Hydrologic forecasting for flood risk management
Predicting flows and inundation in data-limited catchments

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Roadmap

1 Hydrologic forecasting for early warning
   • Lead time
   • Accuracy
   • Challenge of the data-limited basin

2 Remotely sensed precipitation data
   • Opportunities and limitations
   • Designing observation networks to integrate remotely sensed data

3 Inundation
   • Calibrating/validating hydrologic models
Flood Forecasting for Early Warning

Two critical components:

1. Forecast accuracy
2. Forecast lead time
Flood Forecasting for Early Warning

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Increasing forecast lead time, increasing potential response and loss reduction
Flood Forecasting for Early Warning

Economic benefit - damage/loss reduction

“In other words, for every USD 1 invested in this EWS, there is a return of USD 558.87 in benefits.” Subbiah and Bilden, 2008, World Bank Report

### Table 14: Quantifying benefits: July-August 2007 floods

<table>
<thead>
<tr>
<th>No.</th>
<th>Sector</th>
<th>Damage elements</th>
<th>Damage cost (million BDT)</th>
<th>Avoidable Damage (%)</th>
<th>Avoidable Damage (million BDT)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Agriculture (crop)</td>
<td>Crop (Transplanting Aman seedlings, jute, vegetables, T Aman, B. Aman and other crops)</td>
<td>42,165.44</td>
<td>30</td>
<td>12,649.63</td>
<td>For crops at harvest stage only - 30%</td>
</tr>
<tr>
<td>2</td>
<td>Livestock</td>
<td>Cattle, buffaloes, sheep, goats, chicken, ducks, forages and straw</td>
<td>608.55</td>
<td>70</td>
<td>425.99</td>
<td>For livestock, forages/straw moved to safe ground/shelters only - 70%</td>
</tr>
<tr>
<td>3</td>
<td>Fisheries</td>
<td>Fish fingerlings, freshwater fishes, shrimps/prawns, pond embankments</td>
<td>1,964.95</td>
<td>50</td>
<td>982.48</td>
<td>For fish, shrimps/prawns harvested only - 50%</td>
</tr>
<tr>
<td>4</td>
<td>Deep and shallow tube well</td>
<td>Pump house and Deep tube-well machineries and irrigation canals</td>
<td>509.40</td>
<td>-</td>
<td>-</td>
<td>Unavoidable</td>
</tr>
<tr>
<td>5</td>
<td>Seeds &amp; irrigation</td>
<td>Pump house, underground pipe line, water pump, control structure and connecting roads</td>
<td>10.00</td>
<td>-</td>
<td>-</td>
<td>Unavoidable</td>
</tr>
<tr>
<td>6</td>
<td>Forest</td>
<td>Forests, nursery, roads and buildings in forests</td>
<td>37.80</td>
<td>5</td>
<td>1.89</td>
<td>For nurseries only - 5%</td>
</tr>
<tr>
<td></td>
<td><strong>Total damage cost - Food &amp; Agriculture</strong></td>
<td><strong>45,296.14</strong></td>
<td></td>
<td></td>
<td>14,059.99</td>
<td><strong>Avoidable damage (million USD) (31% of actual damage in sector)</strong></td>
</tr>
</tbody>
</table>
Flood Forecasting for Early Warning

Economic benefit—damage/loss reduction: risk assessment in Surma River basin, Bangladesh

“Benefit-cost ratio of early warning system for a 5-year event was 2.71, 12.44 and 33.21 for 24 hours, 48 hours and 7 days lead time, respectively.”

Hyder, 2013
Flood Forecasting for Early Warning

Important to accurately predict:
1. Onset of flooding

![Diagram showing the timeline of events including precipitation, discharge, peak of rainfall, flooding, and peak of water level. The flood stage is highlighted with a red line.](image-url)
Flood Forecasting for Early Warning

Important to accurately predict:
1. Onset of flooding
2. Peak discharge
Flood Forecasting for Early Warning

Important to accurately predict:
1. Onset of flooding
2. Peak discharge
3. Duration of flood
Flood Forecasting for Early Warning

Important to accurately predict:
1. Onset of flooding
2. Peak discharge
3. Duration of flood
4. Spatial extent of inundation, through time
Flood Forecasting for Early Warning

Two critical components:
1. **Forecast accuracy**
2. Forecast lead time

Accuracy of forecast with 10 days lead time

Webster et al., 2010
Flood forecasting in poorly gauged basins

Challenges:

• Insufficient implementation and maintenance of ground-based, real-time hydrologic observation.
  – Lag time between data observation and availability for flood forecasters.
  – Lead time compromised, poor forecasting skill.

• Management across boundaries.
  – Administrative barriers to data availability.
Geopolitically ungauged catchment area

Hydrologic prediction in ungauged basins: a wicked problem for hydrologists

Geopolitically ungauged catchment area:
Areas where comprehensive data observation networks may exist, but due to geopolitical constraints, catchments are effectively ungauged.
Water-related disaster in transboundary river basins

Flood disasters in transboundary river basins:
- Historically more severe, affect larger areas and result in higher costs of human life and economic damages.
- Suggests that international river basins may be uniquely vulnerable to flood hazards.

Bakker, 2009

Limitations in capacity for preparedness – a potential source of vulnerability in transboundary basins?
Integrated Flood Analysis System

Global data: topography, land use, etc.

Ground-gauged and/or satellite rainfall

Model creation

Run-off analysis

River discharge, Water level, Rainfall distribution

Courtesy of JAXA
Several remotely-sensed precipitation products have global coverage.
Resolution (time and space) and observation accuracy are low compared with ground observation rainfall.

<table>
<thead>
<tr>
<th>Product name</th>
<th>3B42RT</th>
<th>CMORPH</th>
<th>QMORPH</th>
<th>GSMaP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Builder</td>
<td>NASA/GSFC</td>
<td>NOAA/CPC</td>
<td>NOAA/CPC</td>
<td>JAXA/EORC</td>
</tr>
<tr>
<td>Coverage</td>
<td>50N～50S</td>
<td>60N～60S</td>
<td>60N～60S</td>
<td>60N～60S</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>0.25°</td>
<td>0.073°</td>
<td>0.073°</td>
<td>0.1°</td>
</tr>
<tr>
<td>Time resolution</td>
<td>3 hours</td>
<td>30 minutes</td>
<td>30 minutes</td>
<td>1 hour</td>
</tr>
<tr>
<td>Delay of delivery</td>
<td>6 hours</td>
<td>18 hours</td>
<td>3 hours</td>
<td>4 hours</td>
</tr>
<tr>
<td>Coordinate system</td>
<td>WGS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data archive</td>
<td>Dec. 1997～</td>
<td>Recent 1week</td>
<td>Recent 1week</td>
<td>Dec.2007～</td>
</tr>
</tbody>
</table>
Rain event with **slow movement** of rainy area

Present + 1 hour later + 2 hours later

(a) Stationary

Rain event with **quick movement** of a rainy area

Present + 1 hour later + 2 hours later

(b) Moving

Ground-based / Satellite rainfall

Satellite rainfall (GSMaP) (mm/3h) vs. Ground rainfall (mm/3h)

Yoshino river

IFAS – Satellite rainfall data calibration

correction method to describe the difference of rainfall events in terms of wind speed

$y = -2.7425 \ln(x) + 6.2042$

$R^2 = 0.8476$
• Corrected GSMaP is more accurate than raw data.
• User may specify any calibration equation.

3 hourly rainfall in Taiwan on typhoon Morakot, 2009 Aug.08 20–23 (UTC)
IFAS – Satellite rainfall data calibration

Sendaigawa
River length = 137 km
Basin Area = 1,600 km²

Correction of satellite data is successful
IFAS – Satellite rainfall data calibration

Kikuchigawa
River Length = 71 km
Basin Area = 996 km²

Why was correction of satellite data unsuccessful?
**IFAS – Satellite rainfall data calibration**

**successful case:** Sendai river

**unsuccessful case:** Kikuchi river

Accuracy of rainfall area distribution depends on frequency of MWR observation (& accuracy of IR motion vectors)

Image Source: JAXA

Ozawa et al. (2010)
Bicol River basin, Philippines: simulated inundation extent and depth for a) 2-year, b) 5-year, c) 10-year, d) 25-year, e) 50-year and f) 100-year return periods.
The Rainfall-Runoff Inundation (RRI) model

- Rainfall-Runoff Model: simulating streamflow discharge with rainfall input.
- River Routing Model: tracking flood wave movement along an open channel with upstream hydrograph.
- Flood Inundation Model: simulating flooded water spreading on floodplains with inflow discharge.
Traditional calibration with discharge

Inundation map (2009-2010), Pampanga river basin.

Observed and simulated discharge (2009-2010) at Arayat station.

NSE = 0.58

Discharge (m³/h)

Rainfall (mm/h)
Calibrating by spatial extent of inundation: RRI vs MODIS

Comparison of inundation extent from RRI model and MODIS images using different NDSIs during selected flood events in Pampanga river basin.
1 Hydrologic forecasting for early warning
   • Objective to achieve long(er) lead time with confidence (accuracy, or at least understanding of uncertainty) in data-limited basins.

2 Remotely sensed precipitation data
   • We still need ground-gauged precipitation, but do we need the same information as before?

3 Spatial inundation patterns
   • Calibrating/validating hydrologic models using discharge or inundation through space and time?