A multi-sensor remote sensing approach to predict cholera

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International Center for Diarrhoeal Diseases Research
World Health Organization
Goal of Research Project

- Development of a cholera prediction system using earth observations.
- Synthesize and quantify role of hydrological, ecological, and climatic processes in triggering cholera outbreak at different spatial and temporal scales from satellites, and provide early warning to vulnerable population.
Research Objectives

Three research objectives are to:

• Identify, synthesize and quantify role of satellite based macro-environmental processes for epidemic, mixed-mode endemic and endemic cholera.

• Develop satellite data based hydroclimatological risk model from conditions favorable for the three types of cholera.

• Develop population based cholera outbreak index.
Cholera Model

Epidemic Cholera
- Sporadic outbreak
- Usually occurs following floods or inundation of large landscapes
- Warm temperatures may increase growth of bacteria in aquatic bodies.

Mixed-mode Cholera
- Usually two seasonal peaks
- One peak related to seawater intrusion; Second peak associated with widespread inundation
- Specific to Bengal Delta region

Endemic Cholera
- Cholera persists throughout year in coastal regions
- Seawater Intrusion from coasts to inland
- Cholera outbreaks occur during low river flow season

Typical cholera seasonality

Satellites data and products
- LANDSAT: ▲▲
  - Land Use, NDVI
- MODIS/ MERIS:
  - Surface Temperature, Ocean Color
- SWOT*:
  - River Discharge
- SMAP*:
  - Soil Moisture
- GRACE:
  - Water Storage, River Discharge
- TRMM/GPM*:
  - Precipitation
- TOPEX/JASON:
  - Sea Surface Height
- AVHRR:
  - Sea surface temperature

* denotes utility for future missions

Background image: Bangladesh and Bay of Bengal

Jutla et al., 2015 (AJTMH)
### Overall timeline for research objective and activities at end user organization

<table>
<thead>
<tr>
<th>Technical Strategy (WVU, UMD, URI)</th>
<th>ARL</th>
<th>Yr1</th>
<th>Yr2</th>
<th>Yr3</th>
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<tbody>
<tr>
<td>A1 Epidemic Cholera</td>
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<td>C</td>
<td></td>
<td></td>
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<tr>
<td>A1 Mixed-Model Cholera</td>
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<tr>
<td>A1 Endemic Cholera</td>
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<td>A2 Estimate Hydroclimatological Cholera Risk</td>
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<tr>
<td>A3 Cholera Index (hydroclimatology + societal)</td>
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<table>
<thead>
<tr>
<th>Decision making activities at the End User Organization, ICDDR, B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organizational challenges identified and managed</td>
</tr>
<tr>
<td>Potential to improve decision making activity</td>
</tr>
<tr>
<td>Projected improvement in simulated environment and decision making activity</td>
</tr>
<tr>
<td>Transition and Sustainability plan: Train-the-trainer workshops</td>
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</tbody>
</table>
Select a region

- Confirm pattern of occurrence if disease data are available else best guess

Yes

Epidemic Cholera

No

Region > 150 miles from coast

Disease data available

Yes

Single Peak

No

Determine HcR (LST, Precipitation)

Mixed-mode Cholera

Determine HcR Autumn or second occurrence (High flow, SST, precipitation, FAA)

Endemic Cholera

Best guess from pattern of occurrence based on geographical setting and literature (WHO), adaptive update, when sufficient information is available

Determine Cholera Outbreak Index (HcR, population, societal determinant)
Epidemic cholera model

- Temperature
  - Below climatological average
    - Above climatological average
    - High Risk
  - Above climatological average
    - Low Risk
- Precipitation
  - Below climatological average
    - Above climatological average
    - Water insecurity, Community instability
  - Above climatological average
    - Water security, Cohesive communities

Cholera Outbreak
Sociological Conditions
Epidemic cholera model

### Composite weighted raster overlay

<table>
<thead>
<tr>
<th>Raster data layers (Environmental variables)</th>
<th>Weight</th>
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<tbody>
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<td>Air temperature anomalies</td>
<td></td>
</tr>
<tr>
<td>Precipitation anomalies</td>
<td></td>
</tr>
<tr>
<td>Population density</td>
<td></td>
</tr>
<tr>
<td>Good sanitation services</td>
<td></td>
</tr>
<tr>
<td>Safe water accessibility</td>
<td></td>
</tr>
</tbody>
</table>

\[ W_{ij} \]

\[ i = \text{environmental variable} \]
\[ j = \text{risk level} \]

### Weighted average

\[ \text{Cholera risk map} \]

### Risk weights used in cholera outbreak risk clustering

#### Hydro - climatological risks (%)

<table>
<thead>
<tr>
<th>Risk level</th>
<th>Precipitation anomalies</th>
<th>Temperature anomalies</th>
<th>Population densities</th>
<th>Cholera outbreak Risk</th>
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</thead>
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<td>Very High</td>
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<td>36</td>
<td>27</td>
<td>100</td>
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<tr>
<td>High</td>
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<td>27</td>
<td>18</td>
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<tr>
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#### Socio - Hydro - climatological risks (%)

<table>
<thead>
<tr>
<th>Risk level</th>
<th>Precipitation anomalies</th>
<th>Temperature anomalies</th>
<th>Population densities</th>
<th>Safe water accessibility</th>
<th>Sanitation services</th>
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<td>21</td>
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<td>16</td>
<td>11</td>
<td>16</td>
<td>16</td>
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<tr>
<td>Moderate</td>
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<td>0</td>
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<td>0</td>
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</table>
Epidemic cholera model

Air temperature and precipitation anomalies: two months lead time
Epidemic cholera model

Cholera risk map post-earthquake scenario considering socio-hydro-climatological triggers
Epidemic cholera model

Legend
- No Risk Cholera
- Very Low Risk Cholera
- Low Risk Cholera
- Moderate Risk Cholera
- High Risk Cholera
- Very High Risk Cholera
- Administrative division
Endemic Cholera: Vibrio niches
Satellite based forecasting (TWS from GRACE and SST from MODIS) may complement traditional river forecasting and water resources management in the region and could enhance knowledge and trust among the stakeholders.

The autumn (September-October-November), cholera outbreaks are related to regional flooding and forecasted using high river discharge (June-July-August).

The spring (March-April-May), cholera is linked to intrusion of coastal water containing the disease causing bacteria to inland and modelled from low river flows (December-January-February).
More than 50% percent of the end users sampled at ICDDR,B indicated that NASA’s satellite based data on prediction of cholera outbreak would enjoy wide applicability at the center.

90% percent of the sampled end user population preferred that the data be hosted at international non-government agencies and indicated a strong preference for development of a cell phone app aimed at information transmission on conditions of cholera outbreak.

Relevance:
Elicited behavior predicated on prediction via early warning systems on cell phone app revealed that more than 85% of the population indicated preferences on changing water collection or hygiene habits when presented with exposition of high degree of predictability of cholera outbreak based/early warning system.
Starting ARL: 2/3
Feasibility studies to assess the potential viability of and provide a proof-of-concept for the application are conducted. In addition, a more complete characterization of the decision making process is completed. Different components of the application system are not yet integrated.

Current ARL: 5 (almost)
Basic components of Earth science products and the decision making activity (decision support system, tool, etc.) are integrated together into a prototype “application system” to establish that they will work together. At this level, the technical, organizational, and human process issues related to the decision support activities are also worked out. Project team must verify that components will work together to achieve this ARL.

Target ARL: 7/8
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<th>Budget</th>
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<tr>
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* Included in April 2016, budget numbers will be available in next fiscal year.
<table>
<thead>
<tr>
<th></th>
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<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
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<td>~20,000.00</td>
<td>15,897.00</td>
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* Includes cost of operations at Moravian college.
• Ponds are effective way to collect water for daily use (including drinking after some questionable filtration). These man-made structures are very intriguing geomorphological formations in the region. Each household has its own pond and each pond is connected to the river to get water.
• During low river discharge season (such as Dec to March), backflow of water from coast brings plankton and bacteria into the rivers that then is accumulated in these ponds.
• Similarly, during monsoon rainfall, each of these ponds spill water all over the landscape, thus cross contaminating water resources.
• We are now working on developing algorithms for water body detection or at least a warning system based on river stage using JASON, ICESAT and TOPEX data.
A tale of two ponds:
A panoramic image of ponds: connected to rivers (above) and no river connection (below). The pond that was not connected to river system, had little to no surface plankton in it. Ponds hold a high sociological importance for local population since measure of wealth is determine by the size of pond. We are still evaluating pond culture.
Plan for Decision Making Activities

• Determination of computing facilities for set up, and accessibility issues with ICDDR,B
  – Set up of web-server at WVU and provide access to ICDDR,B: Prototype in progress

• Start training and bringing officials on board for maximum knowledge disseminations on importance of macro-environmental factors
  – Survey conducted in January 2016
  – World Health Organization is extremely interested in prediction algorithms. Our research group is now an official part of GTFCC (Global Task Force on Cholera Control), the WHO based policy making body in the world on cholera.

• Microbiological data collection and vaccination costs
  – Efficacy of low cost water filtration systems (Sari Filters)
  – Review Board Application filed with ICDDR,B and will get data by January/February 2017

• Development of train-the-trainer module
  – Working with Dr Munir Alam at ICDDR,B to develop a short training module to understand satellite data, models and interpret results.
  – Also exploring options for ARSET, NASA for short training module on prediction of vibrio based infections
Ongoing planned research work

- Algorithms for detection of water bodies, and areas susceptible to inundation.
- Surface temperature analysis for estimating “warmth” of water and linking it to water bodies algorithms
- Ecological niche models for cholera
- Integration of societal determinants into cholera prediction models
- Analysis of economic value of prediction of cholera using satellites.
Thank you
Socio-economic evaluation of prediction of cholera

• Primary data acquisition: We have conducted a pilot survey comprising of ~ 40 household questionnaires in and around endemic slum areas in urban Dhaka.
• We plan to conduct socio-economic surveys from three representative modes of cholera that will be used to evaluate sensitivity of avoided damages to cholera mode in addition to socio-demographic as well as private household characteristics.
• We are currently conducting approximately 1000 household surveys in a prominent endemic urban setting in Dhaka (Mirpur) during the fall season.
• Secondary data acquisition: We have initiated ICDDR,B Research Review Committee approval to obtain secondary cost of illness/patient data in collaboration with ICDDR,B clinical and hospital services.
• We have elicited data from ICDDR,B end-users on mobilizing ground resources in a contingent valuation format with respect to users’:
  • Awareness of early warning systems in context of cholera outbreak
  • Knowledge on viability of NASA’s satellite data usage in context of cholera prediction.
  • Preferences on intervention methods
  • Preferred clearing house/ideal location for data storage and information repository
A woman collecting water from pond, which is lifeline of majority of people in coastal regions, using a Sari cloth. We asked if she knows about Sari Filters, a simple technique developed by Dr R Colwell/ A Huq, where folding a Sari cloth 4-6 times, reduced bacteria from water. The woman was unaware of the fact that there was such technique and apparently, none of the villagers know about this. One of the tasks for this project if to develop an outreach on effective low-cost intervention strategies and Sari Filters are perhaps the starting point for us. We are now working with ICDDR,B to develop educational material for dissemination to population centers.
Interaction with researchers, who are also filling out survey forms, at ICDDR,B. Surveys were designed to determine end-user needs and their understanding on earth observations.
VIIRS

Bay of Bengal Chlorophyll concentration in March

- Time series: 2012-2016
- Spatial resolution: 4km x 4km

Chlorophyll concentration

(mg/m3)

High: 99.9
Low: 0.006