Impact of hydrology and climate change and variability on cholera outbreaks in Bangladesh

by Salima Sultana Daisy

PhD research fellow, Combating cholera caused by climate change (C5) project, IWFM, BUET, Bangladesh

Supervisor: Prof. Dr. A.K.M. Saiful Islam, IWFM, BUET, Bangladesh

1. Problem Statement

Cholera is an infection of the small intestine caused by the bacterium *Vibrio cholerae*. The main symptoms are watery diarrhoea and vomiting. This may result in dehydration and in severe cases greyish-bluish skin (McElroy & Townsend 2009). Cholera transmission occurs primarily by drinking water or eating food that has been contaminated by the *feces* of an infected person, including one with no apparent symptoms. Worldwide, cholera represents about 1.4 billion people at risk in endemic countries; an estimated burden of 2.8 million (uncertainty range 1.4 - 4.3 million) cases; and 91,000 (uncertainty range 28,000 - 142,000) deaths per year in endemic countries as of 2012 (Ali et al. 2012).

Cholera is a global killer with the world witnessing an extraordinary rise in cholera infection and transmission since the 1990s. Cholera outbreaks show biannual peaks in its native homeland, the Bengal Delta, while it shows a single annual peak infection pattern in the most affected areas of the world. The procedure behind this dual peaks has been described by Akanda et al. (2009) as a consequence of low flows in the major rivers Ganges, Brahmaputra and Meghna enhancing coastal phytoplankton to encroach to the inland that can cause pre-monsoon peak cholera outbreak and as a consequence of high flows sourcing floods that might be the reason of post-monsoon peak of cholera outbreaks. Coastal phytoplankton in the Bengal Delta has a unique positive relation with the increase of sea-surface temperature that has been documented by Jutla et al. (2011) while in the most coastal areas of the world this is inversely related. However, combination of seasonal hydroclimatology, high population density, floodplain geography, and coastal ecology has made this delta region more vulnerable to periodic cholera outbreaks. On the other hand, long-term climate change and highly variable seasonal extremes i.e., higher floods and droughts may cause more complex situation in future. In our study, we will investigate the actual hydroclimatological reasons that propagating these dual peaks annually and the impact of climate change on these peaks how the peaks behave with the future scenarios for changing climatic variables e.g., increase of temperature, precipitation, sea-level rise, etc. For the climate change prediction, detail hydrologic models will be developed for Ganges, Brahmaputra, and Meghna (GBM) Basins with last 30 years.

2. Objectives of the study

The general objective of the study is to evaluate the climate change impact on cholera outbreaks in Ganges-Brahmaputra-Meghna (GBM) basins. The specific objectives of the study are:

- To evaluate the relation between seasonal upstream flow in GBM basin and cholera outbreaks in Bangladesh;
- To evaluate the relation between coastal hydrology and morphology and cholera outbreaks in Bangladesh;
- To evaluate the long-term effects of climate change and variability on cholera outbreaks in Bangladesh.

3. Methods

For fulfilling the first objective three SWAT model will be calibrated and validated with river flow data individually and one combined SWAT model will be developed for the GBM basin. For fulfilling the second objective a coastal model will be developed with Delft3D model. Finally for fulfilling the third objective of evaluating the impact of climate change and variability the different scenarios of IPCC will be downscaled from the ensemble of global climate models using PRECIS model to implement the scenarios in the calibrated and validated SWAT and Delft3D models. The details of the model description and data sources are described below.

3.1 SWAT

SWAT (Soil and Water Assessment Tool) model (Arnold et al. 1998) is a river basin, or watershed, scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time. The model is physically based and computationally efficient, uses readily available inputs and enables users to study long-term impacts. It is a public domain model actively supported by the USDA Agricultural Research Service. It is a hydrology model with the components of weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer. SWAT can be considered a watershed hydrological transport model. ArcSWAT ArcGIS extension is a graphical user interface for the SWAT model to make the model input files easy for the users, run the model, and view the model results. The detail data sources for preparing SWAT model input files and state variable (river flow) for model calibration and validation are listed in Table 1. The model domain of the SWAT models is shown in Figure 1.

Table 1: Data sources for SWAT model input and calibration and validation

Data type	Data sources	Scale/Resolution	Description and website
DEM	SRTM	90 m	Elevation (http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1)
Hydrological network	STRM DEM	90 m	River network and corresponding sub-catchments will be delineated from SRTM DEM
Soil	FAO	1:5,000,000	Classified soil and physical properties such as sand, silt, clay, and bulk density (http://www.fao.org/climatechange/54273/en/)
Land Use	GlobCover	1,000 m	Classified land use such as crop, urban, forest, and water etc. http://ionia1.esrin.esa.int/
River flow	BWDB, BfG-GRDC		River discharge (http://www.bafg.de/GRDC/EN/Home/homepage_node.html)
Weather	NOAA-NCDC		Precipitation, temperature, wind speed, solar radiation at stations (http://www.ncdc.noaa.gov/)

DEM - Digital Elevation Model, SRTM - Shuttle Radar Topographic Mission, FAO - Food and Agricultural Organization, BWDB - Bangladesh Water Development Board, BfG-GRDC - Global Runoff Data Centre of the German Federal Institute of Hydrology, NOAA-NCDC - NOAA's National Climatic Data Center

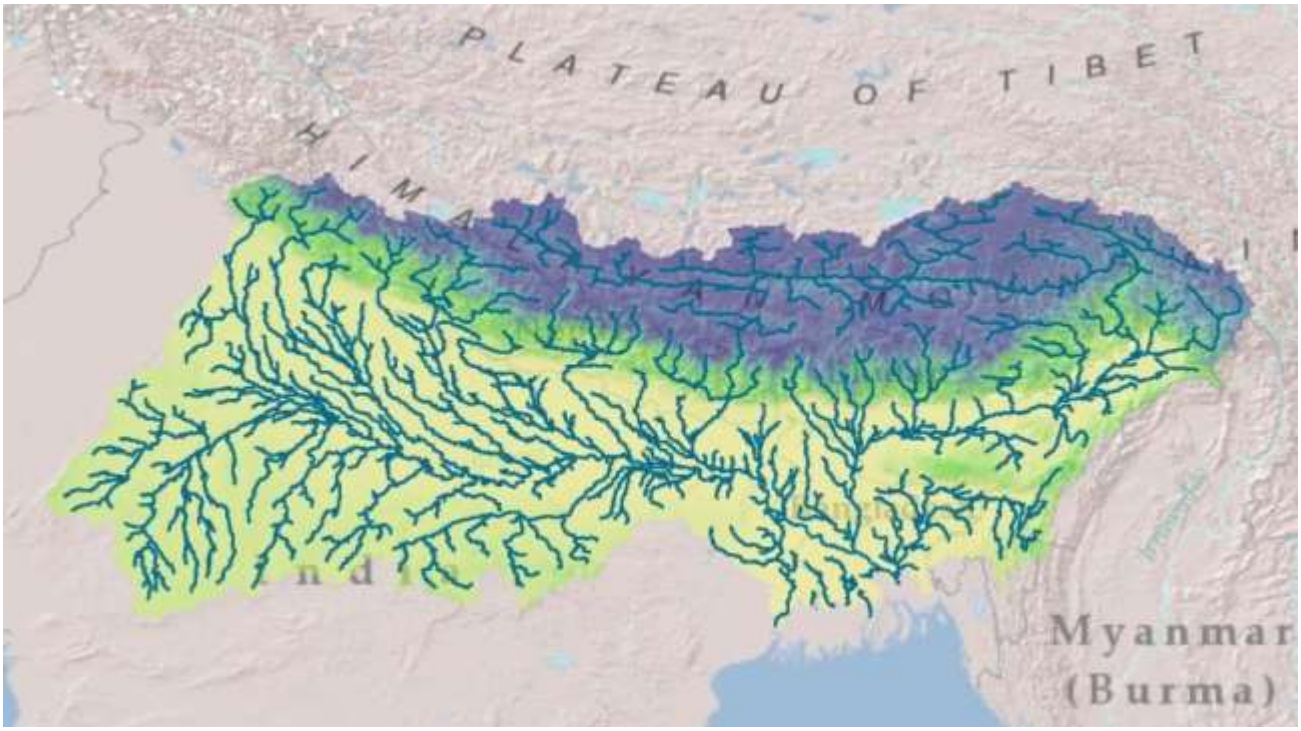

Figure 1: Hydrological model domain of Ganges-Brahmaputra-Meghna (GBM) basin for prediction of climate change and variability

3.2 Delft3D

Delft3D is a world leading 3D modeling suite to investigate hydrodynamics, sediment transport and morphology and water quality for fluvial, estuarine and coastal environments by Deltares Systems of the Netherlands. As per 1 January 2011, the Delft3D flow (FLOW), morphology (MOR) and waves (WAVE) modules are available in open source. The software is used and has proven its capabilities on many places around the world, like the Netherlands, USA, Hong Kong, Singapore, Australia, Venice, etc. The software is continuously improved and developed with innovating advanced modelling techniques.

The FLOW module is the heart of Delft3D and is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation programme which calculates non-steady flow and transport phenomena resulting from tidal and meteorological forcing on a curvilinear, boundary fitted grid or spherical coordinates. In 3D simulations, the vertical grid is defined following the so-called sigma coordinate approach or Z-layer approach. The MOR module computes sediment transport (both suspended and bed total load) and morphological changes for an arbitrary number of cohesive and non-cohesive fractions. Both currents and waves act as driving forces and a wide variety of transport formulae have been incorporated. For the suspended load this module connects to the 2D or 3D advection-diffusion solver of the FLOW module; density effects may be taken into account. An essential feature of the MOR module is the dynamic feedback with the FLOW and WAVE modules, which allow the flows and waves to adjust themselves to the local bathymetry and allows for simulations on any time scale from days (storm impact) to centuries (system dynamics). It can keep track of the bed composition to build up a stratigraphic record. The MOR module may be extended to include extensive features to simulate dredging and dumping scenarios. The detail data sources will be checked later.

3.3 PRECIS

PRECIS (pronounced as in the French précis - "PRAY-sea") is based on the Met Office Hadley Centre's regional climate modelling system. It has been ported to run on a PC (under Linux) with a simple user interface, so that experiments can easily be set up over any region. PRECIS was developed in order to help generate high-resolution climate change information for as many regions of the world as possible. The intention is to make PRECIS freely available to groups of developing countries in order that they may develop climate change scenarios at national centres of excellence, simultaneously building capacity and drawing on local climatological expertise. These scenarios can be used in impact, vulnerability and adaptation studies, and to aid in the preparation of National Communications, as required under Articles 4.1, 4.8 and 12.1 of the United Nations Framework Convention on Climate Change (UNFCCC). PRECIS will give the outputs of different scenarios of meteorological variables for giving input to the calibrated SWAT and Depflt3D models.

4. Expected Outputs

The expected outputs of this research work will include the calibrated and validated SWAT hydrological models for GBM basins individually and combined, and calibrated and validated Delft3D model which will be followed up by three peer reviewed journal articles and the PhD thesis. The tentative titles of the journal articles are as follows:

- Relation between seasonal upstream flow in GBM basin and cholera outbreaks in Bangladesh
- Relation between coastal hydrology and morphology and cholera outbreaks in Bangladesh
- Evaluation of climate change and climate variability on cholera outbreaks in Bangladesh

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