Towards integrated solutions for water, energy, and land using an integrated nexus modeling framework

Yoshihide Wada
IIASA
Utrecht University
wada@iiasa.ac.at
Half our planet’s population still suffer from water insecurity

Absent/unreliable water supply

Poor sanitation

Floods & droughts

Poor irrigation and food production
Time series variation in hydrological drought

Index: Regional mean value of the total number of drought days in a year

Data: Daily discharge derived from 25 ensemble

Hydrological drought

Anomaly from its historical climatology

5 GCMs:
1. HadGEM2-ES
2. IPSL-CM5A-LR
3. GFDL-CM3
4. MIROC-ESM-CHEM
5. NorESM1-M

5 GHMs:
1. H08
2. LPJmL
3. MATSIRO
4. PCR-GLOBWB
5. WBM

[ISI-MIP fast track]
Time series variation in hydrological drought

**RCP2.6**

Index: Regional mean value of the total number of drought days in a year

[dy/yr]

**Data:** Daily discharge derived from 25 ensemble members.

**Hydrological drought**

- **Threshold:** Discharge

**Anomaly from its historical climatology**

**5 GCMs:**
1. HadGEM2-ES
2. IPSL-CM5A-LR
3. GFDL-CM3
4. MIROC-ESM-CHEM
5. NorESM1-M

**5 GHMs:**
1. H08
2. LPJmL
3. MATSIRO
4. PCR-GLOBWB
5. WBM

[ISI-MIP fast track]
Timing of Perception Change in Drought

The range experienced during 35yr historical period

TPCD of consecutive 10 year overshoot at Basin-Country boundary scale

- Regional mean
- RCP8.5
- pressoc

Satoh et al., 2018
Water demand in Asia region, by sector (km³/yr).

Asian total water demand in the 2010s is about 2410 km³/year and will be 3170 - 3460 km³/year (increase 30 - 40%) under the three scenarios.

Satoh et al. (2017; Earth’s Future)
We present six strategies, or water-stress wedges, that collectively lead to a reduction in the population affected by water stress by 2050, despite an increasing population.

- Water productivity – crop per drop
- Irrigation efficiency – decrease losses
- Water use intensity – industry and domestic
- Population
- Reservoir storage
- Desalination

Wada et al. (2014), Nature Geoscience
Key features represented in the model:

**Drivers:** Demand growth; Resource availability; Climate change; etc.

**Processes:** Reservoir management; Irrigation use; Electricity generation; Water pumping; End-use efficiency; Wastewater treatment; etc.

**Impacts:** Prices; Demands; Emissions; Water quality; Environmental flow; Groundwater depletion; Resource security; etc.

**Decisions:** Extract resources; Operate infrastructure; Expand infrastructure; Trade resources

(Kahil et al., 2018)
## Assessment of adaptation measures: technical potential and costs

<table>
<thead>
<tr>
<th>Supply enhancement</th>
<th>Demand management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build/enlarge dams</td>
<td>Efficient irrigation technologies</td>
</tr>
<tr>
<td>Rainwater harvesting</td>
<td>Efficient domestic water appliances</td>
</tr>
<tr>
<td>Drill/improve wells</td>
<td>Energy cooling technologies</td>
</tr>
<tr>
<td>Reuse of wastewater</td>
<td>Better crop management</td>
</tr>
<tr>
<td>Desalination</td>
<td>Diet change</td>
</tr>
<tr>
<td>Reprogram reservoir operation</td>
<td>Food loss reduction</td>
</tr>
<tr>
<td>Inter-basin transfer</td>
<td>Improving education</td>
</tr>
<tr>
<td></td>
<td>Controlling population growth</td>
</tr>
</tbody>
</table>
Model application: the case of Africa

Three socio-economic and climatic scenarios:

1/ Middle of the Road (MoR): SSP2-RCP6.0

2/ Regional Rivalry (RR): Water demand increases over time in all water sectors and water availability decreases, compared to MoR.

3/ Sustainability (Sust): Water demand decreases over time in all water sectors and water availability increases, compared to MoR.
Relative change in human water use (SSP2)

2100 – 2010
Results: Water demand and withdrawals

Water supply

Total water demand increases in 2050 by 190-520 Km$^3$ (40-110%) compared to historical demand.

This increase requires the implementation of demand and supply management options to balance available supply and demand.

After implementing demand management options, withdrawals increase in 2050 by 100-360 Km$^3$ compared to historical withdrawals.
Results: Investment costs
Adaptation of the water resource system to future socio-economic and climatic changes may involve tradeoffs among various environmental and economic objectives.

Some of the identified adaptation options may be inconsistent with climate change mitigation targets because they involve high energy consumption, such as desalination, recycling, pumping, and pressurized irrigation systems.

Our findings highlight that electricity use in the water sector can increase five-fold (or by 125 TWh) by 2050 compared to 2010 in the RR scenario.

**Results:** Energy use intensity
Building reservoirs is a practical solution for water supply and adapting hydrological variability but a costly option. Increase in the use of seawater cooling in coastal basins

Water system cost in Africa is expected to increase from 67 billion USD in 2010 to 70-130 billion USD in 2050 (+5 - +100% compared to 2010)

Following a sustainable pathway (Sust scenario) will result in a smooth increase in the water system cost while following the rocky road (RR scenario) will result in a disproportionate increase in the water system cost

The largest cost by country is in South Africa, followed by Egypt and Sudan, and by basin is in the Nile, Mediterranean South Coast, Niger and Zambezi

Adaptive strategies for hydrological variability need consideration for energy use (e.g., hydropower) and food production

Results: Cost implications
IIASA - RESEARCH FOR A CHANGING WORLD