Impacts of Climate Change on the Water-Energy-Food Nexus in the Indus Basin of Pakistan

Hassaan F. Khan, Yi-Chen E. Yang, Claudia Ringler, Tingju Zhu and Casey Brown
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Objectives

- Identify characteristics of the Water-Energy-Food Nexus and assess the tradeoffs involved

- Evaluate impacts of different operational polices and infrastructure development on the Nexus under climate change

- Policy conclusions
Indus Basin Overview

- Largest Contiguous Irrigation System in the world

- 142* MAF (175 BCM) Annual Flow *WAPDA 2012

- Major tributaries: Chenab, Jehlum and Kabul

*US Senate, 2011
Institutional Structure

- **Ministry of Water and Power**

- **WAPDA** - Water and Power Development Authority

- **IRSA** - Indus River System Authority
  - Determines water allocation based on 1991 Inter-Provincial Accord

- **Indus Water Treaty, 1960**
  - Brokered by World Bank between India and Pakistan
Existing Reservoir Infrastructure

- **Storage ~ 14.5 MAF**
  - *Mangla: 7.4 MAF*
  - Tarbela: 6.6 MAF

- **Installed Hydropower: 6900 MW**
  - *Mangla: 1100 MW*
  - Tarbela: 3478 MW
  - Ghazi Barotha: 1450 MW

*after recent expansion to increase storage

- **Comparison**
  - Hoover Dam: 15 MAF, 2800 MW
Challenges

- Energy Shortages
- Food insecurity
- Flooding
- Insufficient water supply
**Indus Basin: Future Reservoir Infrastructure**

- **WAPDA identified 8 high priority projects**

<table>
<thead>
<tr>
<th>Project</th>
<th>River</th>
<th>Location</th>
<th>Capacity (MW)</th>
<th>Storage (MAF) Gross/Live</th>
<th>Est. Cost ($ million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamer-Basha</td>
<td>Indus</td>
<td>GB</td>
<td>4500</td>
<td>8,1/6,4</td>
<td>11178</td>
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<tr>
<td>Kurram Tangi</td>
<td>Kurram</td>
<td>FATA/KP</td>
<td>84</td>
<td>1,2/0,9</td>
<td>700</td>
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<tr>
<td>Golen Gol</td>
<td>Chitral</td>
<td>KP</td>
<td>106</td>
<td>RoR</td>
<td>130</td>
</tr>
<tr>
<td>Tarbela 4th Ext.</td>
<td>Indus</td>
<td>KP</td>
<td>1350</td>
<td></td>
<td>826</td>
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<tr>
<td>Munda</td>
<td>Swat</td>
<td>FATA/KP</td>
<td>740</td>
<td>1,3/0,7</td>
<td>1401</td>
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<tr>
<td>Kohala</td>
<td>Jhelum</td>
<td>AJK</td>
<td>1100</td>
<td>RoR</td>
<td>2400</td>
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<tr>
<td>Bunji</td>
<td>Indus</td>
<td>GB</td>
<td>7100</td>
<td>RoR</td>
<td>6838</td>
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<tr>
<td>Dasu</td>
<td>Indus</td>
<td>KP</td>
<td>4320</td>
<td>1,15/?</td>
<td>5206</td>
</tr>
</tbody>
</table>

Friends of Democratic Pakistan Water Task Force Report 2012

**Munda and Kurram-Tangi not included due to insufficient data**

- **Neelum-Jehlum HPP also being constructed**
Indus Basin Model Revised (IBMR) – Multi Year

- Hydro-agro-economic optimization model

- Maximizes net economic profits at annual scale using monthly time steps

- **Objective function**

  \[ \text{Basinwide Profit} = \text{WeiAg} \times \sum \sum \sum \text{Crop Price}_{z,g,c} \times \text{Crop Production}_{z,g,c} \]

  \[ - \sum \sum \text{Crop Cost}_{z,g} + \text{WeiHy} \times \sum \text{Energy price} \times \text{Hydropower}_N \]

  \[ + \sum \text{D&I Profit}_D \]
Modelled Scenarios

- 5 different runoff scenarios
  - Historical flow and 4 GCM’s: MIROC, HADGEM2, IPSL, GFDL

- 2 different water allocation methods
  - IRSA Optimization: Optimizing constrained by existing Inter-provincial Accord- (Intraprovincial level)
  - Basin Optimization: Optimizing without constraints of the Inter-provincial Water Accord

- 2 Different levels of Reservoir Infrastructure
  - Current Infrastructure
  - Future Infrastructure
Climate Change -- Effect on Indus Flows

- Flow shifting: Earlier melting

![Graph of Indus River - Main Stem](image)
Under IRSA Optimization, for current infrastructure

- Agricultural Profits: 4538 billion Rs.
- Hydropower Profits: 489 billion Rs.

If we switch to Basin Optimization, for agricultural profits

- Current Infrastructure: 2.6-3.3% increase
- Future Infrastructure: 2.7-5% increase
Water-Energy-Food Nexus Tradeoff

Tradeoff Curves- Composite

- Future Infrastructure
- Current Infrastructure
Results - Tradeoff Curves

- IRSA Optimization
Tradeoff Curves: Insights

- Tradeoffs exist between hydropower and irrigated production outcomes
  - Significantly affected by climate change

- Larger storage does not increase agricultural profits significantly
  - Could mitigate impacts of Climate Change

- Increased Hydropower production
  - More constant head at HPP, at least in the short term

- Climate Change impacts uncertain
  - Impact of increased temperature on crop yields?
Conclusion

- Current and future systems show small trade-offs between irrigated agricultural and hydropower profits

- Contrary to expectations no strong agricultural boost from increased storage

- Climate change may positively impact hydropower production, based on our study
Future Studies

- Complete energy market- with oil/gas supply and demand
- Consider environmental issues for 4 dimensional trade-offs
- Modified cropping patterns and land usage
Acknowledgements

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- Ghazi Alam, NESPAK
- WAPDA
Thank you for your attention

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# Streamflow Variability - Glacial Melt

**Table 4** Estimates of snow and ice melt contribution to total flow in the Indus basin

<table>
<thead>
<tr>
<th>Estimate (%)</th>
<th>Location</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>Total runoff from high altitude belt</td>
<td>Krenke and Gennadyi (1998)</td>
</tr>
<tr>
<td>80–85</td>
<td>Indus flow at Besham</td>
<td>Hewitt (1998), Hewitt et al. (1989); Young and Hewitt (1990)</td>
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<tr>
<td>80</td>
<td>Swat River</td>
<td>Hewitt (1989)</td>
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<tr>
<td>~70</td>
<td>Annual flow of Indus without Ravi and Sutlej</td>
<td>Tarar (1982)</td>
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<tr>
<td>75</td>
<td>Kabul River at Warsak</td>
<td>Hewitt (1989)</td>
</tr>
<tr>
<td>70–80</td>
<td>Annual flow of Indus</td>
<td>Shah et al. (1998)</td>
</tr>
<tr>
<td>65</td>
<td>River Kunhar</td>
<td>De Scally (1994)</td>
</tr>
<tr>
<td>65</td>
<td>Jhelum river at Mangla</td>
<td>Hewitt (1989)</td>
</tr>
</tbody>
</table>

ADB 2010, *Technical Report on Glacial melt and Indus impacts downstream*
Scenario Results

Overall Results - Total System Profit

<table>
<thead>
<tr>
<th></th>
<th>Current Infrastructure</th>
<th>Future Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRSA</td>
<td>5200</td>
<td>6600</td>
</tr>
<tr>
<td>Basin</td>
<td>5600</td>
<td>6000</td>
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</tbody>
</table>