Potential Water Scarcity Risks Assessed by the Sectoral and Statistical Demand to Availability Index (SS-DTA)

Taikan Oki, Ph.D
Professor, The University of Tokyo

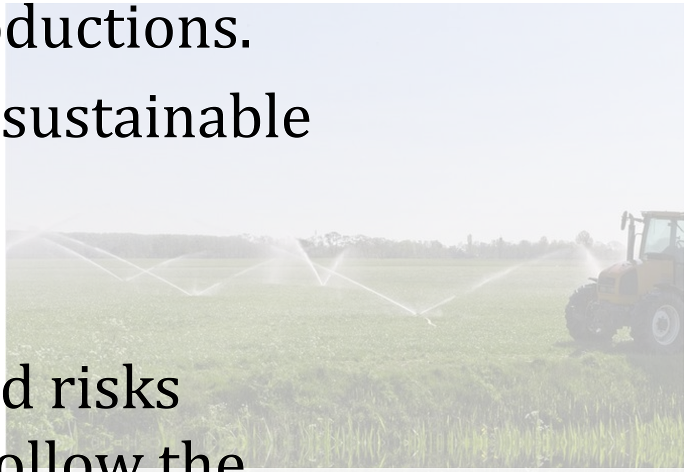
In collaboration with:
The Secretariat of the Headquarters for Water Cycle Policy, Cabinet Secretariat
国立研究開発法人 国立環境研究所 National Institute for Environmental Studies
NIPPON KOEI
CTI Engineering Co., Ltd.

Session 1F3
"Building resilience through data & knowledge-based solutions: Identification, monitoring, early-warning & assessment of water related risks"
9^{th} World Water Forum, Dakar, Senegal, 21^{st} March 2022

Ensuring Water Security

- **Water is vital:**
  - For our livelihoods, healthy ecosystems, and wealthy productions.
  - Failures in water security erode the three dimensions of sustainable development: the economic, social and environmental.
- **The role of the private sector:**
  - It is critical for major companies to disclose water-related risks corresponding to ESG investments, and in particular, to follow the recommendations from TCFD and TNFD under FSB.

    G20 requested FSB (Financial Stability Board) to set TCFD (and TNFD).
    TCFD: Taskforce on Climate-Related Financial Disclosures
    TNFD: Taskforce on Nature-related Financial Disclosures
  - Water-related disclosures nudges business sectors to take actions towards ensuring water security, and to support achieving SDGs.
- **Assessment and disclosure of water risks are critical to our livelihoods and to the business sector.**



Measuring Water Scarcity Risk

Risk assessments rely on indicators

- Indicators show us our progress.
- The Demand To Availability (DTA) ratio is widely used to assess Water Scarcity.

$$\text{DTA} = \frac{\text{Demand (Withdrawals based)}}{\text{Available Water Resources} - \text{Environmental Flow Requirement}}$$

*long-term average volumes

How to improve the DTA ratio and make it more informative

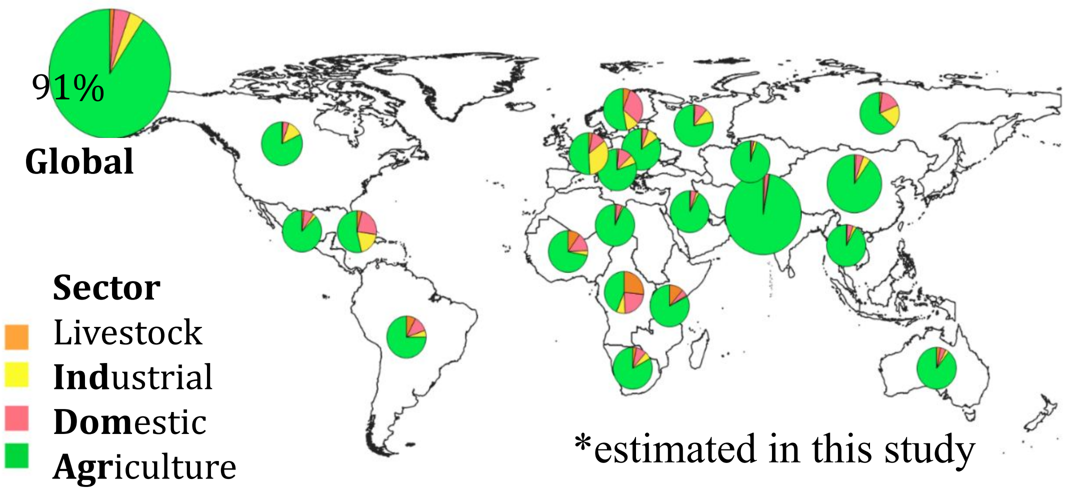
- **Flow-regulating infrastructure effects**: Operation of large reservoirs and construction of canals can drastically change the available water at short timescales.
- **Severe droughts are washed out by long-term averages**: Seasonal and interannual variability are important, but adaptation to risks (like flow regulations) is applied for extreme events, like droughts that may happen once every 5 years.

Adding Value to Water Scarcity Assessment

Water demand by sector

- Magnitude and adaptability of impacts depend on the type of water use even for the same level of water stress.
- A breakdown of water volumes by sectors can be more informative for managing regional risks.

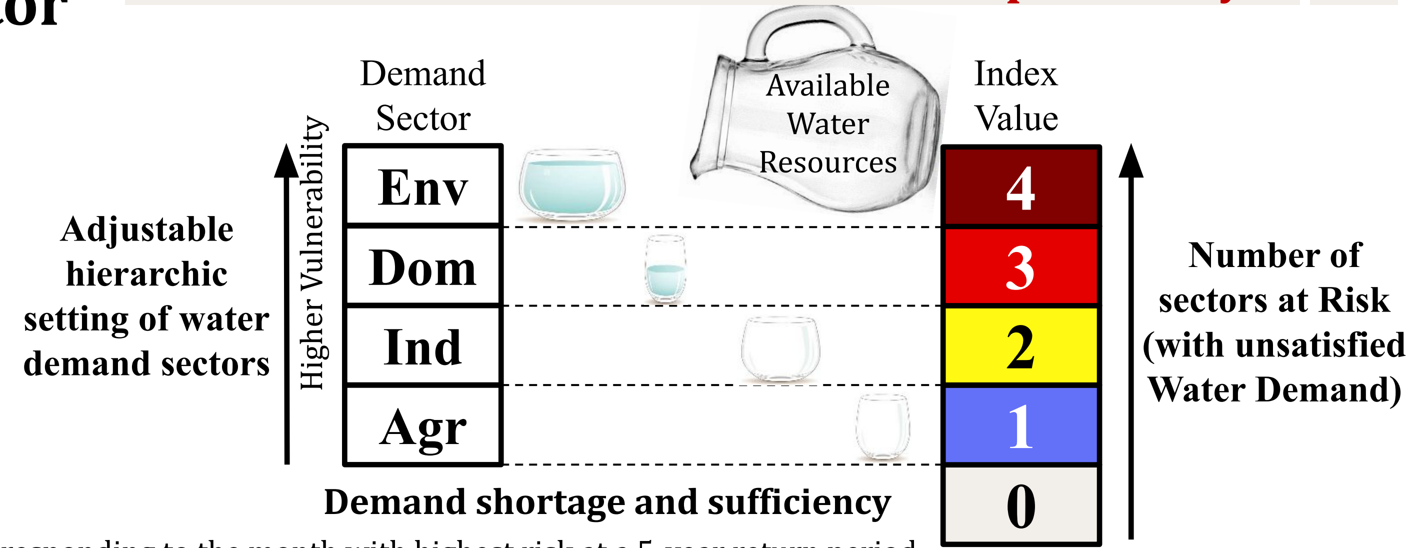
Regional Water Withdrawals by Sectors (2015)



A new water scarcity risk indicator

- **S**ectoral and **S**tatistical **D**emand **T**o **A**vailability (**SS-DTA**):
  - ✔ Water demand by sectors (Sectoral)
  - ✔ Drought probability (Statistical)

How SS-DTA indicates which sectors are potentially at risk

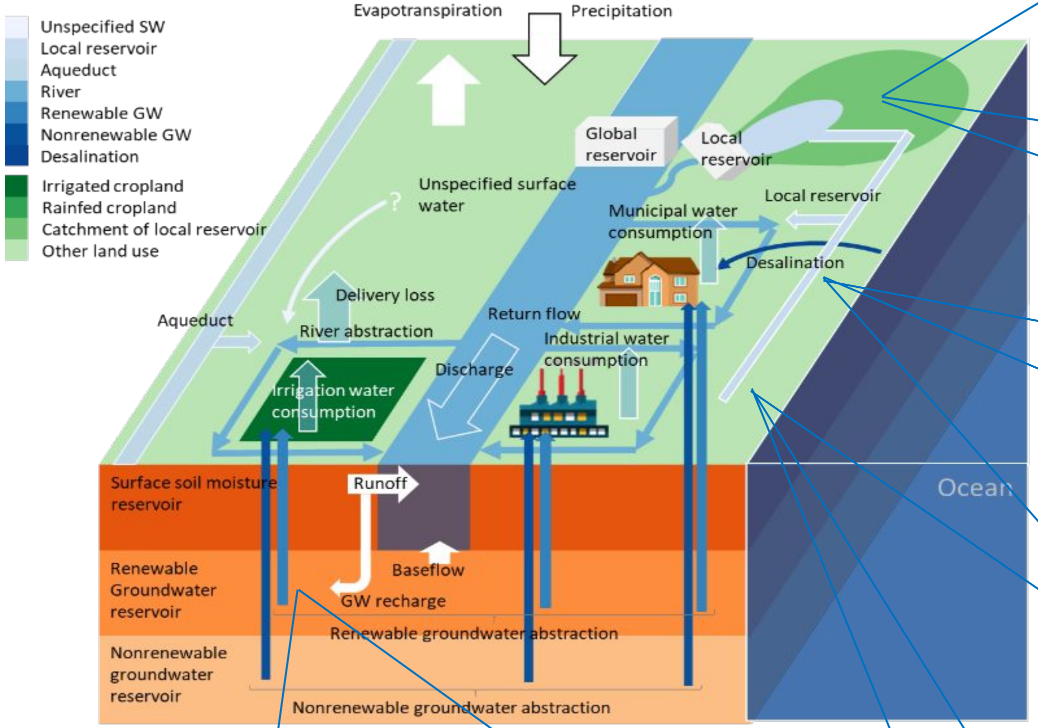


*Corresponding to the month with highest risk at a 5-year return period

The Water Cycle in the Anthropocene

- When evaluating water-related risks, estimates can be misleading if impacts of human activities are neglected in the assessment.
- We employed the free-licensed **H08** global hydrological model that includes human alterations to the water cycle (storage, transportation, and pumping) to estimate available water resources and determine the SS-DTA.

H08 model (Hanasaki et al., 2018)



Dams & Reservoirs

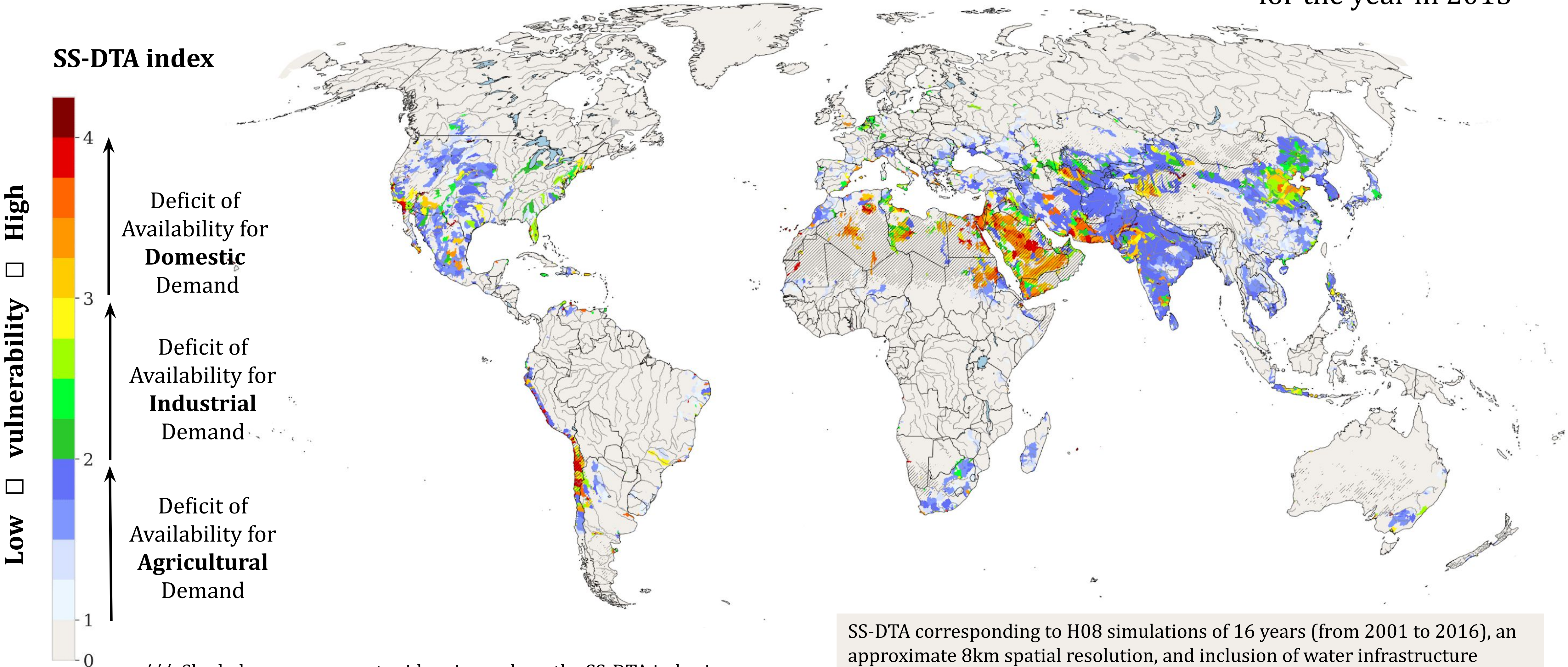
Desalination

Groundwater use

Canals

Water Scarcity Risk Assessed by SS-DTA

for the year in 2015



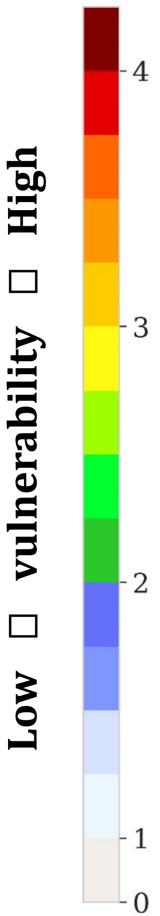
///: Shaded areas represent arid regions where the SS-DTA index is sensitive to small changes due to available water being scarce (<0.5m^3/s). Thus, care must be taken when interpreting the results in the shaded areas.

SS-DTA corresponding to H08 simulations of 16 years (from 2001 to 2016), an approximate 8km spatial resolution, and inclusion of water infrastructure operation. The effect of canals are implicitly considered in the way that the major rivers would supply water to the surrounding grid cells (~80km).

東京大学 THE UNIVERSITY OF TOKYO

The Effect of Water Infrastructure on Risk Assessment (SS-DTA)

SS-DTA index



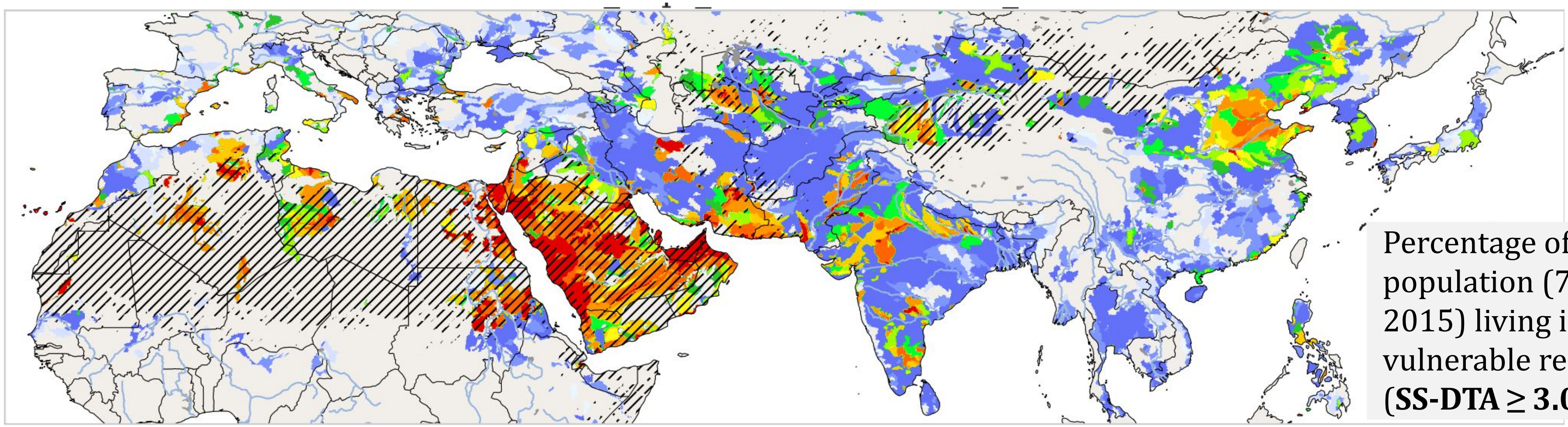
Deficit of Availability for **Domestic** Demand

Deficit of Availability for **Industrial** Demand

Deficit of Availability for **Agricultural** Demand

///: Arid areas (<0.5m^3/s)

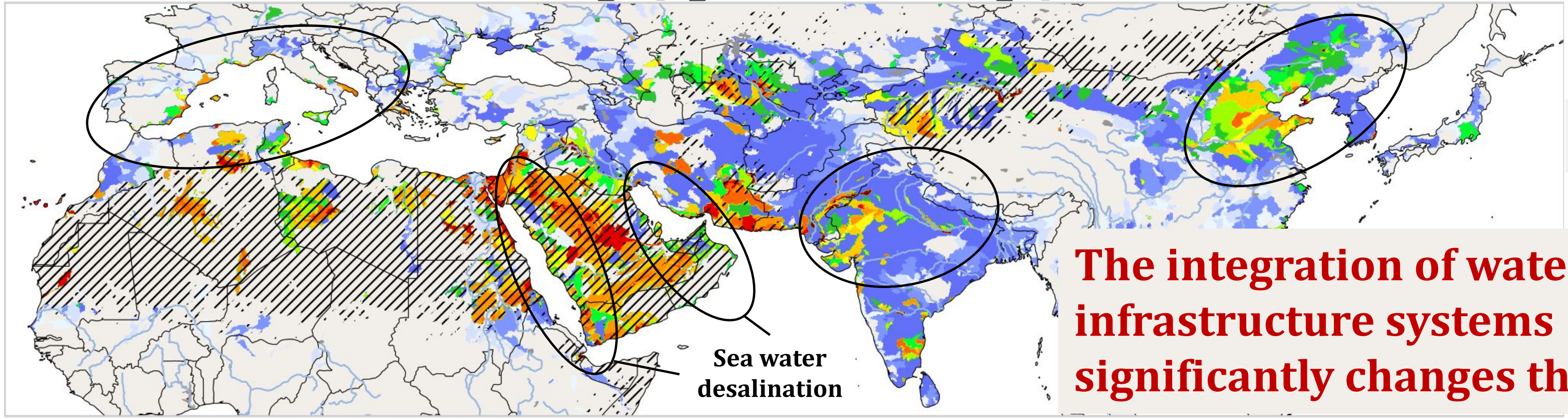
without Infrastructure



17%

Percentage of world population (7.25 billion in 2015) living in highly vulnerable regions (**SS-DTA ≥ 3.0**)

with Infrastructure (Dam, Canal, Seawater desalination)

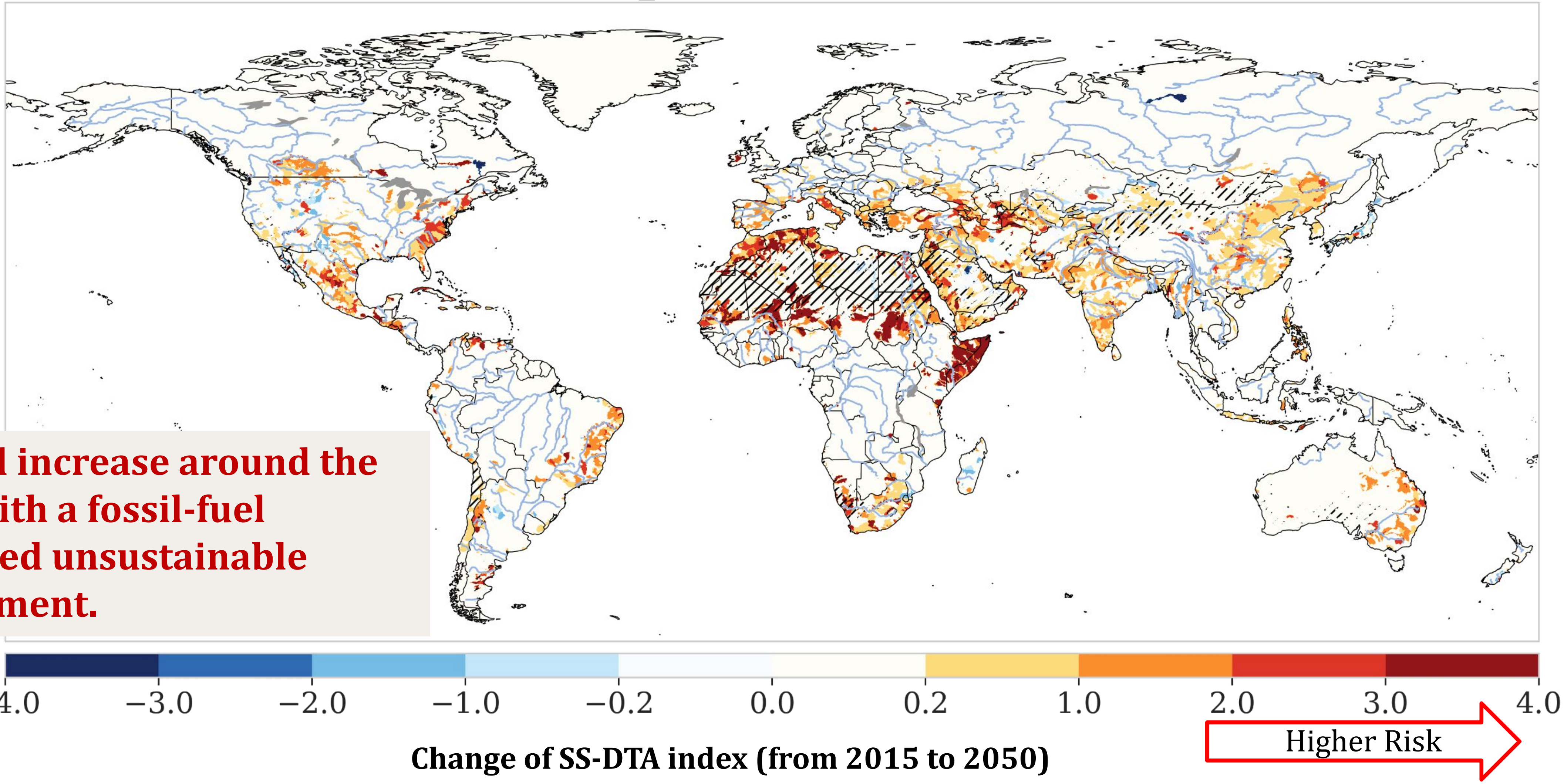


11%

The integration of water infrastructure systems significantly changes the index.

How Risk Changes According to Future Socioeconomic and Climate Scenarios

Pessimistic Scenario: A fragmented world of "resurgent nationalism" (SSP3-RCP7.0)



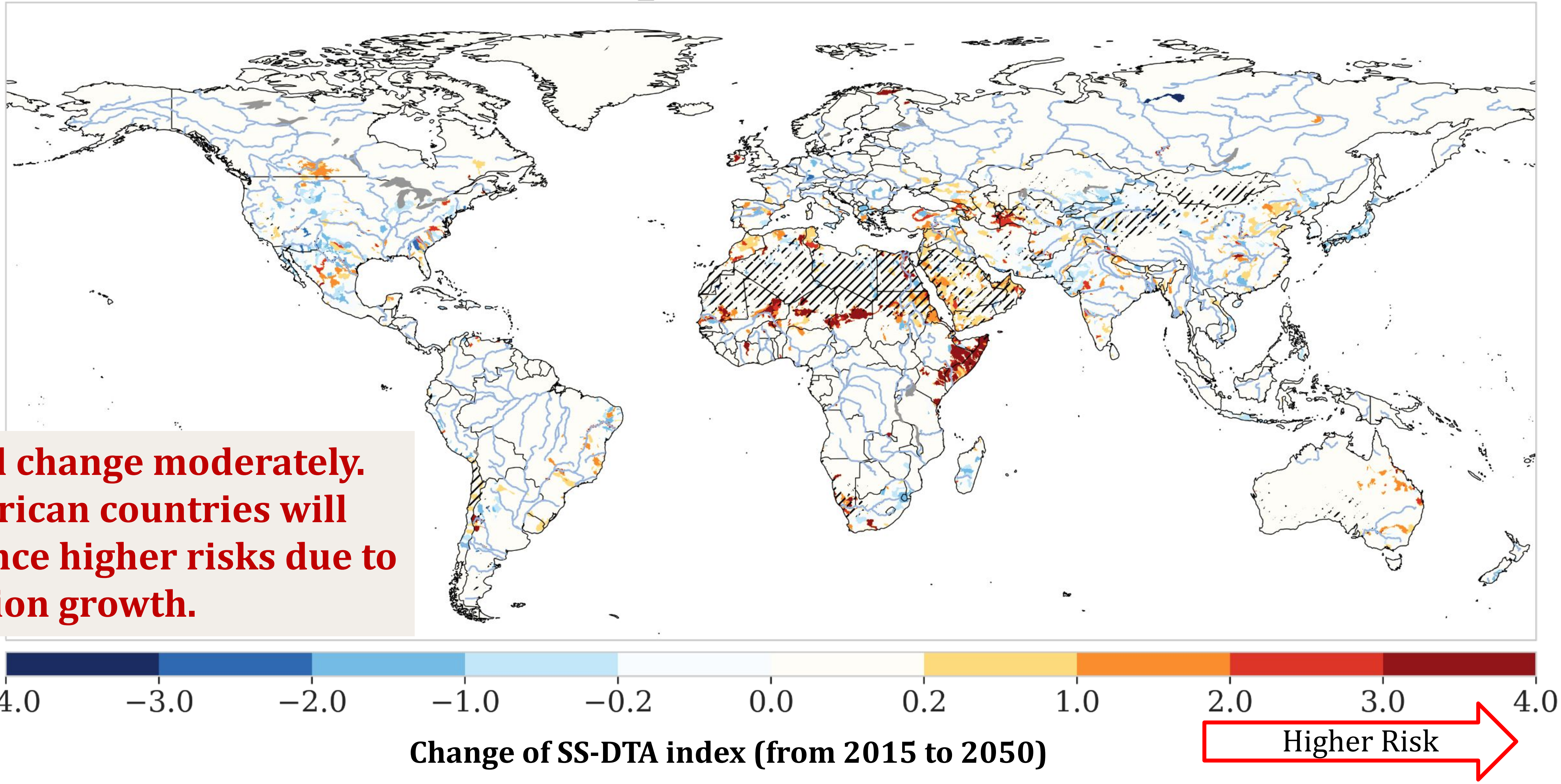
Change of SS-DTA index (from 2015 to 2050)

Risk will increase around the world with a fossil-fuel orientated unsustainable development.

東京大学 THE UNIVERSITY OF TOKYO

How Risk Changes According to Future Socioeconomic and Climate Scenarios

Optimistic Scenario: A world of sustainability-focused growth and equality (SSP1-RCP2.6)



Risk will change moderately. Some African countries will experience higher risks due to population growth.

Remarks

- Assessing and disclosing water-related risks is crucial for ensuring water security.
- Including the anthropogenic flow regulations and interventions on the water cycle helps us estimate the available water resources more realistically.
- The proposed SS-DTA index not only considers seasonal and interannual variability but also makes a breakdown of sectoral water demands, which is aimed to bridge the gap between water risk assessments and comprehensive awareness.
- By introducing the new index SS-DTA, we expect to contribute to the enhancement of water resilience and strengthen our partnership with diverse stakeholders in decision-making processes.

https://www.cas.go.jp/jp/seisaku/mizu_junkan/index.html

Supplementary Material

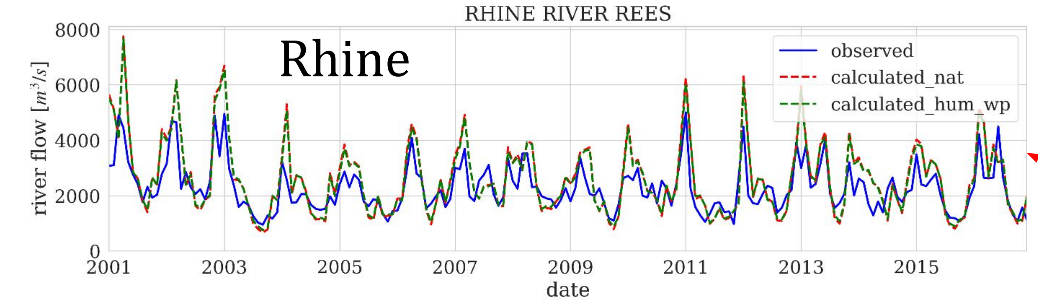
1. Employed Datasets and other Inputs
2. Simulated vs Observed River Discharge (sensible performance)
3. Simulated vs Observed River Discharge (poor performance)
4. Estimated Water Demand
5. Estimation of Future Water Demand
6. Uncertainty in Future Projections
7. Local Case Study: Arakawa River basin
8. AQUEDUCT Baseline Water Stress
9. SS-DTA vs Baseline Water Stress (BWS) 1
10. SS-DTA vs Baseline Water Stress (BWS) 2
11. Limitations

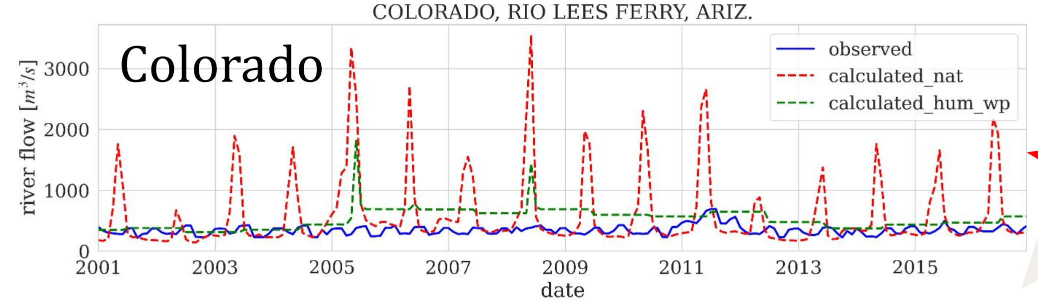
Employed Datasets and other Inputs

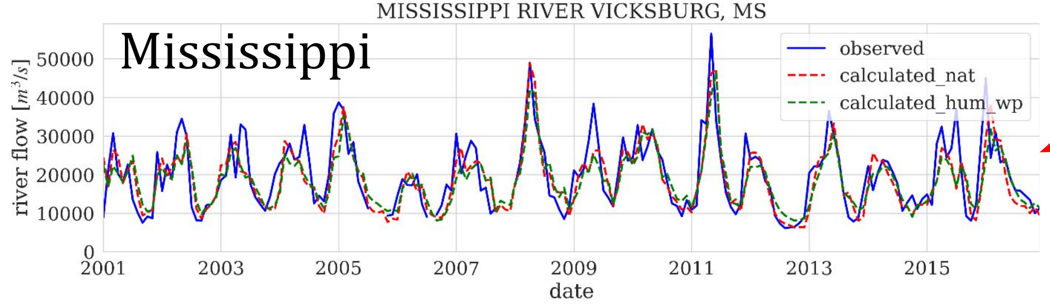
Flow sequence	CaMa-Flood model (Yamazaki et al. (2019))
Domestic/ industrial water demand	Determined by assigning weighting factors to the country statistics archived in AQUASTAT 2015 and the Gridded Population of the World (GPW ver4.11, 2015, 5min-resolution)
Agricultural water demand	Irrigation Area※1: GMIA ver5, Irrigated Regions※2: Siebert et al.（2010） Crop types※2: Monfreda et al. (2008)、Crop cycles※2: Döll and Siebert (2002) Irrigation efficiency※2: Döll and Siebert（2002） ※1: for 2005, ※2: for 2000
GDP	Corresponding to the ones employed in the CMIP6 scenarios (or Shared Socioeconomic Pathways, SSP): SSP Database – Version 2.0
Groundwater use ratio	Domestic and Industrial: IGRAC (2004) corresponding to the year 1995 Agricultural: GMIA ver. 5 corresponding to the year 2005
Climate forcing	W5E5 (Lange, 2019): Global reanalysis data with half-degree resolution
Reservoir	Global Reservoir and Dam Database (GRanD) ver1.3
Water use efficiency	Shiklomanov (2000)
Environmental flow requirement	adjusted from Pastor et al. (2014)
Other	Global Drainage Basin Database (GDBD): Basin boundaries for SS-DTA aggregation
Other geographic	Data such as slope, soil quality, hydraulic geology, permafrost/glacier, and albedo are also used in the calculation of groundwater and land surface processes within the H08 model.
Livestock density	FAO Global Distribution Data: for calculating water demand of livestock

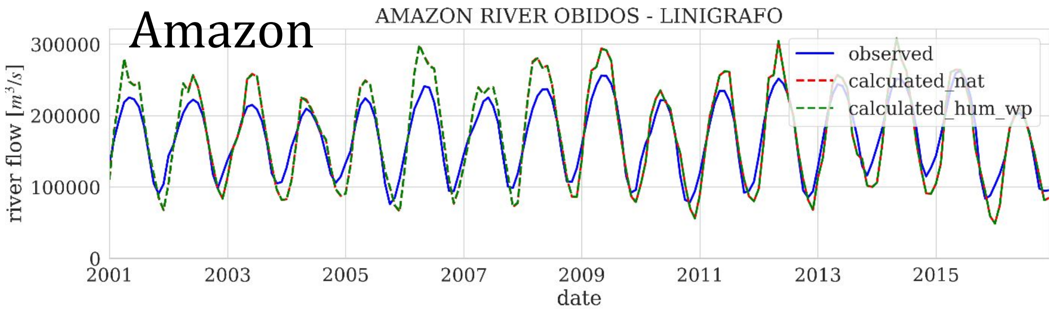
東京大学 THE UNIVERSITY OF TOKYO

Simulated and Observed River Discharge (Champion Data)





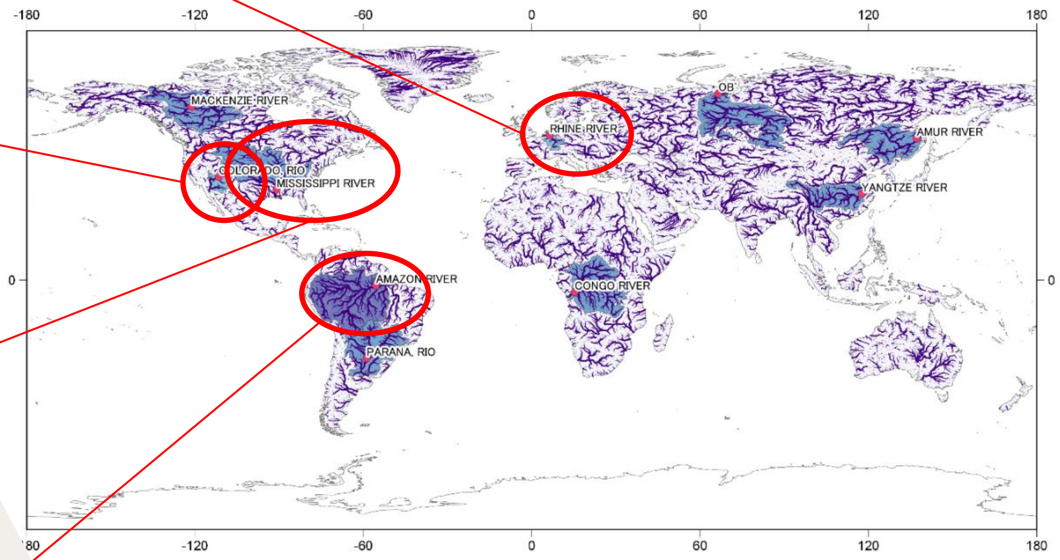




observed (GRDC*) *Global Runoff Data Centre

simulated (without human alterations)

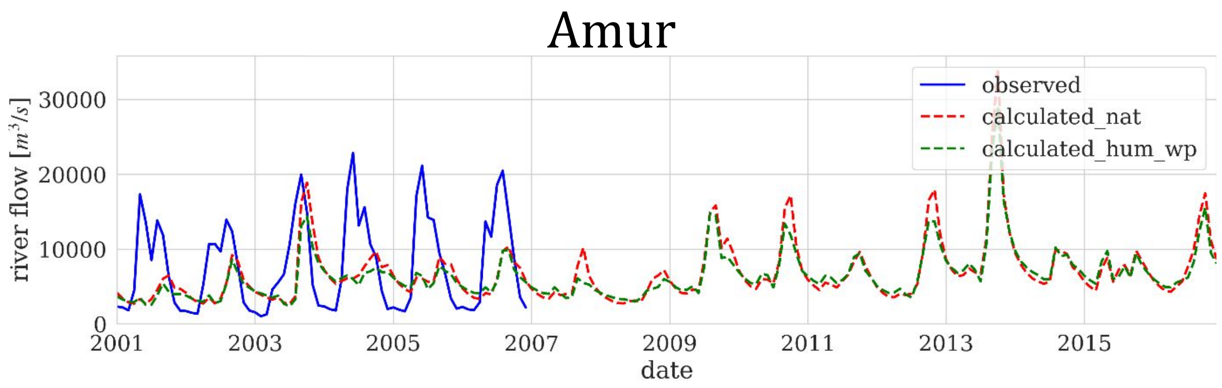
simulated (with human alterations)

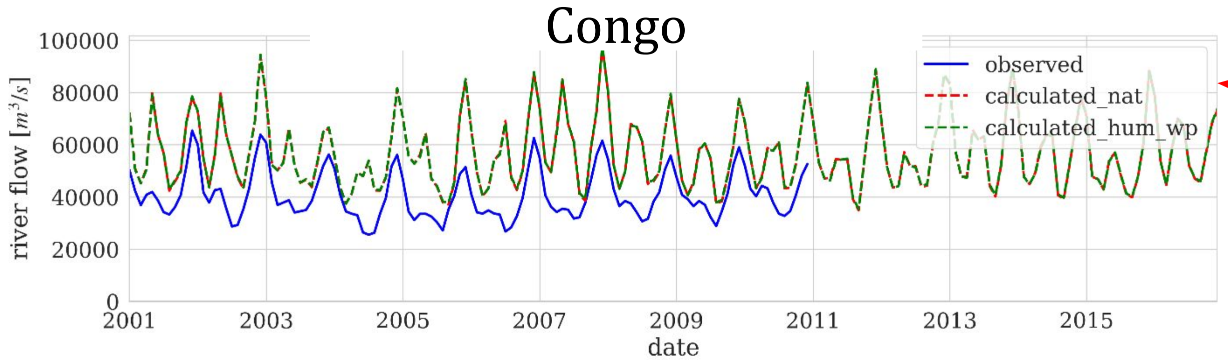


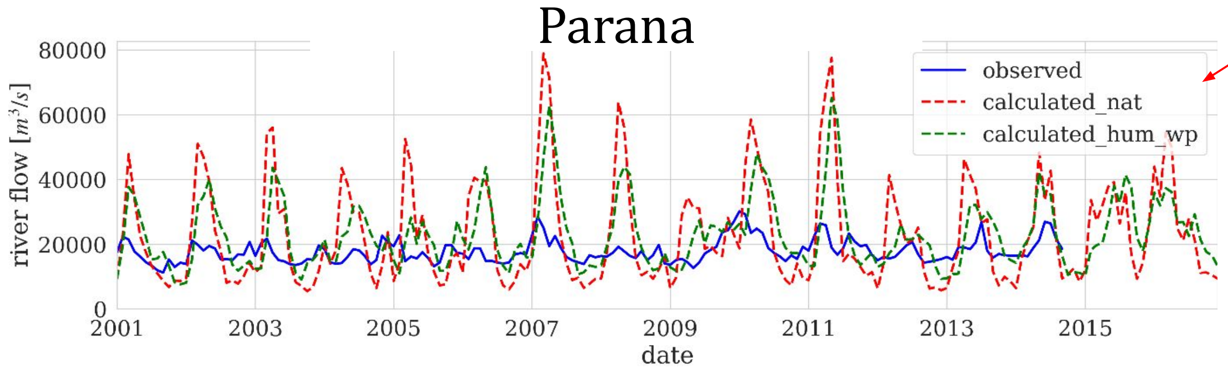
Better agreement between model estimates and observations was observed when anthropogenic alterations of river discharge are considered.

Note: Results were obtained by running the global H08 model with 5-minute resolution. Hydrological parameters are not calibrated.

Simulated and Observed River Discharge (poor results)







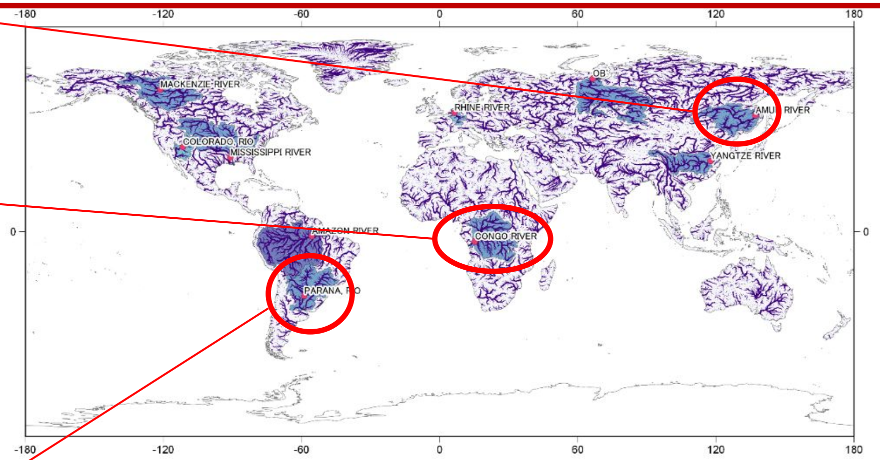
Note: Results were obtained by running the global H08 model with 5-minute resolution. Hydrological parameters are not calibrated.

observed (GRDC*)

simulated (without human alterations)

simulated (with human alterations)

*Global Runoff Data Centre

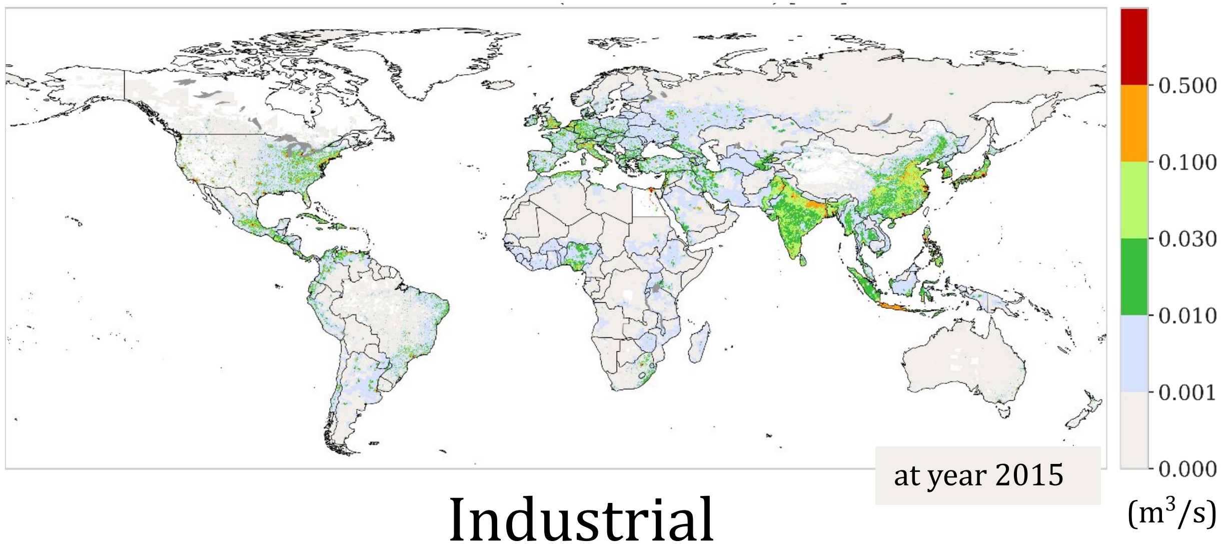


Causes of poor agreement:

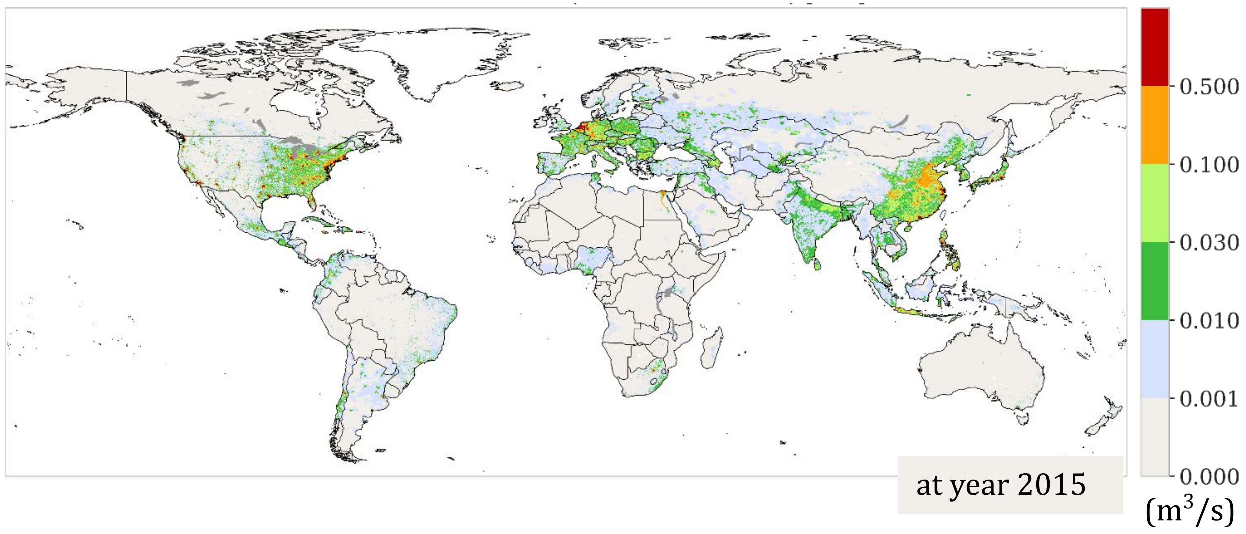
1. **Some hydrological processes are not included (infrastructures, tides, inundation).**
2. **Observed climatic data, such as precipitation, (forcing) are not accurate enough.**
3. **Parameters are not calibrated.**
4. **Other**

Estimated Water Demand

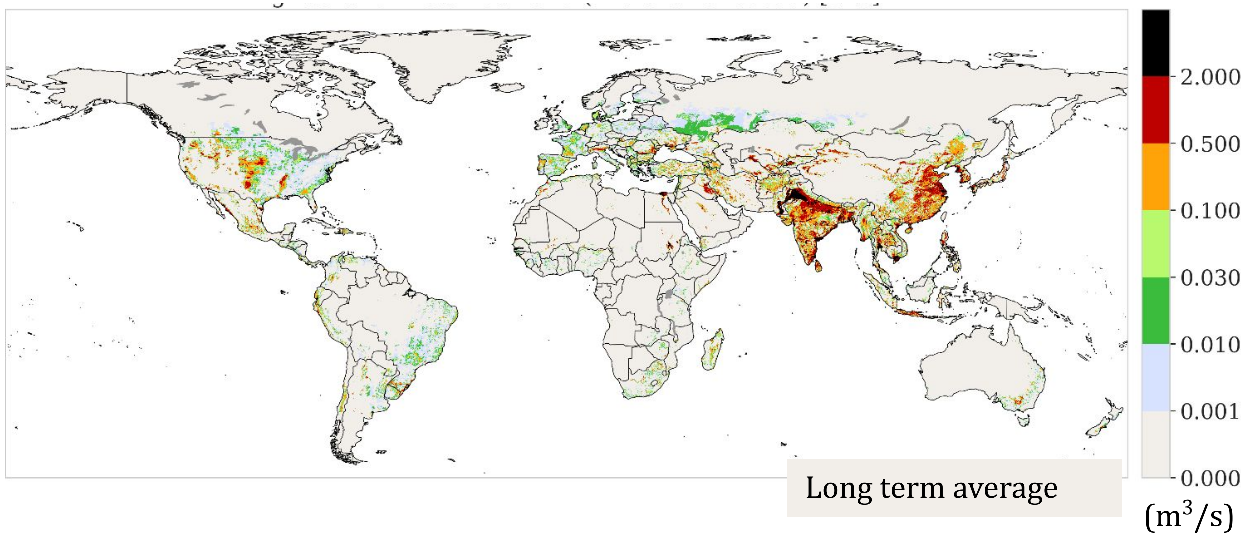
Domestic



Industrial



Agriculture



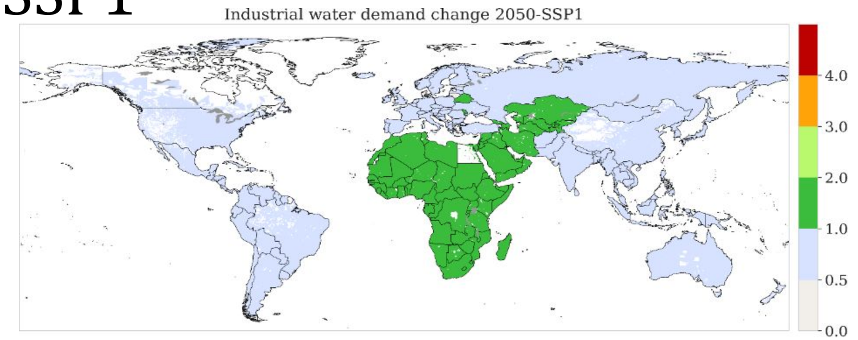
- Domestic/ Industrial water demands are determined by assigning weighting factors to the country statistics archived in AQUASTAT 2015 and the Gridded Population of the World (GPW ver4.11, 2015).
- Agricultural water demand was calculated by H08 crop growth sub-model.

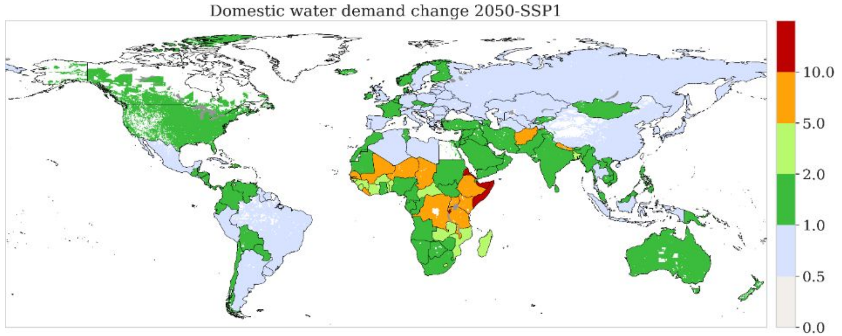
東京大学 THE UNIVERSITY OF TOKYO

Estimation of Future Water Demand

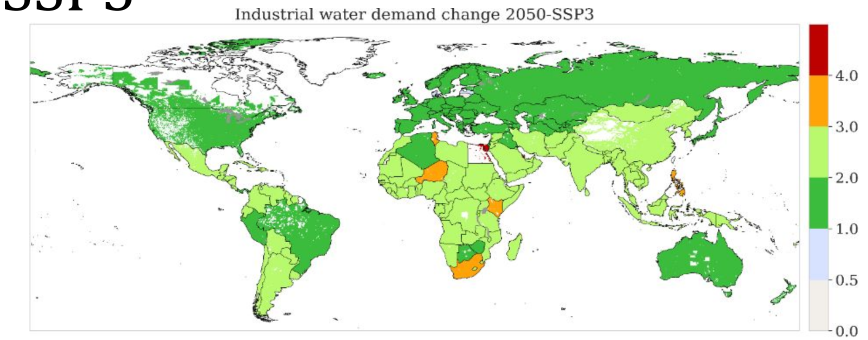
Climate data	5 CMIP6 Earth System Models (GCMs)
Domestic/Industrial water demand	Water use efficiency is adjusted according to SSP narratives (Hanasaki et al., 2013)
Agricultural water demand	Irrigation areas, crop intensity and irrigation efficiency are adjusted according to SSP narratives (Hanasaki et al., 2013)

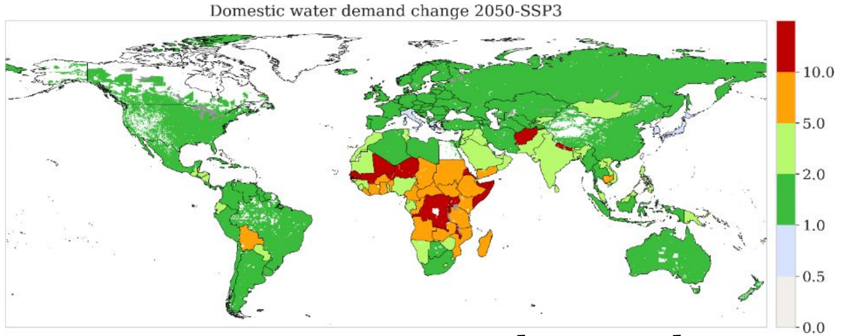
SSP1





SSP3

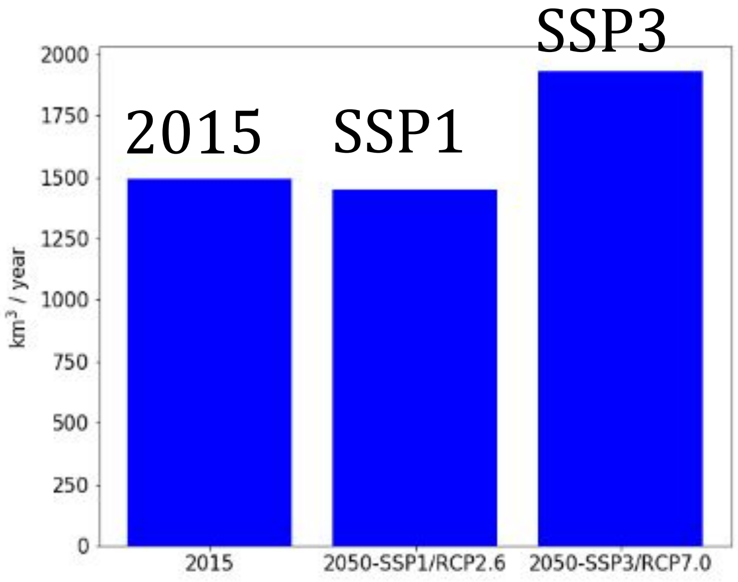




Industrial water demand (change from 2015※)

Domestic water demand (change from 2015※)

※at year 2050



Irrigation water demand (global)

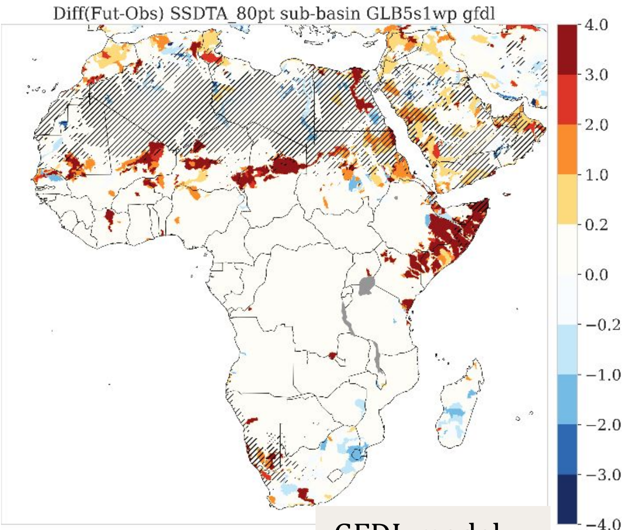
東京大学 THE UNIVERSITY OF TOKYO

Uncertainty in Future Projections by GCMs

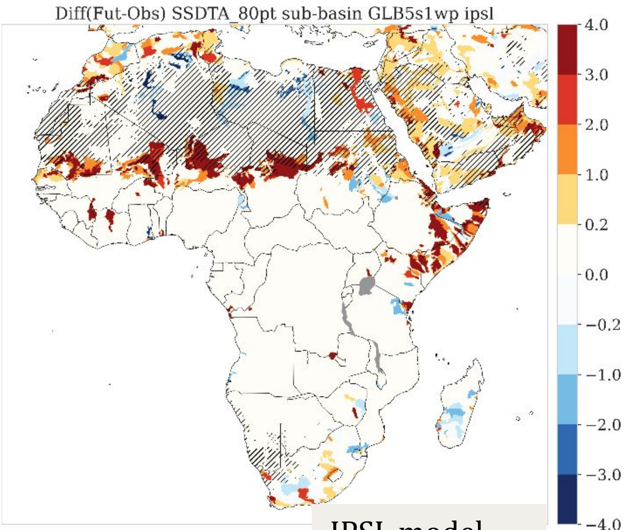
SS-DTA index

Change of SS-DTA index
(from 2015 to 2050)
Future Scenario: SSP1-RCP2.6

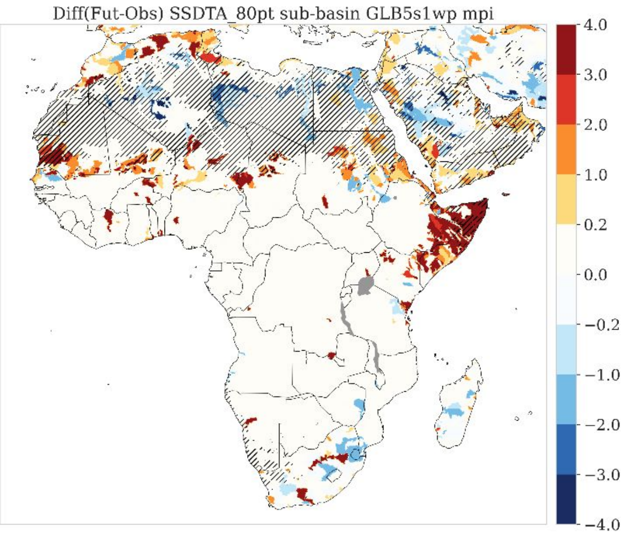
There are uncertainties associated with future climate forcings.



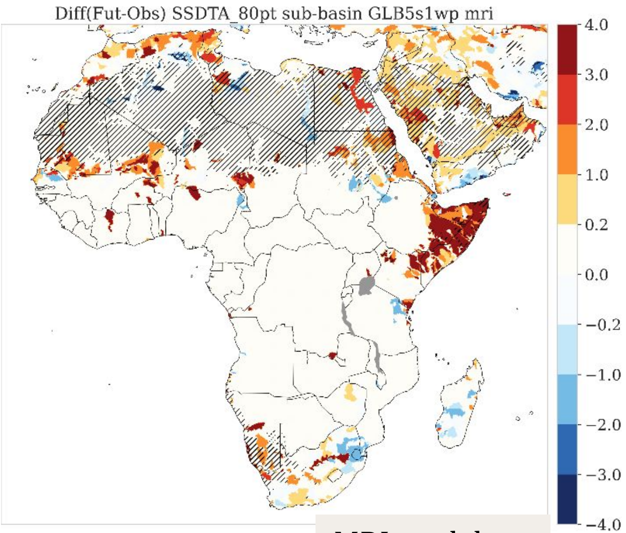
GFDL model



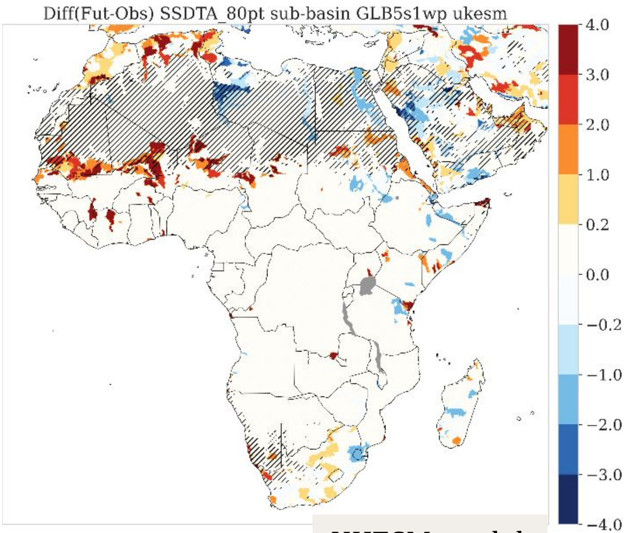
IPSL model



MPI model



MRI model



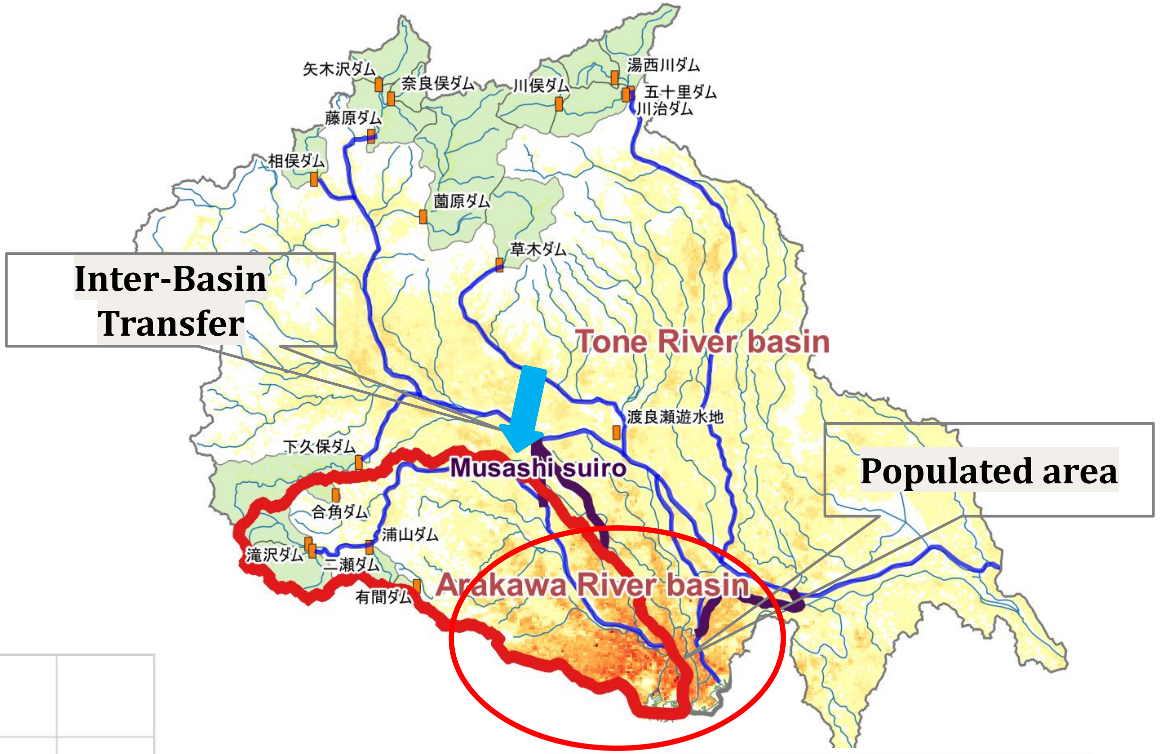
UKESM model

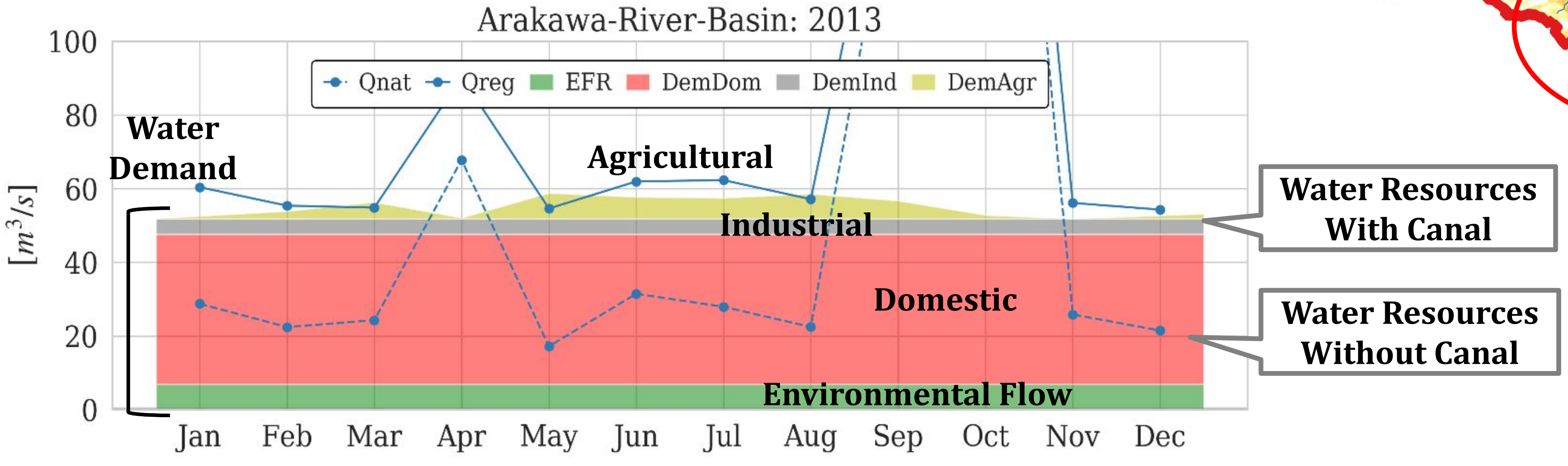
///: Shaded areas represent arid regions where the SS-DTA index is sensitive to small changes due to available water being scarce (<$0.5 m^3/s$). Thus, care must be taken when interpreting the results in the shaded areas.

東京大学 THE UNIVERSITY OF TOKYO

Local Case Study: Arakawa River basin

The Arakawa River basin (2,940 km2) has a metropolitan area and is an important basin where industry and population are most concentrated.
In the past, it had a severe water shortage problem, but now it is supported by water facilities.





Water Demand vs. Available Water Resources

*based on H08 model with local data

photo by Japan Water Agency

Musashi-suiro

AQUEDUCT Baseline Water Stress

- AQUEDUCT2.1

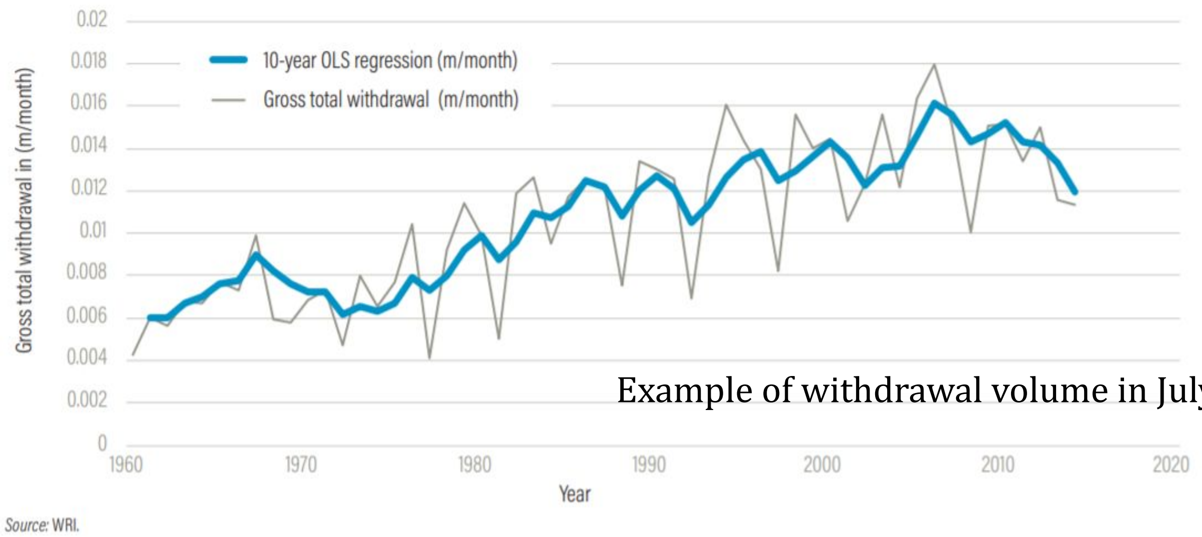
$$BWS' = \frac{Annual\ water\ withdrawal\ volume\ (2010)}{Annual\ available\ water\ volume\ (average\ of\ 1950\text{–}2010)}$$

Finally, BWS' is rescaled to a 0-5 range

- AQUEDUCT3.0

$$WS'_{month,year} = \frac{Withdrawal\ water\ volume_{month,year}}{Available\ water\ volume_{month,year} - Consumption\ water\ volume_{month,year}}$$

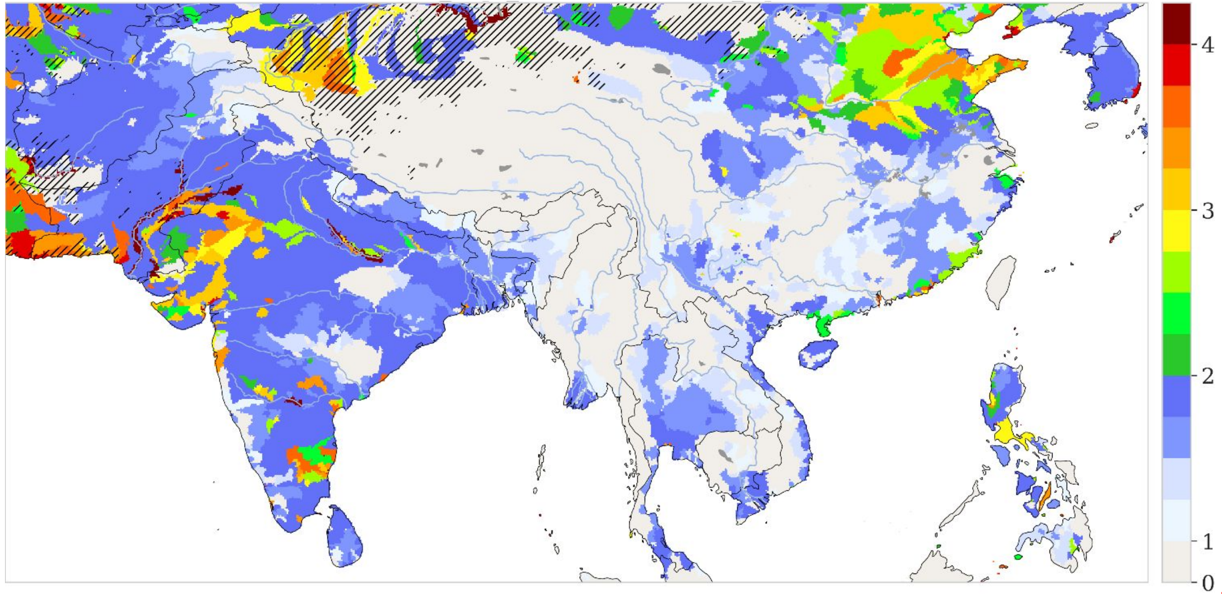
All terms are smoothed by 10-year moving average and regressed by year.
Regressed WS' for year 2014 is scaled to 0-5 to be BWS of each month.



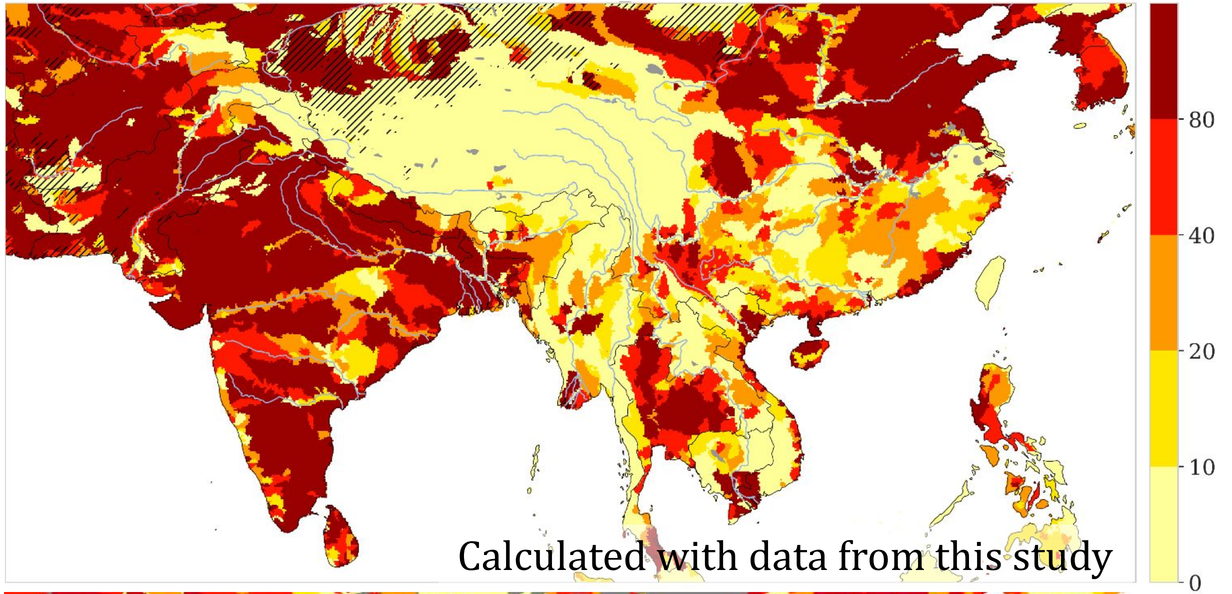
Example of withdrawal volume in July (moving averaged and regressed)

SS-DTA vs Baseline Water Stress (BWS)

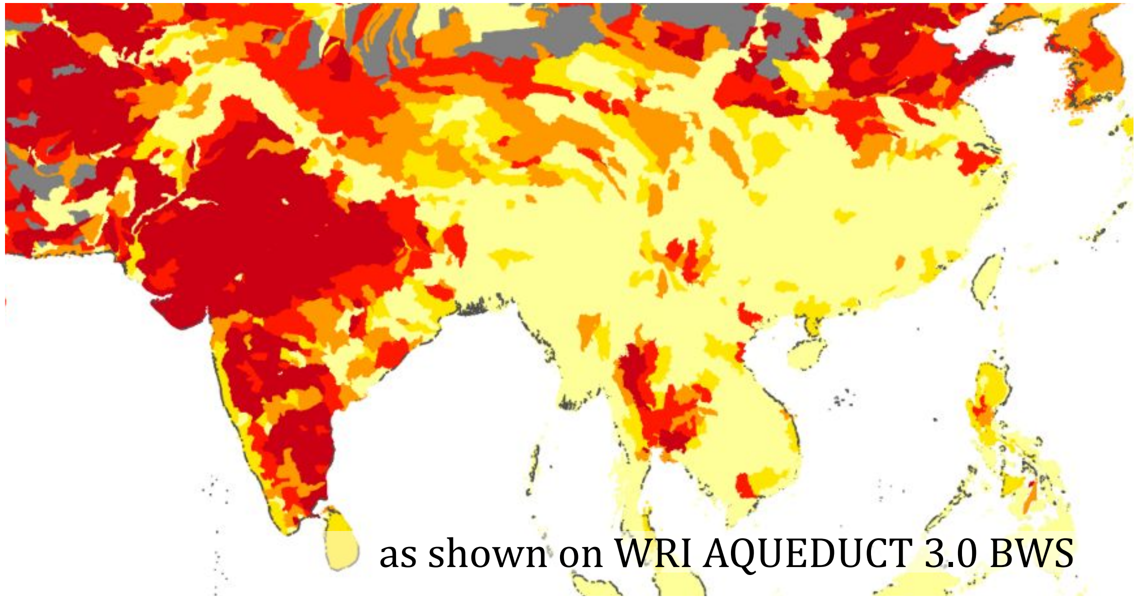
SS-DTA



BWS (WRI AQUEDUCT 3.0)



Calculated with data from this study


as shown on WRI AQUEDUCT 3.0 BWS

Risk in India is high when evaluated in terms of BWS because of the large agricultural water demand. In contrast, the risk ranges between levels 1 and 2 when evaluated with the SS-DTA, which better reflects the regional characteristics of water use.

SS-DTA vs BWS3.0

Indicator	SS-DTA	BWS (WRI Aqueduct 3.0)
Advantages	• Considers seasonal and interannual variability • The level of risk indicated by SS-DTA is associated to a specific drought severeness. Because similar reasoning is employed in water utilization planning, the relationship between SS-DTA and the drought risk it represents is clear. • Represents regional variability of water use	• Simple and easy to understand • Widely accepted • Based on averaged water volumes and not sensitive to outliers
Limitations	• Sensitive to available water volume • Does not fully represent drought management (priority settings are oversimplified) • Downstream water demands are often neglected by upstream water withdrawals	• Does not include interannual variability • Since the BWS value (relationship between averages of available water and demand) is evaluated relatively from a global perspective, it is difficult to interpret the connotations of the drought risk it represents • Downstream water demands are often neglected by upstream water withdrawals

Limitations

- **Accuracy:** Because it is assessed employing global data, it lacks accuracy in some regions. However, its comprehensive approach makes it useful to identify (make a quick screening of) what type of information is needed for a better representation of local risks, like observations of climate at finer resolutions, actual records of water withdrawals, and rules of flow-regulating operations.
- **Assumption:** The default setting of sectoral demand hierarchy is simplistic and arbitrary. In practice, water withdrawals of all sectors are regulated simultaneously. If SS-DTA indicates that the available water resources can cover the demands of only one or two sectors , in reality, it does not mean these two sectors are free of water scarcity risk.
- **Assumption:** In the H08 model, it is assumed that water is withdrawn from upstream regions. Therefore, downstream regions often end up being evaluated as high-risk regions. This issue becomes more relevant when water-regulating infrastructure is included, which means that more water can be withdrawn in upstream regions. In fact, the excessive withdrawal of water is regulated by water-use rights and laws.
- **Assumption:** The volumes of used water that are recycled are not aggregated into the available water volumes.
- **Target:** Green water is not included in the demand volumes. That said, only blue water shortages of irrigation water demand are considered as risk, but water demand for rainfed crops and grasslands is not considered.