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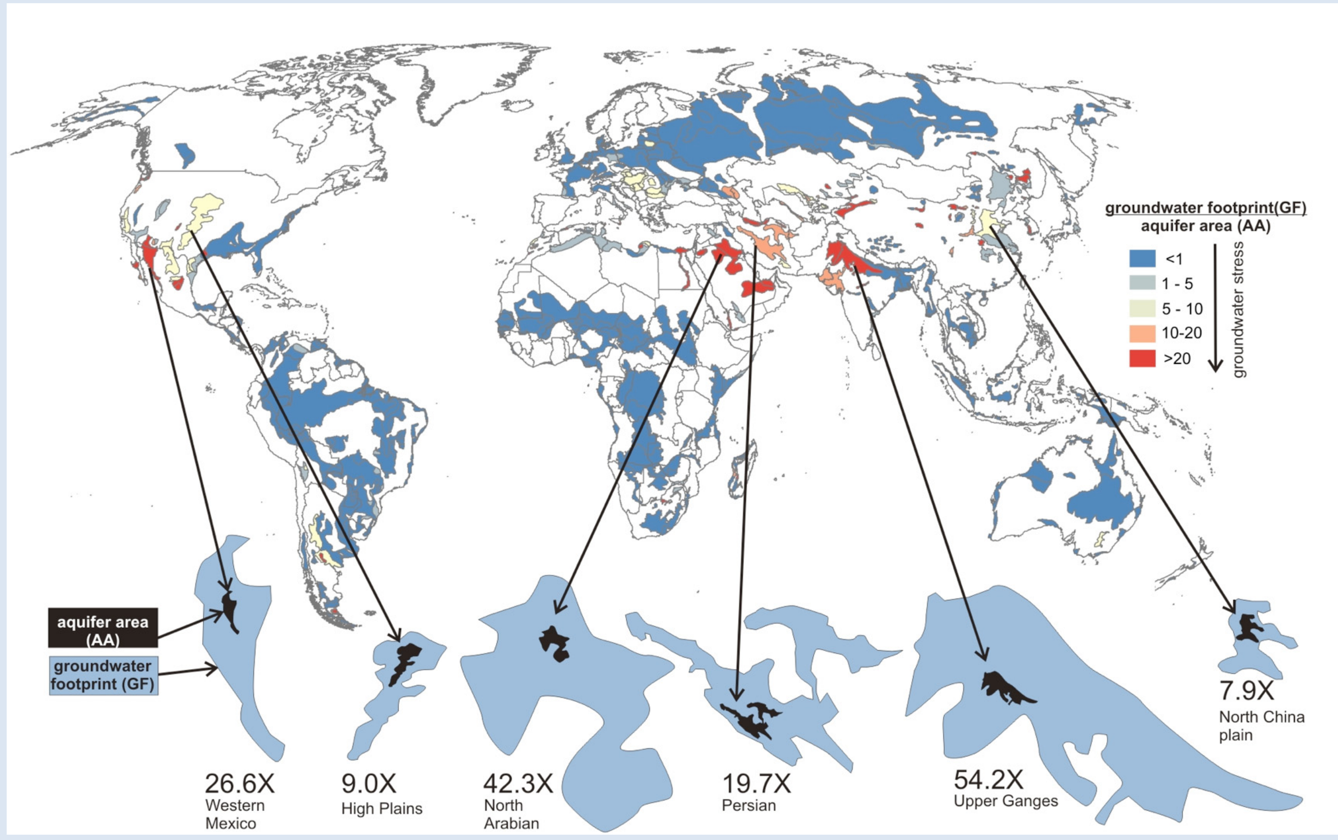
The shadow price of fossil groundwater

Marc F.P. Bierkens, Stijn Reinhard, Jens de Bruijn, Yoshihide Wada

Background



Many of the major aquifers in the world experience groundwater over-exploitation leading to the depletion of groundwater resources. The Figure shows the groundwater footprint: how much area is needed to sustain current groundwater withdrawal compared to the aquifer area (Wada et al., 2010; Gleeson et al., 2012).

Introduction

Knowledge about the actual value of water as a resource is limited (Ziolkowska, 2015). The value of (ground)water for irrigation is represented as the costs of extracting water from aquifers and delivering it to the final consumer. This value does not reflect the value of water as a depletable (non-renewable) resource. Water for irrigating crops may be under-priced, which can lead to irreversible depletion. The actual value of water for irrigation can be represented by the shadow price of water. The higher the shadow price the smaller will be the gap with the unknown value of water as a non-renewable resource.

Methods

- Shadow price: defined as being equal to the benefits produced by the last m^3 of fossil (non-renewable) groundwater
- 12 countries with largest groundwater depletion; 26 crops
- For each crop, each country and each year:
  1. Yield, area irrigated and prize (FAO statistics)
  2. Actual evapotranspiration without irrigation (Green water)
  3. Surface water and renewable groundwater consumption (Blue water)
  4. Non-renewable groundwater use (NRG water)
- 2,3 and 4: Global hydrological model PCR-GLOBWB (Wada et al., 2012)

Methods

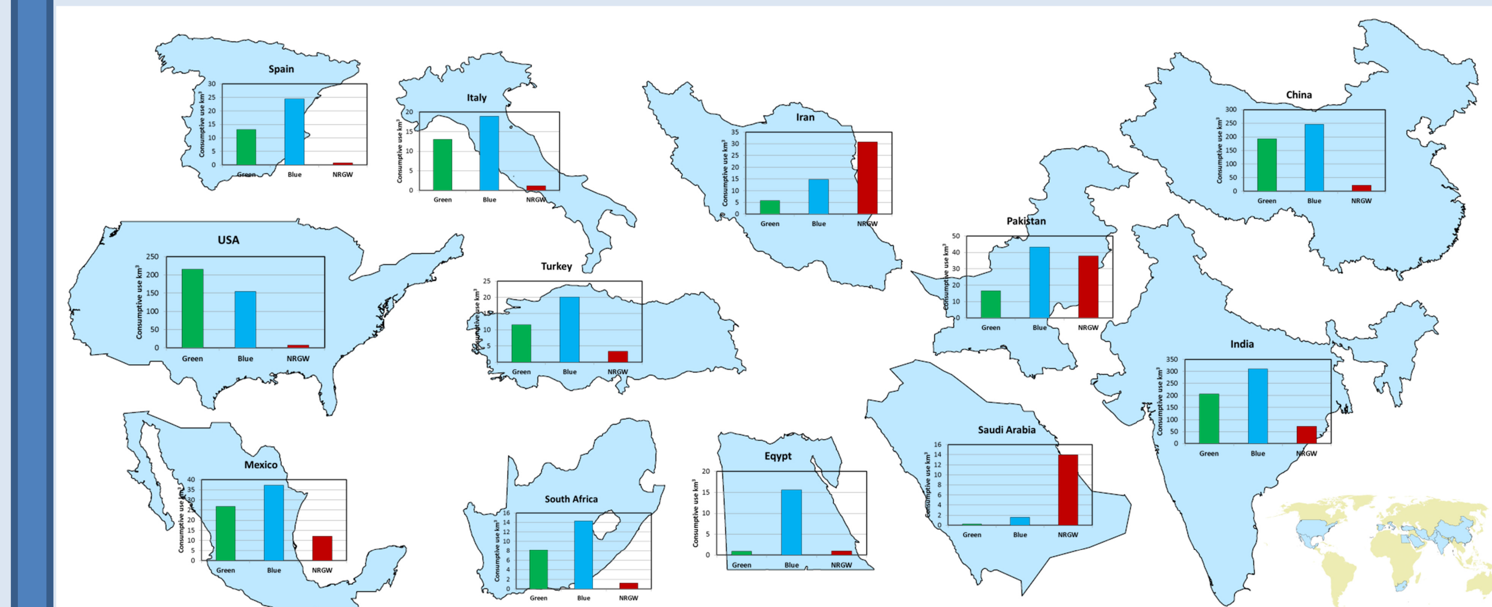
- **Econometric analysis**: fitting panel data per crop (country, yield, year)
- Fitting the CobbDouglas functional form of the production function:

$$Y = \beta_0 \cdot A^{\beta 1} \cdot GW^{\beta 2} \cdot BW^{\beta 3} \cdot NRGW^{\beta 4} \cdot CF^{\beta 5} \cdot t^{\beta 6} \cdot e \quad (1)$$

- The shadow price of the current year t:

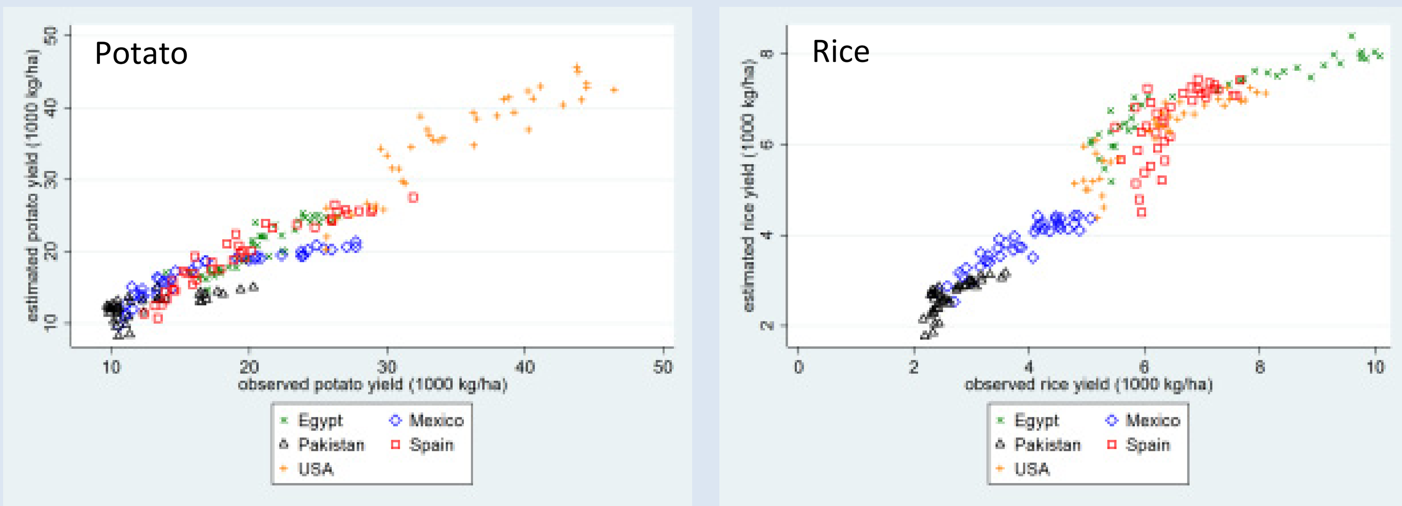
$$SP_{c,t} = p_{c,t} \frac{\partial Y}{\partial NRGW} = p_{c,t} . \beta 4 \frac{Y}{NRGW} \quad (2)$$

Y: Yield (metric tonnes)
A: Area under irrigation (ha)
GW: green water (actual evaporation; km^3)
BW: blue water (renewable irrigation water; km^3)
$NRGW$: non-renewable groundwater (km^3)
CF: country specific factor (dummy) to account for differences in productivity (-)
t: time (trends in cropping technology) (years)
$p_{c,t}$: country-specific price for crop (\$/ton)

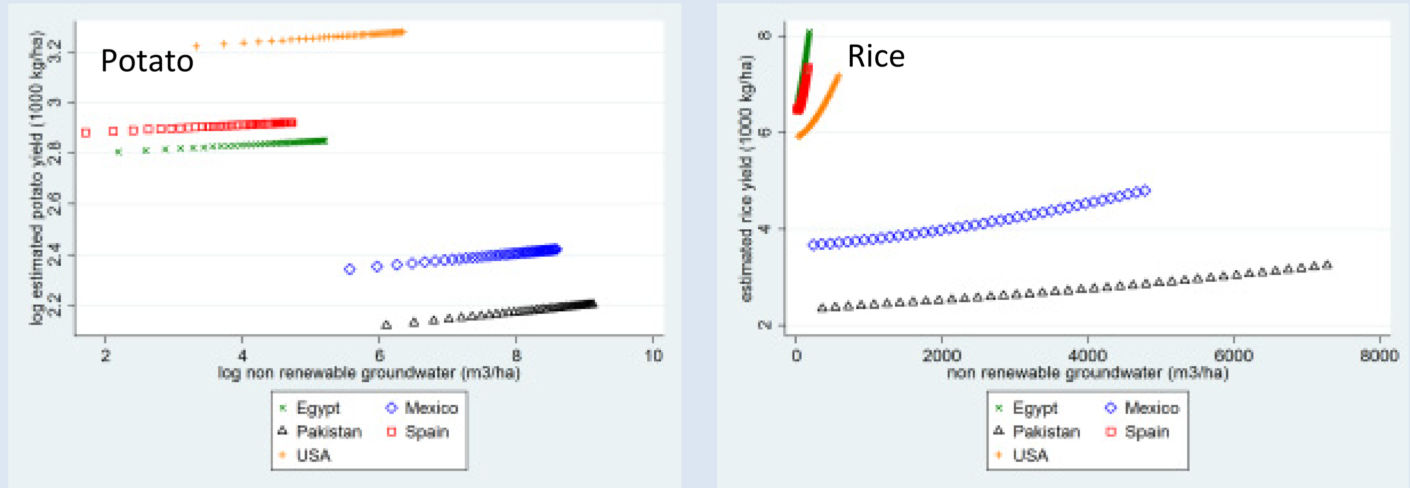


Consumptive use per water type in 12 major groundwater depleting countries

Results



Predicted yield (Eq. 1) versus reported yield (FAO) of potato (left) and rice (right) for five countries



The marginal production function (keeping all other factors at their average value) for non-renewable groundwater use for potato (left) and rice (right) for five countries

Results

Estimated shadow prices for potato and rice (\$/m^3):

Country	Potato	Rice
China	5.44	1.09
Eqypte	4.59	4.48
India	0.67	1.55
Iran		0.03
Italy	0.67	1.62
Mexico	0.28	0.04
Pakistan	0.17	0.02
South Africa	1.43	3.97
Spain	5.05	8.65
Turkey	0.42	5.17
USA	1.81	0.44

Low values of the shadow price of non-renewable or fossil groundwater indicate wasteful application of a non-renewable resource. For instance for Pakistan it would be beneficial to change from rice to another crop (e.g. potatoes) either to reduce non-renewable groundwater use or to generate higher revenues from the use of non-renewable groundwater and use these to invest in e.g. water-saving technologies. Note: some unrealistically high prices indicate that the econometric model needs further improvement.

Conclusions and Discussion

We have shown that the shadow price for non-renewable or fossil groundwater can be determined from the econometric analysis of historical yield and price data supplemented with simulations of crop-water use from a global hydrological model. Our results show that shadow prices per crop and per country vary significantly. This provides opportunities for changing the crop mix within and between countries in order to limit groundwater depletion or to generate more revenue from non-renewable groundwater use.

Improving the econometric model:

- Correcting for the unidirectional substitution of water types and correcting for low NRGW volumes for certain crops and countries
- Enforcing concave marginal production functions expressing diminishing returns

Additional research will focus on optimal cropping configurations and including the costs and benefits of changing the crop mix and water saving technology.

References

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Utrecht University
Deltares Enabling Delta Life
vrije Universiteit amsterdam
WAGENINGEN UNIVERSITY & RESEARCH
International Institute for Applied Systems Analysis IIASA