A Historical Analysis of Cholera Dynamics in Bengal 1870-1940 in relation to climate variability

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Records afford evidence of an undoubted relation
between the meteorology of a place and its liability to cholera
—Bellew, 1885

The search for climatic and environmental explanations of cholera began over 100 years ago through the efforts of British Medical Officers in Bengal and other provinces of former British India. In recent years the interest in these associations has re-emerged, particularly in view of the potential effects of global climate change on disease and the territorial expansion of cholera to the American continent for the first time in many decades. Evidence supporting the autochtonous nature of *Vibrio cholerae* in brackish waters and estuaries (Colwell *et al.*, 1977; Kaper *et al.*, 1979; Feachem *et al.*, 1981) has also highlighted the potential significance of environmental factors to the dynamics of the disease.

A temporal association has been proposed between the El Niño Southern Oscillation, the major source of interannual climate variability, and the recent exacerbations of cholera, including the recent epidemic in South America (Epstein *et al.*, 1993; Colwell, 1996). Environmental variables that could mediate this effect locally are: rainfall, temperature, and sea surface temperature (SST). SST could directly, or indirectly through plankton, influence the population dynamics of the bacterium in coastal estuarine regions; it could also serve as a surrogate for environmental conditions in water bodies further from the coast (Colwell, 1996). There is indeed both field and experimental evidence for the attachment of the bacterium to chitin surfaces and to plankton, as well as experimental evidence for a positive effect of such attachment on survival (Nalin *et al.*, 1979, Huq *et al.*, 1983; Huq *et al.*, 1984; Sirajul Islam *et al.*, 1990). Rainfall and air temperature were in earlier studies associated with the severity of the disease in former British India. Results were confounded, however, by associations which correlated positively or negatively according to location. Thus, the early and recent literature provides suggestive but not yet conclusive evidence for environmental influences on the dynamics of cholera. Many questions remain; in particular, whether and how climate variability can be used to anticipate temporal exacerbations of the disease.

For the ENSO experiment, our work focused on the hypothesis that the El Niño Southern Oscillation leads to exacerbations of cholera incidence in areas were the disease is endemic. To examine this hypothesis without the limitation of data set length, we searched for historical records of long temporal extent. We report here on preliminary results of our retrospective

studies with data for cholera mortality in former Bristish India. Although the seasonal and interannual dynamics of cholera may have changed in the present, e.g. as a result of possible mutations in the pathogen, a historical study can facilitate the interpretation of current dynamical patterns and point to appropiate statistical methods for the development of predictive models. Cholera remains today an important public health problem in many countries of the developing world, including Bangladesh and India where the disease is endemic.

Data

Historical records from the yearly medical reports in former British India provide a rich source of data on the magnitude of diseases such as malaria (Bouma and van der Kaay, 1996) and cholera. For former Bengal, which includes present Bangladesh and adjacent parts of India, monthly cholera mortality data are available between 1870 and 1940. The data are reported at the spatial levels of divisions within the province, and of districts within divisions.

As an ENSO parameter, SST anomalies in the Eastern Equatorial Pacific were used (Parker *et al.*, 1994). The data were provided by David Parker, UK Meteorological Office, Bracknell UK. Local SST values in coastal regions of the Bay of Bengal were obtained from the reanalysis data set known as GISST.2 and produced as a collaboration by MIT and the UKMO. Finally, rainfall and air temperature data were obtained from the same source as that for the cholera mortality.

Results

The fact that ENSO and the seasonality of cholera are related does indeed support the view of climatic drivers of cholera. We have found an effect of El Niño on the seasonality of the disease, with shifts in the timing of the major peak from late fall-early winter to spring. In several of the divisions (and districts) of Bengal, cholera exhibited (as it does today in Bangladesh) a bimodal yearly cycle with a large peak in the late fall-early winter followed by a smaller peak in the spring. To determine the proportion of deaths falling into these two periods, we subdivided the year into two parts, corresponding respectively to spring and to fall-winter. We then obtained for each year the fraction of the total mortality that occurred in the two temporal intervals. We found that this fraction increases for the spring, and decreases in the fall-winter, during El Niño and post-El Niño years. For example, the difference between the proportion of deaths occurring in the spring in pre-El Niño and post-El Niño years is statistically significant for the district of Dhaka ($p=0.009$; El Niño years as in Quinnn *et al.*, 1987). Thus, there appears to be a shift in the timing of the dominant seasonal peak from the fall-winter to the spring with ENSO.

We also found weak but significant positive correlations ($r \approx 0.3$) between sea surface temperatures (SST) in the Eastern Equatorial Pacific and cholera deaths in the following year in the Bengal province and also on smaller geographical scales (division and district levels).

Finally, we have begun to investigate the relationship of cholera mortality and regional climate variables (rainfall, air temperature, and SST in the Bay of Bengal). Using simple

linear regression, we have found higher (r=0.4-0.5) significant correlations than for the ENSO parameter, particularly with temperature (sea surface and land) in certain months. We will report on these results in more detail as the research progresses.

On predictability

Based on the described historical effect of ENSO on cholera seasonality, we could have hypothesized that the dominant cholera peak in 1997 and/or 1998 was likely to occur in the spring. Would we have been right? Data from a surveillance program in Dhaka, Bangladesh, tell us as described below, that the hypothesis was correct.

A more difficult type of prediction, however, regards the actual magnitude of outbreaks. On this matter, our results with linear correlation and linear regression analysis would indicate a low quantitative predictability of cholera dynamics. One key to prediction (at least to short-term prediction) is the existence of a low number of variables accounting for a large fraction of the variance in the data. The linear statistical relationships described so far do not account, however, for a large fraction of the variance in cholera mortality.

One explanation often invoked for this type of result is the high-dimensional nature of cholera dynamics, the idea that noise and/or a large number of factors must be at play. An alternative but seldom considered explanation is nonlinearity. We have begun to investigate the latter possibility using methods at the interface of dynamical systems and nonlinear time series analysis (e.g. Ellner and Turchin, 1995; Ellner *et al.*, 1998). With these methods, we have found that nonlinear time series models with a low number of independent variables can account for a substantial fraction of the variance in the data ($\approx$ 70% to 80%). We are currently pursuing this work with both the historical data described here and a recent time series from Dhaka (1980-present) to better understand the role and identity of environmental drivers.

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