Amanda Allnutt

The Role of El Niño – Southern Oscillation in Shaping Cholera Disease Dynamics: The Case of Bangladesh

Cholera remains a major public health problem in many developing nations. Areas with large cholera epidemics include Bangladesh, India and countries in Africa and South Africa (Kovats et al., 2003). Figure 1 shows areas that reported cholera outbreaks in 2009-2010. Traditionally, cholera has been viewed as a fecal-oral infection (Constantin de Magny et al., 2008). Prior to the 1970s, cholera was argued to be transmitted through person-person contact, where epidemics started with contaminated water and food (Constantin de Magny et al., 2008). More recently, the environmental determinants of the disease have been recognized, since Vibrio cholerae, the bacteria causing Cholera, is found to inhabit coastal waters, estuaries, and rivers (Pascual et al. 2000) Outbreaks of cholera emerge when V. cholerae is present in food and drinking water, and thus, are more likely to occur in regions with limited or damaged infrastructure (Cash et al., 2005). A growing body of research has emerged concerning the correlation between cholera epidemics and climate variability associated with El Niño Southern Oscillation (ENSO) (WHO, 1999). Increased attention has been paid to ENSO and cholera since the re-emergence of cholera in 1991-1992 in Peru coincided with an El Nino event, which motivated the hypothesis that ENSO events may influence cholera dynamics (Pascual, 2008). In addition, several outbreaks in 1997 in East Africa occurred, following heavy rains attributable to ENSO and because of an observed relationship between sea surface temperatures (SSTs) and cholera cases in coastal areas, most notably in Bangladesh near the Bay of Bengal (WHO, 1999).

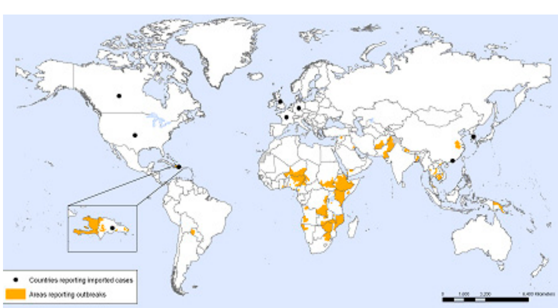

Figure 1 Reported Cholera Outbreaks in 2009-2010;
Source: World Health Organization, 2011

The aim of this paper is to critically analyze and characterize the role of ENSO on cholera outbreaks in Bangladesh, where the disease is endemic. The objectives herein include: 1. Describe the basic knowledge and trends that characterize cholera and ENSO events, to determine if there is a causal link, by drawing on a case study from Bangladesh. 2. Determine if the relationship between cholera and ENSO can be used to forecast outbreaks.

Analysis

I. Overview of Cholera and ENSO

Cholera is an acute diarrheal illness, caused by an infection of V. Cholerae bacteria in the small intestine (CDC, 2010). Symptoms of the disease include profuse diarrhea, vomiting, leg cramps, circulatory collapse, and shock (CDC, 2010). When cholera goes untreated, mortality rates of 50 per cent are common; however, with proper treatment, mortality rates are less than 1 per cent (Cash et al., 2010). Environmental signatures have been associated with cholera epidemics, as V. cholerae, in autochthonous to riverine, estuarine, and coastal ecosystems consisting of phytoplankton, aquatic plants and with its host, the copepod, a member of the zooplankton community (Constantin de Magny et al., 2008). Temperature, salinity, and plankton are suggested to be important factors to the ecology of V. cholera (Patz et al., 2005). Bacterial growth increases with warmer temperatures, mainly in combination with blooms of phytoplankton, aquatic plants, or algae (Colwell, 1996). These blooms increase the amount of food available for copepods, which the V. cholerae attach to, protecting the bacteria from exterior environmental factors and allowing it to multiply (Lipp et al., 2002). Transmission occurs in two stages; primary and secondary. The former is a result of eating contaminated shellfish (copepods) or aquatic plants, or drinking contaminated water. Secondary transmission occurs from person to person contact (Ruiz-Mureno et al., 2010). Primary transmission shapes the seasonal patterns in endemic areas and secondary transmission determines the level of infection (Ruiz-Mureno et al., 2010). Figure 2 depicts how cholera is transmitted in nature. Ingesting a small amount of copepods carrying V. cholerae can initiate the disease (Koelle et al., 2005). Therefore, the disease transmission occurs in areas of the world where main sources of drinking water go untreated (Constantin de Magny et al., 2008).

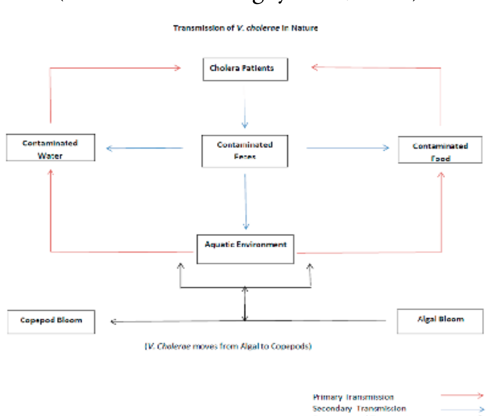

Figure 2: Cholera transmission in nature (Schoolnik, 2008)

ENSO is the strongest naturally occurring source of climate variability around the globe, following natural seasonal variability (Kovats et al., 2003). El Niño is characterized by a warming of the waters in the equatorial Pacific, and the southern oscillation is defined as the oscillation in air pressure mirroring the warming and cooling associated with El Niño (Kump et al., 2009). (El Niño is an abbreviated term often used to denote ENSO). The ocean warming associated with El Niño has a significant impact on climate around the globe, described in figure 3. With the exception of North America and Australia, the countries that experience the greatest environmental impacts from ENSO are in developing nations where the events are atypically hot or wet. In Bangladesh, the effects are typically warm in June - August and dry in December - February (Patz et al., 2005). ENSO occurs on time scales of 2-7 years and is associated with extreme weather conditions, such as floods and drought (Kovats et al., 2003). Given that ENSO is a large source of climate variability and V. cholera is greatly influenced by environmental conditions, an association between the two

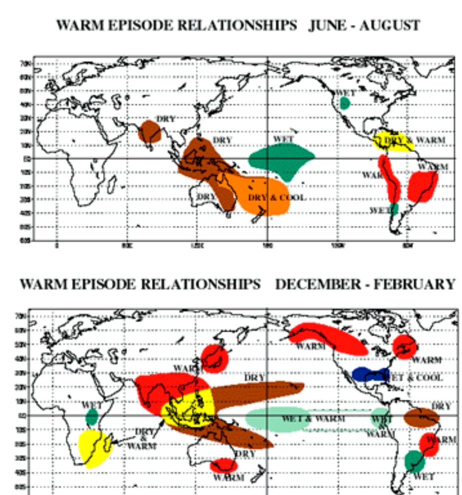

Figure 3. ENSO Impact on regional climate (Kump et al., 2009)

has emerged (Cash et al., 2010).

II. The Bangladesh Case Study

According to the WHO (2011), cholera incidence is underestimated in the Indian subcontinent and Southeast Asia because countries do not report their cholera cases. Although there are no reported cases from Bangladesh, experts estimate that there may be 1 million cases a year in Bangladesh (WHO, 2011). Therefore, WHO (2011) estimates the Burden of disease in Bangladesh is much higher than is reflected among cases reported to the WHO. Cholera estimates can be made, since the International Centre for Diarrheal Disease Research in Bangladesh (ICDDRB) operates hospitals in Matlab and Dhaka Bangladesh and keeps records of cholera patients (Emch, 2010). It is suggested that the number of patients arriving to hospitals in Bangladesh in shock due to cholera is increasing (WHO, 2011). Moreover, there is a large body of literature discussing the role of ENSO events shaping cholera disease dynamics (Patz et al., 2002; Pascaul et al., 2000; Koelle et al., 2005; Cash et al., 2010). Given the quantity and quality of work on the subject in Bangladesh and the fact that the disease is becoming more virulent, this provides an informative case study for how ENSO affects cholera outbreaks over time.

There exists a clear climatic sensitivity to cholera epidemics in Bangladesh. Many researchers suggest a bimodal seasonal pattern to the outbreaks (Cash et al., 2010; Kovats, 2000; Kovats et al., 2003). That is, cholera incidence is at its maximum during fall, following the abatement of summer monsoons, and reaches another maximum in the spring, before summer monsoons begin (Cash et al., 2010). ENSO is emerging as a significant predictor of cholera risk because it is observed that ENSO events alter the traditional bimodal distribution (Patz et al., 2005). Cholera in Bangladesh has varied with climatic fluctuations and SSTs influenced by ENSO phenomena over multi-decadal time periods (Patz et al., 2005). An association between fall cholera incidence and winter ENSO events has been observed since cholera incidence has been shown to increase following winter El Niño events (Cash et al., 2010). The physical basis for this is that Bangladesh summer rainfall increases as a result of warm winter SST anomalies in the tropical pacific initiated by winter El Niño events. Cholera incidence, consequently, rises through increased flooding and breakdown in sanitation (Cash et. al., 2010). Outbreaks also increase because rainfall improves insoluble iron levels, which advances the survival of V. cholerae in marine ecosystems suggesting that increased rainfall associated with ENSO events may improve conditions for the bacteria and increase food and water contamination (Robo et al., 2005).

The correlation between cholera and ENSO in Bangladesh has become more pronounced in recent years. An analysis of historical data in Bengal from 1890-1940 indicates that effects of El Niño on cholera was historically confined to coastal regions, and may have caused spring epidemics, a shift from the usual seasonal outbreaks (Kovats et al., 2003). Trends have become more pronounced since the 1980s in Bangladesh as the ENSO events have become stronger (Rodo et al., 2002; Pascual et al., 2000) examined the association between cholera and ENSO using 18 year records from Bangladesh. Monthly time series data for cholera incidence between January 1980 and March 1998 and SST anomaly data in the equatorial Pacific was used to create an ENSO index during the same period. A significant correlation was observed between cholera and ENSO, with strong associations happening during more pronounced ENSO fluctuations (Pascual et al., 2000). This is largely due to a relationship between cholera cases in Bangladesh and sea surface temperature in the Bay of Bengal. Copepods bloom in response to warming sea surface temperatures that are associated with ENSO (Patz et al., 2005; Kovats, 2003). However, the possible mechanism by which

SST disease transmission increased beyond the norm is not greatly understood.

On the other hand, understanding the role of environmental determinants of cholera requires a more holistic approach that includes a combined analysis of intrinsic host immunity to the disease because, "evidence that climate variability drives these inter-annual cycles has been highly controversial, chiefly because it is difficult to isolate the contribution of environmental forcing while taking into account nonlinear epidemiological dynamics generated by host immunity" (Koelle et al., 2005, p. 696). Koelle et al (2005) consider the interplay of these factors and find there is evidence for the role of climate variability in the transmission of cholera. It is suggested that inter-annual variability of cholera is strongly correlated to ENSO, SSTs in the Bay of Bengal over short time spans, during refractory periods, when population susceptibility is considered low. That is, under suitable climate conditions, such as ENSO, epidemics are likely to occur only if a sufficient proportion of the population is non-immune.

III. Forecasting the risk of a cholera outbreak

ENSO events are becoming easier to predict with dynamical and statistical climate models that are used to indicate the likelihood of typical ENSO temperature and precipitation anomalies. Although, the magnitude of an event has high levels of uncertainty and the severity of impacts is hard to predict (McPhaden et al., 2006). Pascual et al. (2008) attempted to predict cholera outbreaks with ENSO data retrospectively. The results illustrate that ENSO is a key covariate and confirm its interplay with immunity levels. Moreover, it is suggested that when v. cholera is considered in predictive models, a robust early warning system for cholera in endemic regions can be developed (Constantin de Magny et al., 2008). The feasibility of using a model as a forecasting tool is established and it is argued that, regardless of model limitations, valuable information for the development of risk management strategies for climate sensitive diseases can be provided (McPhaden et al., 2006). Therefore, the environmental determinants of cholera epidemics can help provide a foundation to build predictive mechanisms for cholera outbreaks and reduce regional vulnerability.

Early warning systems for enhancing public health measures in Bangladesh and other at risk areas have been proposed (Kovats et al., 2000; Constantin de Magny et al., 2008). Seasonal forecasts are becoming sufficiently useful for health purposes on the seasonal level, because major climate trends can be predicted. They are also useful at the short term level because weather can be more accurately predicted approximately one week in advance (Kovats et al., 2003). Seasonal forecasts indicate areas where the probability of some deviation from the climate mean is increased, such as wet or dry or warmer or cold conditions (Kovats et al., 2003). For operational use, however, seasonal climate trends are not sufficient, as our climate system is chaotic. Therefore local weather conditions are needed to provide early warning of epidemic risk (Patz et al., 2005). In addition, it is argued that seasonal forecasts are more accurate during ENSO events than other times (Kovats, 2000; Kovats et al., 2003). This is likely because it is known that ENSO SSTs, in the second half of the year, persist for two seasons and the evolution can be monitored quite accurately proving useful for decision makers (McPhaden et al., 2006). Early warning system can help limit health impacts because it can influence response times. Figure 4 depicts the time-scale of El Niño early warning systems with both weather and climate.

Given that cholera occurs from ingesting contaminated food or water, it is not always possible to provide adequate treatment in a timely manner once the epidemic has begun (Cash et al., 2010). Therefore, it is suggested that better methods of forecasting cholera risk would be a great benefit to societies that

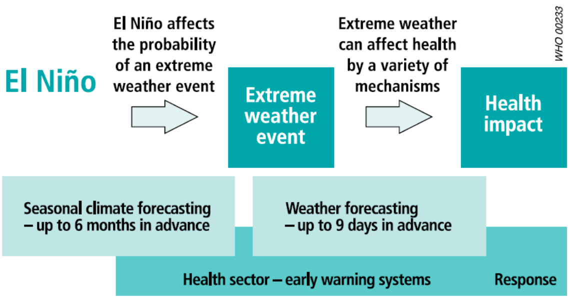

Figure 4: Time-scale model for El Niño early warning Systems (Kovats, 2000).

face cholera outbreaks, because medical supplies could be prepared in advance. For example, in 1997, the regional WHO Cholera Surveillance Team was aware of an El Niño related drought that had been forecast for South-East Africa and were able to institute measures to help decrease the severity of the outbreak by preparing health care institutions and increasing supplies (WHO, 1999). Thus, it is suggested that disease surveillance and forecasting systems can be effective in reducing vulnerability to climate extremes as the ability to predict high or low transmission seasons can help target the timing and place of public health interventions.

Discussion

Although research suggests the association between cholera and ENSO can act as a predictive mechanism for cholera outbreaks, there are other issues in the prevention of the disease. Access to clean water, proper sanitation methods, health education, and good food hygiene are important prevention measures (WHO, 2011). Proper water infrastructure is important, since cholera outbreaks generally emerge in areas that lack the necessary infrastructure, such as proper plumbing systems (CDC, 2011). The flooding associated with El Niño can cause damage to local infrastructure (such as sewage systems and water supply systems), which can exacerbate the epidemic (WHO, 1999). Moreover, Emch et al (2010) posit that local socio-economic status (SES) modifies the effect of regional environmental forces in Matlab, Bangladesh. SES has a significant on cholera incidence, with lower incidence rates in higher SES households (Emch, 2010). Thus, there are important social factors such as infrastructure quality and economic status that contribute to cholera risk. Theses social determinants of the disease are important to consider because they can have a large impact on disease prevention.

Other limitations to the analysis described above emerge because, in infectious disease epidemiology, it is rare for a disease to be consistently attributed to one factor, and there are multiple pathways in which endemic cholera can emerge. The internal dynamics of the disease need to be better researched in association to ENSO events, in order to portray a more complete picture. Although, there is a plausible link between ENSO and cholera, it is suggested that, "non-linear disease hosts dynamics can generate cycles of variability independently of climate" (Hashizume et al., 2011). In the Koelle et al (2005) study mentioned previously, these dynamics were accounted for and a correlation was observed that suggested a link to ENSO. However, there is another body of research that suggests cholera incidence is characterized by internal disease dynamics. For example, Hashizume et al (2011) suggest there is a "significant fraction of observed variability of cholera incidence that can be attributed to internal disease dynamics" (p. 239). Thus, further research needs to reflect a more comprehensive picture.

The relationship between health and environment can be influenced by climate change. How ENSO dynamics will change due to climate change is still speculative (Ohtomo et al., 2010). Collins (2005) posits that there may be an increase in the probability of ENSO-like events due to anthropogenic climate change. Rodo et al (2002) claim that most observational and modeling evidence suggest an increase in both variability and amplitude of ENSO under global warming model scenarios. Furthermore, it is suggested that areas that are currently strongly affected by ENSO could experience greater risks if ENSO variability or the strength of ENSO intensifies (Patz et al., 2005). Understanding the environmental determinants of cholera are important because it is possible that future climate change may significantly influence outbreaks. Ohtomo et al (2010) argue that clarifying the correlation between prevalence of infectious disease and climate change is important given our current warming trends. Enhanced warming, not just changes in ENSO, has the ability to change disease transmission by changing human behavior, especially with increased contact with contaminated water before and during the spring where cholera outbreaks normally start in Dhaka, Bangladesh (Rodo et al., 2002). Therefore, risk associated with climate change and ENSO should be investigated further because it can have a significant impact on the emergence of cholera epidemics.

Conclusion

The associations between cholera outbreaks and ENSO climate patterns can have a profound impact on public health. El Niño is associated with increased risk of cholera in Bangladesh because climate anomalies are linked with El Niño. The relationship with El Niño illustrates the ecological basis of cholera in Bangladesh and represents one pathway of cholera emergence. However, the social determinants of the disease need to be examined in conjunction with the environmental determinants, since they also play a big role in disease transmission. These additional factors are often overlooked in the ENSO literature and future research should consider them.

Moreover, since cholera incidences appear to increase following winter El Niño events, there is a window of opportunity to improve cholera risk through forecasts. Areas where El Niño can be reliably associated with regional climate variations, such as Bangladesh, can provide decision makers with early warning of increased risk, as seen in the aforementioned WHO Cholera Surveillance Team example. That is, the effect ENSO has on cholera can be a useful predictor of disease outbreaks, can help preparedness for disease outbreaks, and reduce population vulnerability to climate extremes. Thus, the relationship between the two needs to be considered by policy makers and health care professionals, because of its use in predicting epidemic risk and determining location and timing of public health interventions. Although the notions presented here focus on Bangladesh, the concepts can be transferred to other locations that are vulnerable to the effects of El Niño climate variability, such as Africa and South America. El Niño affects sea surface temperatures around the world, which may increase risk for a disease epidemic in non-endemic regions.

References

Cash, B. A., Rodo, X., & Kinter, J. L. (2008). Links between Tropical Pacific SST and cholera incidence in Bangladesh: Role of the Eastern and Central Tropical Pacific. Journal of Climate, 21, 4647-4663.

Cash, B. A., Rodo, X., Kinter, J. L., & Yunus, M. (2010). Disentangling the impact of ENSO and Indian Ocean variability on the regional climate of Bangladesh: Implications for cholera risk. Journal of Climate, 23, 2817-2831.

Collins, M. (2005). El-Nino or La Nina like climate change? Climate Dynamics, 24, 89-104.

Colwell, R. R. (1996). Global climate and infectious disease: the cholera paradigm. Science, 274, 2025–2031.

CDC, (2010). Centres for Disease Control and Preventions disease index: Cholera. Retrieved from http://www.cdc.gov/cholera/index.html

Constantin de Magny, G., Murtugudde, R., Sapiano, M., & Colwell, R. (2008). Environmental signatures associated with cholera epidemics. Proceedings of the National Academy of Sciences of the United States of America, 105 (46), 17676-17681.

Emch, M., Yunus, M., Escamilla, V., Feldacker, C., & Ali, M. (2010). Local population and regional environmental drivers of cholera in Bangladesh. Environmental Health, 9 (2), 1-8.

Hashizume, M., Faruque, A. S. G., & Terao, T. (2011). The Indian Ocean dipole and cholera incidence in Bangladesh: A time-series analysis. Environmental Health Perspectives, 119 (2), 239–244.

Koelle, K., Rodo, X., Pascual, M., Yunus, M.,& Mostafa, G. (2005). Refractory periods and climate forcing in cholera dynamics. Nature, 436 (4), 696-700.

Kovats, R. S., Bouma, M. J., Worrall, E., & Haines, A. (2003). El Niño and health. The Lancet. Retrived from http://image.thelancet.com/extreas/02art5336.web.pdf

Kovats, R. S. (2000). El Niño and human health. Bulletin of the World Health Organization, 78 (9), 1127-1136.

Kump, L. R., Kasting, J. F., & Crane, R. G. (2009). The Earth System, 3rd ed. Prentice-Hall.

Lipp, E. K, Huq, A., & Colwell, R. R. (2002). Effects of global climate on infectious disease: The cholera model. Clinical Microbiology Review, 15, 757–770.

McPhaden, M. J., Zebiak, S. I., & 2 Glantz M. I. (2006). ENSO as an integrating concept in earth science. Science, 314(1740), 1740-1745.

Pascual, M., Chaves, L. F., Cash, B., Rodo, X., & Yunus, M. (2008). Predicting endemic cholera: The role of climate variability and disease dynamics. Climate Research, 36, 131-140.

Pascual, M., Rodo, X., Ellner, P., Colwell, R., & Bouma, M.J. (2000). Cholera dynamics and El Nino southern oscillation. Science, 289, 1766-1769.

Patz, J. A, Gibbs, H. K., Foley, J., Rogers, J. V., & Smith, K. R. (2007). Climate change and global health: Quantifying a growing ethical crisis. Eco-Health, 4, 397-405.

Patz, J. A., Cambell-Lendrum, D., Holloway, T., & Foley, J.A. (2005). Impact of regional climate change on human health. Nature, 438 (17), 310-317.

Ohtomo, K., Kobayashi, N., Sumi, A., & Ohtomo, N. (2010). Relationship of cholera incidence to El Niño and solar activity elucidated by time-series analysis. Epidemiology and Infectection, 138, 99-107.

Rodo, X., Pascual, M., Fuchs, G., Faruque, A. S. G. (2002). ENSO and cholera: A non-stationary link related to climate change?. Proceedings of the National Academy of Sciences of the United States of America, 99 (20), 12901-12906.

Ruiz-Moreno, D., Pascual, M., Emch, M., & Yunus, M. (2010). Spatial clustering in spatio-temporal dynamics of endemic cholera. Infectious Diseases, 10 (15), 1417-1487.

Schoolnik, G. (2008). Environment degradation begets epidemics: Cholera in Bangladesh. Retrieved from http://med.stanford.edu/medcast/2008/cholera-bangladesh.html

WHO (1999). Task force on climate and health: El Niño and health. Geneva 1999. Retrieved from http://www.who.int/globalchange/publications/en/elnino.pdf

WHO (2011). "Health topics: cholera." Retrieved from http://www.who.int/topics/cholera/en/