Assessing opportunities to increase global food production within the safe operating space for human freshwater use

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Human ingenuity as the ultimate resource

Neolithic Revolution
10,000 – 5,000 yr BP

Industrial Revolution
1700-2000 yr AD

Food / Environmental consequences
Growing societies in face of environmental limits

Adapted from: Siebert et al. (2015), Müller Schmied et al. (2016)
Anthropocene in face of environmental limits

1989 - 2014
Concept of the safe operating space for humanity

Intro

Human Water Use

PB Water

Social Boundary

Social Foundation

safe space

PB Water

Environmental Impact

Human Water Use

PB Water

Social Boundary

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safe space
Twin challenge: people and planet
2.1 End hunger and achieve food security
6.4 Sustainable withdrawals
2.3 Double agricultural productivity
6.6 Protect and restore water ecosystems
2.4 Sustainable and resilient food production

= ?
Water and food as key factors

Food Production

Human Water Use

Current Overdraft

PB Water

Current situation

Food gap: +80% kcal required in 2050

Current Production

Demand in 2050
Research Questions

What does it take to respect PB water?
1. Status of PB water?
2. Constraints on food production?

Food production potentials within PB water?
1.1 Saving potentials in irrigation?
2.1 Closing the food gap with integrated water management?
2.2 Reconciling SDG water and food targets?

Human water use

PB water

Demand in 2050

Food Production

Constraints on food

Savings in irrigation

Closing food gap

Reconciling SDG targets
Methods

Agro-hydrological modeling framework LPJmL

0.5° grid (67,000 cells) daily iteration

Dynamic process representation

Agricultural model

Hydrological model

New mechanistic irrigation module

New mechanistic representation of environmental flows
Methods

LPJmL’s capacity to simulate key variables

![Discharge graph](image)

- $R^2 = 0.99$

Jägermeyr et al. (2017), Nature Comm.
What does it take to respect PB water?

1.1 Status of PB water?
1. Conceptual revision of global PB water

Water overdraft does not balance globally.

→ I refer to the regional water boundary hereinafter (PB water) via environmental flow requirements.
Regional PB water = Environmental Flow Requirements (EFRs)

Example:
VMF method allocates fractions of pristine river flow

<table>
<thead>
<tr>
<th>Low flow period</th>
<th>Medium flow period</th>
<th>High flow period</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td>45%</td>
<td>30%</td>
</tr>
</tbody>
</table>

EFR range

EFR validation

- $R^2 = 0.85$
- $R^2 = 0.95$
- $R^2 = 0.85$
Simulation protocol: maintain EFRs

Simulation period: 1980-2009
1 Respect PB water

1.1 Current global EFR violations

Human water use:
- 2400 km$^3$ irrigation
- 1070 km$^3$ other uses

40% of today’s irrigation water use at the expense of EFRs

Jägermeyr et al. (2017), Nature Comm.
Respect PB water

What does it take to respect PB water?

1.1 Status of PB water?

1.2 Constraints on food production?
EFR constraints on food production

- Half of irrigated cropland faces ≥10% kcal loss
- >20% of total production depends on EFRs in hot-spot regions

Jägermeyr et al. (2017), Nature Comm.
EFR constraints on food production

Jägermeyr et al. (2017), Nature Comm.
Summary: What does it take to respect PB water?

Maintaining EFRs would impinge on 30% of irrigation’s contribution to food production.

40% (1000 km$^3$) of irrigation water use is unsustainable – at the cost of ecosystems.
Food production potentials within PB water?
Options for sustainable intensification

2.1 Irrigation

2.1 Varieties

2.2 Intercropping

2.2 Soil and nutrients

2.2 Cropping intensity

2.2 Pest and disease

2.2 Soil water management

2.2 Rainwater management
2. Food production potentials within PB water?

2.1 Saving potentials in irrigation?
Global mechanistic representation of irrigation systems

Surface irrigation

Sprinkler irrigation

Drip irrigation
Food production potentials

2.1 Irrigation facelift for LPJmL Jägermeyr et al. 2015, HESS
No explicit contribution from nonrenewable groundwater!

Jägermeyr et al. 2015
Simulation protocol: irrigation upgrade

“Ambitious” irrigation transition:
- Drip systems where feasible
- Sprinkler is default
- Surface irrigation for paddy rice
+ Irrigation expansion using thus saved water

Simulation period: 1980-2009
Global gridded map of irrigation efficiencies

Global average irrigation efficiency at 33%

50% of consumptive water use is currently lost (600 km³)

Jägermeyr et al. 2015, HESS
Potential of irrigation water savings

- 40% of irrigation losses are savable
- Return-flows stay untouched

"Ambitious" irrigation transition:
- Drip systems where feasible
- Sprinkler is default
- Surface irrigation for paddy rice
### Food production potentials within PB water?

<table>
<thead>
<tr>
<th>2.1</th>
<th>Saving potentials in irrigation?</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2</td>
<td>Closing the food gap with integrated water management?</td>
</tr>
</tbody>
</table>
Hydro-climatic opportunities

Only 40% of water used productively!

- Transpiration: 33% (100%), 46% (100%)
- Evaporation: 23% (100%), 30% (100%)
- Surface runoff: 27% (26%)
- Seepage and lateral runoff: 16% (7%)

Rain and irrigation water

Jägermeyr et al. 2016, ERL
Rain-fed management options

1. **Soil moisture conservation (SMC)**
2. **Water harvesting (WH)**
Simulation protocol: integrated options

Food production potentials

Simulation period: 1980-2009

“Ambitious” rainwater management:
- 50% alleviation of bare soil evaporation
- Collecting 50% surface runoff for supplemental irrigation

Integrated options:
- Combining rainfed and irrigation strategies

1. Maintain EFRs
2. Current situation
   - Irrigation upgrade
   - Rainfed options (SMC)
   - Maintain EFRs + Irrigation upgrade
2.1 Irrigation upgrade + expansion
2.2 Integrated options + Climate Change
   - Rainfed options (WH)
   - Integrated options
2.3 Maintain EFRs + Integrated options
Food production opportunities in rainfed farming

Soil moisture conservation

Kcal production [% change]

- +7%
- +18%
Integrated options

“ambitious” options in rainfed and irrigated farming combined

- Global +40% kcal gain
- No land expansion
- Reduced water use

(1980-2009 mean)
Food production potentials within PB water?

2.1 Saving potentials in irrigation?

2.2 Food gap under integrated water management?

2.3 Reconciling SDG water and food targets?
Simulation protocol: EFRs and water management

- Current situation
- Irrigation upgrade
- Irrigation upgrade + expansion
- Integrated options
- Integrated options + Climate Change
- Maintain EFRs
- Maintain EFRs + irrigation upgrade
- Maintain EFRs + integrated options

Simulation period: 1980-2009

“moderate” intensity scenarios only

Rainfed options (SMC)
Rainfed options (RWH)
Integrated options

2.3
2.3
2.2
2.1
2.1
1.1
1.2
1.1

Food production potentials

2

38/47
Reconciling EFRs and food production across countries

EFR constraints on production
- Total kcal
- Irrigated kcal
- Total kcal with improved irrigation
- Total kcal with integr. water managem.

Ratio of kcal irrigated
- < 20%
- < 40%
- < 60%
- ≥ 60%

Population
- High human development
- Low human development (HDI < 0.7)

Irrigation upgrade:
- ±0%
- ±10%

Integrated scenario:
- Same irrigation setup
- 25% SMC + 25% WH

Large gains in e.g.:
- Pakistan, Afghanistan, Turkmenistan

Small gains in:
- Israel, Spain

Summary: Food production potentials within PB water

- Irrigation (ambitious): +20%
- Integrated options (ambitious): +40%
- EFR + irrigation (moderate): ±0%
- EFR + integrated options (moderate): +10%
- EFR + integrated options: ~+40%

Climate Change uncertainty (RCP2.6 – RCP 8.5)

Cuts food gap in half

Jägermeyr et al. (2017), Nature Comm.
Synthesis
Synthesis

Cited as new benchmark for sustainable intensification (MacDonald et al., 2016)
Challenge for human ingenuity

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safe and just space
Challenge for human ingenuity

The Growroom - IKEA’s answer to sustainable farming?

The Ring Garden - Solar-powered desalination and agriculture plant

https://thepanoptic.co.uk/

http://inhabitat.com
In the first place - an implementation challenge

Environmental Impact

PB Water

safe space

safe and just space

Social Foundation

Social Boundary
Synthesis

Outlook

Environmental Impact

Social Foundation
Thank you.

Related publications

Gerten, D., Heck, V., Jägermeyr, J., Bodirsky, B.L., Fetzer, I., Jalava, M., Kummu, M., Lucht, W., Rockström, J., Schaphoff, S., Schellnhuber, H.J. “Feeding ten billion people is narrowly possible within planetary boundaries” Submitted.


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References cited


