Assessing Climate Impacts that May Generate Migration Flows

Hydrological Modeling and Impacts

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20th and Early 21st Century
Groundwater and Surface Water Use

[Graph showing consumption/abstraction over time from 1900 to 2010 in km³ yr⁻¹, with categories including households, industry, livestock, irrigation, groundwater abstraction, and total withdrawal.]
Water Scarcity Index

\[ WSI = \frac{D}{A} \]

Global population under high water stress (WSI > 0.4)

<table>
<thead>
<tr>
<th>Year</th>
<th>Billions</th>
<th>(% of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>0.5</td>
<td>17%</td>
</tr>
<tr>
<td>1970</td>
<td>0.7</td>
<td>19%</td>
</tr>
<tr>
<td>1980</td>
<td>1.0</td>
<td>23%</td>
</tr>
<tr>
<td>1990</td>
<td>1.2</td>
<td>23%</td>
</tr>
<tr>
<td>2000</td>
<td>1.8</td>
<td>30%</td>
</tr>
</tbody>
</table>

Wada et al. (2011; WRR)
Human and Climate Impacts

- Water use quintupled from 1960 to 2001 in Romania.
- Agriculture: 60%, Industry: 30% and Households: 10%
- High water stress since 1980s has been anthropogenically driven rather than climate induced.
PCR-GLOBWB v2.0

Wada et al. (2014; Earth System Dynamics)
Hydrological Impact Assessment

- How climate change affects future hydrology and water resources?
- How certain are we? Where are the sources of the uncertainties in ensemble projections?

Methods (socio-economic fixed to the present):

11 Global Hydrological or Impact Models (GHMs/GIMs):
DBH, H08, JULES (CO₂), LPJmL (CO₂), Mac-PDM, MATSIRO, MPI-HM, PCR-GLOBWB, VIC, WaterGAP, WBM

5 Global Climate Models (GCMs):
HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, NorESM1-M (0.5 degree, bias-corrected; Hempel et al. (2013; ESD))

4 Representative Concentration Pathways (RCPs): 2.6, 4.5, 6.0, 8.5
Simulation period: 1971-2099

Impact Assessments and Associated Uncertainty:
- River discharge/Runoff
- Groundwater recharge
- Hydrological drought
- Flood
- Irrigation
- Water scarcity
Change in hydrological drought occurrence

Percentage change in the occurrence of days under drought conditions by the end of this century (2070–2099) relative to the present (1976–2005) under RCP8.5

Prudhomme et al. (2014; PNAS)
Ensemble projections (45 in total) showing an increase or decrease in the magnitude of $Q_{30}$ of more than 10% by the end of this century relative to the present under RCP8.5 with the 30-y return level of river flow ($Q_{30}$)

Dankers et al. (2014; PNAS)
Human water consumption

Wada and Bierkens (2014; ERL)
In cooperation with IIASA for WFaS project

Total blue water consumption [million cubic meter per year]
- 0 - 2
- 2 - 20
- 20 - 100
- 100 - 300
- 300 - 1000
- > 1000
Relative change in human water consumption
Global groundwater stress

Gleeson et al. (2014; Nature)
Average nonrenewable groundwater abstraction over the total (2069-2099)

Wada and Bierkens (2014; ERL)
Past trends and future projections of human water use (SSP2; 1960-2100)
Imbalance between demand and supply

Middle of the Road

Population under water scarcity in the 2050s

Water stress index

Water scarcity index = \frac{Water demand}{Available water resource}

Water scarcity index =

- Safe
- Water scarce
- Severe water scarce

Scenario comparison

Population under water scarcity in the 2050s

Increase under all scenarios in the range of 1.7 to 2.1 billion, which represents approximately 40% of Asian total population.
Country level Hydro-Economic Analysis

**Economic-institutional capacity**

- GDP per capita
  - Very low: CL1 ... 3000 > GDPC > 250
  - Low: CL2 ... 10000 > GDPC > 3000
  - Medium: CL3 ... 10000 > GDPC > 20000
  - High: CL4 ... 35000 > GDPC > 20000
  - Very high: CL5 ... 90000 > GDPC > 35000

**Hydro-climatic complexity**

- Total renewable water resources per cap
  - Very high: CL1 ... 20000 > TWRC > 10000
  - High: CL2 ... 10000 > TWRC > 5000
  - Medium: CL3 ... 5000 > TWRC > 2000
  - Low: CL4 ... 2000 > TWRC > 1000
  - Very low: CL5 ... 1000 > TWRC > 100

- Intensity of water use
  - Very low: CL1 ... 0.01 < TWD/TWR < 0.05
  - Low: CL2 ... 0.05 < TWD/TWR < 0.15
  - Medium: CL3 ... 0.15 < TWD/TWR < 0.30
  - High: CL4 ... 0.30 < TWD/TWR < 0.60
  - Very high: CL5 ... 0.60 < TWD/TWR < 1.00

- Inter- and intra-annual variability of runoff
  - Very low: CL1 ... 0 < CVTWR < 30
  - Low: CL2 ... 30 < CVTWR < 60
  - Medium: CL3 ... 60 < CVTWR < 100
  - High: CL4 ... 100 < CVTWR < 150
  - Very high: CL5 ... 150 < CVTWR < 225

- Dependency share of external water resources
  - Very low: CL1 ... 0.05 < DPC < 0.30
  - Low: CL2 ... 0.30 < DPC < 0.45
  - Medium: CL3 ... 0.45 < DPC < 0.55
  - High: CL4 ... 0.55 < DPC < 0.70
  - Very high: CL5 ... 0.70 < DPC < 0.95

**Middle of the Road scenario**
Country level

Hydro-Economic Analysis

Pakistan, Afghanistan, and Azerbaijan will remain the most vulnerable countries in Asia, as they will be highly stressed with low adaptive capacity under all scenarios.
Conclusions and Outlook

• Growing water use and scarcity is projected for Africa, new hotspot.

• ~30% of the present human water consumption is supplied from nonsustainable water resources, and is projected to increase to 40% by the end of this century.

• Nonrenewable groundwater is a major source for irrigation: India, Pakistan, Iran, the Middle East (20-50%), but may not last…

• Some countries are more vulnerable under growing water demands and climate change, e.g. Pakistan, Afghanistan, and Azerbaijan.

• Current degree of nonsustainable use may compromise the future food production.