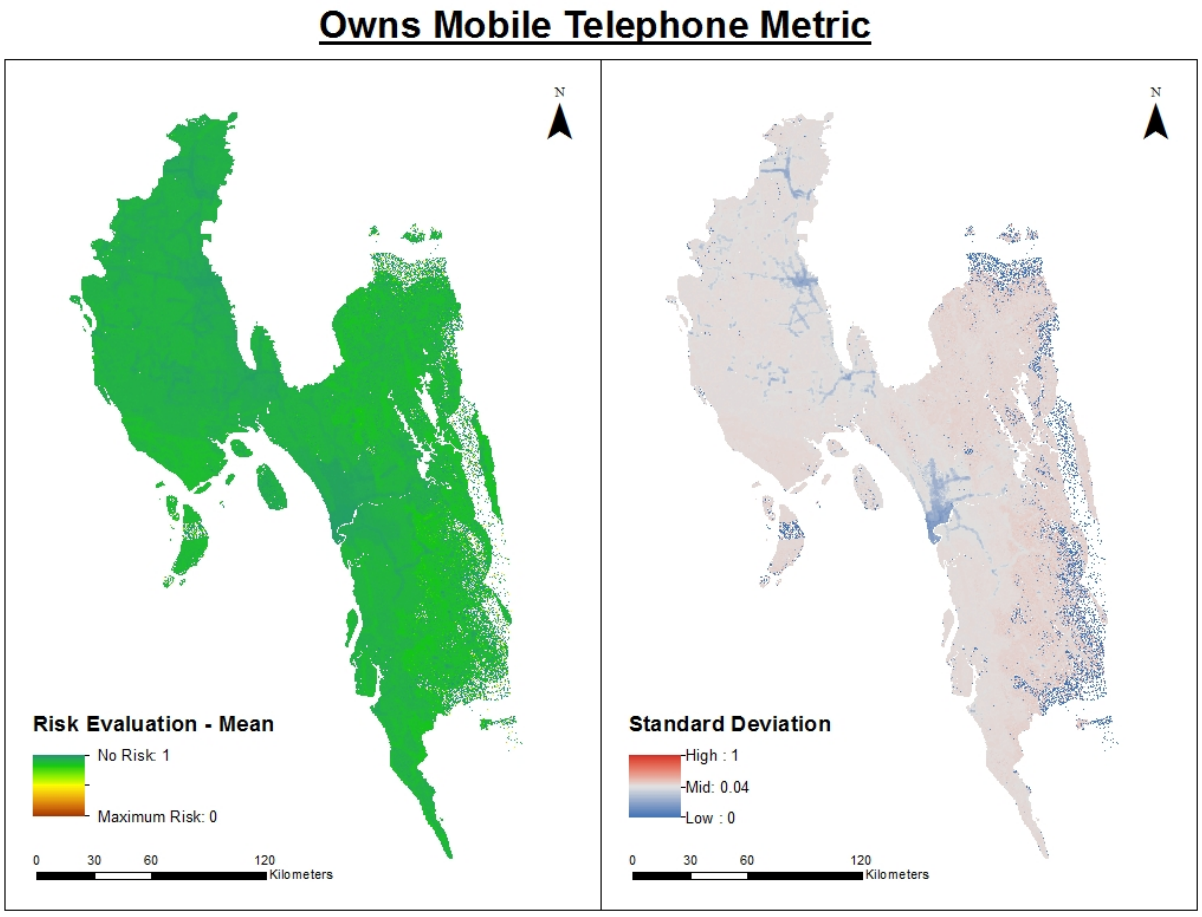
Indicator:	Socioeconomic Status
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.0625, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Penrose et al. (2010); USAID (2016)
Logic:	DHS stat compiler for the 2011 survey results from Bangladesh breaks down socioeconomic indicators such as mobile telephone ownership by urban/rural residence. 78.4% of households owned a mobile telephone

in 2011. 89.2% of urban households possessed a mobile telephone, while 74.8% of rural households possessed a mobile telephone in 2011.

Penrose et al. (2010)'s model suggests that there is "close to a fifty percent decrease in cholera incidence in wards where informal residents had minimally improved income levels, as measured by ownership of a radio or CD player on average, in comparison to wards where informal residents did not own any items about which they were asked."

Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "No" are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map

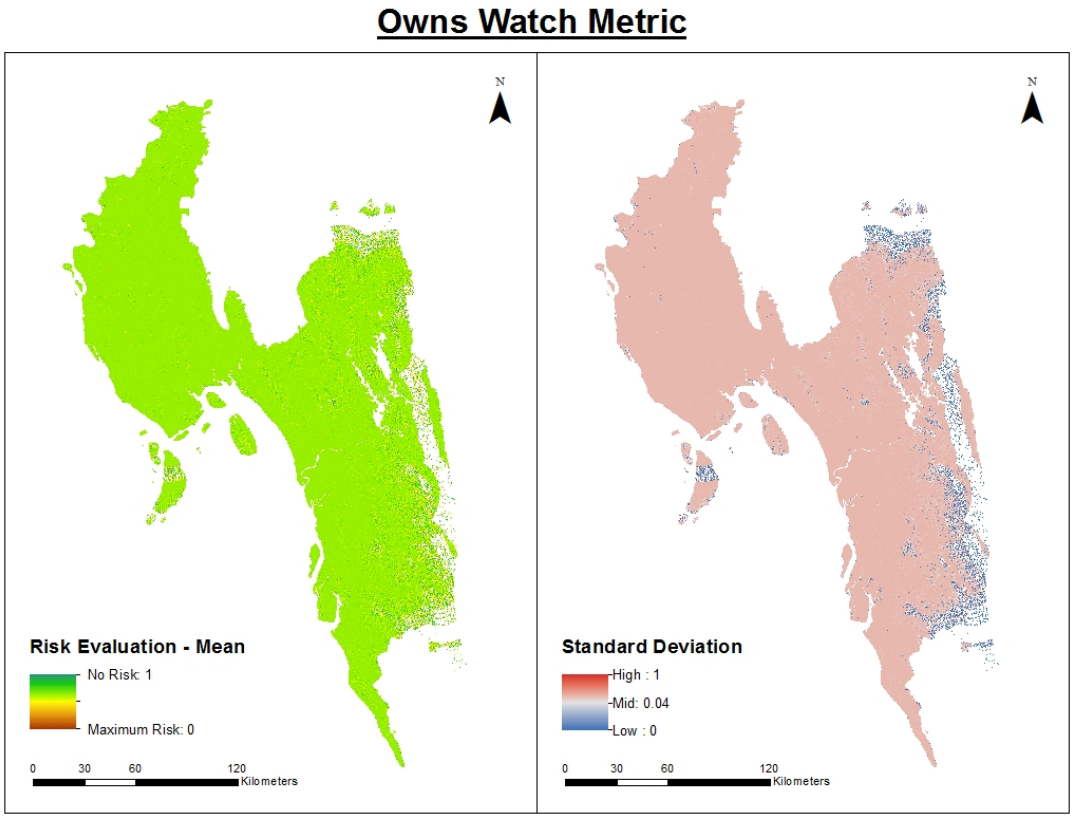


Metric: Own Watch?

Indicator:	Socioeconomic Status
Factor:	Household Economic Resilience

Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.0625, max: 0.9)
Survey:	DHS - Household
Survey Date:	2011
Other Data Sources:	Penrose et al. (2010)
Logic:	Penrose et al. (2010)'s model suggests that there is "close to a fifty percent decrease in cholera incidence in wards where informal residents had minimally improved income levels, as measured by ownership of a radio or CD player on average, in comparison to wards where informal residents did not own any items about which they were asked." Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "No" are given a minimum value of 0.0625 (extreme risk, $\frac{1}{2}^4$) and a maximum value of 0.9 (minimal risk). Maps will range from extreme risk to no risk.

Example realization metric map



A.5.1.2 Indicator: Household ownership

This indicator focuses on ownership of household and land. Owning a home and/or land can correlate with a higher socioeconomic status, and therefore a lower risk of contracting cholera. Colombara et al (2014) found that cholera patients were less likely to be homeowners (40% vs. 73%). Metrics include the ownerships of agricultural land, of land in general, whether homes/land are owned alone or jointly, and whether homes are owned or rented.

Metric weighting logic

According to the 2011 DHS survey, ownership of a homestead is more common than ownership of other land (94% vs. 47%). As such, the metrics which measure whether a man or a woman owns a home are weighted the highest. These metrics are the most constraining on this indicator. As the metric measuring the ownership of agricultural land (from the DHS survey) is the most specific and the least supported by literature as an indicator of cholera, it is weighted the lowest.

It should be noted that metric maps, once produced, should be observed for quality control of weights.

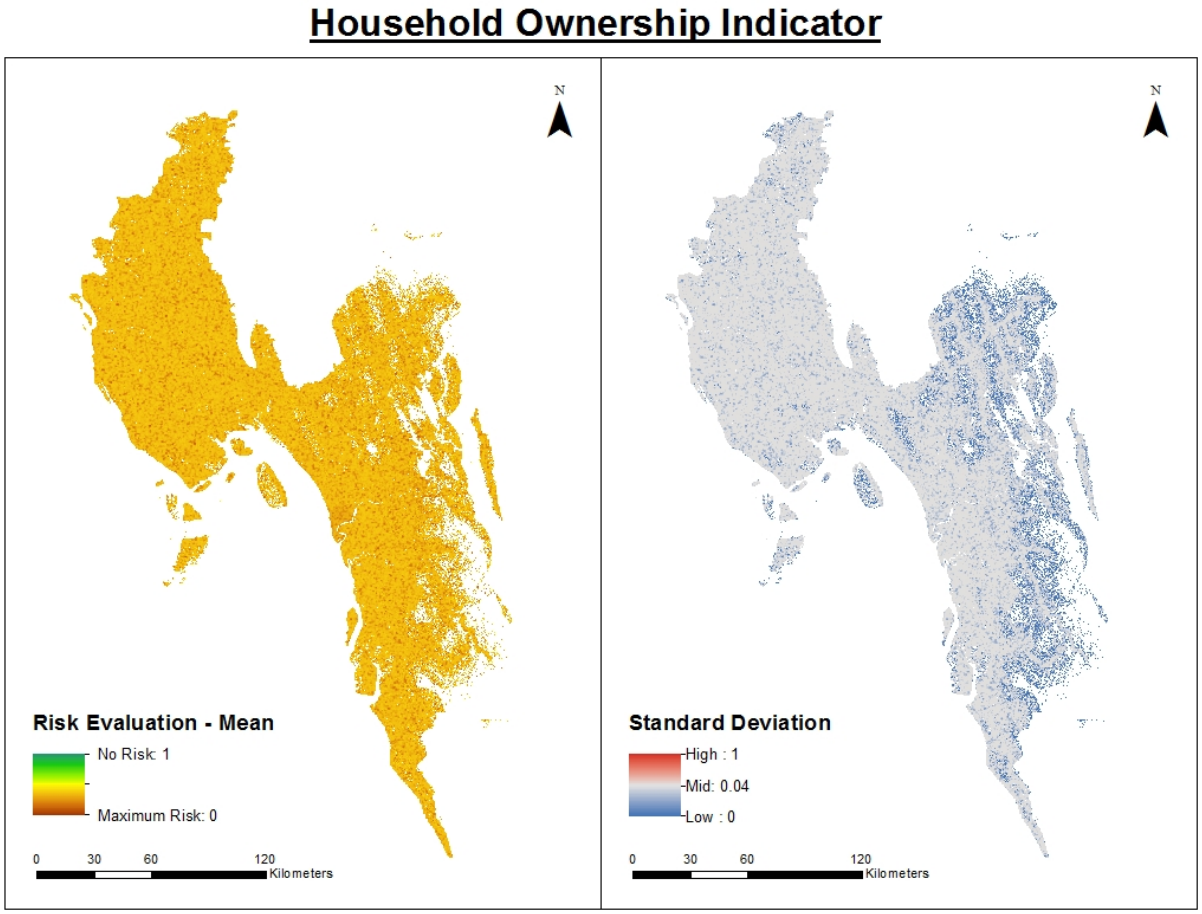
Metric	Weight Minimum Value	Weight Maximum Value
Owns Agricultural land	0.2	0.3
Man Owns House	0.8	0.9
Woman Owns House	0.8	0.9
Man Owns Land	0.4	0.6
Woman Owns Land	0.4	0.8
Tenancy	0.4	0.6

Uncertainty values

This indicator is given an uncertainty minimum value of 0.1 and an uncertainty maximum value of 0.2, reflecting the breadth of the metrics in addressing the indicator ask.

Indicator Uncertainty Min:	0.1
Indicator Uncertainty Max:	0.2

Example outcome



References

Colombara, Danny, Abu SG Faruque, Karen D Cowgill and Jonathan D Mayer 2014. Risk factors for diarrhea hospitalization in Bangladesh, 2000–2008: a case-case study of cholera and shigellosis. *BMC Infectious Diseases* 14:440. DOI: 10.1186/1471-2334-14-440

Metric: Owns Agricultural Land

Indicator:	Household Ownership
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	Yes (min: 1.0, max: 1.0) No (min: 0.25, max: 1.0)
Survey:	DHS - Household

Survey Date: 2011

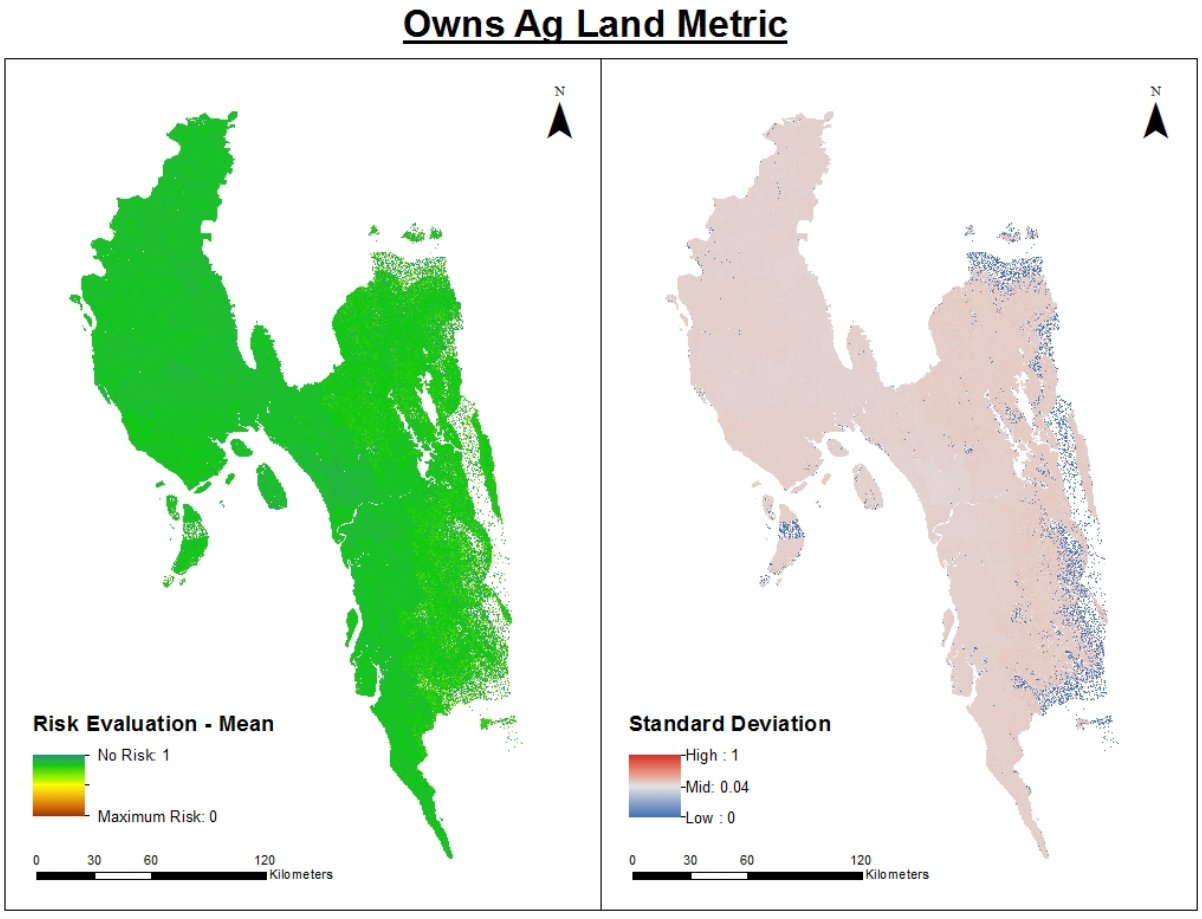
Other Data Sources:

Logic: From the 2011 DHS Bangladesh Survey Final Report:

"Ninety-four percent of households own a homestead, while 47% own land other than a homestead. Ownership of a homestead or other land is less common in urban than in rural areas. Ownership of land other than a homestead has declined slightly since 2004, from 52 to 47%, especially in rural areas, while ownership of a homestead has remained unchanged."

The metric consists of the question which asks respondents whether or not they own agricultural land (a different question asks if they own any land). Answers of "Yes" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "No" are given a minimum value of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 1.0. Maps will range from medium risk to no risk.

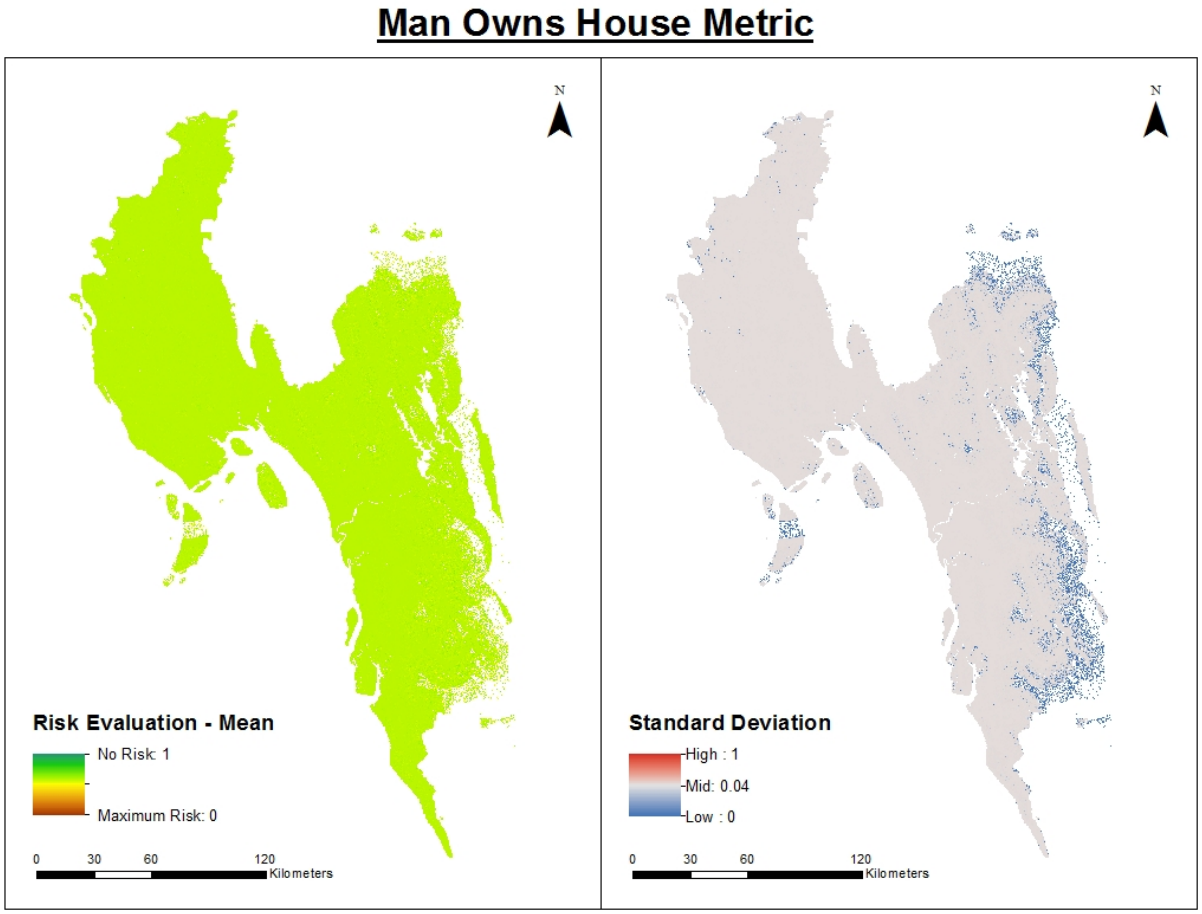
Example realization metric map



Metric: Man Owns House

Indicator:	Household Ownership
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	0DoesNotOwn (min: 0.25, max: 0.5) 1AloneOnly (min: 1.0, max: 1.0) 2JointlyOnly (min: 1.0, max: 1.0) 3BothAloneAndJointly (min: 1.0, max: 1.0)
Survey:	DHS - Men
Survey Date:	2011
Other Data Sources:	
Logic:	From the 2011 DHS Bangladesh Survey Final Report: "Ninety-four percent of households own a homestead, while 47 percent own land other than a homestead. Ownership of a homestead or other land is less common in urban than in rural areas. Ownership of land other than a homestead has declined slightly since 2004, from 52 to 47 percent, especially in rural areas, while ownership of a homestead has remained unchanged." Colombara et al (2014) found that cholera patients were less likely to be homeowners (40% vs. 73%). Answers of "Does Not Own" are given a minimum value of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "Alone Only," "Jointly Only," and "Both Alone and Jointly" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$).

Example realization metric map



Metric: Woman Owns House

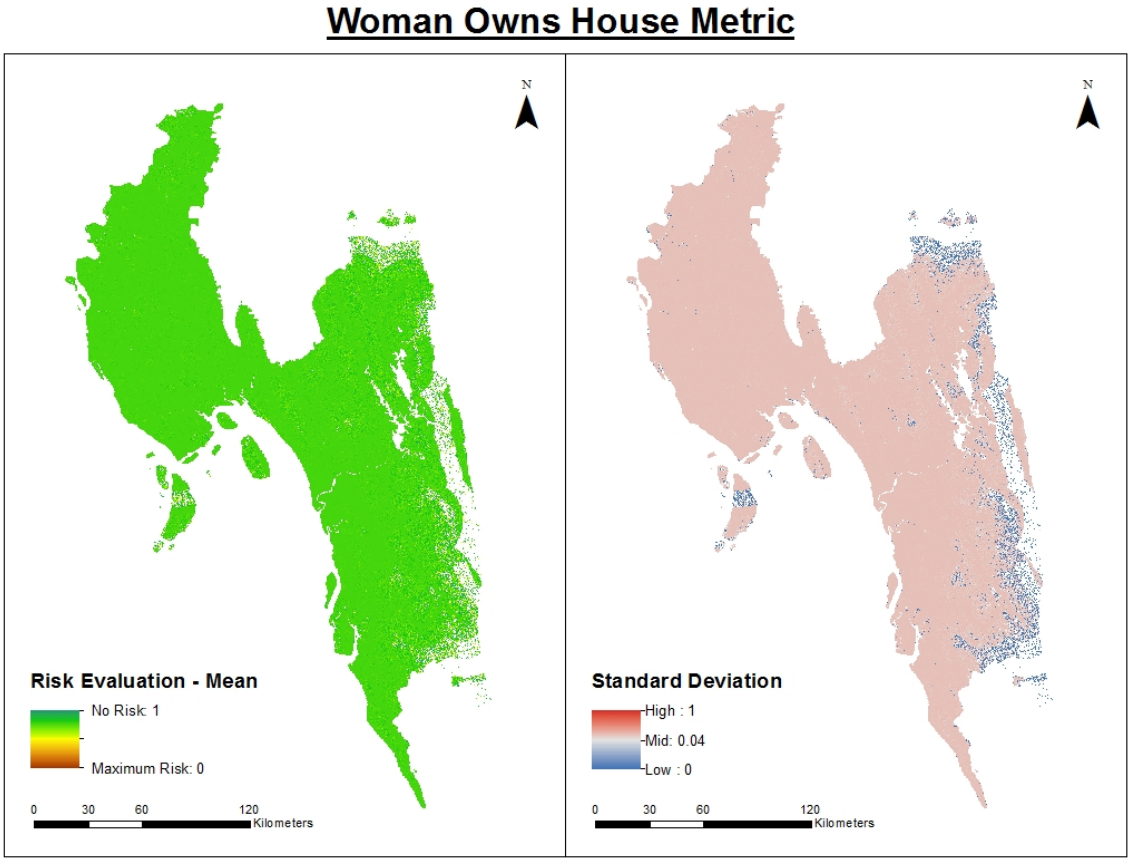
Indicator:	Household Ownership
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	0DoesNotOwn (min: 0.25, max: 0.5) 1AloneOnly (min: 1.0, max: 1.0) 2JointlyOnly (min: 1.0, max: 1.0) 3BothAloneAndJointly (min: 0.8, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	
Logic:	From the 2011 DHS Bangladesh Survey Final Report:

"Ninety-four percent of households own a homestead, while 47 percent own land other than a homestead. Ownership of a homestead or other land is less common in urban than in rural areas. Ownership of land other than a homestead has declined slightly since 2004, from 52 to 47 percent, especially in rural areas, while ownership of a homestead has remained unchanged."

Colombara et al (2014) found that cholera patients were less likely to be homeowners (40% vs. 73%).

Answers of "Does Not Own" are given a minimum value of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "Alone Only" and "Joint Only" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "Both Alone and Jointly" are given a minimum value of 0.8 and a maximum value of 1.0. Maps will range from medium risk to no risk.

Example realization metric map

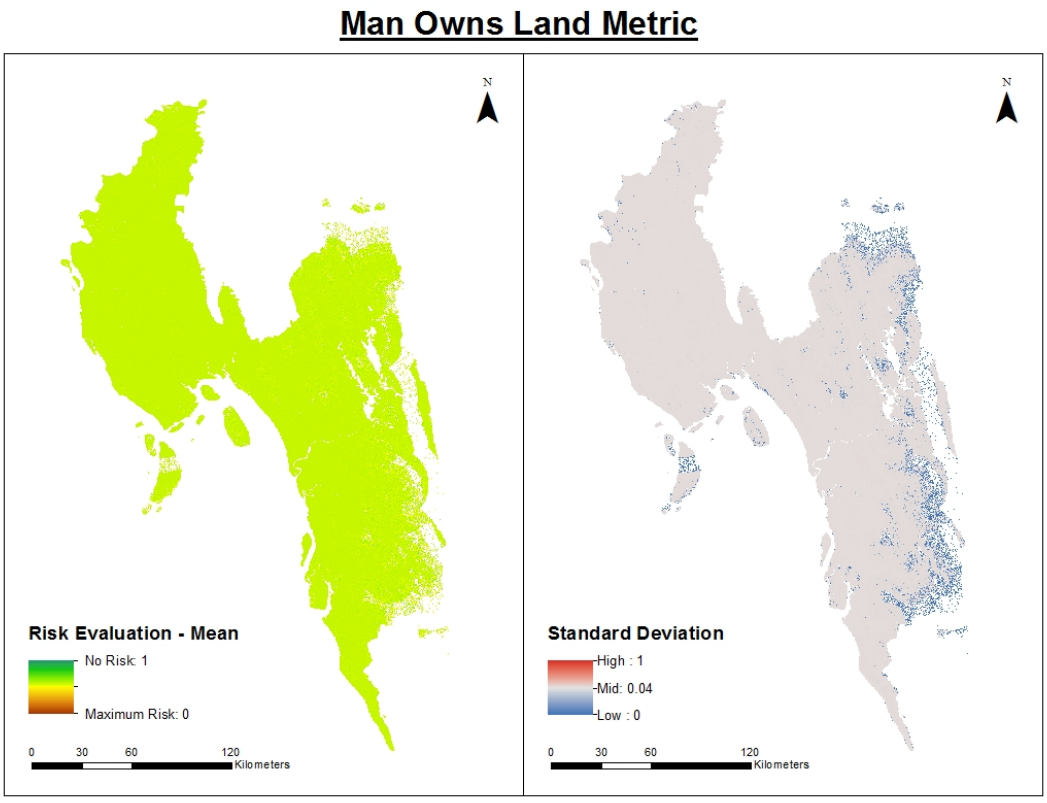


Metric: Man Owns Land

Indicator:	Household Ownership
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies

Framework:	Cholera
Metric Assigned Values:	0DoesNotOwn (min: 0.25, max: 0.5) 1AloneOnly (min: 1.0, max: 1.0) 2JointlyOnly (min: 1.0, max: 1.0) 3BothAloneAndJointly (min: 1.0, max: 1.0)
Survey:	DHS - Men
Survey Date:	2011
Other Data Sources:	
Logic:	From the 2011 DHS Bangladesh Survey Final Report: "Ninety-four percent of households own a homestead, while 47 percent own land other than a homestead. Ownership of a homestead or other land is less common in urban than in rural areas. Ownership of land other than a homestead has declined slightly since 2004, from 52 to 47 percent, especially in rural areas, while ownership of a homestead has remained unchanged." Answers of "Does Not Own" are given a minimum value of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "Alone Only," "Jointly Only," and "Both Alone and Jointly" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$).

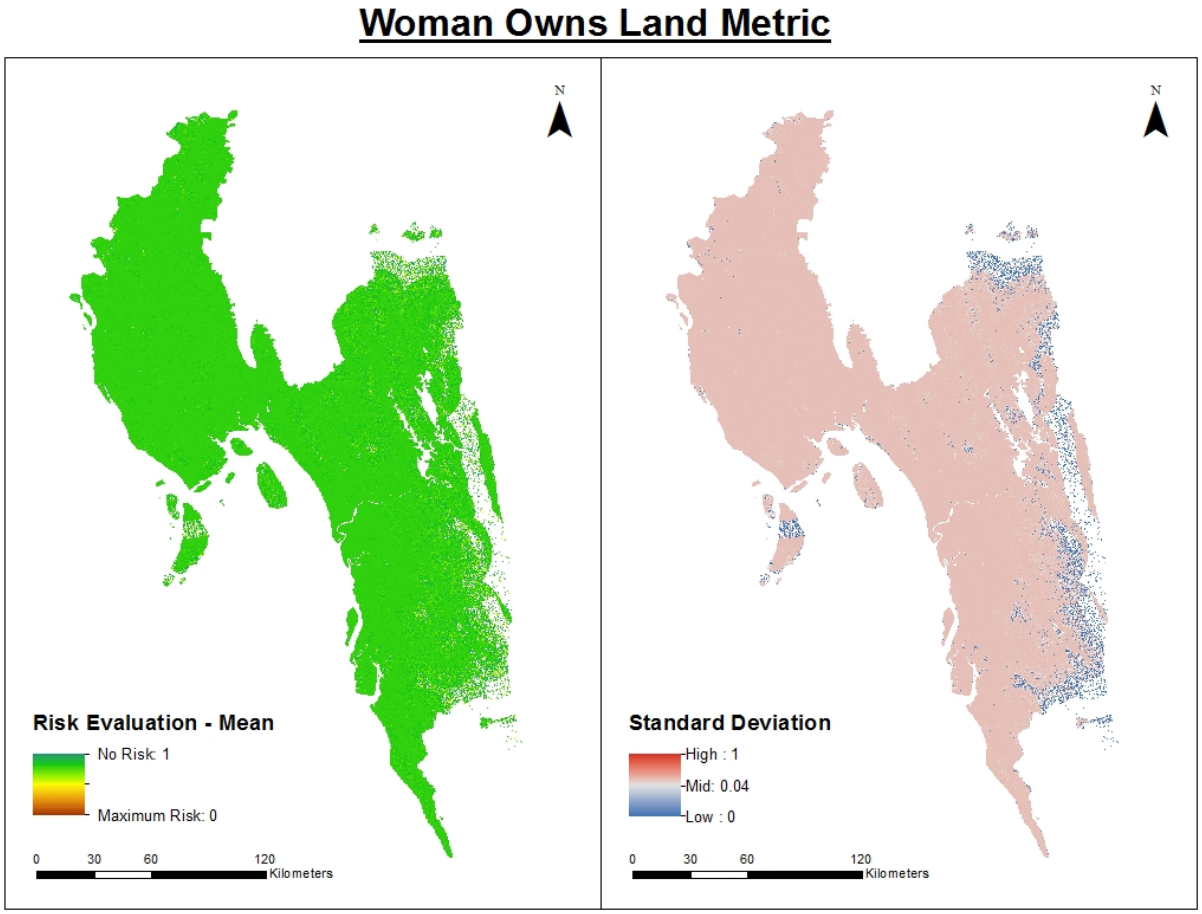
Example realization metric map



Metric: Woman Owns Land

Indicator:	Household Ownership
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	0DoesNotOwn (min: 0.25, max: 0.5) 1AloneOnly (min: 1.0, max: 1.0) 2JointlyOnly (min: 1.0, max: 1.0) 3BothAloneAndJointly (min: 0.8, max: 1.0)
Survey:	DHS - Women
Survey Date:	2011
Other Data Sources:	
Logic:	From the 2011 DHS Bangladesh Survey Final Report: "Ninety-four percent of households own a homestead, while 47 percent own land other than a homestead. Ownership of a homestead or other land is less common in urban than in rural areas. Ownership of land other than a homestead has declined slightly since 2004, from 52 to 47 percent, especially in rural areas, while ownership of a homestead has remained unchanged." Answers of "Does Not Own" are given a minimum value of 0.25 (medium risk, $\frac{1}{2}^2$) and a maximum value of 0.5 (slight risk, $\frac{1}{2}^1$). Answers of "Alone Only" and "Joint Only" are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $\frac{1}{2}^0$). Answers of "Both Alone and Jointly" are given a minimum value of 0.8 and a maximum value of 1.0. Maps will range from medium risk to no risk.

Example realization metric map



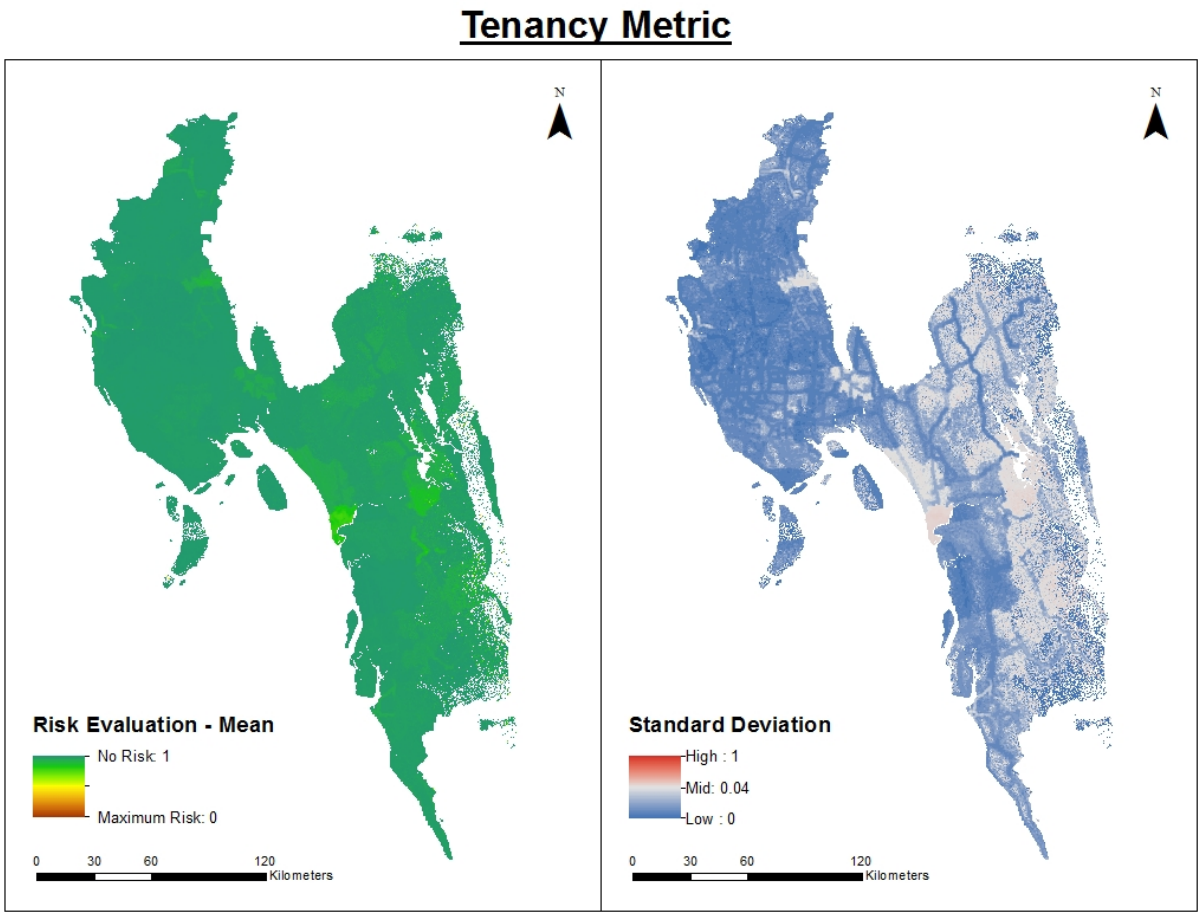
Metric: Tenancy

Indicator:	Household Ownership
Factor:	Household Economic Resilience
Condition:	Resilience Deficiencies
Framework:	Cholera
Metric Assigned Values:	1Own (min: 1.0, max: 1.0) 2Rented (min: 0.25, max: 0.9) 3RentFree (min: 0.0625, max: 0.9) 9NotInUniverse (min: 0.625, max: 1.0)
Survey:	IPUMS
Survey Date:	2011
Other Data Sources:	
Logic:	This metric consists of answers to the question of ownership of the surveyed dwelling from the IPUMS survey. Colombara et al (2014)

found that cholera patients were less likely to be homeowners (40% vs. 73%).

Answers of “Own” are given both a minimum and a maximum value of 1.0 (minimal risk with no impact on risk, $½^0$). Answers of “Rented” are given a minimum value of 0.25 (medium risk, $½^2$) and a maximum value of 0.9 (minimal risk). Answers of “Rent Free” are given a minimum value of 0.0625 (extreme risk, $½^4$) and a maximum value of 0.9. Answers of “Not in Universe” are given a minimum value of 0.0625 and maximum value of 1.0. Maps will range from extreme risk to no risk.

Example realization metric map



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
09/01/2019	Final Technical Report (TR)	

4. TITLE AND SUBTITLE
Development of a Cholera Epidemiological Risk Assessment Framework

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT
622784AT41

6. AUTHOR(S)
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5d. PROJECT NUMBER
P2 458304

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
PO Box 9005,
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CERL TR-19-13

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA[ALT])
3010 Defense Pentagon
Washington, DC 20301-3010

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report presents technical explanations and specific enumerations for a cholera risk framework developed as a part of a multi-year project funded by the Army Research, Development, Test and Evaluation Program. This effort employed a novel data-conflation technology called the Framework for the Integration of Complex Urban Systems (FICUS), which uses a broad base of peer-reviewed research on established indicators of sociocultural or health-driven risk conditions of interest for intelligence or threat analysis in a given region. Researchers performed a specialized case study that incorporates results and data from previous programmatic work, including FICUS development and an existing theoretical humanitarian crisis (HC) framework. New data required for this framework included identification of conditions for contracting cholera, micro-survey data from global resources, and a digital population model that matches the survey data to existing population census data. The cholera framework research succeeded in using relevant microdata from the HC framework, then manipulating the HC framework to better inform cholera risk modeling. In general, the use of risk-analysis frameworks with FICUS is intended to produce case studies that provide non-obvious insights to the user while accounting for and reducing data gaps and uncertainties.

15. SUBJECT TERMS
Metropolitan areas, Cities and towns, Cholera--Transmission, Epidemics, Humanitarian assistance, Epidemiology

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
Unclassified	Unclassified	Unclassified	SAR	302	