Climate change and its impact on transmission dynamics of cholera

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Climate Change Cell
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Foreword

The impacts of global warming and climate change are worldwide. For Bangladesh they are most critical because of its geographical location, high population density, high levels of poverty, and the reliance of many livelihoods on climate-sensitive sectors, such as agriculture, fisheries.

To address current impacts and manage future risks of climate change and variability towards development of a climate resilient Bangladesh, the government has established the Climate Change Cell (CCC) in the Department of Environment (DoE) under the Comprehensive Disaster Management Programme (CDMP). Climate change research, covering modeling and adaptation is one of the major activities of the Cell.

CCC in association with its Technical Advisory Group (TAG) and other stakeholders identified a set of research activities related to climate change in Bangladesh through a number of consultations. The activities have been prioritized and a number of projects have been commissioned in last few years.

Cell is facilitating adaptation research in order to, fill knowledge gaps in the arena of adaptation to climate change and its impacts on the life and livelihoods; explore options to adapt with the climate change; and contribute in better understanding of adaptation options. In this regard, a number of projects have been commissioned in the field of Crop agriculture, Crop insurance, Health, Gender and disadvantaged groups.

Cholera is one of a number of infectious diseases that appears to be influenced by climate change, and unfortunately in Bangladesh, a large number of people died of cholera each year. In order to find out the role of climate change and its impact on transmission dynamics of cholera in Bangladesh, the study correlates various data on climate and its relation with the transmission dynamics of cholera.

The study revealed that increase of temperature, sunshine hour, humidity and tidal height increased the incidence of cholera occurrence in the cholera epidemic region. A cholera prediction model has been developed under the study.

It is expected that the research will create a strong link between health service providers and other stakeholders to share research results and needs. More in-depth for various water borne or vector borne diseases including cholera, diarrhea, malaria, dengue need to be carried out to facilitate policy makers and planners for formulation of viable adaptation and policies, strategies and action plan.

Zafar Ahmed Khan, PhD
Director General
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Acronyms and Abbreviations

ACC	:	Autocorrelation coefficient
ARIMA	:	Autoregressive Integrated Moving Average
BIWTA	:	Bangladesh Inland Water Transport Authority
BMD	:	Bangladesh Meteorological Department
CART	:	Classification and Regression Tree
ENSO	:	El Nino Southern Oscillation
FFWC	:	Flood Forecasting and Warning Center
PCA	:	Principal Component Analysis
SLR	:	Sea Level Rise
SST	:	Sea Surface Temperature

Table of Contents

Acronyms and Abbreviations **v**
Table of Contents **vii**
List of Tables **vii**
List of Figures **vii**
Executive summary **ix**

1. **Background and objectives of the study** **1**
2. **Methodology** **2**
3. **Trends of cholera epidemic in Matlab** **3**
4. **Association of cholera with climatic and ecological variables** **11**
5. **Effects of local climate variability on cholera occurrence in Chandpur** **18**
6. **Climate based cholera prediction model** **24**
7. **Future Research** **29**

Appendices **31**

References **33**

List of tables

Table 4.1 Association of maximum tide level with cholera incidence. 13

Table 5.1 Descriptive statistics of the studied variables. 20

Table 5.2 Results of PCA. 22

Table 6.1. Estimates of the model parameters and test statistics and some values of the model adequacy checking statistics. 26

List of figures

Figure 3.1 Number of cholera patients reported in ICDDR,B; Matlab hospital from 1989-2006 4

Figure 3.2 Monthly mean number of cholera cases from 1989-2006. 4

Figure 3.3 Monthly mean number of cholera cases during the first (1989-93) and the last (2001-05) five years of the considered time period in Matlab, Bangladesh. 5

Figure 3.4 Mean number of monthly cholera cases classified into three groups of 5 years interval: 1989-1993 (A), 1994-1998 (B) and 1999-2003 (C) and a group of two years from 2004-2005 (D). 5

Figure 3.5 Autocorrelation plot of monthly cholera cases, for the period of 1989-2006, in Matlab, Bangladesh. 6

Figure 3.6 Autocorrelation plot of monthly Inaba cholera cases, for the period of 1989-2006, in Matlab, Bangladesh. 6

Figure 3.7 Autocorrelation plot of monthly Ogawa cholera cases, for the period of 1989-2006, in Matlab, Bangladesh. 7

Figure 3.8 Autocorrelation plot of monthly *V. cholerae* 0139 cholera cases, for the period of 1994-2004, in Matlab, Bangladesh. 7

Figure 3.9 Inaba cholera cases from 1989-2006 in Matlab, Bangladesh. 8

Figure 3.10 Ogawa cholera cases from 1989-2006 in Matlab, Bangladesh. 8

Figure 3.11 *V. cholerae* O139 cholera cases from 1994 to 2004 in Matlab, Bangladesh. 9

Figure 4.1 Monthly rainfall and Inaba cholera cases from January 2003 to December 2005. 12

Figure 4.2 Monthly maximum tidal levels from 1989 to 2004. 12

Figure 4.3 Cholera and maximum tidal level of the year 1998, and monthly average maximum tide from 1989-2004. 13

Figure 4.4 Relationship between water temperature (^{0}C) and chlorophyll (μg/l), aggregated from the pond, Matlab, Chandpur. 14

Figure 4.5 Seasonality of cholera outbreak and chlorophyll concentration aggregated from the pond, Matlab, Chandpur from October 2003 to December 2005. 14

Figure 4.6 Phytoplankton data derived from the pond, Matlab, Chandpur overlaid with cholera cases from December 2002 to January 2005. 15

Figure 4.7 Zooplankton data derived from the pond, Matlab, Chandpur overlaid with cholera cases from December 2002 to January 2005. 15

Figure 4.8 Phytoplankton data collected from the studied pond in Matlab, Chandpur overlaid with number of cholera cases reported from January to December, 2004. 16

Figure 5.1 Monthly plot of the data considered for analysis in this study from January 1989 to December 2005. 19

Figure 5.2 Contour Plot of cholera cases/month for different temperature (^{0}C) and average sunshine hour/day. Level 1, 2, and 3 means *low, Medium* and *High level*. 20

Figure 5.3 Classification tree of cholera cases based on different climatic variables. 21

Figure 5.4 Relative contributions of climatic variables to the CART. 21

Figure 5.5 Scatter plots of the variables and the scores of the principal components. 23

Figure 6.1. Study variables after filling the missing observations and deleted outlying observations. 25

Figure 6.2. Three-dimensional surface plot of monthly cholera cases with respect to different levels of daily average temperature and rainfall. 25

Figure 6.3 Time series plot of the five Principal Components along with standardized monthly cholera cases. 26

Figure 6.4 The actual and modeled output along with the residuals. 27

Figure 6.5 Observed and predicted cholera cases using the prediction model. 28

Executive Summary

It is now widely accepted that human intervention is responsible for global warming and climate change. Climate change may influence functioning of many ecosystems either directly or indirectly. Scientists agree that impact of climate change in human health will be adverse, especially for the water borne and vector borne diseases. It was thought that climate change would have an impact on transmission dynamics of cholera, a water borne disease.

Therefore the present study was carried out to find out the impact of climate change on the transmission dynamics of cholera and to develop a climate based prediction model of cholera epidemic.

The key achievements and findings are summarized below

- Temperature is detectable as the ‘agent of change’ for transmission dynamics of cholera due to changing climatic parameters. The last eighteen years data of temperature and cholera showed that the cholera epidemic has a relation with shifting of temperature from higher to lower during post-monsoon cholera season and lower to higher during pre-monsoon cholera season.
- The disease “Cholera” is associated with climatic as well as ecological variables and the seasonal outbreak of cholera in Bangladesh is a local phenomenon. Significant association of cholera incidence with local climatic variables (rainfall and tide) and biological factors (Phytoplankton) has been observed.
- Significant increase in temperature, rainfall, humidity and tidal height influence the incidence of cholera.
- A cholera prediction model has been developed based on 18 years monthly record of cholera incidence and local climatic variables of Matlab, Chandpur, Bangladesh. The model can explain 68% variability of the monthly cholera incidence.

1. Background and objectives of the study

Human induced changes in the global climate and associated sea level rise are widely accepted by policy makers and scientists. According to IPCC (Inter Governmental Panel on Climate Change) 2007 summary, surface air warming in the 21st century (best estimates for low scenario) is 1.8^{0}C with a range of 1.1°C to 2.9°C (Ahmed and Alam, 1998). It is broadly accepted that Bangladesh is one of the most vulnerable countries that would be affected by the adverse impact of climate change because of its geographical position as well as vulnerable socio-economic condition.

Cholera is one of a number of infectious diseases that appears to be influenced by climatic changes (Colwell, 1996). Climate change influences the epidemiology of cholera, as cholera is a water borne disease, the changes of various bio-physico-chemical parameters of water e.g. temperature, salinity, pH, abundance of phytoplankton have an impact on distribution and survival of *Vibrio cholerae*, the causative agent of cholera (Islam *et al*., 1994b). After the discovery of phytoplankton as a reservoir of cholera (Islam *et al*., 2004, 1996, 1995, 1994a, 1994c, 1994c, 1993, 1992, 1990a, 1990b) remote sensing data has shown that cholera epidemics in Bangladesh can be predicted by monitoring phytoplankton bloom in the Bay of Bengal (Lobitz *et al.*, 2000).

Temperature rise and impact on cholera

Temperature trends for the country for the daily maximum series and the daily minimum series on annual and seasonal basis have shown that the overall temperature regime in Bangladesh is showing a rising trend (Ahmed and Alam, 1998). Therefore, the ultimate effect of climate change would be more floods and more water borne diseases like cholera.

Sea level rise (SLR) and impact on cholera

Various scenarios have been predicted about sea level rise (SLR) in Bangladesh. The sea level rise will have similar impact on the transmission dynamics of infectious diseases especially cholera. Sea level rise will inundate coastal area. This coupled with reduced flows from upland during winters will accelerate the saline water intrusion in land. Coastal waters will become more saline. People will be more inclined to use unsafe surface water and will contract various water borne infectious diseases like cholera.

Therefore, this study has gathered data needed to develop a cholera prediction model that would monitor climatic variables as well as biological factors which might have an impact on the transmission dynamics of cholera. Once the role of these variables are known, it might help to develop preventive or control measures to reduce the transmission of the diseases.

Objectives

1. To correlate various data on climate and its relation with the transmission dynamics of cholera
2. To find out the changes of various bio-physicochemical conditions (e.g., temperature, salinity, pH, phytoplankton, zooplankton etc.) in cholera endemic areas and its impact on transmission dynamics of cholera in Bangladesh
3. To develop capacity for research and analysis of data on climate change and its relation with transmission dynamics of cholera
4. To establish infrastructure for long term monitoring of climate change and its impact on various diseases.

2. Methodology

Site selection

In this study we have accounted the reported cholera cases of Matlab, which, is a riverine area, situated in Chandpur district, Bangladesh. Matlab is well known to be a highly cholera endemic area. Since 1966, cholera surveillance has been going on there in a systematic way by the ICDDR,B.

Data collection

Cholera data has been collected for the last 18 years (1989-2006) from the hospital records of ICDDR,B. All the cholera cases were confirmed by isolating *Vibrio cholerae* O1 and O139 using culture and serological techniques. Local Meteorological data were collected from the Bangladesh Meteorological Department (BMD). The data on phytoplankton and physico-chemical properties (water temperature, dissolved oxygen, and pH) of different water bodies in Matlab were collected from the Environment Microbiology Laboratory of ICDDR,B.

Quality control of data

In most of the cases digital copies of data were collected to avoid further recording error as well as to save time. Databases of different variables were developed from the raw data sources after running different relevant software and programs. Quality of the recorded data was first diagnosed manually to find out typing error. Data were further checked to find out anomalies through different exploratory graphical analysis. Points of disputes were double checked to ensure clean dataset. In some cases direct communications with the responsible person were done. Partial values were removed from the dataset to minimize the effect on average.

Data analysis

Detail methodology and data analysis have been included in the respective chapters.

3. Trends of cholera epidemic in Matlab

In this study we have used 18 years reported cholera case data (1989-2006) collected from Matlab hospital, Chandpur, Bangladesh to find out epidemic characteristics of cholera in relation to climate change and immunity of population. Tendency to shift maximum cholera incidence from the month of October to November during fall outbreak was observed. Both Inaba and Ogawa (mostly El Tor) showed short-term immunity to the population. It was found that *V. cholerae* O139 is almost absent in recent years. Therefore, attention needs to be concentrated on the epidemiology of Inaba and Ogawa serotypes of El Tor biotypes.

Introduction

Cholera is an acute intestinal disease that is endemic in Bangladesh and the epidemic of cholera is reported to be linked strongly with climate change. In recent times the relation between climate change and cholera epidemics is well pronounced. The hypothesis is that climate related variability as well as natural calamity which are well documented effect of global warming may bring changes in cholera dynamics.

The epidemic *Vibrio cholerae* has two major serogroups: O1 and O139. The *V. cholerae* O139 has emerged in recent times (Albert *et al*., 1993) and the two major serotypes Inaba and Ogawa under *V. cholerae* O1 serogroup are found to replace each other over time. The replacement of Ogawa and Inaba with time in an endemic area is thought to be an indicator of immunity level of the serotype in a population.

In this study we have considered 18 years (1989-2006) well-documented data collected from Matlab hospital, Bangladesh which is a cholera prone area. Several important changes of cholera dynamics took place in the time period which we have considered in this study e.g. absence of classical O1 biotypes, emergence and absence of O139 serogroup, devastating natural calamity etc., gave us opportunity to do an in depth study of the epidemic characteristics of cholera.

Methodology

Autocorrelation analysis was done to measure the strength of association of cholera at time t and $t-1$. Here we considered t as monthly cholera cases, thus $t-1$ represents monthly cholera cases of the previous month. In every case Bartlett's approximation and 95% confidence interval ($p<0.05$) were constructed to determine the significance level.

Results

Figure 3.1 shows the time series plot of monthly cholera cases from 1989-2006 reported in Matlab hospital, Bangladesh. Comparatively higher incidence of cholera outbreak took place from 1992 to 1995 and also in the year 1998. The monthly mean number of cholera cases shows (Figure 3.2) a bimodal distribution pattern over an annual cycle. One in the month of September through December (Fall outbreak/Post-monsoon outbreak) and the second outbreak takes place in the month of April-May, before the monsoon season (Spring outbreak/pre-monsoon outbreak). The magnitude of fall outbreak is comparatively higher than the spring outbreak.

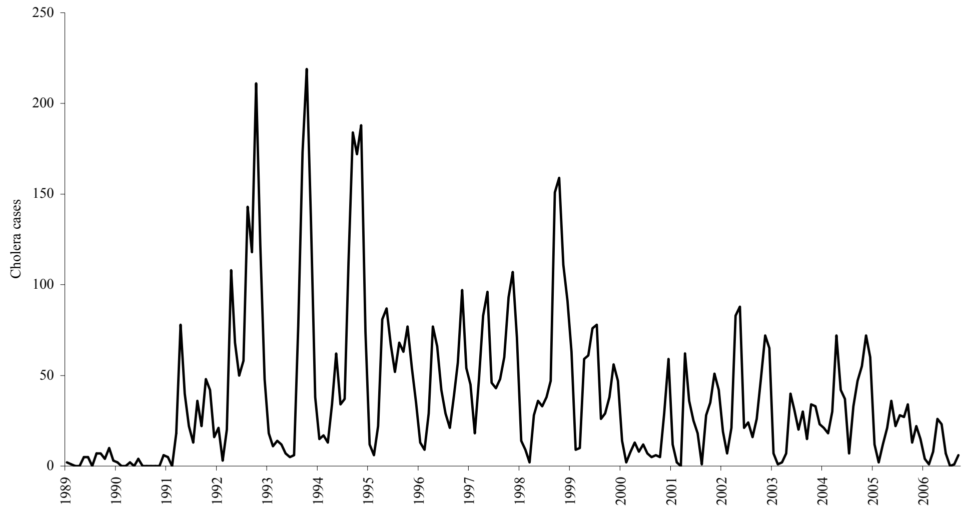


Figure 3.1: Number of cholera patients reported in ICDDR,B; Matlab hospital from 1989-2006.

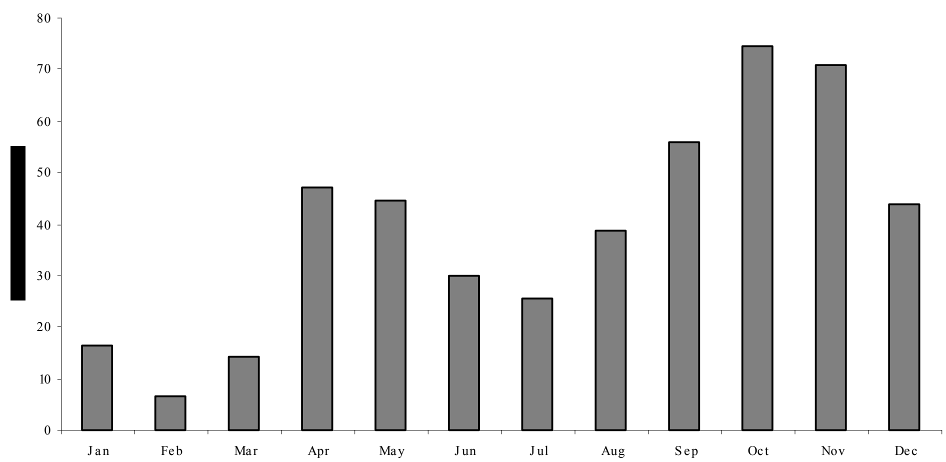


Figure 3.2: Monthly mean number of cholera cases from 1989-2006.

Figure 3.3 indicates that the bimodal distribution pattern of cholera with large annual fall outbreak and comparatively small spring outbreak is not unique and eventually the difference between two outbreaks is minimized during the last five years (2001-05). Comparative study between the first and the last five years of the study period shows that the difference between the incidence of cholera in post-monsoon season (Aug-Nov) is more prominent than pre-monsoon season (March-May).

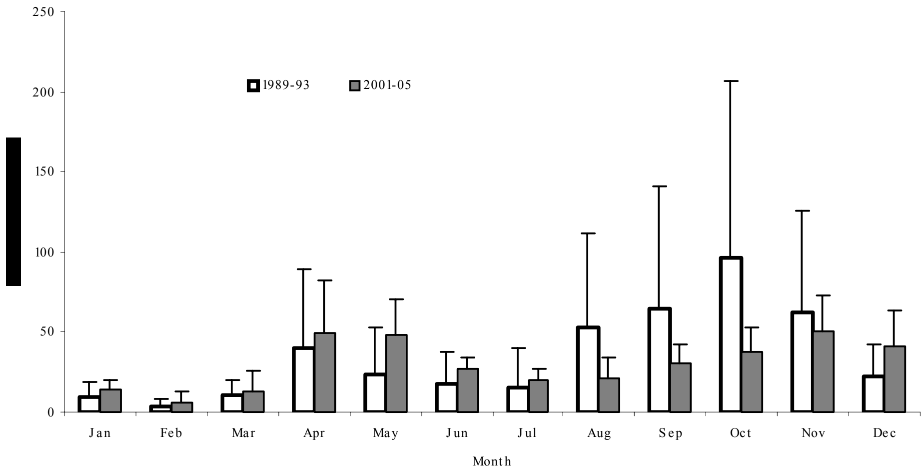


Figure 3.3: Monthly mean number of cholera cases during the first (1989-93) and the last (2001-05) five years of the study period in Matlab, Bangladesh.

Figure 3.4 represents the shifting of cholera outbreak. It has been observed that the highest incidence of post-monsoon cholera cases has shifted from October to November.

Figure 3.4: Mean number of monthly cholera cases classified into three groups of 5 years interval: 1989-1993 (A), 1994-1998 (B) and 1999-2003 (C) and a group of two years from 2004-2005 (D).

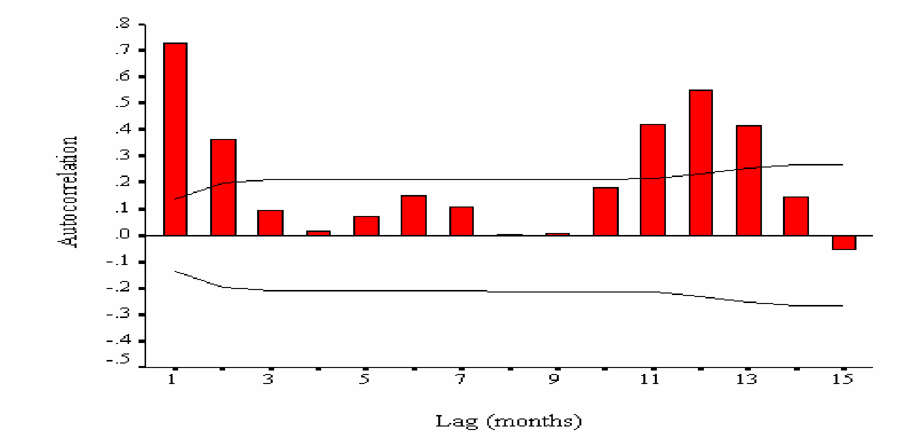


Figure 3.5: Autocorrelation plot of monthly cholera cases, for the period of 1989-2006, in Matlab, Bangladesh.

Correlogram of the monthly cholera cases (Figure 3.5) represents that present (Y_t) number of cholera cases strongly (ACC 0.765) depends on the number of cholera cases of the previous month (Y_{t-1}). After two-months lags, autocorrelation is insignificant (95% confidence limits). Again after 12 months the monthly lag becomes significant.

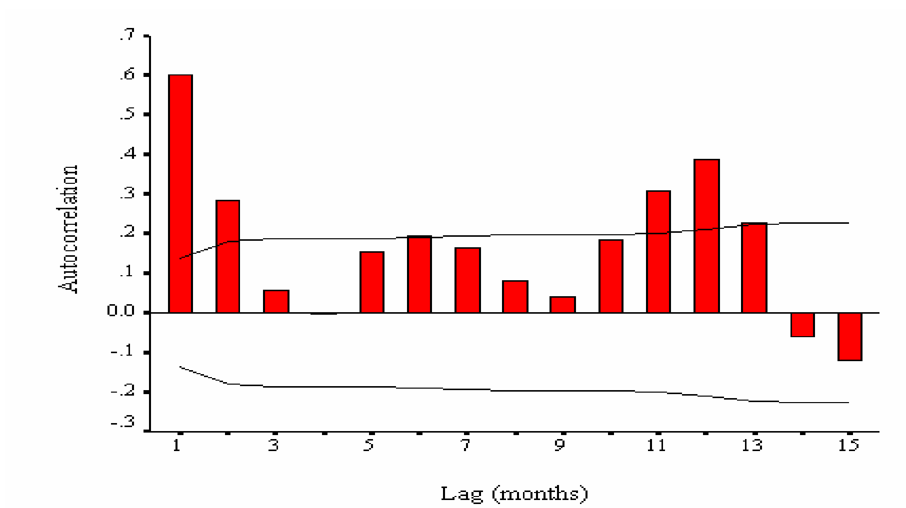


Figure 3.6: Autocorrelation plot of monthly Inaba cholera cases, for the period of 1989-2006, in Matlab, Bangladesh.

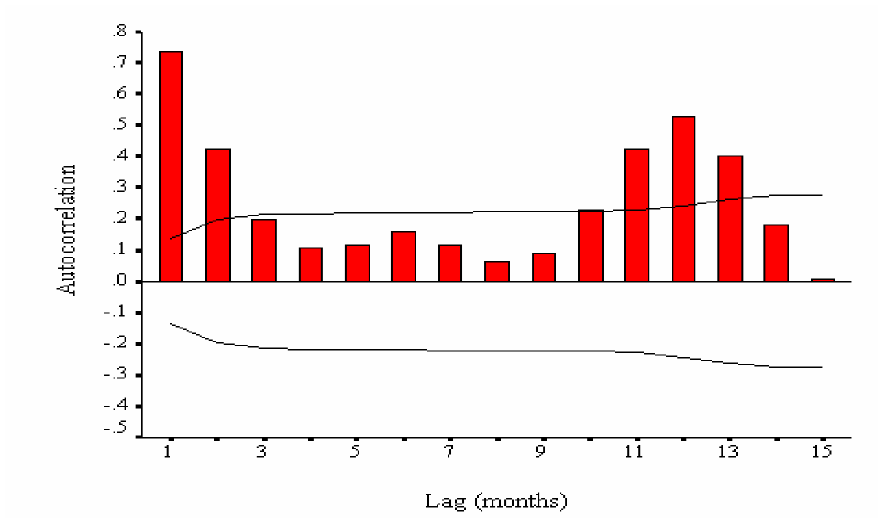


Figure 3.7: Autocorrelation plot of monthly Ogawa cholera cases, for the period of 1989-2006, in Matlab, Bangladesh.

Figure 3.6 and Figure 3.7 indicate almost similar type of correlogram that exists both in Inaba and Ogawa serotypes. In both serotypes, AC is significant for monthly lag of 1 and 2. Significant ACC of the lag 12 indicates its strong yearly seasonality.

Figure 3.8 shows autocorrelgram of *V. cholerae* O139 biotype over a period of 1994-2004. ACC is significant with next monthly lag, indicates that outbreak due to *V. cholerae* O139 biotype stays for one month only. Significant AC value in lag 12 represents its ability to maintain yearly seasonality.

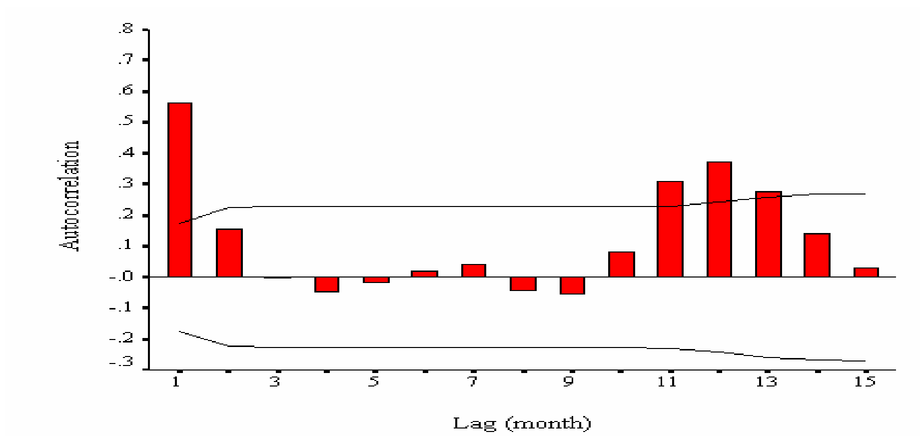


Figure 3.8: Autocorrelation plot of monthly *V. cholerae* O139 cholera cases, for the period of 1994-2004, in Matlab, Bangladesh.

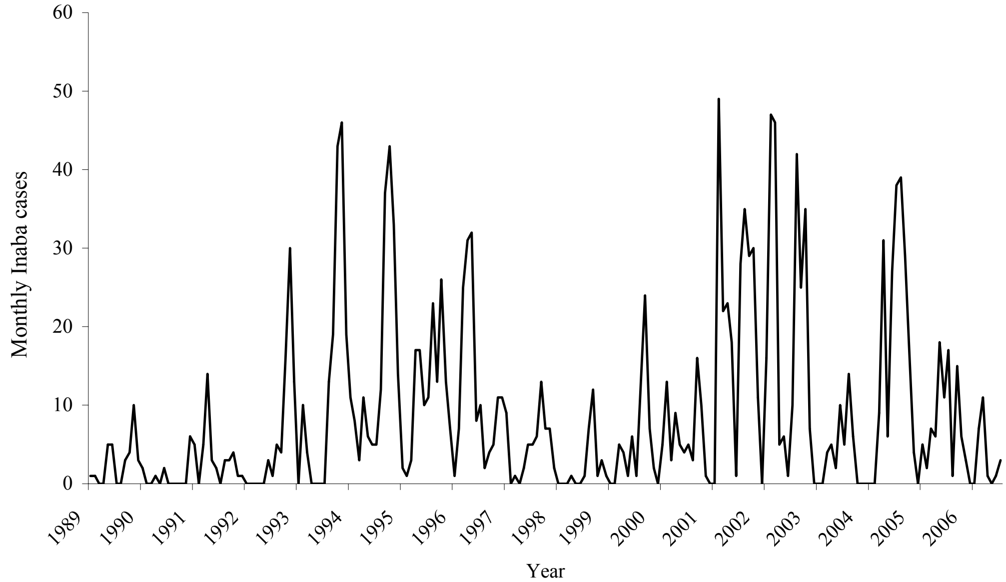


Figure 3.9: Inaba cholera cases from 1989-2006 in Matlab, Bangladesh.

Figures 3.9, 3.10 and 3.11 represent the time series plot of Inaba, Ogawa and *V. cholerae* O139 cholera cases respectively. Only Inaba shows an increasing trend. Interestingly, among these serotype and biotype, *V. cholerae* O139 shows different pattern. In most cases after one outbreak number of cholera cases due to *V. cholrae* O139 tends to touch zero value. After 2004, almost absence of *V. cholerae* O139 cholera cases indicates that *V. cholerae* O139 may disappear from Bangladesh in near future.

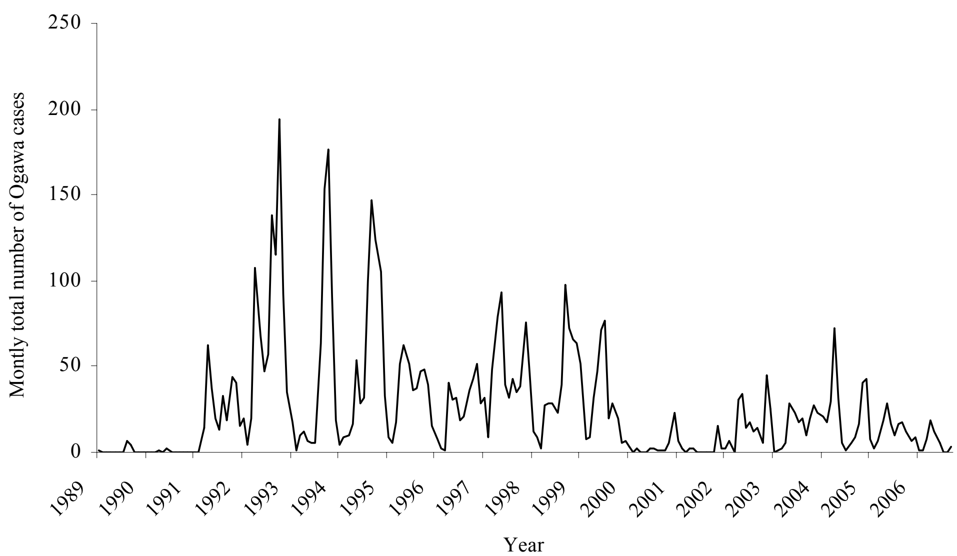


Figure 3.10: Ogawa cholera cases from 1989-2006 in Matlab, Bangladesh.

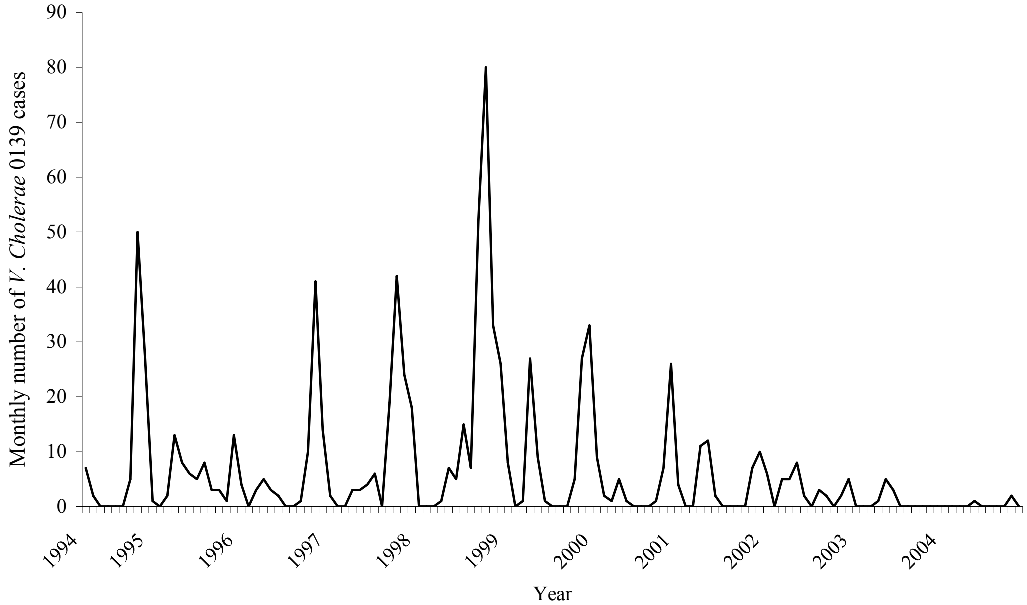


Figure 3.11: ***V. cholerae*** **0139 cholera case from 1994 to 2004 in Matlab, Bangladesh.**

Discussion

Higher incidence of cholera during 1992-95 (Figure 3.1) might be due to emergence of the new strain of *V. cholerae* 0139. The presence of *V. cholerae* 0139 has been confirmed since 1992 in the country. The epidemic was first noticed in the southwestern coastal part of Bangladesh and from there, the epidemic moved very first to the northern part of the country (Colwell, 1996).

Remarkable increase of cholera incidence in 1998 might have relation with the devastating flood in that year. Two-thirds of the country was under water and water remained above the danger level for 68 days in Meghna river (FFWC, 1998). Therefore people became more vulnerable to infection by *V. cholerae*. Flood causes break down of sanitation system, scarcity of drinking water and is a potential way for the rapid transmission of water borne diseases like cholera.

The present study indicates the change of some important aspects of cholera epidemics. The tendency to shift the cholera incidence month from October to November during fall outbreak might have relation with the climatic factors. The seasonal trend of cholera incidence is strongly related with environmental and climatic factors (Colwell, 1996; Patz *et al*. 2005). Moreover, inter-annual variability of cholera incidence in Dhaka, Bangladesh was found to have association with the climatic factors (Rodó *et al*. 2002). Increase of temperature as an effect of global warming may affect the phenology of plant and animals i.e. their seasonal occurrence (Steffen, 2006). Therefore recent trends of cholera epidemics might have relation with the climatic change.

Increase of temperature is a major concern to the scientists as an impact of climate change. Further more climatologists forecast increase of temperature in winter and prolongation of rainfall during rainy season in Bangladesh (Ahmed and Alam, 1998). In Matlab, seasonal outbreak of cholera is predicted by increase of water temperature (Sack *et al*., 2001) and presence of higher number of *V. cholerae* during times of warm water temperature (Lipp *et al*., 2002).

Association of *V. cholerae* with algae is now well known. Blue-green algae and several related algal species serve as reservoir of cholera pathogen during the inter-epidemic period (Islam, 1994_a; 1990_b; 1993). Warm water temperature may lead to the formation of algal bloom in natural waterbodies and thereby favour *V. cholerae* pathogen. Association of cholera incidence with sea surface temperature and chlorophyll has been reported in several previous studies (Lobitz *et al*. 2000; Colwell, 1996)

Simple exploratory time series analysis shows that only Inaba shows an increasing trend of incidence over the study period, where as Ogawa and *V. cholerae* O139 shows a decreasing trend.

4. Association of cholera with climatic and ecological variables

Cholera is an intestinal disease that frequently strikes in the form of epidemic in endemic areas. The seasonal outbreak of cholera in Bangladesh is very often considered as local and postulated to be a model disease for those infectious diseases, which have close association with climatic variables. In this study we have considered local climatic variables as well as biological and physico-chemical parameters of water with cholera incidence in Matlab, Chandpur. A significant positive association ($P<0.01$) between monthly rainfall and incidence of cholera (Inaba serotype) was observed from January 2003 to December 2005. Maximum tidal height in Chandpur showed a distinct increasing trend (1989-2004). Significant association of maximum tidal height with cholera ($P<0.01$) was found. A significant association of phytoplankton with cholera incidence ($r=0.67$, $P<0.01$) was also observed.

Introduction

Resurgence of many old infectious diseases and their effect on human health is an ongoing concern. The 1990s have already experienced increase in incidence of many vector borne and water borne diseases such as cholera, malaria, dengue etc. in different parts of the world (Collins, 1998).

Cholera is a water borne acute intestinal disease that is endemic in Bangladesh and it is assumed that the seasonal outbreak of cholera in Bangladesh has close association with climatic and ecological variables (Clowell, 1996). Therefore it is one of the major concerns to the scientists how climate change is going to create impact on the transmission dynamics of cholera, as climate change may disrupt functioning of many ecosystems. Alteration of ecosystem may result in new disease distribution and higher rate of incidence in affected areas. To develop climate based early warning system, it is important to understand the relationship between climate, ecosystem and infectious disease.

In this study, we used different local climatic variables, physical environmental variables and ecological variables of Matlab, Chandpur which is a cholera prone area, with particular attention to association of these variables with cholera outbreak.

Methodology

Daily cholera case data from 1989-2006 were obtained from the International Center for Diarrhoeal Disease, Matlab hospital, Chandpur, Bangladesh. Since 1966, cholera surveillance has been going on in Matlab in a systematic way.

Different biological and physical data i.e. phytoplankton, chlorophyll and water temperature of the pond were collected from Environmental Microbiology Laboratory, ICDDRB. The phytoplankton was identified following the procedures described elsewhere (Ward & Whipple, Islam *et al.*, 1992).

Respective rainfall data of Chandpur was collected from Bangladesh Meteorological Department (BMD), Agargaon, Dhaka. Daily tide data was collected from Bangladesh Inland Water Transport Authority (BIWTA). In this study we used monthly maximum tidal height data for analysis.

Exploratory Data Analysis and Pearson's correlation were done to find out the association and correlation of the climatic, biological and physical variables with cholera outbreak.

Results

Figure 4.1 represents line plot of monthly rainfall of Chandpur and monthly number of cholera cases (Inaba serotype) reported in Matlab, Chandpur from January 2003 to December 2005. Cholera outbreak showed a statistically significant correlation, and this correlation was found the strongest with two monthly lag, r=0.59, *P*<0.000 during the study period.

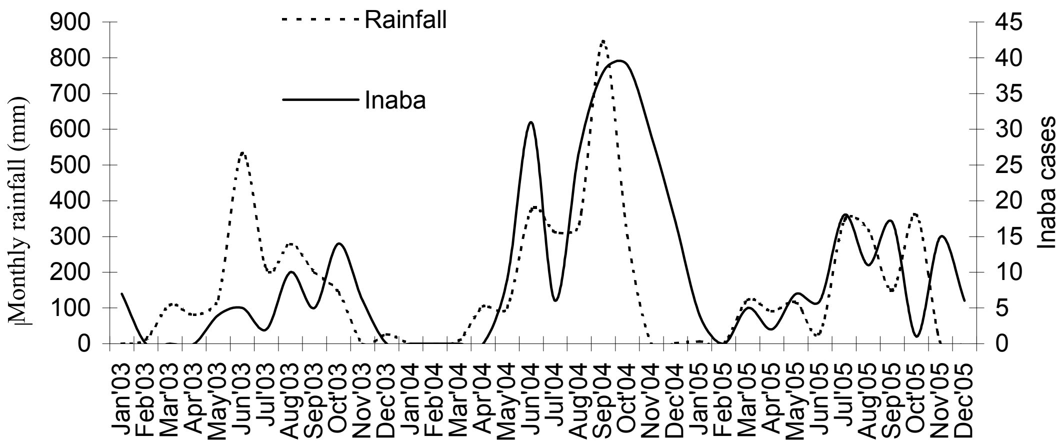


Figure 4.1: Monthly rainfall and cholera cases from January 2003 to December 2005.

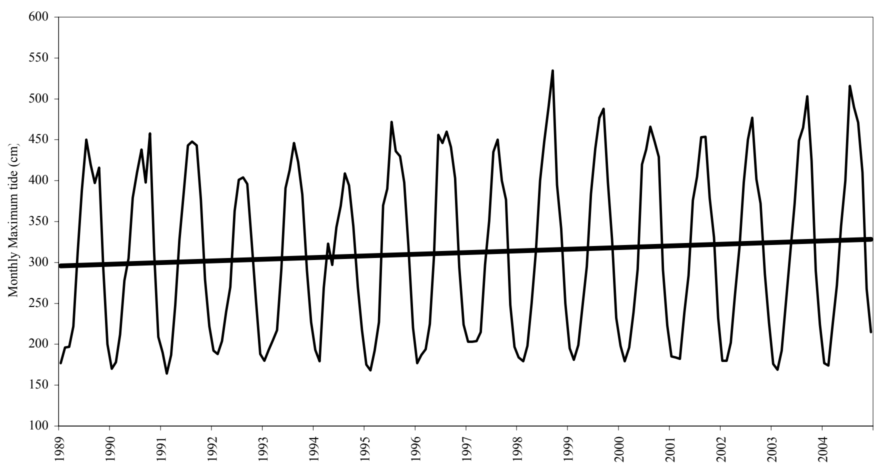


Figure 4.2: Monthly maximum tidal height from 1989 to 2004.

Figure 4.2 represents time series plot of monthly maximum tidal height of Chandpur from 1989 to 2004. An indication of increasing tidal height is distinct. In 1998 the maximum tidal height was comparatively higher compared to other years (Figure 4.3). That year was remembered for severe flood. Overall cholera cases showed a significant positive correlation (r=0.174, *P*<0.01) whereas higher incidence years (1992-1995) in terms of number of cholera cases were found strongly correlated with the maximum tidal height (Table 4.1). In 1998, one monthly lag of maximum tidal height showed the strongest correlation with the number of cholera cases reported in the same time (r=0.83, *P*<0.01).

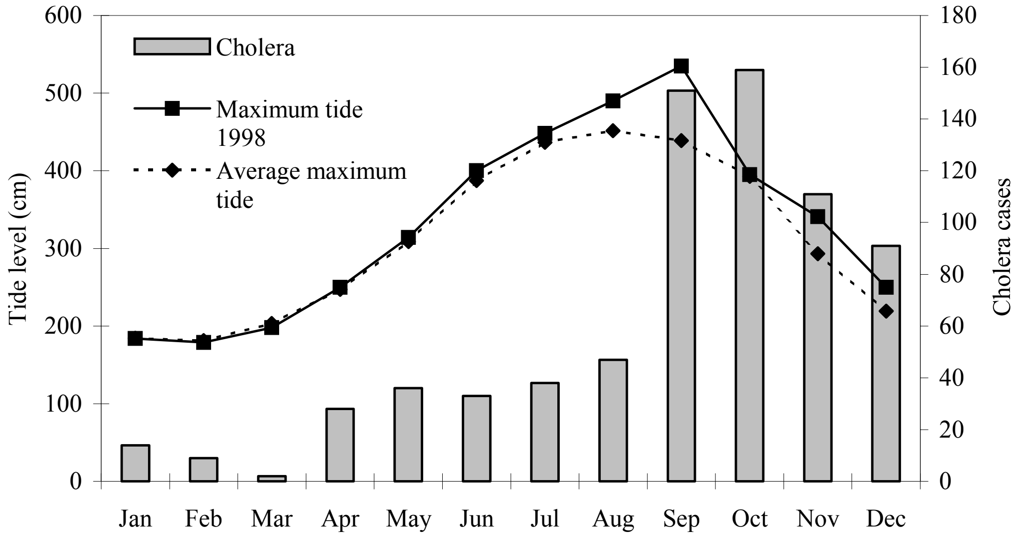


Figure 4.3: Cholera and maximum tidal level of the year 1998, and monthly average of maximum tidal height from 1989-2004.

Table 4.1: Association of maximum tidal height with cholera incidence

Year	Correlation coefficient (*r*)	Remarks
1989-2004	0.174*	-
1992-1995	0.425**	-Exceptional increase of cholera incidence -Emergence of *V. cholerae* O139
1998	0.566*	-High incidence of cholera cases -Two-thirds of the country was under water because of severe flood
1998	0.834**	Lag=1 month

** and * indicate significant at 0.01 and 0.05 level respectively

Figure 4.4 shows the relationship between water temperature and chlorophyll concentration (μg/l), collected from pond in Matlab, Chandpur. A significant positive correlation ($P<0.05$) was found. Higher temperature facilitates faster growth of phytoplankton. Therefore, plankton bloom occurs. Although other variables like sunshine hour, nutrient load and nutrient mixing etc. may also directly or indirectly control plankton in natural water bodies.

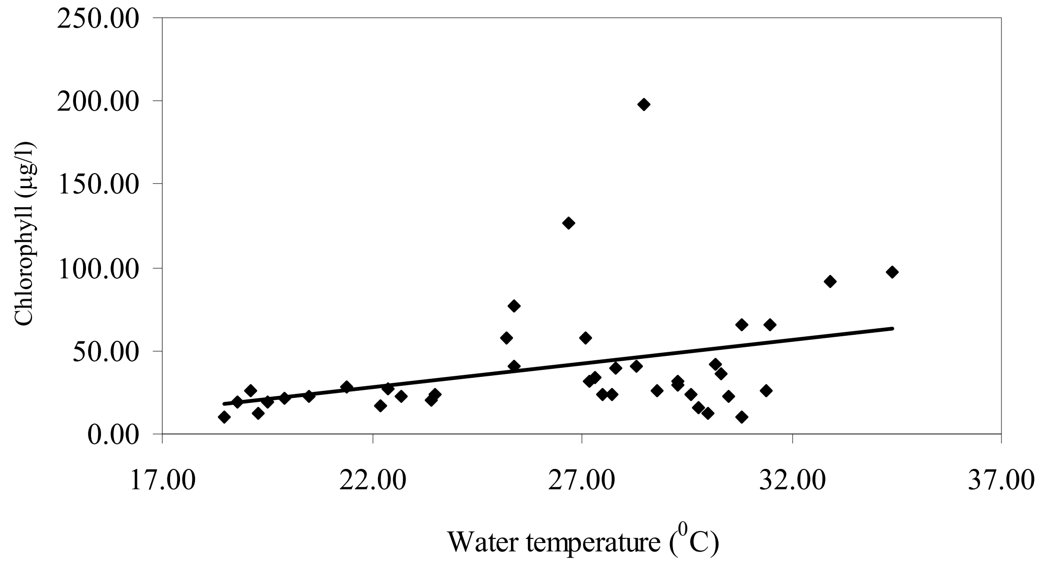


Figure 4.4: Relationship between water temperature (^{0}C) and chlorophyll (µg/l) of the pond in Matlab, Chandpur.

Figure 4.5 represents seasonality of cholera outbreak and chlorophyll concentration. Monthly average chlorophyll data showed seasonal cycle which coincided with monthly average cholera cases in the same period.

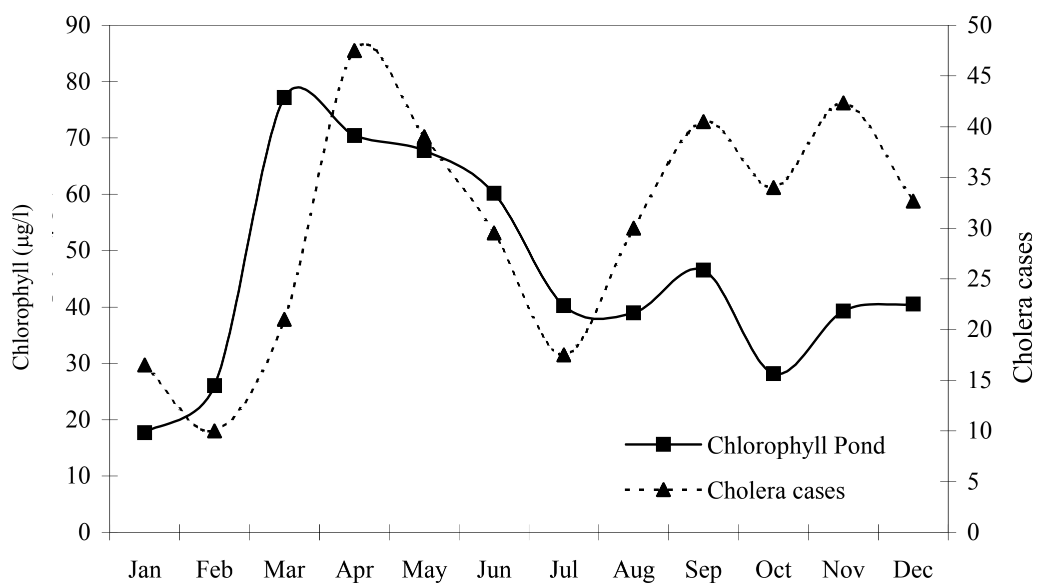


Figure 4.5: Seasonality of cholera outbreak and chlorophyll concentration in pond of Matlab, Chandpur from October 2003 to December 2005.

Figures 4.6 and 4.7 represent seasonality of cholera cases in relation to phytoplankton and zooplankton from December 2002 to January 2005, collected from pond in Matlab, Chandpur. The seasonality of cholera cases coincided better with the seasonality of phytoplankton than zooplankton.

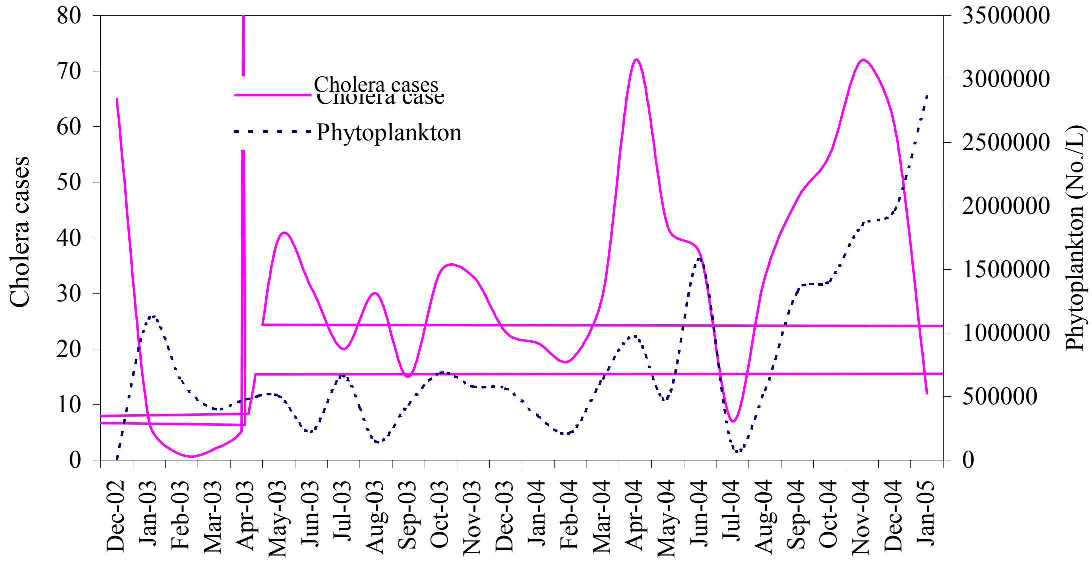


Figure 4.6 Seasonality of phytoplankton and cholera cases.

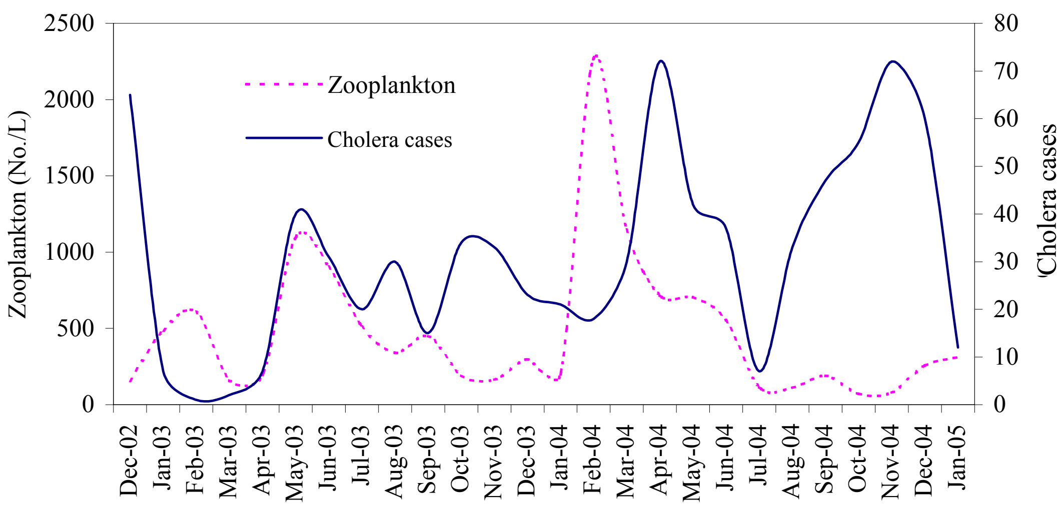


Figure 4.7: Seasonality of zooplankton and cholera cases.

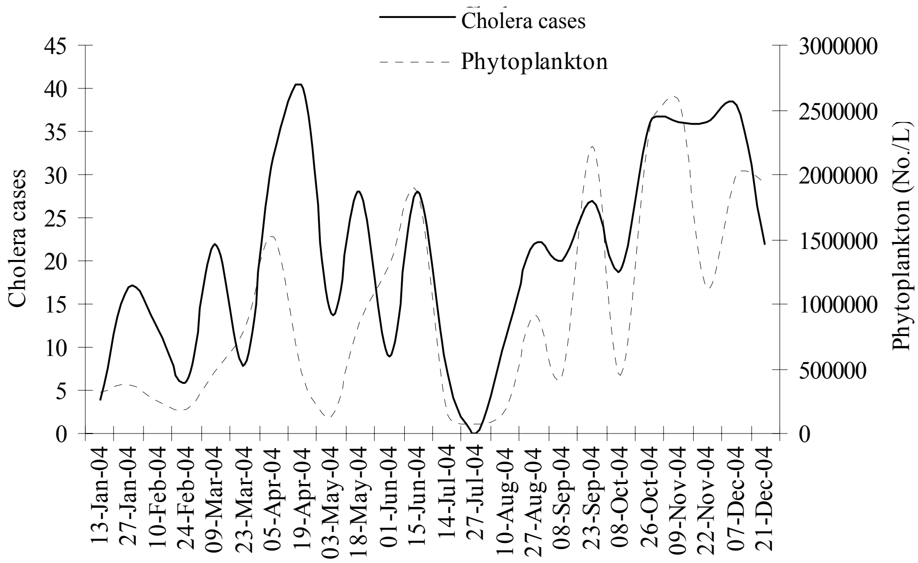


Figure 4.8: Phytoplankton data collected from the studied pond in Matlab, Chandpur overlaid with number of cholera case reported from January to December, 2004.

Figure 4.8 represents biweekly line plot of phytoplankton concentration collected from the pond in Matlab and cholera case reported in the Matlab hospital in the same period form January to December 2004. Cholera outbreak showed a statistically significant correlation with phytoplankton concentration ($r=0.67$, $p<0.01$).

Discussion

Our study reveals association between local rainfall and cholera cases. Rainfall is a potential way of adding nutrients in the pond and other type of closed water bodies. Rainwater brings a lot of nutrients in water bodies from land. This influx of nutrients favours growth of algae, which serve as a reservoir of cholera. Significant positive association between rainfall and number of reported cholera cases has also been reported in Mozambique (Collins, 1998).

Significant association of maximum tidal height and cholera has been observed in our study. This relation was highly significant during flood. In 1998, maximum tidal height was considerably higher compared to average maximum tidal height in that area, as a result severe flood took place. A combination of these factors might be responsible for the severe outbreak of cholera in the same year. During flood, breakdown of sanitation system is very often reported in Bangladesh and heavy contamination of the surface water happens (Islam *et al.* 1994_c), make people more vulnerable to contract cholera.

The close relationship between phytoplankton with cholera cases was expected. The blooming of *V. cholerae* O1 in the environment is related with the algal bloom formation, as algae serve as a reservoir of cholera. The nutrient rich mucilaginous microenvironment of blue-green algae favour *V. cholerae* to maintain a symbiotic relationship with the algae (Islam *et al*, 1995, 1993, 1992, 1990_a)

Our study provides further evidence of the association of cholera with chlorophyll and water temperature. Higher water temperature facilitates faster growth of plankton and chlorophyll is a measure of the of phytoplankton biomass. A general agreement in the pattern of sea surface temperature (SST) and chlorophyll concentration in the Bay of Bengal with the cholera incidence in Bangladesh has been mentioned in other studies (Lobitz *et al*., 2000; Colwell, 1996). Temporal evolution of *V. cholerae* non-O1 reported to be highly correlated with several environmental factors e.g. temperature, pH and chlorophyll concentration. Moreover, *V. cholerae*, the pathogen of cholera is reported to show increased growth rate at warm water temperature (Lipp *et al*., 2002)

Our research findings support the previous hypothesis that these small ponds can act as a source of cholera epidemic. These ponds, which serve as the source of village water supply has great potential for spread of cholera (Cockburn and Cassanos, 1960). Other study reveals the isolation rate of *V. cholerae* non-O1 is significantly higher in pond compared to river and lake water (Khan *et al*., 1984), these ponds are potential source of *V. cholerae* in endemic areas.

5. Effects of Local Climate variability on Incidence of Cholera in Matlab, Chandpur, Bangladesh

The variability pattern of cholera events is studied in relation to the variability of the local climate variables. Classification and Regression Tree (CART) and Principal Component Analysis (PCA) were used to study the dependency and variability pattern of monthly cholera cases. Study revealed that the sunshine hour and temperature affects positively to the increase of monthly cholera cases. The longer sunshine hour and moderate to higher level temperature occurs at pre-monsoon and post-monsoon season, which creates favorable environment of plankton bloom in pond, river and estuaries which coincided with cholera epidemics.

Introduction

The geographical distribution of many infectious as well as water borne diseases are often influenced by climatic variability and change. Cholera is one of such diseases, which has strong relation with climatic events. Therefore it is considered as a model for climate-related infectious disease (Lipp *et al*., 2002). The geographical distribution of infectious as well as vector borne diseases are often characterized by local climate variability and change (WHO, 1990) rather than the global climatic indicator like ENSO. For example the natural boundaries of malaria are determined by temperature and rainfall in a region (Bouma and Kaay, 1996). The occurrence of cholera in Bangladesh as well as in different parts of the world is thought to be influenced by ENSO related anomalies (Colwell, 1996). El Niño related changes in temperature, precipitation and other environmental variables might affect cholera incidence directly through dispersion of *Vibrio cholerae*, the causative agent of cholera or indirectly through affecting its reservoirs. Plankton serves as a reservoir of cholera (Islam, 1994_b; 1993). The hypothesis is that increase of sea surface temperature may enhance plankton bloom that may in turn enhance cholera incidence. This relationship with El Niño has already been observed in Bangladesh. Strong association also found with cloud cover and absorbed solar radiation (Pascual *et al*., 2000).

El Niño might have varying effects on regional or local climate that sometimes affect unlikely to the different region (Checkley *et al*., 2000). So the endemicity and seasonality of cholera in Bangladesh may largely dependent on the local climate variability. Therefore, this study was conducted to find out the impact of local climate on the transmission dynamics of cholera.

Methodology

To map the variability pattern of cholera cases with the variability of local climate, we used monthly reported cholera cases, monthly average of daily *temperature*, *humidity*, *sunshine hour* and *rainfall* of Chandpur meteorological station. Meteorological data were collected from the Bangladesh Meteorological Department from 1989 to 2005. The cholera cases data were collected from ICDDRB, Matlab, Chandpur for the same time period. Unusual observations in the meteorological data were checked by exploratory methods. Autoregressive Integrated Moving Average (ARIMA) models were used to estimate the missing observations. Based on sufficiently long part of observations available, suitable ARIMA models was fitted for each variable. ARIMA models finalized following the Box-Jenkins (1976) modeling cycle. Those models were used to fill the missing values by means of forecasting and backcasting and finally we obtained the complete data set of five variables (Figure 5.1)

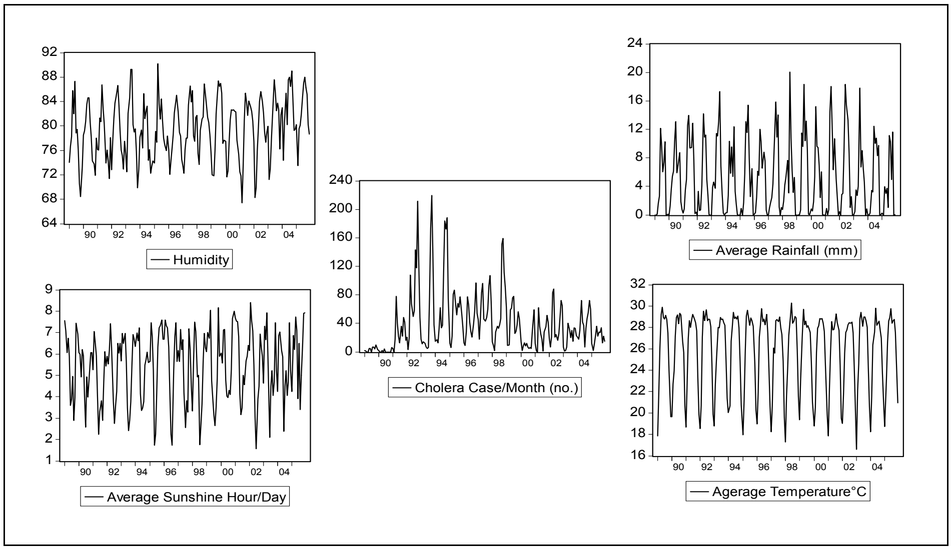


Figure 5.1: Monthly plot of the data considered for analysis in this study from January 1989 to December 2005.

Exploratory data analysis was used in the first step to realize the variability patters exists in the cholera cases data in context with different climatic factors. To identify the independent orthogonal components and their characteristics in the climate and cholera system, Principal Component Analysis (PCA) was used. First each variable was standardized and then PCA was performed on the standardized data set. Classification and Regression Tree (CART) was also used to study the relationship existing in the data.

Decision Tree

Decision trees are useful tools for exploring data to gain insight into the relationships of a large number of candidate input variables to a target variable because this combines both data exploration and modeling. To explore our data we used the Classification and Regression Tree (CART) algorithm (Brieman *et al*., 1984). The CART algorithm grows binary trees and continues splitting as long as new split can be found that increase purity. The CART model was tested in the test data set and the efficiency of the model was measured by means of misclassification rate.

For analyzing relationship we categorized all climatic variables into the following three mutually exclusive groups.

Low	:	Lowest observation through first quartile
Medium	:	First quartile to third quartile
High	:	Observations higher than the third quartile

Monthly cholera cases were classified based on different clusters.

Results

Figure 5.2 shows that medium and/or high levels of sunshine hour along with high-levels of temperature give the suitable environment for cholera outbreak. Even when temperature level is medium, the high level sunshine can contribute for cholera outbreak.

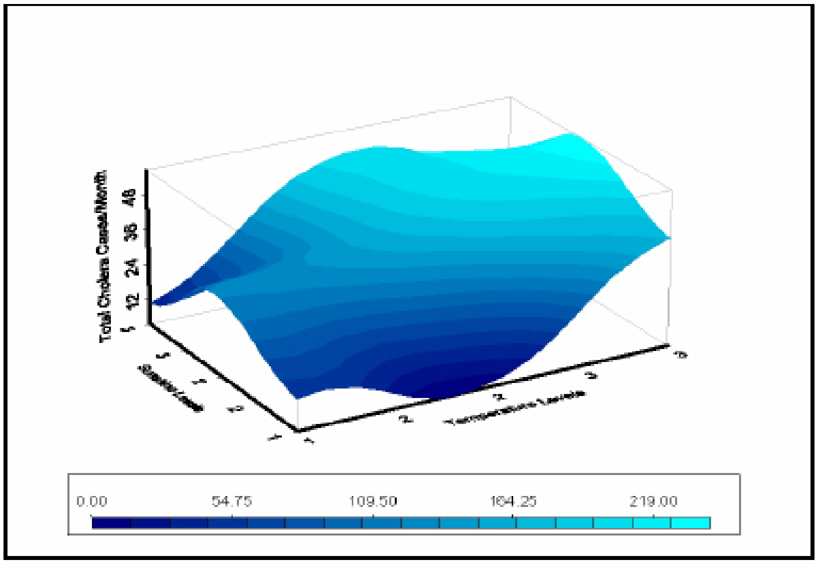


Figure 5.2: Contour Plot of reported cholera cases/month for different temperature (°C) and average sunshine hour/day. Level 1, 2, and 3 mean the *low, medium* and *high level* respectively.

Table 5.1: Descriptive statistics of the studied variables.

Statistics	**Humidity (%)**	**Rainfall/day**	**Sunshine hour/day**	**Temperature (°C)**
Minimum	67.45	0	1.58	16.58
1st Quartile	76.03	0.45	4.13	23.25
Mean	79.54	5.39	5.44	25.89
Median	79.47	3.65	5.68	27.75
3rd Quartile	83.29	9.48	6.82	28.66
Maximum	90.15	30.55	8.42	30.28

For data exploration by Classification and Regression Tree we estimated the minimum, 1st quantile, median, 3rd quartile and maximum of each variable. The statistics are presented in table 5.1. Using those statistics, we classified the variables as categorical variables. Monthly cholera cases were then classified based on different categories of the climatic parameters. The tree is presented in Figure 5.3.

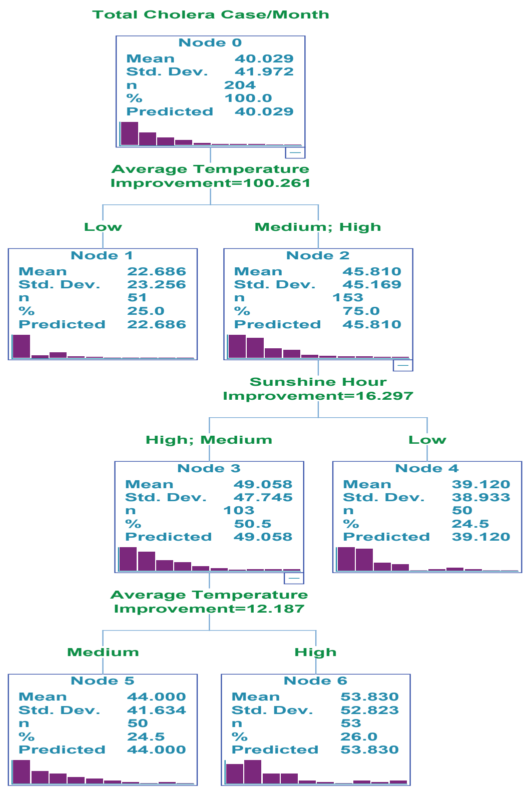


Figure 5.3: Classification tree of cholera cases based on different climatic variables.

The figure shows that the overall mean of the study sample is 40.029. Application of CART algorithm identified four significant nodes that improved the purity of the classified nodes. Low level of the daily average temperature corresponded to the lowest average (23/month) of cholera occurrence (Node 1). Medium or high-level temperature and low level of sunshine hour corresponded to the comparatively higher monthly mean number (39.12/month) of cholera patients (Node 4). The largest average (53/month) occurred at high or medium level of sunshine hour and high level of temperature (Node 6). The second largest average took place at medium level of temperature and high and/or medium level of sunshine hour (Node 5). The result supports the result obtained from the surface plot (figure 5.2). It is remarkable that the categories of the other variables failed to contribute the classification significantly. The contribution of temperature and sunshine hour was evaluated and presented in figure 5.4.

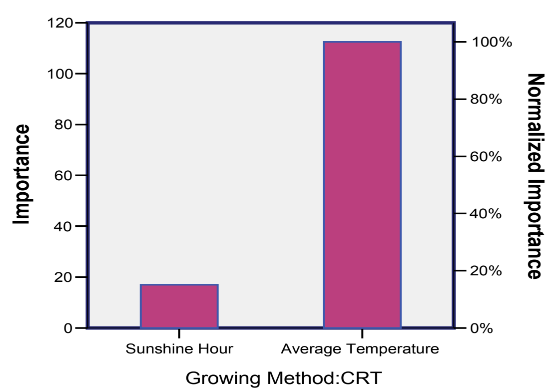


Figure 5.4: Relative contribution of climatic variables to the CART

Figure 5.4 shows that the contribution of temperature to the classification was very high whereas contribution of sunshine hour was comparatively low but significant. Exploratory data analysis failed to incorporate high dimensionality. Again it is important to know whether such type of relationship exists when the climatic variables are considered as the continuous variables. Principal component analysis was performed to study the variability pattern within the data sets.

Principal Component Analysis

To study the variability patterns of monthly cholera cases along with different climatic variables we performed PCA. The results of PCA is given in table 5.2

Table 5.2: Loadings and some other analysis of the first three components

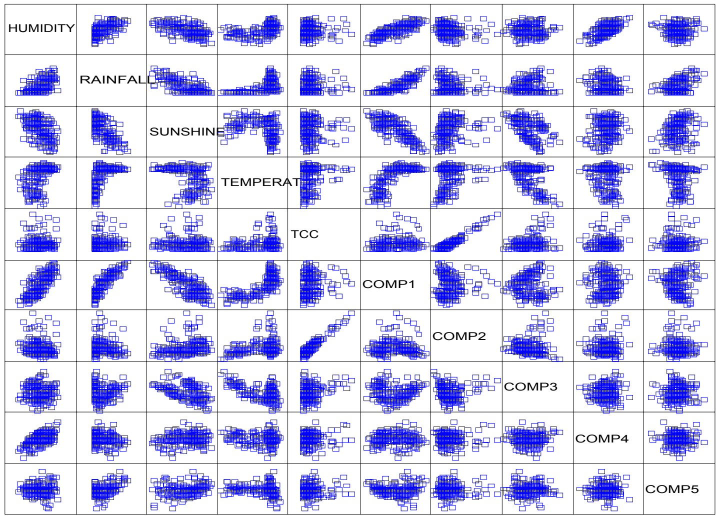
Variables	$PC^{(1)}$	$PC^{(2)}$	$PC^{(3)}$
Humidity	**0.47978**	-0.15	-0.03
Rainfall	**0.54844**	-0.07	0.03
Sunshine hour	**-0.49298**	**0.21**	**-0.61**
Temperature	**0.46626**	**0.27**	**-0.71**
Total cholera case (monthly)	0.09271	**0.93**	**0.34**
Importance of components			
Standard deviation	1.65	1.03	0.74
Proportion of Variance	0.54	0.21	0.11
Cumulative Proportion	0.54	0.75	0.86
λ_i	2.71	1.06	0.55
λ_j - λ_i (λ_j is the closest eigen value of λ_i)	1.65	0.51	0.08
$\Delta\lambda_i$	0.26833	0.104956	0.054458

*Bold face indicates the significant values

The loadings of the first principal component were all positive except the *Sunshine Hour*. The negative sign corresponding to *Sunshine* indicates that the variable contributed in opposite direction to the climate variability explained by the 1st component. The first principal component is able to explain about 54% of total variability of the climate.

In the second component, *cholera* cases weighted most heavily. The contribution of *Sunshine hour* and *Temperature* followed by *cholera cases*. The second principal component can explain 21% variability of the total climate and cholera system individually and 75% jointly with the first PC.

The third principal component explains 11% of the remaining variability. Loadings corresponding to *Sunshine* and *Temperature* are high and negative. The loading of the monthly *cholera* cases is positive and significant which implies that these variables affect negatively to the variability of monthly *cholera* cases within the remaining unexplained 25% variability of the system. Again since the 2nd principal component included the positive effect and the third principal component included the negative effects explains that there may exist at least one nonlinear relationship within the variables of the system and it is likely that such type of nonlinear relationship may exist within the variables, *temperature, sunshine and monthly cholera cases*. It is also remarkable that the eigen values corresponding to the 3rd PC is less than 1.



*TCC indicates monthly cholera cases

Figure 5.5 Scatter plots of the variables and the scores of the principal components.

The scatter plot presented in the Figure 5.5 shows the relationship between the scores of the principal components and all standardized variables. The horseshoe effect of temperature indicates a nonlinear relation within temperature and some other variables combined in 1st principal component. The scatter plot also shows that nonlinear relationship may exist with sunshine and humidity.

Discussion

The regional climate has effects on the variability of the outbreaks and transmission of infectious diseases (Patz *et al*. 2005). In this study, local climatic variables (temperature, humidity, rainfall and sunshine) have been considered to find out variability of cholera occurrence in Matlab, Chandpur, Bangladesh. Considering climate along with monthly cholera cases as a system, we have identified three orthogonal components that explain 86% variability of the total system. The first component identifies the characteristic of local climate variability of Chandpur. The result is reasonable. We see that all the climate variables have almost same contribution to the local climate system that is explained by the first principal component. The second extracted component that explains the cholera outbreak system, which is the main concern of the study that explains 21% variability of the total system. The monthly cholera case has the largest contribution to the component. The contribution of temperature and sunshine are also remarkable and positive. Humidity affects less and negatively to the second principal component. The result suggests that increase in temperature and sunshine hour and dry air condition affects positively to the variability of the cholera occurrence. The same results have been observed from the exploratory data analysis and CART algorithm. But the algorithm failed to signify the effect of humidity. Low humidity (dry day) and longer sunshine hour and relatively high temperature are the climatic phenomena of pre-monsoon and post- monsoon seasons of Bangladesh and in those two seasons, two inter-annual peak of cholera incidence took place. Longer sunshine hour and warmer air temperature enhance water temperature, which creates favorable conditions for algal bloom formation. Algal bloom provides conditions suitable for *V. cholerae* multiplication (Islam *et al*., 1994$_b$). Thus we conclude that temperature, sunshine and humidity might have an effect on the variability of cholera incidence of a region.

6. Interrelationship of environmental parameters and cholera: Development of a prediction model

Cholera prediction model was developed based on eighteen years monthly record of cholera occurrence and local climatic variables of Matlab, Chandpur, Bangladesh. The model explained 68% variability of the monthly cholera record. Temporal and conjugate effects of temperature, rainfall, sunshine hour and humidity were identified from the model. Study revealed a positive association of temperature, sunshine hour, humidity and tidal height with the incidence of cholera occurrence in the cholera epidemic region. Rainfall and tidal height contributed positively to the increased incidence of cholera after two and three monthly lag respectively. Cholera pattern itself explained 58% of its transmission dynamics.

Introduction

Climate influences ecological characteristics that have an impact on infectious diseases through local weather conditions. It is necessary to understand how the climatic parameters interact themselves and how they modify the ecology and hence the etiology of climate linked diseases. Interplay between climate and infectious diseases may determine the seasonality, magnitude as well as the future pattern of the disease in context of climate change. The common practice is to study the association between El Niño Southern Oscillation (ENSO) and the vector borne infectious diseases (Nicholls, 1993; Bouma and Kaay, 1996; Hales, 1996; Lindo *et al*., 1997; Checkley *et al*., 2000; Rodó *et al*., 2002, Patz *et al*., 2005, Pascual 2000.) The ENSO is supposed to be the main source of climatic variability and affect the climates of bordering countries of Pacific and Indian oceans. ENSO has significant role in the transmission dynamics of cholera and several recent studies are focused on cholera dynamics model based on ENSO (Pascual *et al*., 2000; Rodó *et al*., 2002; Checkley *et al*., 2000). In this article we have tried to develop a model based on local climatic variables of Matlab, Chandpur.

Methodology

To study the relationship of cholera cases with local climate variables, we used monthly cholera incidence, monthly average of daily *temperature*, *humidity*, *sunshine hour* and *rainfall* of Chandpur. Meteorological data were collected from the Bangladesh Meteorological Department (BMD) for the year 1989-2005. The cholera incidence data were collected from ICDDR,B hospital, Matlab, Chandpur for the same period of time. Unusual observations in the meteorological data were checked by exploratory methods. Univariate time series models like Autoregressive Integrated Moving Average (ARIMA) model were used to estimate the missing observations. Based on sufficiently long part of observations available, suitable ARIMA models were fitted for each variable. ARIMA models were finalized by following the Box-Jenkins (1976) modeling cycle properly. Using those models by means of forecasting and backcasting, missing values were filled up and finally we obtained the complete data set of six variables plotted in Figure 6.1.

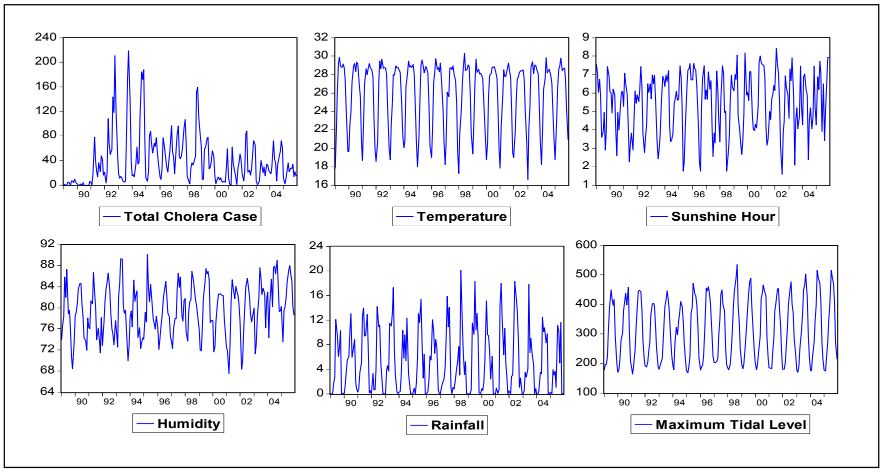


Figure 6.1: Study variables after filling the missing observations and deleted outlying observations.

Climatic variables are interrelated which violates the basic assumptions of regression analysis. Therefore, we used the Principal Component Regression (PCR) to have regressor variables, which were uncorrelated with each other. Since the dataset may contain some outliers and inliers, we used the minimum covariance determinant correlation matrix for principal component analysis. Ordinary List Square (OLS) method was used to estimate the parameters. Model adequacy was checked by conventional diagnostic checking method. The observations of the months of 2005 were left from the analysis to check the forecasting efficiency of the selected model. Finally the model was used to forecast the observations left from the analysis.

Results and discussion

Figure 6.2 shows that temperature and rainfall jointly affect the event of cholera cases. When, rainfall was lower and the temperature level was higher, the highest incidence of cholera was observed.

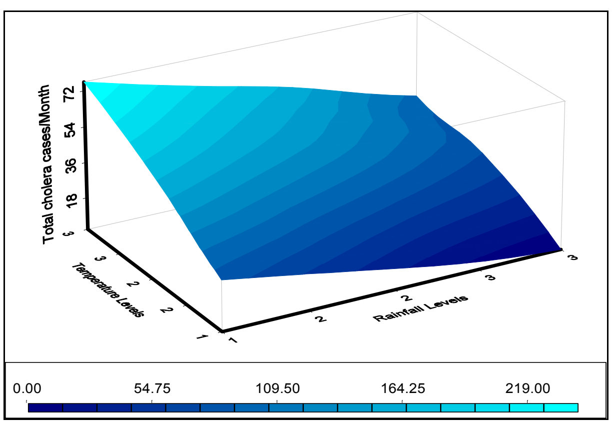


Figure 6.2: Three-dimensional surface plot of monthly cholera cases with respect to different levels of daily average temperature and rainfall.

The principal components scores are shown in Figure 6.3 and the estimates of the model parameters are given in table 6.1 and the corresponding lodgings of the principal components are given in Appendix-I.

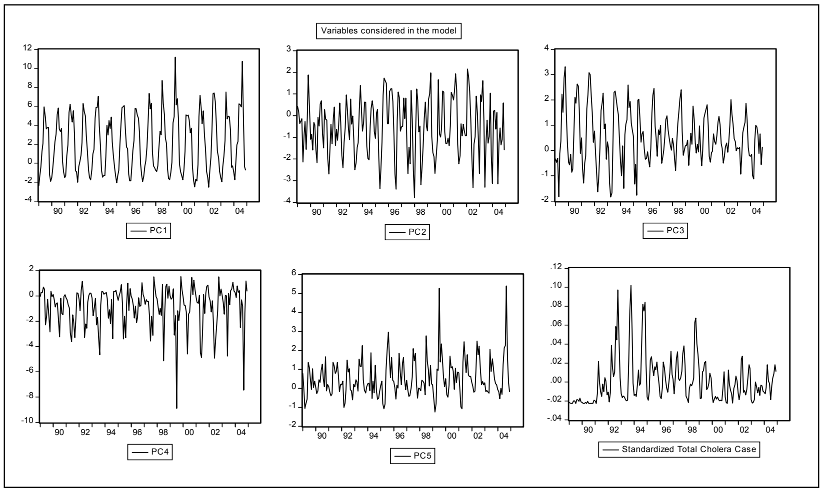


Figure 6.3: Time series plot of the five Principal Components along with standardized monthly cholera cases

Table 6.1: Estimates of the model parameters and test statistics and some values of the model adequacy checking statistics.

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Probability**
C	-0.00249	0.001412	-1.76413	0.0794
TCC_{t-1}	0.864763	0.066438	13.01614	0
TCC_{t-2}	-0.17904	0.068195	-2.62548	0.0094
$PC_t^{(1)}$	0.00241	0.000663	3.632614	0.0004
$PC_t^{(2)}$	0.002967	0.001068	2.777784	0.0061
$PC_{t-3}^{(2)}$	-0.00338	0.000962	-3.51036	0.0006
$PC_{t-2}^{(4)}$	-0.00236	0.000734	-3.21849	0.0015
$PC_{t-3}^{(4)}$	0.001572	0.000777	2.021827	0.0447
$PC_t^{(5)}$	-0.00569	0.001709	-3.3318	0.001
Model adequacy				
R-squared	0.676513	Mean dependent var		0.001058
Adjusted *R*-squared	0.662136	S.D. dependent var		0.024376
R-squared (without PC)	0.579230	Akaike info criterion		-5.62912
S.E. of regression	0.014169	Schwarz criterion		-5.47475
Sum squared residual	0.036135	*F*-statistic		47.05457
Durbin-Watson stat	2.042463	Prob (*F*-statistic)		0

The model explained 67.65% variability of the monthly cholera cases and included both seasonality and the influences of local weather variability. The model was selected by the minimum Akike Information Criterion (AIC). *F*-statistics signified the overall regression parameters. The Durbin-Watson test statistic implied that there was no serial correlation left in the residual. Proper diagnostic method such as checking the presence of autocorrelation, normality and some other necessary diagnostic techniques certified the model a best one. The actual and model version along with the residuals is presented in Figure 6.4.

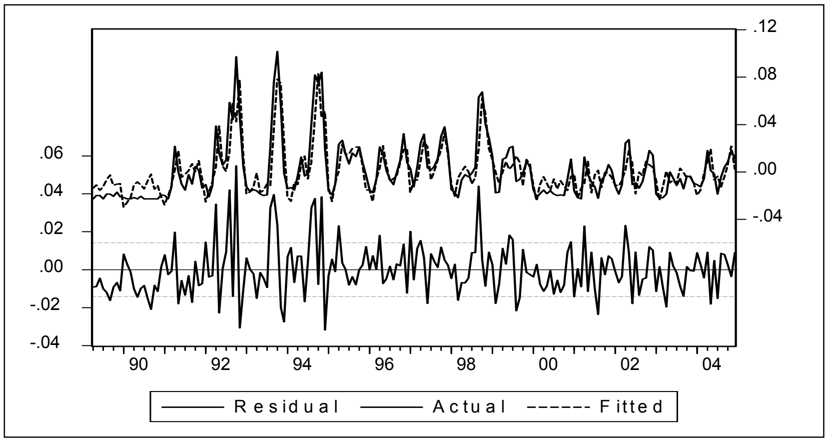


Figure 6.4: The actual and modeled output along with the residuals.

The data were presented in the standardized version. The mean and variance of the data are given in appendix-II.

The model shows that the climatic variables as well as cholera itself have significant effects on the over all transmission dynamics of cholera. Cholera case itself explained 58% of the monthly cholera cases. The rest of the variability was explained by the climatic variables and maximum tidal height. The result suggests that both intrinsic (previous level of monthly cholera cases) and extrinsic factors (environmental variables) have strong effect in the transmission dynamics of cholera. The two-month lag of the monthly cholera cases affected negatively implying that the epidemics of cholera started to decrease in the third month.

A positive effect of first PC and second PC and the negative effect of the third lag of the second PC scores were observed. In terms of original variables we see that except sunshine all climatic factors contributed significantly and positively to the first PC score. Positive effect of $PC_t^{(1)}$ indicates that significant increase in temperature, rainfall, humidity and tidal height may increase cholera incidence. Positive influence of the second PC indicates the effective positive contribution of sunshine hour on the cholera occurrence. The second lag of fourth PC contributed negatively whereas the third lag of fourth PC affected positively. In the fourth PC rainfall contributed negatively and the maximum tidal height affected positively (appendix-I). So the negative effect of the $PC_{t-2}^{(4)}$ indicated the positive effect of rainfall and negative effect of maximum tidal level to the increase of cholera incidence two months later. Three month lagged rainfall and the maximum tidal height affect negatively and positively to cholera incidence respectively. This result implies that the maximum tidal height and rainfall have some role in maintaining the seasonality of cholera outbreak. The negative effect of $PC_t^{(5)}$ ensures again the positive effect of temperature on cholera incidence. During the cholera season high rainfall may spread the disease more easily.

Using the model we predict the monthly cholera cases in Matlab, Chandpur region as presented in figure 6.5. From the figure we see that the prediction model is able to maintain the seasonality and variability. The model can forecast future monthly cholera cases with absolute error 13no./month and root mean squared forecast error 15no./month.

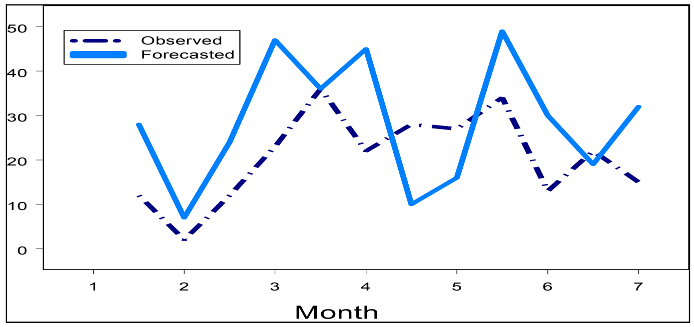


Figure 6.5: Observed and predicted cholera case using the prediction model.

Climate change due to global warming will result the increase in ambient temperature, short or over rainfall as well as intrusion of saline water in the inland due to sea level rise. Our study reveals that any significant change in the above one may increase cholera incidence. High ambient temperature corresponds to high water temperature that provides the favorable environment for the multiplication of the causative agents of cholera or its reservoirs. Direct influence of ambient temperature on cholera is also remarkable (Checkley *et al*., 2000). Again high rainfall associated with increased tidal height level causes flooding and inundation. Therefore people will be more vulnerable to contract cholera from the environment. Cholera is mainly the disease of coastal countries of Asia and Pacific. Association was found with cholera incidence and plankton bloom in the Bay of Bengal (Pascual *et al*., 2000). So the saline water intrusion at the time of high tide may increase the risk of cholera incidence particularly to the people of coastal region, as they would be first exposed to the favorable situation for cholera, which would be created due to climate change.

Future Research Scopes

Evidence collected over eighteen (1989-2006) years indicate close association of cholera incidence with climatic factors. Therefore, climate change may influence the transmission dynamics of many water borne diseases as we observed in case of cholera in this study. From the perspective of this study, we recommend the following:

- Water bodies need to be monitored regularly to identify *Vibrio cholerea* as well as its reservoir, as their abundance and persistence will be influenced by salinity intrusion due to sea level rise.
- Comprehensive study on cholera risk management in relation to climate change needs to be carried out.
- In depth research to identify the most vulnerable communities to cholera in relation to climate change scenario needs to be studied.
- Similar type of research need to be undertaken for other type of water borne or vector borne diseases like diarrhea, malaria, dengue etc. which are thought to have association with climate.
- To find out the impact of climatic variables on transmission dynamics of cholera, an in-depth study needs to be carried out.

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Appendix

Appendix-I: Principal Component Loadings

Varibles	PC_t^1	PC_t^2	PC_t^3	PC_t^4	PC_t^5
Humidity	0.4000	-0.4600	-0.6900	0.3800	0.1300
Rainfall	0.5300	0.0600	-0.0800	-0.7500	0.3900
Sunshine	-0.1800	0.7800	-0.4900	0.1500	0.3100
Temperature	0.5300	0.3700	-0.0700	0.0200	-0.7600
Maxtidal level	0.5000	0.1800	0.5300	0.5200	0.4000
Standard Deviation	1.57737	1.10903	0.76485	0.68796	0.47291
Proportion of Variance	0.49762	0.24599	0.11700	0.09466	0.04473
Cumulative Proportion	0.49762	0.74361	0.86061	0.95527	1.00000

Appendix –II: Table of means and standard deviations used for standardization of the variables

Statistics	Humidity	Rainfall	Sunshine hour	Temperature	Total Cholera Cases	Maximum Tidal Level
Mean	79.54	5.39	5.44	25.89	40.03	313.15
Standard Deviation	23.47	31.11	2.62	13.14	1761.64	11062.01

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