The Mekong River Basin under Environmental Change: Evidence from Modeling Studies

4th International Forum for Sustainable Future in Asia
4th NIES International Forum
Jan. 23-24, 2019, Hanoi, Vietnam

Sangam Shrestha
Associate Professor and Program Chair
Water Engineering and Management
Asian Institute of Technology
Presentation Contents

• Background
  o About Mekong River Basin
  o Environmental management issues

• Case studies
  o Sekong River Basin, Cambodia, Laos and Vietnam (Climate change and hydropower development on hydrology)
  o Songkhram River Basin, Thailand (Climate & land use change and its impact on streamflows and water quality)

• Key challenges and ways forward
Mekong River Basin

- Transboundary River Basin shared by 6 countries: China, Myanmar, Thailand, Laos, Cambodia and Vietnam

- The Mekong River Basin is a living place for more than 60 million people settling mainly along the main river and its tributaries.

- The 4,400 km long Mekong River collects and supplies water for a large basin of nearly 795,000 km².

- The Mekong River plays an important role in the supply of water resources for food production, energy generation and ecological sources.
Environmental Issues in Mekong River Basin

- Climate Change
- Landuse Change
- Dam Development
Water Resources Management Questions

How the changes (climate change, landuse change and hydropower development) impact the water resources?

How to manage water resources under climate change, landuse change and hydropower development?
### Study Areas in Mekong Basin

<table>
<thead>
<tr>
<th>No.</th>
<th>Basin, Country</th>
<th>Location (Lat, Long)</th>
<th>Area (km²)</th>
<th>Altitude (masl)</th>
<th>Climate</th>
<th>Rainfall (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kabul, Afghanistan</td>
<td>34.52, 69.17</td>
<td>76,908</td>
<td>5,000</td>
<td>Arid</td>
<td>1,035</td>
</tr>
<tr>
<td>2</td>
<td>Mangla, Pakistan</td>
<td>33.13, 73.63</td>
<td>33,342</td>
<td>4,000</td>
<td>Sub-</td>
<td>1,200</td>
</tr>
<tr>
<td>3</td>
<td>Jhelum, Pakistan</td>
<td>32.93, 73.37</td>
<td>33,342</td>
<td>3260</td>
<td>Sub-</td>
<td>1,265</td>
</tr>
<tr>
<td>4</td>
<td>Tamakoshi, Nepal</td>
<td>27.88, 86.27</td>
<td>2,926</td>
<td>4,082</td>
<td>Sub-tropical</td>
<td>1,900</td>
</tr>
<tr>
<td>5</td>
<td>Bagmati, Nepal</td>
<td>27.78, 85.30</td>
<td>3,750</td>
<td>1,400</td>
<td>Sub-tropical</td>
<td>1,300</td>
</tr>
<tr>
<td>6</td>
<td>Indrawati, Nepal</td>
<td>27.67, 85.56</td>
<td>1,240</td>
<td>3,200</td>
<td>Sub-tropical</td>
<td>3,000</td>
</tr>
<tr>
<td>7</td>
<td>Sikkim, India</td>
<td>27.52, 88.50</td>
<td>7,096</td>
<td>3,800</td>
<td>Sub-</td>
<td>3,050</td>
</tr>
<tr>
<td>8</td>
<td>Wangchu, Bhutan</td>
<td>27.45, 90.43</td>
<td>4,000</td>
<td>2,500</td>
<td>Sub-tropical</td>
<td>2,200</td>
</tr>
<tr>
<td>9</td>
<td>Dudhkoshi, Nepal</td>
<td>27.23, 86.60</td>
<td>3,718</td>
<td>4,650</td>
<td>Sub-</td>
<td>1,930</td>
</tr>
<tr>
<td>10</td>
<td>Koshi, Nepal</td>
<td>26.90, 87.30</td>
<td>69,300</td>
<td>4,032</td>
<td>Tropical</td>
<td>1,800</td>
</tr>
<tr>
<td>11</td>
<td>Nam Ou, Laos</td>
<td>26.22, 100.70</td>
<td>7,150</td>
<td>1,930</td>
<td>Tropical</td>
<td>1,700</td>
</tr>
<tr>
<td>12</td>
<td>Belu Chaung, Myanmar</td>
<td>19.66, 97.20</td>
<td>8,329</td>
<td>760</td>
<td>Tropical</td>
<td>1,273</td>
</tr>
<tr>
<td>13</td>
<td>Bago, Myanmar</td>
<td>17.33, 96.29</td>
<td>4,883</td>
<td>30</td>
<td>Tropical</td>
<td>2,500</td>
</tr>
<tr>
<td>14</td>
<td>Quang Nam, Vietnam</td>
<td>15.53, 107.92</td>
<td>10,438</td>
<td>690</td>
<td>Tropical</td>
<td>2,700</td>
</tr>
<tr>
<td>15</td>
<td>Mun, Thailand</td>
<td>15.47, 105.48</td>
<td>119,180</td>
<td>530</td>
<td>Tropical</td>
<td>1,080</td>
</tr>
<tr>
<td>16</td>
<td>Yang, Thailand</td>
<td>14.62, 105.00</td>
<td>4,145</td>
<td>300</td>
<td>Tropical</td>
<td>1,390</td>
</tr>
<tr>
<td>17</td>
<td>Bangkok, Thailand</td>
<td>13.75, 100.50</td>
<td>1,569</td>
<td>2</td>
<td>Tropical</td>
<td>1,500</td>
</tr>
<tr>
<td>18</td>
<td>3S (Laos, Cambodia, Vietnam)</td>
<td>13.50, 106.00</td>
<td>78,529</td>
<td>1,060</td>
<td>Tropical</td>
<td>2,450</td>
</tr>
<tr>
<td>19</td>
<td>Mekong Delta</td>
<td>10.77, 105.49</td>
<td>39,734</td>
<td>0.3</td>
<td>Tropical</td>
<td>1,727</td>
</tr>
<tr>
<td>20</td>
<td>Pak Phanang, Thailand</td>
<td>8.30, 100.12</td>
<td>422</td>
<td>4</td>
<td>Tropical</td>
<td>2,200</td>
</tr>
<tr>
<td>21</td>
<td>Citarum, Indonesia</td>
<td>-5.95, 107.00</td>
<td>6,080</td>
<td>800</td>
<td>Tropical</td>
<td>2,500</td>
</tr>
</tbody>
</table>

Location map of selected basins for climate and landuse change impact and adaptation studies

---

4th International Forum for Sustainable Future in Asia
4th NIES International Forum
Jan. 23-24, 2019, Hanoi, Vietnam
Methodology of Impact Assessment (Modeling Chain)

**Future Climate Projection**
- Global Climate Model (GCMs)
- Regional Climate Model (RCMs)

**Downscaling/Bias Correction**
- Future climate at local/basin

**Hydrological Modeling**

**Landuse Modeling**

**Reservoir Modeling**

**Water Quality Modeling**

**Results**
- Future climate
- Future landuse
- Future streamflow
- Future hydropower
- Future water quality
Assessment of Climate Change and Hydropower Development Impact on Hydrology of the Sekong River Basin in Cambodia, Laos and Vietnam

Hok Panha, M.Eng
Project: Connecting climate change, hydrology & fisheries for energy and food security in Lower Mekong Basin

Funding: USAID (PEER Program Cycle 6)

Period: 2017-2020

USG Partner: Prof. John Sabo, ASU, USA

Website: www.connect-chf.com

Dr. Sangam Shrestha, AIT
Dr. Vilas Nitivattananon, AIT
Dr. Thanapon Piman, SEI
Dr. Cheng Phen, IFReDI
Prof. John Sabo, ASU
Sekong River Basin (Cambodia, Laos and Vietnam)

- Second largest basin among the 3S Basins containing 36% of the entire drainage area, transboundary tributary of the Mekong River
- Population: 330,000 (in 2012)
- Area: 28,816 km²
- Average annual rainfall: 1,400 to 2,900 mm
- The Sekong River inhabits: 300-350 fish species
- Currently, the basin has only three large hydropower dams. However, five more are under construction and another 16 under consideration.
Water Resources Management Questions

What will be the future climate in the Sekong River Basin?

How the climate change and hydropower development affects hydrology of the Sekong River Basin?
Methodology

Step 1: Pre-processing “EXCEL and GIS”
- Data preparation and checking
  - Geospatial data
    - DEM
    - Soil types
    - Land use
    - River
  - Meteorological data
    - Rainfall
    - Temperature (max, min)
    - Relative humidity
    - Solar radiation
    - Wind speed
  - Hydrological data
    - Discharge

Step 2: During- and Post-processing “SWAT/SWAT_CUP”
- Watershed delineation
- HRU analysis
- Writing input tables
- Edit SWAT input
- SWAT simulation
- Model calibration
- Sensitivity analysis
- Model validation
- Calibrated and validated model
- Analyze results
- Current and future river discharge

Step 3: Future climate
- Climate Models
  - RCMs
    - RCP 4.5 and RCP 8.5
  - Bias correction
    - Linear Downscaling
  - Compared with observed data
  - Future climate scenarios

Step 4: Reservoir Simulation Model
- HEC-ResSim
- Dam characteristics and properties
- Operation sets
- Model simulation
- Analyze results
### Data

<table>
<thead>
<tr>
<th>Data type</th>
<th>Time</th>
<th>Frequency</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topography (DEM)</td>
<td>-</td>
<td>-</td>
<td><a href="http://srtm.csi.cgiar.org">http://srtm.csi.cgiar.org</a></td>
</tr>
<tr>
<td>Land cover map (2003)</td>
<td>-</td>
<td>-</td>
<td>Mekong River Commission (MRC)</td>
</tr>
<tr>
<td>Soil types map (2003)</td>
<td>-</td>
<td>-</td>
<td>Mekong River Commission (MRC)</td>
</tr>
<tr>
<td>Meteorological data</td>
<td>1980–2011</td>
<td>Daily</td>
<td>MRC, Ministry of Water Resources and Meteorology (MOWRAM), and Department of Meteorology and Hydrology (DMH)</td>
</tr>
<tr>
<td>Hydrological data (discharge)</td>
<td>2001–2011</td>
<td>Daily</td>
<td>MRC, MOWRAM, and DMH</td>
</tr>
<tr>
<td>Dam characteristics</td>
<td>-</td>
<td>-</td>
<td>Piman et al., (2013) and feasibility study</td>
</tr>
</tbody>
</table>

#### Features "Project: CORDEX"

<table>
<thead>
<tr>
<th>Research Institute</th>
<th>ACCESS</th>
<th>CNRM</th>
<th>MPI</th>
<th>BCCR</th>
<th>REMO2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commonwealth Scientific and Industrial Research Organization, Australia</td>
<td>2015</td>
<td>2015</td>
<td>2015</td>
<td>2015</td>
<td>Helmholtz-Zentrum Geesthacht, Climate Service Center Germany</td>
</tr>
<tr>
<td>Resolution</td>
<td>0.5° × 0.5°</td>
<td>0.5° × 0.5°</td>
<td>0.5° × 0.5°</td>
<td>0.5° × 0.5°</td>
<td>0.5° × 0.5°</td>
</tr>
<tr>
<td>Driving GCM model</td>
<td>ACCESS1.0</td>
<td>CNRM-CM5</td>
<td>MPI-ESM-LR</td>
<td>NorESM-M</td>
<td>IPSL-IPSL-CM5A-LR</td>
</tr>
</tbody>
</table>

#### Dam Characteristics

<table>
<thead>
<tr>
<th>Name</th>
<th>Status</th>
<th>Drainage area (km²)</th>
<th>Full supply level (m.msl)</th>
<th>Low supply level (m.msl)</th>
<th>Live storage (MCM)</th>
<th>Design ed disch barge (m³/s)</th>
<th>Design ed head (m)</th>
<th>Installed capacity (MW)</th>
<th>Mean energy (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xekaman 1</td>
<td>Existing</td>
<td>3,580.0</td>
<td>230.0</td>
<td>218.0</td>
<td>1,683.0</td>
<td>336.6</td>
<td>99.0</td>
<td>290.0</td>
<td>1,096.0</td>
</tr>
<tr>
<td>Xekong 4A</td>
<td>Planning</td>
<td>5,182.0</td>
<td>200.0</td>
<td>180.0</td>
<td>654.9</td>
<td>400.4</td>
<td>50.1</td>
<td>175.0</td>
<td>785.1</td>
</tr>
</tbody>
</table>
Reservoir operation schematic for the Xekaman 1 hydropower dam “Scenario 1” (left) and Xekaman 1 and Sekong 4A hydropower dams “Scenario 2” (right)
- Average annual and wet season rainfall is projected to decrease and dry season rainfall is projected to increase in future under RCP 4.5 and RCP 8.5, respectively.

- Higher increase in dry season rainfall.

- Average annual temperature in projected to increase >2°C and 3.5°C by 2090s under RCP 4.5 and RCP 8.5, respectively.

- Higher increase in wet season temperature.
• Changes in discharge at **Siempang** (downstream) in the 2030s, 2060s, and 2090s from ensemble RCMs under RCP4.5 in the Sekong River Basin

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>Climate change only</td>
</tr>
<tr>
<td>CC+XK1</td>
<td>Climate change and Xekaman 1 hydropower (Existing)</td>
</tr>
<tr>
<td>CC+XK1+SK4A</td>
<td>Climate change and Xekaman 1 (Existing) + Sekong 4A (Planed) hydropower</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Changes in river discharge (%)</th>
<th>2030s</th>
<th>2060s</th>
<th>2090s</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC+XK1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC+XK1+SK4A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC+XK1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC+XK1+SK4A</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Annual
- Wet season
- Dry season

**Change in River Discharge**
Changes in discharge at **Attapeu** (upstream) in the 2030s, 2060s, and 2090s from ensemble RCMs under RCP4.5 and RCP8.5 in the Sekong River Basin
Conclusions

- Sekong River Basin is expected to be warmer with variability of rainfall in future.

- Climate change and hydropower operation will reduce the river discharge at the downstream (Siempang) in future.

- In upstream (Attapeu) annual and dry season river discharge is expected to decrease and wet season discharge is expected to increase in near and mid future.

- River discharge is seen to be more impacted by climate change compared to hydropower operation in future.
Case Study 2

Assessment of Climate and Land use Change Impact on Streamflow and Water Quality in the Songkhram River Basin, Thailand

Binod Bhatta, M.Eng
Project: Building Capacity and Strengthening Community Participation for Water Resources Management and Wetland Ecosystem Restoration in the context of Climate Change in Lower Songkhram River Basin, Thailand

Funding: HSBC

Period: 2015-2018

Partner: WWF- Thailand

Website: www.wetlandwatchthailand.org

Dr. Sangam Shrestha, AIT

Mr. Amornwatpong Khemratch, WWF
Songkhram River Basin (SRB), Thailand

- Second largest basin in Northeast Thailand
- Population: 1.94 million (in 2000)
- Drainage area: 12,880 km², total length of river: 420 km, flows to Mekong River
- Temperature: 10-40°C
- Annual rainfall: 1200mm (South); 2100mm (North) [90% rainfall in monsoon]
- Annual average flow 350m³/s ~ (860mm)
- Landuse: 48% Agriculture
- Wetland of International Importance
Water Resources Management Questions

What will be the future climate and landuse and landcover in SRB?

How the climate change and landuse& land cover change impact the streamflow and water quality of SRB?
Methodology

Spatial data (Landuse, Soil, DEM) → Rainfall and Meteorological data → Flow and Nitrate-N → Selection of RCMs

Future Landuse Simulation (Dyna-CLUE) → ArcSWAT-2012 Set Up

Simulation of flow Q → LOADEST

Daily Nitrate-N Load → Bias Correction (Rain, Tmax, Tmin)

Calibrate and validation for flow → Calibration and Validation for NO$_3$-N

Calibrated SWAT Model for Q and NO$_3$-N → RCP 4.5 and RCP 8.5

Future Analysis on (Q, NO$_3$-N)
- Only climate change impact
- Both climate and landuse change impact
- Only landuse change impact
## Data

<table>
<thead>
<tr>
<th>SN</th>
<th>Data</th>
<th>Source/Developer</th>
<th>Spatial/Temporal Resolution</th>
<th>Number/Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Physical characteristics of the catchment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Elevation</td>
<td>ASTER GDEM version 2</td>
<td>30 m/-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Soil</td>
<td>FAO/UNESCO—the digital soil map of the world</td>
<td>1:5,000,000/-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Landuse</td>
<td>Land Development Department (LDD) Thailand</td>
<td>1 km/-</td>
<td>2 maps—2009, 2014</td>
</tr>
<tr>
<td></td>
<td><strong>Time series observations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Meteorology</td>
<td>Thai Meteorological Department (TMD)</td>
<td>Point/Daily</td>
<td>30 (rain stations), 6 (climatic stations)/1975–2014</td>
</tr>
<tr>
<td>2</td>
<td>Hydrology</td>
<td>Royal Irrigation Department (RID) Thailand</td>
<td>Point/Daily</td>
<td>1 station/1990 –2014</td>
</tr>
<tr>
<td>3</td>
<td>Water Quality</td>
<td>Pollution Control Department (PCD) Thailand</td>
<td>Point/3 to 4 times a year</td>
<td>9 stations/2005– 2015</td>
</tr>
<tr>
<td></td>
<td><strong>RCMs data for future climate projections</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>ACCESS-CSIRO-CCAM</td>
<td>Collaboration for Australia Weather and Climate Research, Australian Government</td>
<td>0.50/ Daily ACCESS1.0</td>
<td>RCP 4.5 and 8.5 / 1975–2099</td>
</tr>
<tr>
<td>2</td>
<td>CNRM-CM5-CSIRO-CCAM</td>
<td>National Centre for Meteorological Research</td>
<td>0.50/ Daily CNRM-CM5</td>
<td>RCP 4.5 and 8.5 / 1975–2099</td>
</tr>
<tr>
<td>3</td>
<td>MPI-ESM-LR-CSIRO-CCAM</td>
<td>European Network for Earth System Modelling</td>
<td>0.50/ Daily MPI-ESM-LR</td>
<td>RCP 4.5 and 8.5/1975–2099</td>
</tr>
</tbody>
</table>
Future Climate

- Minimum temperature (Tmin) likely to increase by 2.7 and 4.5 °C by 2080s under RCP 4.5 and RCP 8.5 respectively.

- Maximum temperature (Tmax) likely to increase by 2.3 and 4.3 °C by 2080s under RCP 4.5 and RCP 8.5 respectively.

- Rainfall is projected to decrease in future. However it is projected to increase by 7% and 2% by 2080s under RCP 4.5 and RCP 8.5 respectively (ACCESS).
## Future Landuse

Projected landuse area (km²) in the SRB during the years 2030, 2050, and 2080, and relative changes (%) with respect to the baseline area of 2009

<table>
<thead>
<tr>
<th>Landuse type (km²)</th>
<th>Economic</th>
<th>Conservation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2030</td>
<td>2050</td>
</tr>
<tr>
<td>Crop (764.2)</td>
<td>0 (-100)</td>
<td>337.5 (-55)</td>
</tr>
<tr>
<td>Urban (492.4)</td>
<td>642.24 (30)</td>
<td>994.12 (102)</td>
</tr>
<tr>
<td>Rubber farm (1876.27)</td>
<td>3954.9 (110)</td>
<td>4814.37 (156)</td>
</tr>
<tr>
<td>Paddy (6165.38)</td>
<td>4139.68 (-33)</td>
<td>2757.56 (-55)</td>
</tr>
<tr>
<td>Water (639.74)</td>
<td>633.87 (-1)</td>
<td>633.87 (-1)</td>
</tr>
<tr>
<td>Miscellaneous (747)</td>
<td>1655.2 (122)</td>
<td>1840.06 (146)</td>
</tr>
<tr>
<td>Forest (2192.3)</td>
<td>1797.06 (-18)</td>
<td>1445.5 (-34)</td>
</tr>
</tbody>
</table>
Climate change and land use change impacts on streamflow

- Streamflows is projected to decrease under climate change and combined impact.
- Streamflow is projected to increase under land use change only.
- The magnitude of impact of climate change and combined impact is greater than land use change impact.

CC: Climate change only
CC+LU: Climate change and land use change
LU: Land use change only
Nitrate nitrogen loading is projected to decrease under individual and combined impact of climate change and land use change scenarios in future.

The magnitude of impact of climate change and combined impact is greater than only landuse change impact.

Higher reduction of nitrate nitrogen loading under combined impact of climate and land use change.
Conclusions

- SRB is expected to be warmer and drier in future.

- Annual streamflow is expected to decrease but with variations in seasonal flow under climate change. Under climate change scenarios (only), summer and rainy seasons streamflow are expected to decrease whereas winter season flows are expected to increase in future.

- Streamflow is projected to decrease under combined impact of climate and landuse change. However streamflow is projected to increase under landuse change scenarios only in future.

- Nitrate-nitrogen loadings is expected to decrease in future. The decrease is lesser under only landuse change scenario compared to combined and climate change scenarios only.
Key Challenges and Ways Forward

- Challenges in reducing uncertainty in impact assessment studies
- Challenge with the impacts to crosscutting issues
- Multi-level impact assessment and adaptation studies
- Towards interdisciplinary approach for cumulative impact assessment
Thank you!

sangam@ait.ac.th