The Influences of Climatic and Socioeconomic Variables on Cholera Incidence in India During the Seventh Pandemic, 1961-2008

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The Influences of Climatic and Socioeconomic Variables on Cholera Incidence in India
during the Seventh Pandemic, 1961-2008

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Abstract

Background:
Cholera outbreaks result in significant morbidity worldwide. Transmission of the disease may be influenced by weather fluctuations, such as El Niño-Southern Oscillation (ENSO) and excessive rainfall, and socioeconomic status (SES), including income and education. El Niño events may influence many aspects of the climate, including the amount of rainfall occurring in a given year and surface water temperature. This study aimed to assess the influences of extreme weather and SES factors on cholera incidence in India during the seventh cholera pandemic (1961-2008).

Methods:
Data for all variables were obtained for 1961-2008. Indian population estimates and cholera incidence (IR) were obtained from the World Bank and World Health Organization (WHO). Data for climatic variables were obtained from Indian and US climate agencies. SES measures, gross national income (GNI), Human Development Index (HDI), and infant mortality rate (IMR), were collected from the World Bank, WHO, and United Nations Development Programme. Spearman Correlations, t-tests, ANOVA, and linear regressions were carried out using SPSS.

Results:
There was no significant difference between cholera IR during ENSO and non-ENSO years using ANOVA (F=0.478, p=0.623). GNI, HDI, and IMR were significant in all linear regression models. Significant associations were observed between IR and GNI (R²=0.37, p<0.001), IMR (R²=0.62, p<0.001), and HDI (R²=0.43, p<0.001). Rainfall and ENSO events were not significant (α<0.05) in any model.

Conclusion:
While weather fluctuations did not influence cholera incidence, SES measures were significantly associated with cholera IR, suggesting that economic development is important to address in cholera control.

Keywords: cholera, El Niño-Southern Oscillation, extreme weather, socioeconomic status
The Influences of Climatic and Socioeconomic Variables on Cholera Incidence in India
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Cholera, a waterborne disease caused by *Vibrio cholerae*, is associated with tens of thousands of cases of severe diarrhea during an epidemic. In addition to sanitation, personal hygiene, and socioeconomic factors, this bacterium is sensitive to numerous environmental influences (Ackers, Quick, Drasbek, Hutwagner, & Tauxe, 1998). Temperature, extreme weather fluctuations, and rainfall impact the concentration of the vibrio and have the potential to overwhelm sanitation infrastructure (Colwell, 1996).

Extreme weather events have been increasing in frequency over the last few decades. Among these events are El Niño and La Niña phenomena, which result in widespread changes in rainfall and surface water temperature. Climate change and extreme weather patterns are projected to increase disease incidence rates and their geographic range (Bush et al., 2011; Koelle, 2009).

Socioeconomic variables have been suggested to play a role in the vulnerability of communities to cholera epidemics. Extreme poverty impacts access to safe housing, clean water, adequate food, and healthcare, all of which increase vulnerability to infectious disease outbreaks. Migration and human movement due to civil unrest, lack of economic opportunity, or natural disasters can lead to poor living conditions and disease outbreaks (Ruiz-Moreno, Pascual, Bouma, Dobson, & Cash, 2007). Populations with higher income coupled with access to clean water, better hygiene practices, adequate sanitation, and safe housing have lower levels of infectious diseases (Bartram & Cairncross, 2010).

As India continues to develop economically, the country is able to provide better access to safe water supplies and adequate sanitation. At the same time, a decrease in cholera incidence
has been noted in India since 1961 (World Health Organization [WHO], 2010). Environmental and climatic variables, however, remain unpredictable and uncontrollable. Many factors influencing cholera transmission remain underexplored and are of research interest. This culminating experience explores climatic factors and socioeconomic measures that may influence cholera incidence rates in India.

**Literature Review**

**Background**

Cholera is a classic waterborne disease that can cause severe diarrhea leading to dehydration and death. The natural habitat of *V. cholerae* is brackish water with moderate salinity, though it can also persist in freshwater (Lipp, Huq, & Colwell, 2002; Salyer & Whitt, 2002). The microorganism can be found in wells, ponds, rivers, coastal waters, and estuaries (Codeço, 2001). Cholera transmission is greatly influenced by environmental factors including temperature, water salinity, sea surface temperature, and rainfall (De Magny, Cazelles, & Guégan, 2007). The exact effect of changes in these factors and their combined influences is still a subject of great interest to scientists, though the complex interactions are not fully understood (Ruiz-Moreno et al., 2007). Humans were once thought to be the only reservoirs of *V. cholerae*, but it has been determined that the vibrio lives in several marine organisms (Glass & Black, 1992; Lipp et al., 2002).

Humans may be infected via an environmental source, also known as primary transmission, which is most common along coastal regions where the vibrio is found in its natural reservoirs (Colwell & Spira, 1992). Primary infections usually occur in brackish waters used for occupational or recreational purposes (Lipp et al., 2002). Humans most commonly ingest the pathogen through water or food contaminated with the fecal matter of another cholera
patient, known as secondary transmission (Colwell & Spira, 1992; Mandal, Mandal, & Pal, 2011). *V. cholerae* can survive in non-aquatic environments, such as in feces and on contaminated vegetables, for up to seven days, making cholera a potential threat in areas lacking sufficient sanitation infrastructure (Colwell & Spira, 1992). Increased disease incidence, however, cannot be linked to just one causative factor. Environmental, climatic, and socioeconomic factors interact to impact cholera prevalence, disease risk, and incidence rates.

**Public Health Implications of Cholera**

The World Health Organization (WHO) estimates that there are between three and five million cases of cholera each year, with more than 120,000 deaths (WHO, 2012). It is probable that the numbers of cases are higher in both Africa and Asia, with Latin America reporting far fewer cases (Mandal et al., 2011). The WHO has declared cholera a “global threat to public health and one of the key indicators of social development,” with nearly every developing country now reporting outbreaks or being at risk for an epidemic (Mandal et al., 2011, p. 573). When left untreated, severe cholera has a case fatality rate ranging from 50% to over 70% (Guerrant, Carneiro-Filho, & Dillingham, 2003; Sack, Sack, Nair, & Siddique, 2004).

**The Seven Pandemics**

Cholera has been a scourge of humankind since ancient times, and it continues to pose a serious public health risk today. Prior to the 19th century, cholera was restricted to the Indian subcontinent. There have been seven documented pandemics since 1817, when cholera first left the Ganges delta and spread to the Middle East and other parts of Asia (Huq, Sack, & Colwell, 2001). The second pandemic began in 1829, and the spread of cholera reached as far as Europe and the New World (Huq et al., 2001). Four more pandemics occurred before 1925, and cholera spread to Africa, Australia, and both American continents (Huq et al., 2001). *V. cholerae*, the
causative agent of the disease, was discovered during the fifth pandemic in 1884 by Robert Koch (Huq et al., 2001).

The seventh pandemic of cholera began in 1961 in Sulawesi, Indonesia and continues to this day (Barua, 1992; Mutreja et al., 2011). Unlike the first six pandemics, this pandemic is the first caused by the hardier El Tor biotype (Barua, 1992; Mutreja et al., 2011). El Tor cholera is capable of causing asymptomatic infection, meaning an infected person is still mobile and often unknowingly shedding pathogenic vibrios (Barua, 1992). Mutreja et al. (2011) have found evidence to suggest that three distinct waves of the El Tor strain have spread from the Bay of Bengal, where the biotype remains endemic. Most cholera experts agree that the seventh pandemic is still ongoing, making it the longest pandemic with a duration of more than fifty years. The longest previous pandemic was the sixth pandemic, which lasted for twenty four years at the turn of the 20th century (Huq et al., 2001).

**Molecular Epidemiology of V. Cholerae**

Cholera can be categorized as serogroups with similar cell antigens. These serogroups can be further grouped as biotypes and serotypes based on genetic and phenotypic characteristics, as shown in Figure 1.
There are over 200 serogroups, or strains with similar cell antigens, of *V. cholerae*, but only serogroups O1 and O139 have been known to cause epidemics in humans (Faruque & Mekalanos, 2008). Thus far, O139 has been confined to eleven countries in Southeast Asia since its appearance in India in 1992, with the O1 serotype responsible for the rest of the outbreaks around the world (Menon, Mintz, & Tauxe, 2009; Sepúlveda, Valdespino, & García-García, 2006; Sow, Antonio, Oundo, Mandomando, & Ramamurthy, 2011). The emergence of O139 is significant because this strain appears to have originated due to genetic recombination and horizontal gene transfer, implying that it is essentially a novel strain. The ability of O139 to cause pandemics is unknown (Huq et al., 2001). There is no residual immunity between the strains because O1 and O139 serotypes have different surface proteins, meaning developing
immunity from an O1 infection will not protect the same individual if exposed to an O139 strain (Todar, 2012).

The O1 serogroup can be further categorized by biotype and serotype. The serotype is dictated by which of three possible surface antigens are present on a given bacterium (Todar, 2012). The serotypes have been named Ogawa, Inaba, and Hikojima (Zuckerman, Rombo, & Fisch, 2007). The biotype refers to the phenotypic variations of the strain, and the O1 serogroup has two biotypes: Classical or El Tor. Although the biotype classification does not determine clinical treatment, biotypes may help epidemiologists identify the source and geographic spread of an outbreak (Raychoudhuri et al., 2008).

The El Tor biotype was first isolated in El Tor, Egypt in 1905, and can be differentiated from the classical strain by its ability to produce hemolysins (Sack et al., 2004; Todar, 2012). It is believed that the first six pandemics were caused by the classical biotype of *V. cholerae*, but the seventh pandemic has been mostly driven by the O1 El Tor strain (Faruque & Mekalanos, 2008; Huq et al., 2001). The classical strain tends to cause more cases of severe cholera, but the El Tor strain produces many more carriers who excrete *V. cholerae* for an extended period of time following infection (DiRita, Neely, Taylor, & Bruss, 1996; Todar, 2012). It is now believed that the classical strain is largely extinct and has been replaced with O1 El Tor, which is more adaptable and better able to survive both in the environment and in humans (Mandal et al., 2011).

Countries may experience epidemic or endemic cholera. Endemicity typically occurs when *V. cholerae* is consistently found in the environment, leading to immunity or semi-immunity in large proportions of the population (Zuckerman et al., 2007). Cholera is currently endemic in over fifty countries, including many parts of Asia, and endemicity is growing in parts
of Latin America and Africa (Ryan, 2011). In much of Asia, the humidity, rainfall patterns, and high temperatures create an ideal climate for the persistence of cholera (Mukhopadhyay & Ramamurthy, 2011). *V. cholerae* is able to survive under stressful conditions by entering into a viable but not culturable state, which allows it to persist in the environment up to fifteen months despite less than ideal conditions (Codeço, 2001). Cholera can also persist in an endemic state without the presence of an environmental reservoir in areas lacking proper sanitation (Codeço, 2001). The vibrio does not need to survive long in the environment if numerous people are coming in contact with contaminated water on a daily basis (Codeço, 2001).

Epidemic cholera occurs mainly in developing areas that lack adequate sanitation infrastructure and access to safe water supplies and have population with little to no immunity to cholera (Zuckerman et al., 2007). Epidemics of cholera often follow events that can disrupt sanitation and hygiene practices, such as war, natural disasters, and civil unrest (Zuckerman et al., 2007). In an area with contaminated water, a major risk factor for a cholera epidemic is a large number of susceptible individuals. These individuals may be susceptible to cholera due to immigration or migration, or loss of previously acquired immunity (Codeço, 2001). Populations most at risk of contracting cholera include those under the age of five and women of reproductive age (Sepúlveda et al., 2006). An individual’s biochemistry can also influence his or her risk of contracting cholera. Those with low levels of stomach acidity are at an increased risk for developing the disease as the vibrio is sensitive to high acid levels (Nalin et al., 1978). Individuals with blood type O are also at a greater risk, though the reason for this is currently unknown and is under investigation (Harris et al., 2005).
Characteristics of *V. cholerae* and Clinical Features of Cholera

*V. cholerae* is able to infect healthy humans if a high enough dose (10⁵-10⁸ bacteria) is ingested (Mandal et al., 2011). Disease in humans is caused not by a colonization of the bacteria but rather by the cholera toxin (CT) produced by the bacteria. CT1, produced by classical biotypes, and CT2, produced by El Tor biotypes and the O139 serogroup, are not identical toxins but cause virtually identical symptoms in patients (Raychoudhuri et al., 2008). The cholera toxin is not invasive, nor does it damage the intestinal mucosa (Salyer & Whitt, 2002). Rather, the toxin binds to intestinal mucosa cells and causes hypersecretion of water and electrolytes (Mandal et al., 2011). Furthermore, CT leads to increased intestinal secretion of chloride and bicarbonate and the uptake of water from other parts of the body (Mandal et al., 2011). The massive secretion of fluids and electrolytes into the intestines leads to overall decreased blood volume, resulting in severe electrolyte imbalance and massive diarrhea (Salyer & Whitt, 2002). The severe loss of fluid, up to 20 liters per day, can cause the circulatory system to collapse and lead to death in as little as 6-8 hours (Mandal et al., 2011).

Climatic Factors

**Variations in rainfall.**

Excessive rainfall can have a serious impact on cholera transmission. Excess rain dilutes the number of vibrios in the water, typically leading to a decrease in the number of cases of primary transmission, as individuals do not ingest nearly as many pathogenic organisms as they did before the dilution. Increased rainfall during the monsoon season, however, is capable of moving *V. cholerae* inland from its normal habitat along coastal waters (Ruiz-Moreno et al., 2007). Excessive rainfall can stress and damage drainage and sewer systems, as well as cause damage to treated water supply systems (WHO, 1999). Flooding can also overwhelm
wastewater treatment plants or cause septic systems to fail, which in turn can contaminate surface waters and wells in nearby areas (Lipp et al., 2002).

Drought-like conditions can also trigger an outbreak of cholera by forcing more people to rely on fewer and diminishing water sources while simultaneously increasing the concentration of \textit{V. cholerae} in these waters (Ruiz-Moreno et al., 2007). Secondary transmission typically increases during droughts for a variety of reasons. Droughts can cause human migration towards a water source, which can lead to importation of the microbe into a previously uninfected region (Ruiz-Moreno et al., 2007). Also, increased human density, due to either migration or crowding around a precious source of water, can strain existing sanitation infrastructure. A breakdown or overload in the sanitation structure can greatly increase the risk of fecal contamination in a limited water supply that must suffice for multiple uses, including drinking, food preparation, cleaning, and bathing (Lipp et al., 2002; Ruiz-Moreno et al., 2007). Furthermore, drought conditions may mean there is not sufficient water for personal hygiene and sanitation, as scarce water supplies are typically prioritized for cooking purposes (WHO, 1999).

\textbf{El Niño-Southern Oscillation.}

The El Niño Southern Oscillation (ENSO) phenomenon is made up of two phases: El Niño and La Niña. Air pressures, water temperatures, and trade winds in the equatorial Pacific shift from optimal values and cause a warming or cooling in the region, which in turn triggers weather changes around the world (Lipp et al., 2002). The El Niño phase, which takes its name from the Spanish for the Christ child, occurs every two to seven years, usually beginning around Christmastime (Lipp et al., 2002; WHO, 1999). Weaker El Niño events may begin in the early months of the calendar year, and anomalous values typically reach their most extreme measurements between April and June (Rasmusson & Carpenter, 1981). Once begun, the ENSO
events last an average of 18-24 months, though the individual events are “never exactly the same and can vary in magnitude, spatial extent, onset, duration, cessation, etc.” (Allan, 2000, p. 4).

Climatic changes associated with El Niño events have been linked to increases in the incidence of vector-borne diseases, such as malaria and dengue, waterborne diseases, such as cholera, and may also impact rodent-borne diseases, such as hantaviruses (Lipp et al., 2002; WHO, 1999).

The weaker La Niña phase may follow an El Niño event and is roughly a reversal of the El Niño effect, resulting in a general cooling in the eastern equatorial Pacific region (Lipp et al., 2002; WHO, 1999). La Niña events tend to last longer and occur more infrequently than El Niño events (Wolter & Timlin, 2011). ENSO events trigger climatic variations and environmental changes most directly seen in countries bordering the Indian and Pacific Oceans, but variations called teleconnections impact interior and coastal regions around the world (Allen, 2000; WHO, 1999).

ENSO events typically strongly impact precipitation levels, through either extended periods of drought or heavy rains (WHO, 1999). In addition to seriously impacting the yearly Asian monsoon rains, it has also been predicted that an El Niño event can trigger an increase in cholera cases up to eleven months later (Colwell & Huq, 1999). The warmer than usual ocean water during the winter months due to El Niño tends to increase precipitation the following summer over the Indian subcontinent (Cash, Rodó, & Kinter, 2009). The warmer sea surface temperatures generate an increase in phyto- and zooplankton, both natural reservoirs for \textit{V. cholerae} (Lipp et al., 2002; Paz, 2009). A greater number of phytoplankton typically signals an increase in cholera vibrios, any number of which could be pathogenic to humans (Mishra, Taneja, & Sharma, 2011). Furthermore, the local climate changes associated with ENSO, particularly warmer surface water temperatures, can expand the geographic range of these
phytoplankton, allowing cholera pathogens to increase their geographic range beyond endemic regions (Lipp et al., 2002; WHO, 1999). The occurrence of El Niño events and the frequency of global cholera outbreaks have been increasing since the 1970s, and the frequency of ENSO events may continue to increase due to anthropogenic climate change (Lipp et al., 2002; WHO, 1999).

**Identifying El Niño – Southern Oscillation events.**

There are multiple ways to determine the existence of an El Niño or La Niña event, which leads to some years being classified as ENSO events in some systems but not in others. One way of classifying ENSO looks solely at sea surface temperature measurements in the Niño 3.4 region (5°N - 5°S, 120°-170°W), with a deviation of ±0.5°C over at least five consecutive three-month seasons considered an anomaly (Wolter & Timlin, 2011). Others determine the existence of an ENSO event by looking at Southern Oscillation Index (SOI) values, which measure pressure differences between Tahiti and Darwin, Australia (Wolter & Timlin, 2011). The Bivariate EnSo Timeseries, also known as the ‘BEST’ ENSO Index, combines sea surface temperature (SST) and SOI measurements into one, which may be a more stringent method of classification (Smith & Sardeshmukh, 2000). The Multivariate ENSO Index (MEI) looks at six variables (sea-level pressure, two surface winds components, SST, surface air temperature, and total cloudiness) when monitoring ENSO events (Wolter & Timlin, 2011). Most indices list the same years for El Niño events, though perhaps in a different rank order for strength of the event, so there is no clear consensus as to which index is the best index for measuring ENSO events (Wolter & Timlin, 2011). Consensus on La Niña events is much less common, with the indices varying widely on their rankings of strength of these cold events (Wolter & Timlin, 2011).
Cholera and Socioeconomic Status

Socioeconomic differences can explain the variations in incidence rates within and between countries during epidemic of cholera. Studies in Mexico and Brazil have identified an association between high rates of cholera and high poverty, low urbanization, and low proportions of the population receiving piped water (Sepúlveda et al., 2006; Waldman, Antunes, Nichiata, Takahashi, & Cacavallo, 2002). Ackers, Quick, Drasbek, Hutwagner, and Tauxe (1998) found a correlation between cholera incidence and infant mortality rates (IMR), human development index (HDI), female literacy, and gross domestic product (GDP) per capita. Waldman, Antunes, Nichiata, Takahashi, and Cacavallo (2002) noted that regions in Brazil with higher education levels and better urban infrastructure were able to manage cholera outbreaks more quickly and efficiently. Tappero and Tauxe (2011) noted that during the 2010-2011 outbreak on the island of Hispaniola, Haiti saw over 400,000 cases, while the neighboring Dominican Republic saw fewer than 15,000 cases. Although the two countries share the same small island, the Dominican Republic has an IMR that is one third that of Haiti, a per capita gross domestic product five times that of Haiti, nearly 90% of the Dominican population has access to improved sanitation (Tappero & Tauxe, 2011). Such vast differences in socioeconomic status most likely played a role in the dramatically different outcomes in the cholera outbreak.

Cholera has been linked in the past to poverty, and this has led to misconceptions of those most at risk of contracting the disease. Briggs and Mantini-Briggs (2002) assert that cholera is a disease that almost exclusively affects the very poor, which can lead to more resistant stereotypes in areas with social and economic disparities. In Venezuela, for instance, there was a widely held belief that poor people in the slums fell ill with cholera due to their ignorance and failure to practice good hygiene (Briggs & Mantini-Briggs, 2002).
Socioeconomic measures may also explain the decrease in cholera incidence in India as the country as a whole develops over time. India has seen a rise in its Human Development Index (HDI) value and gross national income (GNI), while infant mortality rate (IMR) and cholera incidence rates have decreased over the past forty years (World Bank, 2012).

It is estimated that nearly three-quarters of the rural population in India lack access to proper sanitation and water treatment options, leaving many vulnerable to cholera in the event of an outbreak (Bush et al., 2011).

**Poverty and water quality.**

Access to clean water and adequate sanitation are two key promoters of overall health and wellbeing. The United Nations (UN) has included both in Millennium Development Goal (MDG) 7, aiming to increase access to safe drinking water to 85% of the world’s population and sanitation to 75% of humanity by 2015 (UN, 2010). Interventions focused on improving water and sanitation for a population can “weaken the link between poverty and disease…and so contribute to health equity” (Bartram & Cairncross, 2010, p. 3). It is important to note, however, that meeting the MDG 7 objectives will still mean that 1.6 billion people worldwide will not have access to improved sanitation and 800 million will still be forced to collect their water from distant and/or unprotected sources (Bartram & Cairncross, 2010). Improving hygiene, sanitation, and water for populations around the world has the potential to lower under-5 mortality rates by one third (Bartram & Cairncross, 2010).

Water quality is important not just on a community-wide infrastructure level, but also on the level of households and individuals. If the community’s water supply is not potable, water must be treated by boiling or using chlorine tablets or bleach, all of which may be cost-prohibitive in a resource-poor area (Njoh, 2010). Storing water in the home for future use,
whether due to unreliable piped water or access only to distant sources, is a significant risk factor for cholera and other waterborne infections because the water is subject to contamination every time a person or utensil touches the water (Deb et al., 1986).

Access to properly constructed and well-maintained latrines is also vital in the prevention of cholera. Much like water infrastructure, sanitation requires governmental financing and the political will to carry out such a massive project (Njoh, 2010). The cost of such massive infrastructure creation or overhaul has led many governments to use funding on health education interventions instead (Njoh, 2010).

Insufficient access to potable water and adequate sanitation is not limited to poor, rural areas. As more individuals move to urban areas in search of a better life, slums are becoming an increasingly serious problem. Slums, also known as informal settlements, are urban areas lacking at least one of the following: durable housing with secure tenure, access to improved sanitation, access to an improved source of drinking water, sufficient living area, and a location in a non-hazardous environment (United Nations Human Settlements Programme [UN-HABITAT], 2006). In 2006, it was estimated that there were nearly one billion slum dwellers worldwide, and this figure is projected to increase to 1.4 billion by 2020 (UN-HABITAT, 2006). Slum dwellers are at an increased risk for many infectious diseases, including cholera, due to tenuous or nonexistent access to safe water and sanitation and overcrowding (Penrose, de Castro, Werema, & Ryan, 2010). It is likely that cholera will continue to pose a serious risk to impoverished slum dwellers as urbanization continues and the number of inhabitants in informal settlements increases.

The greatest disease burden of cholera is borne by countries in the tropics and subtropics. Cholera disease rarely occurs in developed countries with adequate sanitation systems and good
hygiene practices, even though *V. cholerae* is often found in nearby coastal waters suggesting good sanitation can essentially eliminate the illness (Lipp et al., 2002). The seventh pandemic of cholera impacted countries of all socioeconomic strata in Latin America, but the disease was only a temporary, minor public health concern in high-income countries and a continuous problem in lower-income countries (Waldman et al., 2002). The concept of socioeconomic factors influencing cholera transmission has been observed in Africa, a non-endemic region, while environmental factors typically explain cholera incidence in endemic regions experiencing seasonal trends, including the Indian subcontinent and coastal South America (Collins, Lucas, Islam, & Williams, 2006; Sow et al., 2011).

**Measuring socioeconomic status and development.**

No single measure can capture the complex, multifaceted socioeconomic status of a population. For many years, economic factors, including gross domestic product (GDP) per capita and gross national income (GNI) per capita, were considered sufficient indicators of a country’s development (United Nations Development Programme [UNDP], 1990). GDP per capita looks at the total value produced by all residents of the country in current U.S. dollars, divided by the midyear population (World Bank, 2012). The GNI per capita measures the total value in current U.S. dollars produced by all residents of the country, product taxes, and primary income of citizens living abroad, divided by the midyear populations (World Bank, 2012). These economic indicators, however, leave much to be desired, as income averaged over the entire population does not give a true picture of citizens’ actual economic situation, nor the quality of their lives (UNDP, 1990).

The UNDP created the HDI in an effort to better capture socioeconomic status with one indicator. The index combines life expectancy at birth, mean years of schooling, expected years
of schooling, and GNI per capita into one number on a scale of 0.0 to 1.0 (UNDP, 1990). These four indicators were chosen in an attempt to capture the “three essential elements of human life – longevity, knowledge, and decent living standards” (UNDP, 1990, p. 12). Each country’s statistics are compared to the current highest global values for life expectancy and mean educational attainment, and the natural logarithm of the country’s GNI is compared to the natural logarithm of the highest global GNI in purchasing-power-adjusted international dollars (UNDP, 2011). The sub-indices are then aggregated and the resulting geometric mean is the value used for a country’s HDI (UNDP, 2011). While this number is much more indicative of a country’s development as opposed to GDP or GNI alone, it still fails to capture numerous factors associated with human development, including political freedom, crime, and insecurity (UNDP, 1990; UNDP, 2011).

Other measures may offer additional insight into the socioeconomic status of a region or country. Tappero and Tauxe (2011) suggest that a high IMR reflects “major gaps in sanitation and health care” (p. 2091). Calculating the number of physicians or nurses per 10,000 population is a way of assessing the resources of a country’s health care system (Tappero & Tauxe, 2011).

The ability to predict potential cholera outbreaks based on environmental influences could prove to be very beneficial, particularly in countries with limited medical resources and underdeveloped public health infrastructure (Cash, Rodó, & Kinter, 2009). The changing global climate and weather patterns make predicting cholera incidence an almost impossible challenge, leaving millions at risk of illness in the event of a cholera epidemic (Bush et al., 2011).

Cholera continues to pose a serious threat to public health worldwide, with millions of cases reported each year. The morbidity associated with the disease affects all members of a
population, due in large part to fleeting immunity but also due to the waterborne nature of the disease. Many factors, both climatic and socioeconomic, influence the spread and growth of the vibrio. India is subject to extreme weather, including ENSO and extreme rainfall variations, while facing challenges associated with socioeconomic development, including building sanitation infrastructure and providing safe drinking water. Understanding the complex interplay between climatic and socioeconomic variables and cholera incidence rates may help India better control and prevent cholera outbreaks in the future.

**Research Questions**

1. Which socioeconomic and climatic factors are significantly associated with cholera incidence in India?
2. Does cholera IR differ during flood years versus drought years?
3. Does cholera IR differ during El Niño years versus La Niña years?
4. Which of the above factors have the strongest influence on cholera IR?

**Methods**

**Data Collection**

The study period ranged from 1961-2008. Two types of data were used in this analysis; demographic characteristics and meteorological measures. Population estimates were obtained from the World Bank DataBank (2012) for each year from 1961-2008. The number of reported cases of cholera in India for each year in the study was obtained from the Epidemic prone diseases section of the World Health Organization Global Health Observatory Data Repository.

Several variables were used to represent extreme weather events. Annual monsoon rainfall in millimeters was gathered from the Indian Institute for Tropical Meteorology and the Indian National Climate Research Centre (Munot & Kothawale, 2010; National Climate Centre,
India Meteorological Department, 2006). The figures obtained from these two sources were averaged to obtain the rainfall measures used in this study. The National Oceanic and Atmospheric Administration (NOAA) provided data from the Bivariate EnSo Timeseries, or ‘BEST’ ENSO Index, necessary to determine years experiencing El Niño or La Niña events (Smith & Sardeshmukh, 2000).

Socioeconomic measures were collected from a variety of sources. GNI per capita figures, reported in current international dollars, were taken from the World Bank World DataBank (2012) and were available for the years 1962-2008. IMR figures, reported as number of deaths occurring before one year of life per 1000 live births, were collected from the World Bank DataBank (2012) for the years 1961-2008. The UNDP (2011) provided HDI figures for India for 1980, 1990, 2000, and 2005-2008. These years were the only ones with HDI values calculated from actual data, but the report provided interpolated values for the other years in the 1980-2008 range.

**Data Analysis**

The data were entered into IBM Statistical Package for Social Sciences (SPSS) for Windows, version 20 (IBM Corporation, 2011). The outcome (dependent) variable was cholera incidence rate (IR) per million. This IR was calculated using the number of reported cases for each year in the study period. The independent variables of interest included: monsoon rainfall (continuous), ENSO (categorical: none, El Niño, La Niña), extreme weather events (categorical: none, El Niño, La Niña, flood, drought, El Niño/flood, El Niño/drought, La Niña/flood, La Niña/drought), GNI (continuous), Human Development Index (continuous), and IMR (continuous).
Descriptive statistics were calculated for the variables of interest. Means and standard deviations were obtained for continuous variables (rainfall, IMR, GNI, and HDI). Deviations from the mean rainfall were calculated. It was determined *a priori* that a value of 75mm greater than the mean would denote a flood year and a decrease would denote a drought year. Counts and percentages were tabulated and calculated for years experiencing drought, flood, El Niño, La Niña, or a combination of extreme weather events.

Spearman Correlation coefficients were calculated for continuous variables and cholera IR. A t-test was calculated to examine the differences in IR during drought and flood years. A one-way ANOVA test was used to explore differences in cholera IR among years experiencing El Niño, La Niña, or neither. Another one-way analysis of variance (ANOVA) was conducted to examine differences in IR between years experiencing various combinations of extreme weather events (none, El Niño, La Niña, flood, drought, El Niño/flood, El Niño/drought, La Niña/flood, La Niña/drought).

Linear regression was used to explore the relationship of independent variables and the dependent variable, cholera IR. A model building approach was used in the statistical analysis. The models examining ENSO events were adjusted *a priori* for each of the other variables separately. The models examining IMR were controlled independently for GNI, HDI, and rainfall. The GNI and HDI models were controlled only for rainfall.

**Results**

**Descriptive Statistics**

For the study period of 1961-2008 (n=49), the mean rainfall was 857.09mm (standard deviation (SD)=73.59), (range: 694.75mm-1020.30mm). The cholera incidence rate had a mean of 25.53 cases per 1,000,000 (SD=33.53), (range: 1.68-125.98/1,000,000).
Correlation.

Table 1 shows the Spearman correlation coefficients of one climatic variable (rainfall) and three socioeconomic variables (IMR, GNI, and HDI) with cholera IR. The three SES variables were all significantly correlated ($\alpha<0.05$) with cholera IR.

Table 1

<table>
<thead>
<tr>
<th>Spearman Correlation Coefficient</th>
<th>Variable</th>
<th>Cholera IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>0.023</td>
<td></td>
</tr>
<tr>
<td>IMR</td>
<td>0.903*</td>
<td></td>
</tr>
<tr>
<td>GNI</td>
<td>-0.893*</td>
<td></td>
</tr>
<tr>
<td>HDI</td>
<td>-0.718*</td>
<td></td>
</tr>
</tbody>
</table>

*Correlation is significant at $p < 0.05$.

Climatic variables.

Eleven years between 1961 and 2008 experienced a drought, with rainfall of at least 75mm below the mean annual rainfall (Table 2). Eight years during the study period were classified as a flood year, with annual rainfall measuring at least 75mm above mean rainfall.
Table 2

*Drought and Flood Year Rainfall Deviations and Cholera Incidence Rate (IR) in India, 1961-2008*

<table>
<thead>
<tr>
<th>Number</th>
<th>Year</th>
<th>Deviation from Average Monsoon Rainfall (in mm) – Drought Years</th>
<th>IR (cases per 1,000,000)</th>
<th>Year</th>
<th>Deviation from Average Monsoon Rainfall (in mm) – Flood Years</th>
<th>IR (cases per 1,000,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1965</td>
<td>-124.3</td>
<td>88.4</td>
<td>1961</td>
<td>+163.2</td>
<td>108.6</td>
</tr>
<tr>
<td>2</td>
<td>1966</td>
<td>-85.3</td>
<td>26.5</td>
<td>1964</td>
<td>+76.6</td>
<td>112.2</td>
</tr>
<tr>
<td>3</td>
<td>1968</td>
<td>-75.7</td>
<td>43.8</td>
<td>1970</td>
<td>+87.1</td>
<td>28.0</td>
</tr>
<tr>
<td>4</td>
<td>1972</td>
<td>-162.3</td>
<td>36.3</td>
<td>1975</td>
<td>+114.6</td>
<td>36.7</td>
</tr>
<tr>
<td>5</td>
<td>1974</td>
<td>-86.2</td>
<td>52.5</td>
<td>1983</td>
<td>+95.3</td>
<td>11.9</td>
</tr>
<tr>
<td>6</td>
<td>1979</td>
<td>-114.6</td>
<td>7.7</td>
<td>1988</td>
<td>+130.0</td>
<td>21.5</td>
</tr>
<tr>
<td>7</td>
<td>1982</td>
<td>-93.0</td>
<td>6.6</td>
<td>1994</td>
<td>+96.3</td>
<td>5.4</td>
</tr>
<tr>
<td>8</td>
<td>1986</td>
<td>-77.0</td>
<td>5.5</td>
<td>2007</td>
<td>+87.5</td>
<td>2.3</td>
</tr>
<tr>
<td>9</td>
<td>1987</td>
<td>-130.0</td>
<td>15.2</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>10</td>
<td>2002</td>
<td>-114.9</td>
<td>3.3</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>11</td>
<td>2004</td>
<td>-93.9</td>
<td>4.4</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

A t-test was completed to compare the mean IRs of drought and flood years (Table 3). The t-test showed no significant difference (p=0.395) in mean IRs for drought years and flood years.

Table 3

*T-test Results for Cholera Incidence Rates in Drought and Flood Years*

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Standard Error of the Mean</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
<th>Mean Difference (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought Years</td>
<td>11</td>
<td>25.60</td>
<td>26.22</td>
<td>7.90</td>
<td>-.87</td>
<td>17</td>
<td>.395</td>
<td>-13.82 (-47.26, 19.63)</td>
</tr>
<tr>
<td>Flood Years</td>
<td>8</td>
<td>39.42</td>
<td>42.95</td>
<td>15.18</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

Twenty-six years during the study period experienced ENSO events (Table 4). Fifteen years experienced an El Niño event; while eleven years experienced La Niña phenomena.
Table 4

Cholera Incidence Rates in India during El Niño and La Niña Events

<table>
<thead>
<tr>
<th>Number</th>
<th>Year – El Niño Event</th>
<th>Rainfall (in mm)</th>
<th>IR (cases per 1,000,000)</th>
<th>Year – La Niña Event</th>
<th>Rainfall (in mm)</th>
<th>IR (cases per 1,000,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1964</td>
<td>933.45</td>
<td>112.2</td>
<td>1965</td>
<td>732.8</td>
<td>88.4</td>
</tr>
<tr>
<td>2</td>
<td>1966</td>
<td>771.8</td>
<td>26.5</td>
<td>1971</td>
<td>885.05</td>
<td>130.3</td>
</tr>
<tr>
<td>3</td>
<td>1969</td>
<td>854.5</td>
<td>36.6</td>
<td>1972</td>
<td>694.75</td>
<td>36.3</td>
</tr>
<tr>
<td>4</td>
<td>1973</td>
<td>911.35</td>
<td>72.3</td>
<td>1974</td>
<td>770.85</td>
<td>52.5</td>
</tr>
<tr>
<td>5</td>
<td>1978</td>
<td>913.2</td>
<td>16.4</td>
<td>1975</td>
<td>971.65</td>
<td>36.7</td>
</tr>
<tr>
<td>6</td>
<td>1983</td>
<td>952.4</td>
<td>11.9</td>
<td>1976</td>
<td>875.55</td>
<td>24.4</td>
</tr>
<tr>
<td>7</td>
<td>1987</td>
<td>727.1</td>
<td>15.2</td>
<td>1989</td>
<td>883.35</td>
<td>6.9</td>
</tr>
<tr>
<td>8</td>
<td>1988</td>
<td>987.1</td>
<td>21.5</td>
<td>1999</td>
<td>855.8</td>
<td>3.9</td>
</tr>
<tr>
<td>9</td>
<td>1992</td>
<td>811.5</td>
<td>7.8</td>
<td>2000</td>
<td>808.65</td>
<td>4.0</td>
</tr>
<tr>
<td>10</td>
<td>1994</td>
<td>953.35</td>
<td>5.25</td>
<td>2001</td>
<td>829.1</td>
<td>3.9</td>
</tr>
<tr>
<td>11</td>
<td>1995</td>
<td>852.5</td>
<td>3.6</td>
<td>2008</td>
<td>877.4</td>
<td>2.3</td>
</tr>
<tr>
<td>12</td>
<td>1998</td>
<td>889.05</td>
<td>7.3</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>13</td>
<td>2003</td>
<td>905.7</td>
<td>2.8</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>14</td>
<td>2005</td>
<td>879.3</td>
<td>2.77</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>15</td>
<td>2007</td>
<td>944.6</td>
<td>2.3</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

According to the t-test conducted to compare means of El Niño and La Niña years (Table 5), the IRs in years experiencing El Niño events and La Niña events were not significantly different (p = 0.390).

Table 5

T-test Results for Cholera Incidence Rates in El Niño and La Niña years

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Standard Error of the Mean</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
<th>Mean Difference (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Niño Years</td>
<td>15</td>
<td>22.30</td>
<td>29.90</td>
<td>7.72</td>
<td>-0.88</td>
<td>24</td>
<td>.390</td>
<td>-11.99 (-40.25, 16.28)</td>
</tr>
<tr>
<td>La Niña Years</td>
<td>11</td>
<td>34.29</td>
<td>40.07</td>
<td>12.08</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
Weather phenomena, such as droughts, floods, and ENSO events, can overlap and occur in the same year. Table 6 shows the frequencies of the extreme weather phenomena during the study period. Fifteen years (30.61%) experienced no extreme weather event. Fifteen years (30.61%) experienced only ENSO events: eight years experienced solely El Niño, and seven years experienced strictly La Niña. Eight years (16.33%) experienced an extreme in rainfall without an accompanying ENSO event. Two years experienced just flood-level monsoon rains, whereas six years experienced only drought conditions. A total of eleven years (22.45%) experienced two different extreme weather phenomena. Five years experienced both El Niño and flood-level rains, whereas two years had an El Niño event and drought rainfall. One year saw simultaneous flood-level rainfall and a La Niña event, while three years saw both drought-level rains coupled with a La Niña event.

Table 6

<table>
<thead>
<tr>
<th>Extreme Weather Phenomena</th>
<th>Frequency (n=49)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>15</td>
<td>30.6</td>
</tr>
<tr>
<td>El Niño</td>
<td>8</td>
<td>16.3</td>
</tr>
<tr>
<td>La Niña</td>
<td>7</td>
<td>14.3</td>
</tr>
<tr>
<td>Flood</td>
<td>2</td>
<td>4.1</td>
</tr>
<tr>
<td>Drought</td>
<td>6</td>
<td>12.2</td>
</tr>
<tr>
<td>El Niño, Flood</td>
<td>5</td>
<td>10.2</td>
</tr>
<tr>
<td>El Niño, Drought</td>
<td>2</td>
<td>4.1</td>
</tr>
<tr>
<td>La Niña, Flood</td>
<td>1</td>
<td>2.0</td>
</tr>
<tr>
<td>La Niña, Drought</td>
<td>3</td>
<td>6.1</td>
</tr>
</tbody>
</table>

There was no significant difference in cholera IR across the years experiencing El Niño, La Niña, or neither using ANOVA test, $F(2, 46) = 0.478$, $p = 0.623$ (Table 7). In further ANOVA models, no significant difference in cholera IR was noted across the eight categories of years experiencing extreme weather events (none, El Niño, La Niña, flood, drought, El
Niño/flood, El Niño/drought, La Niña/flood, La Niña/drought), $F(8, 40) = 0.904, p = 0.523$ (Table 8).

Table 7

One-way ANOVA Comparing Cholera Incidence Rates of Years Experiencing El Niño, La Niña, or No ENSO Event

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1099.314</td>
<td>2</td>
<td>549.657</td>
<td>0.478</td>
</tr>
<tr>
<td>Within Groups</td>
<td>52849.273</td>
<td>46</td>
<td>1148.897</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>53948.588</td>
<td>48</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8

One-way ANOVA Comparing Cholera Incidence Rates of Years Experiencing Extreme Weather Events

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>8257.548</td>
<td>8</td>
<td>1032.194</td>
<td>0.904</td>
</tr>
<tr>
<td>Within Groups</td>
<td>45691.039</td>
<td>40</td>
<td>1142.276</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>53948.588</td>
<td>48</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Linear Regression Models

Table 9 summarizes the influences of climatic variables on cholera IR in India. IMR had the most significant influence on cholera IR when controlled for all other variables. GNI was also a significant influence on IR. IMR and GNI remained significant even when modeled together. When controlled for GNI and IMR, La Niña was marginally significant. Rainfall and El Niño were not significant ($\alpha<0.05$) in any model.
**Table 9**

**Bivariate Analyses of Climatic and Socioeconomic Variables and their Association with Cholera Incidence Rate**

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Independent Variable(s)</th>
<th>Independent Variable (controlled)</th>
<th>R²</th>
<th>p-value (model)</th>
<th>p-value (independent variable(s))</th>
<th>p-value (controlled independent variable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cholera (IR)</td>
<td>El Niño</td>
<td>---</td>
<td>0.020</td>
<td>0.002</td>
<td>0.919</td>
<td>0.388</td>
</tr>
<tr>
<td></td>
<td>La Niña</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cholera (IR)</td>
<td>El Niño</td>
<td>IMR</td>
<td>0.622</td>
<td>&lt;0.001</td>
<td>0.279</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td>La Niña</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cholera (IR)</td>
<td>El Niño</td>
<td>Rainfall</td>
<td>0.041</td>
<td>0.568</td>
<td>0.754</td>
<td>0.350</td>
</tr>
<tr>
<td></td>
<td>La Niña</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cholera (IR)</td>
<td>El Niño</td>
<td>GNI</td>
<td>0.368</td>
<td>&lt;0.001</td>
<td>0.406</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>La Niña</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cholera (IR)</td>
<td>El Niño</td>
<td>HDI</td>
<td>0.429</td>
<td>&lt;0.001</td>
<td>0.347</td>
<td>0.052</td>
</tr>
<tr>
<td></td>
<td>La Niña</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cholera (IR)</td>
<td>IMR</td>
<td>Rainfall</td>
<td>0.600</td>
<td>0.012</td>
<td>&lt;0.001</td>
<td>0.225</td>
</tr>
<tr>
<td>Cholera (IR)</td>
<td>IMR</td>
<td>GNI</td>
<td>0.622</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.067</td>
</tr>
<tr>
<td>Cholera (IR)</td>
<td>IMR</td>
<td>HDI</td>
<td>0.569</td>
<td>0.938</td>
<td>0.711</td>
<td>0.993</td>
</tr>
<tr>
<td>Cholera (IR)</td>
<td>GNI</td>
<td>Rainfall</td>
<td>0.329</td>
<td>0.732</td>
<td>&lt;0.001</td>
<td>0.481</td>
</tr>
<tr>
<td>Cholera (IR)</td>
<td>HDI</td>
<td>Rainfall</td>
<td>0.356</td>
<td>0.133</td>
<td>0.001</td>
<td>0.240</td>
</tr>
</tbody>
</table>

**Discussion and Conclusions**

Cholera continues to be a significant public health concern in developing regions with an estimated 2.8 million cases occurring in these countries (Ali et al., 2012). Cholera incidence is influenced by many factors, including climatic and socioeconomic variables examined in this study. India experiences severe weather, including ENSO events and widely varying annual monsoon rainfall, which can impact environmental factors that in turn may influence the proliferation and spread of *V. cholerae*. This study examined the influences of various climatic and socioeconomic variables. None of the climatic variables were found to have a significant effect on cholera IR in India. Among the socioeconomic variables studied, HDI, IMR, and GNI were significantly associated with cholera IR.
There was a significant inverse association between India’s GNI and cholera IR. As the per capita GNI increases, interpreted as a measure of economic development, the cholera IR decreases. While the exact side effects of this increased income and development are unknown and immeasurable, it could be that some of the money was put towards improving sanitation infrastructure and social development including education, primary health care that reduced cholera IR.

Cholera IR was significantly correlated with development as measured by India’s HDI measure. The increase of India’s rating over the years, meaning education, income, and life expectancy in the country improved, was significantly correlated with a decrease in cholera IR.

The most significant correlation in this study was between cholera IR and IMR. The IMR measurement can be viewed as a proxy measure of socioeconomic status, as a decrease in the number of infants dying suggests an improvement in general health, better access to medical care, and improved sanitation. India’s IMR at the end of the study period was less than one third the IMR in 1961, which may indicate that the country has made great strides in the health and sanitation infrastructure (World Bank, 2012).

These socioeconomic variables are merely proxy measures for development and cannot give definitive answers regarding the influence of socioeconomic status on cholera IR. An examination of the countries just above and below India in global rankings for GNI, HDI, and IMR includes Ghana, Yemen, and Papua New Guinea, (UN, 2011; UNDP, 2013; World Bank, 2012). The majority of these countries falling on either side of India have much higher cholera IRs, despite being very similar in socioeconomic standing (WHO, 2010; World Bank, 2012). The wide range of cholera IRs in seemingly similar countries suggests that the variables
influencing cholera incidence are incredibly complex and vary despite comparable socioeconomic situations.

Further research could provide greater insight into the complex interplay of climatic, geographic, socioeconomic, and cultural variables potentially influencing cholera IRs in India and around the world. Of particular interest are variables related to access to sanitation and clean water. At the time of this study, these variables are of relatively new interest, and the figures for India are available in five year intervals (World Bank, 2012). Ideally, these figures would be available for each year in order to view possible change over time.

This study was limited by several factors beyond the control of the researcher. The data for all variables were available only on a national level, which is not as illuminating as data on a regional level. The regions of India are subject to very different temperatures and levels of rainfall in addition to having varying levels of income and undergoing development at different paces. The cases of cholera reported to the WHO each year were likely underestimates of the actual burden of cholera in India, particularly in the earlier decades of the study. With the advent of electronic communications and disease monitoring technology, the cases reported in more recent decades may be more reliable and accurate.

Cholera continues to pose a threat to billions of individuals around the world, and many aspects of the disease’s transmission remain unknown to researchers. Climate change and socioeconomic development will likely continue to play important roles in cholera incidence rates, and continued research is imperative.
References


United Nations [UN], Department of Economic and Social Affairs, Population Division, Population Estimates and Projections Section. (2011). World population prospects, the


Appendix 1: IRB Exemption Letter

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(937) 775-3781 (FAX)
c-mail: rsp@wright.edu

WRIGHT STATE
UNIVERSITY

DATE:  April 19, 2013
TO:  Kathleen Henschel, PI, MPH Student
       Public Health
       Naila Khalil, PhD, Fac. Adv.
       Community Health
FROM:  B. Laurel Elder, Chair
       WSU Institutional Review Board
SUBJECT:  SC#  5156
       'The Influences of Climatic and Socioeconomic Factors on Cholera Incidence in India during the Seventh Pandemic, 1961-2008'

At the recommendation of the IRB Chair, your study referenced above has been recommended for exemption. Please note that any change in the protocol must be approved by the IRB; otherwise approval is terminated.

This action will be referred to the Full Institutional Review Board for ratification at their next scheduled meeting.

NOTE: This approval will automatically terminate two (2) years after the above date unless you submit a "continuing review" request (see http://www.wright.edu/rsp/IRB/CR_sc.doc) to RSP. You will not receive a notice from the IRB Office.

If you have any questions or require additional information, please call Robyn Wilks,
IRB Coordinator at 775-4462.

Thank you!

Enclosure
RESEARCH INVOLVING HUMAN SUBJECTS

SC#: 5156

ACTION OF THE WRIGHT STATE UNIVERSITY
EXPEDITED REVIEW
Assurance Number: FWA00002427

Title: The Influences of Climatic and Socioeconomic Factors on Cholera Incidence in India during the Seventh Pandemic, 1961-2008

Principal Investigator: Kathleen Hensche, Pl MPH Student
Public Health
Nailsa Khalil, PhD, Fac, Adv.
Community Health

The Institutional Review Board Chair has approved an exemption with regard to the use of human subjects on this proposed project.

REMINDEER: Federal regulations require prompt reporting to the IRB of any changes in research activity [changes in approved research during the approval period may not be initiated without IRB review (submission of an amendment), except where necessary to eliminate apparent immediate hazards to subjects] and prompt reporting of any serious or on-going problems, including unanticipated adverse reactions to biologicals, drugs, radioisotope labeled drugs or medical devices.

Signed Chair, WSU-IRB

Approval Date: April 19, 2013
IRB Mtg. Date: May 20, 2013
## Appendix 2: List of Tier 1 Core Public Health Competencies Met

<table>
<thead>
<tr>
<th>Domain #1: Analytic/Assessment</th>
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<tbody>
<tr>
<td>Identify the health status of populations and their related determinants of health and illness (e.g., factors contributing to health promotion and disease prevention, the quality, availability and use of health services).</td>
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<tr>
<td>Describe the characteristics of a population-based health problem (e.g., equity, social determinants, environment).</td>
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<tr>
<td>Use variables that measure public health conditions.</td>
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<tr>
<td>Use methods and instruments for collecting valid and reliable quantitative and qualitative data.</td>
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<tr>
<td>Identify sources of public health data and information.</td>
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<tr>
<td>Recognize the integrity and comparability of data.</td>
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<td>Identify gaps in data sources.</td>
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<tr>
<td>Adhere to ethical principles in the collection, maintenance, use, and dissemination of data and information.</td>
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<tr>
<td>Describe the public health applications of quantitative and qualitative data.</td>
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<tr>
<td>Collect quantitative and qualitative community data (e.g., risks and benefits to the community, health and resource needs).</td>
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<tr>
<td>Use information technology to collect, store, and retrieve data.</td>
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<tr>
<td>Describe how data are used to address scientific, political, ethical, and social public health issues.</td>
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<tr>
<th>Domain #2: Policy Development and Program Planning</th>
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<tr>
<td>Gather information that will inform policy decisions (e.g., health, fiscal, administrative, legal, ethical, social, political).</td>
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<th>Domain #3: Communication</th>
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<tr>
<td>Communicate in writing and orally, in person, and through electronic means, with linguistic and cultural proficiency.</td>
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<td>Participate in the development of demographic, statistical, programmatic and scientific presentations.</td>
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<th>Domain #4: Cultural Competency – N/A</th>
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<tr>
<td>Domain #5: Community Dimensions of Practice- N/A</td>
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<tr>
<td>Domain #6: Public Health Sciences</td>
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<tr>
<td>Describe the scientific evidence related to a public health issue, concern, or, intervention.</td>
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<td>Retrieve scientific evidence from a variety of text and electronic sources.</td>
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<tr>
<td>Discuss the limitations of research findings (e.g., limitations of data sources, importance of observations and interrelationships).</td>
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| Domain #7: Financial Planning and Management – N/A |  |
| Domain #8: Leadership and Systems Thinking – N/A |  |