Global Water Scarcity, Food & Storage: *a critical review*

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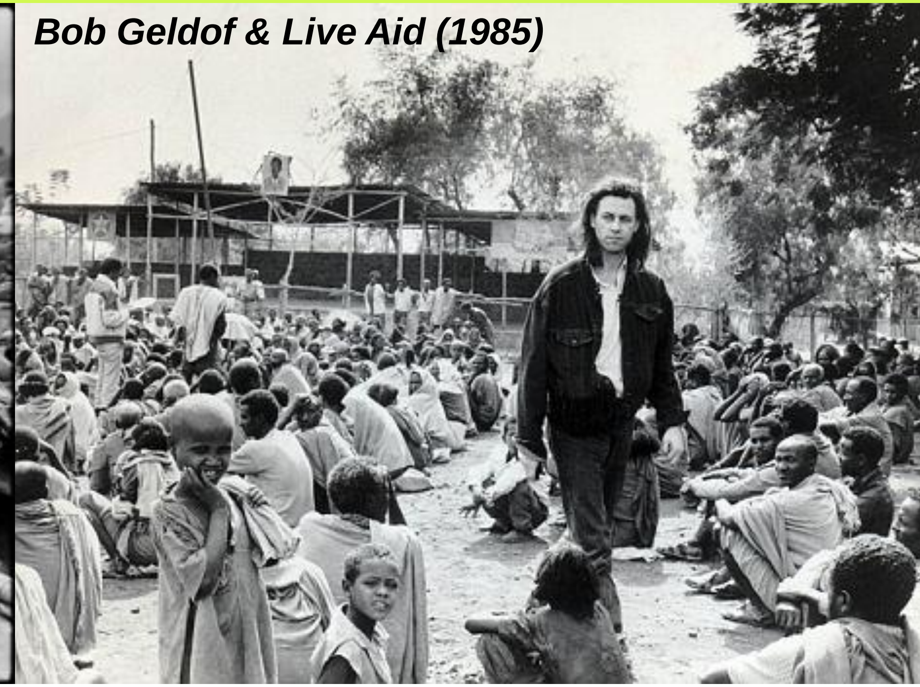
UCL-ISR Water SDGs and Future Water Management, 8-9 November 2016

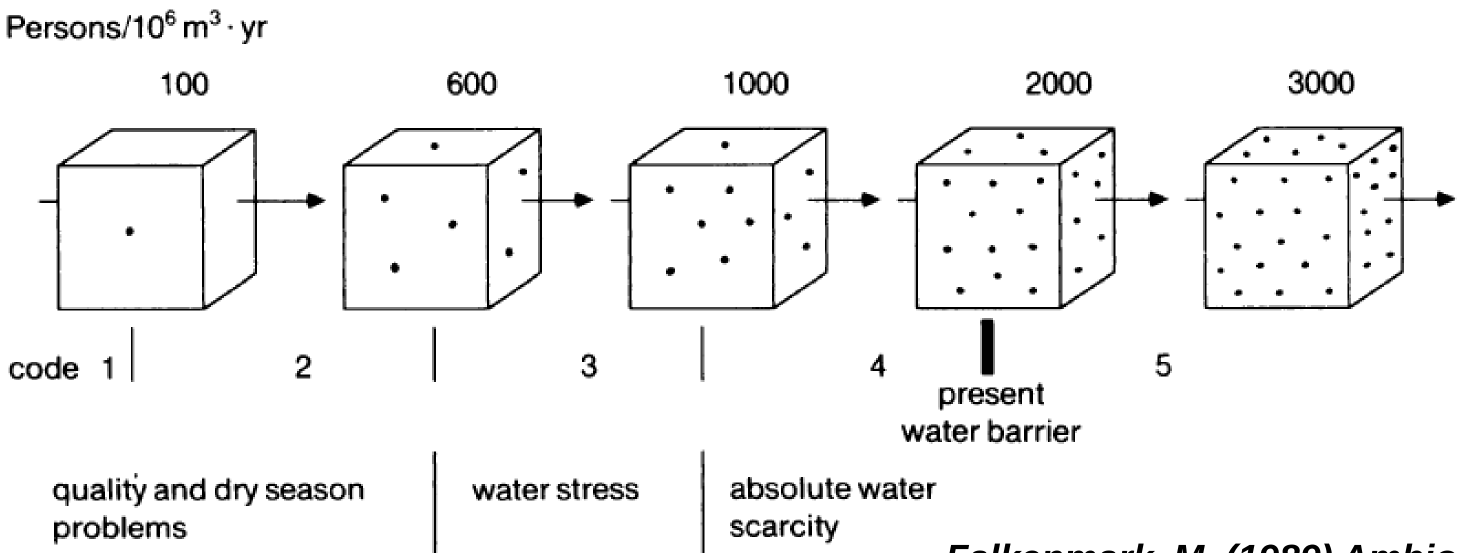
groundwater-fed irrigation of maize (Zambia)

"water scarcity" – water stress index

Ethiopian famine (1984)



Bob Geldof & Live Aid (1985)

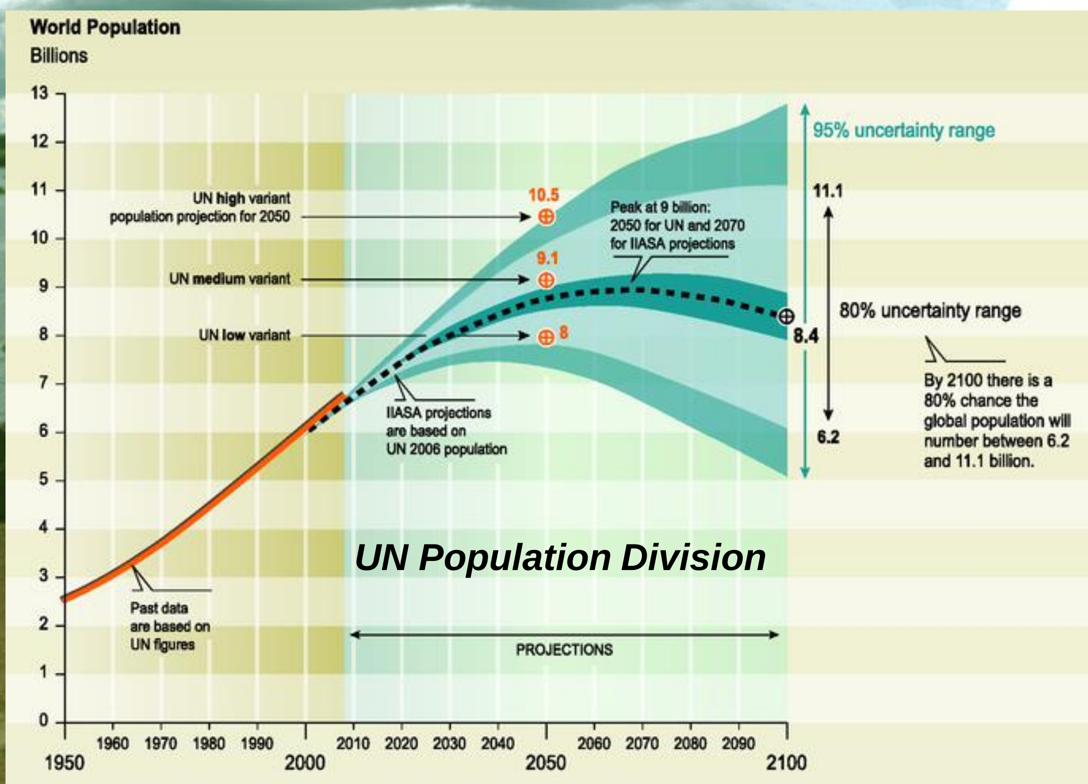


Falkenmark, M. (1989) Ambio Vol. 18, 112-118.

renewable freshwater resources defined by ***mean annual river discharge*** from models/observations

– net contribution of **“blue water”** to the land surface from precipitation after deducting ET

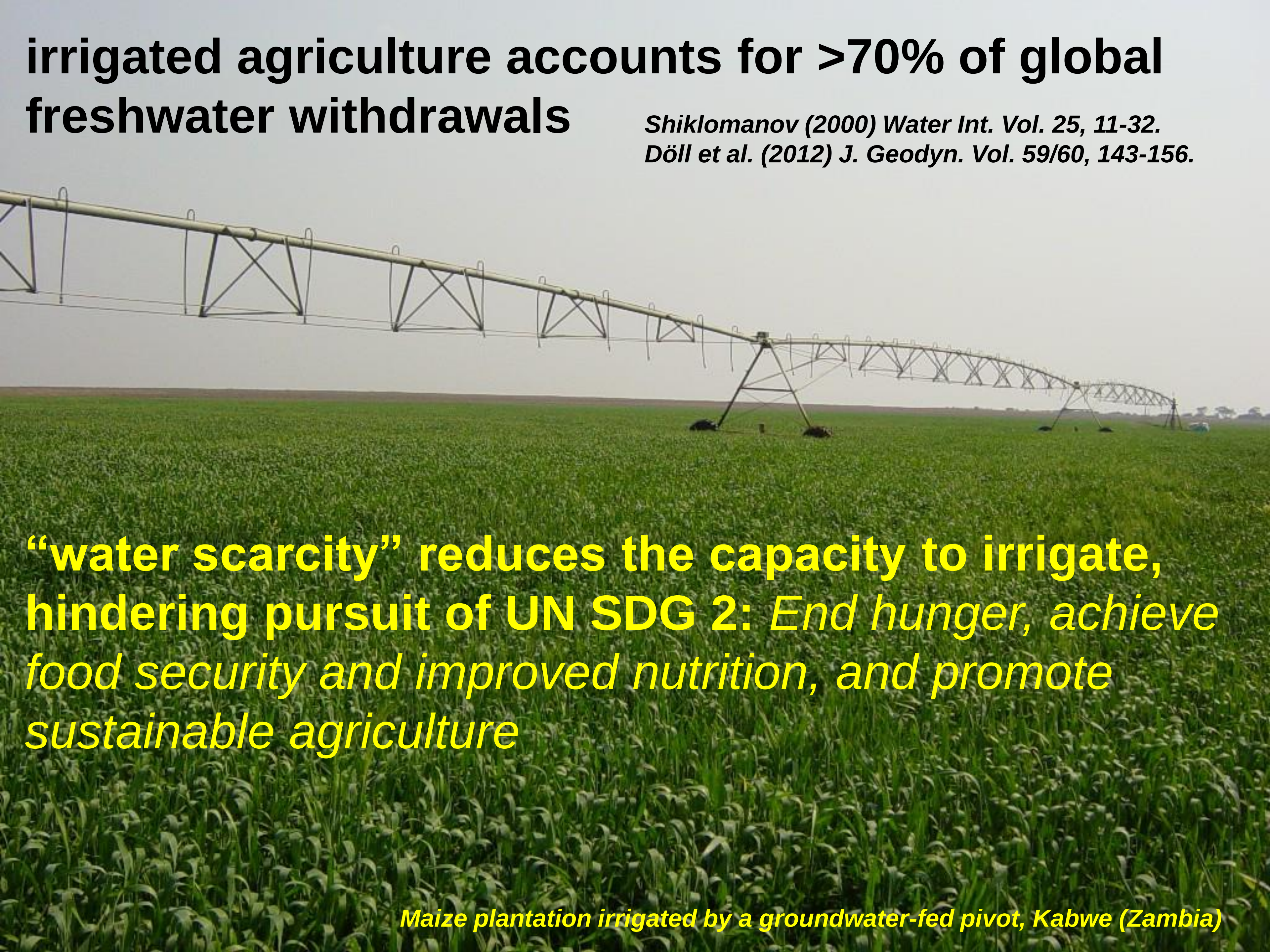
– population data enable estimation of a per capita freshwater availability



River Nile at Masindi Port, Uganda

irrigated agriculture accounts for >70% of global freshwater withdrawals

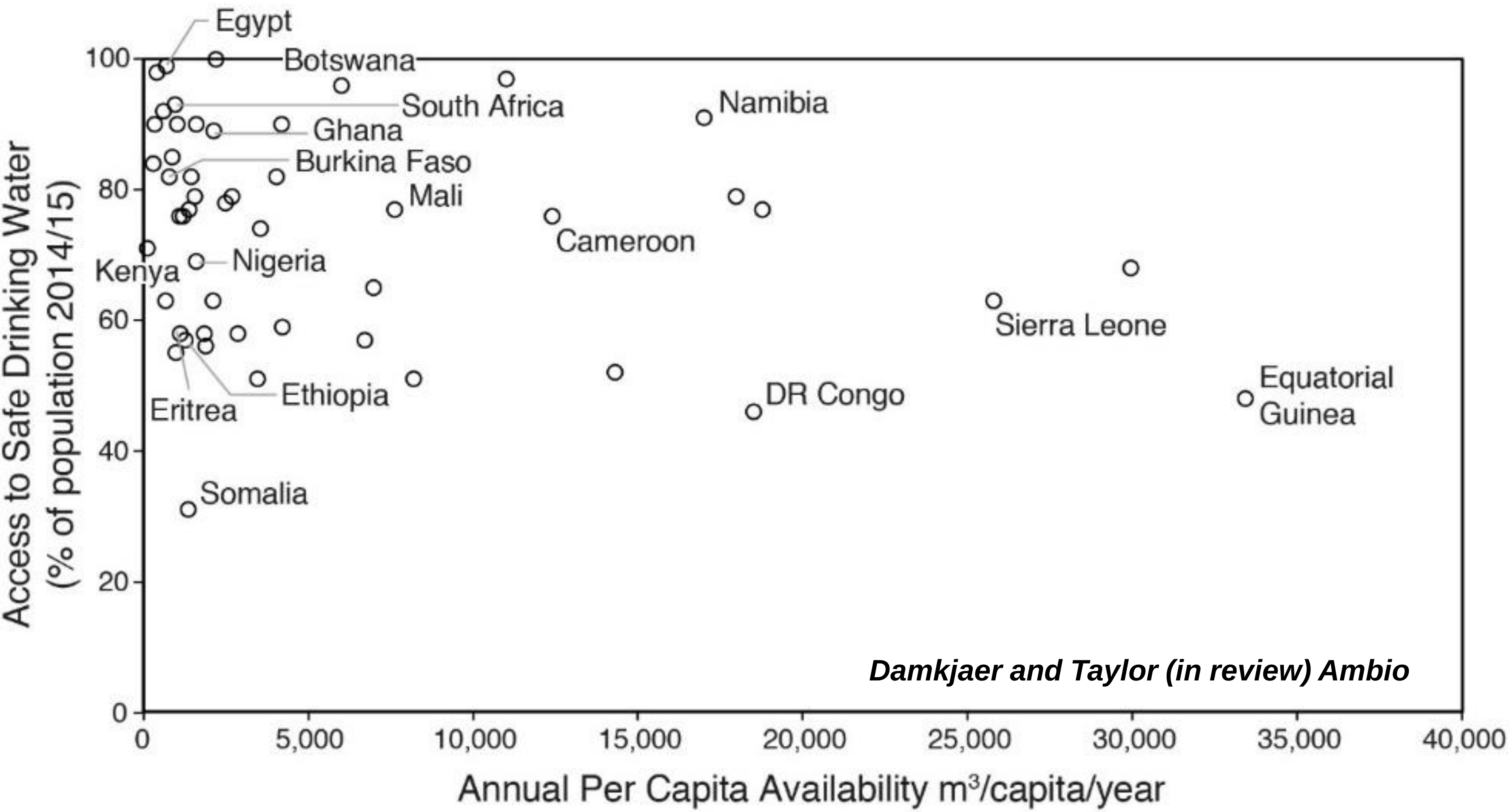
Shiklomanov (2000) Water Int. Vol. 25, 11-32.
Döll et al. (2012) J. Geodyn. Vol. 59/60, 143-156.



"water scarcity" reduces the capacity to irrigate, hindering pursuit of UN SDG 2: *End hunger, achieve food security and improved nutrition, and promote sustainable agriculture*

Maize plantation irrigated by a groundwater-fed pivot, Kabwe (Zambia)

It is unrelated to 'access to safe water' and UN SDG 6.1: *By 2030, achieve universal and equitable access to safe and affordable drinking water for all*



Damkjaer and Taylor (in review) Ambio

In sub-Saharan Africa, food production depends primarily upon soil water, “green water”

~4% of cultivated land was under irrigation in 2000

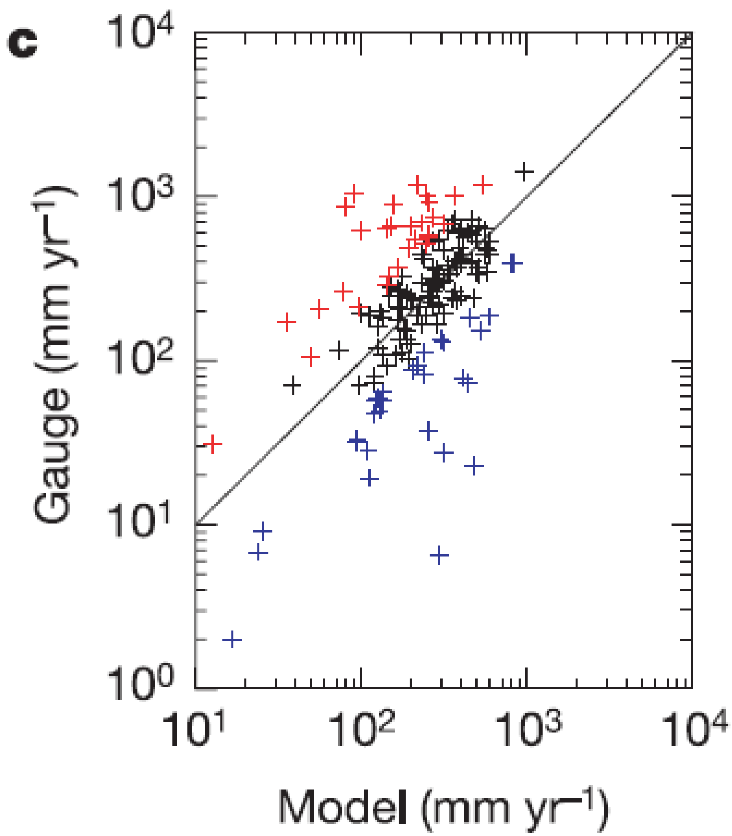
Giordano (2006) Hydrogeol. J., Vol. 14, 310-318.
Döll et al. (2012) J. Geodyn., Vol. 59/60, 143-156.

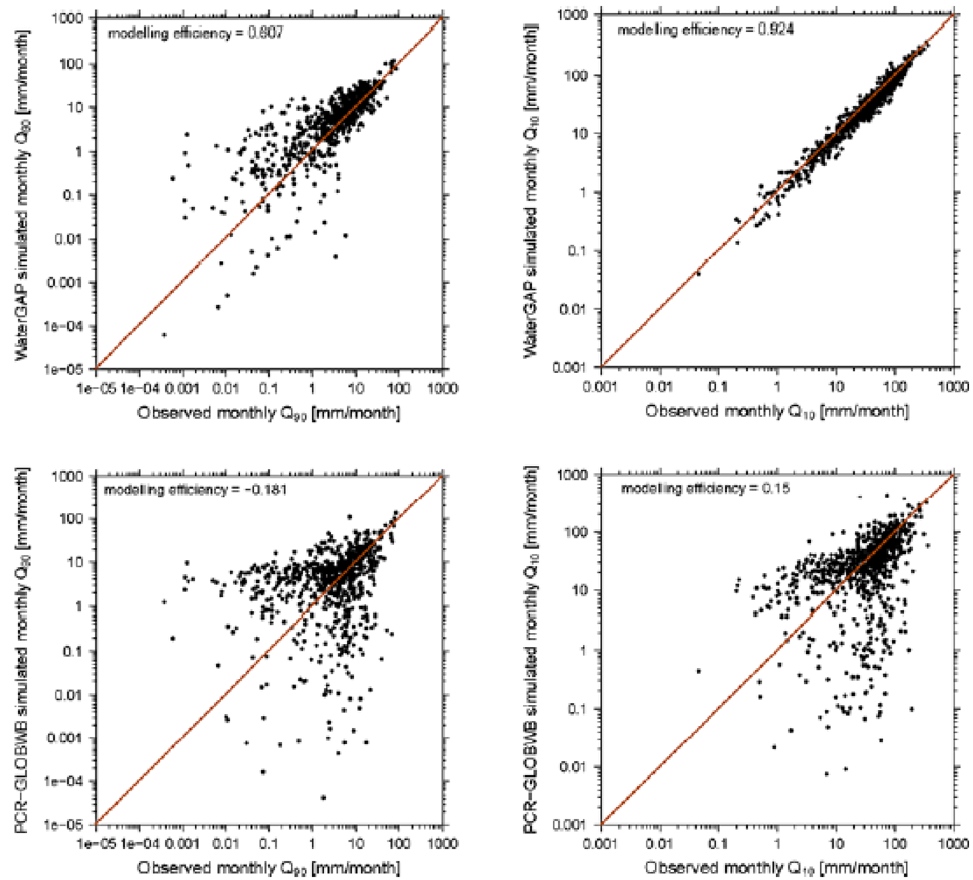
- **‘water scarcity’ per capita threshold of 1000 m^3 per year greatly exaggerates freshwater demand where observed per capita use is typically 20 to 25 m^3 per year**

tea and matooke (unsweet banana) in Bushenyi, Uganda

uncertainty in renewable freshwater resources

- global models are uncalibrated* and provide very imperfect estimates of river discharge





Milly et al. (2005) Nature Vol. 438, 347-350.

Döll et al. (2016) Surv. Geophys. Vol. 37, 195-221.

Global Water Scarcity **remains inadequately defined by current models and metrics.**

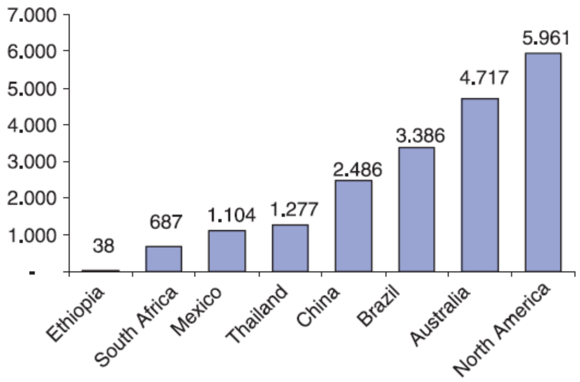
sand river, headwater of the Great Ruaha River, Tanzania

human adaptations to water shortage

- draw from water storage or store seasonal flows

- reservoir storage = “development”

Grey and Sadoff (2007) Water Policy Vol. 9, 545-571.

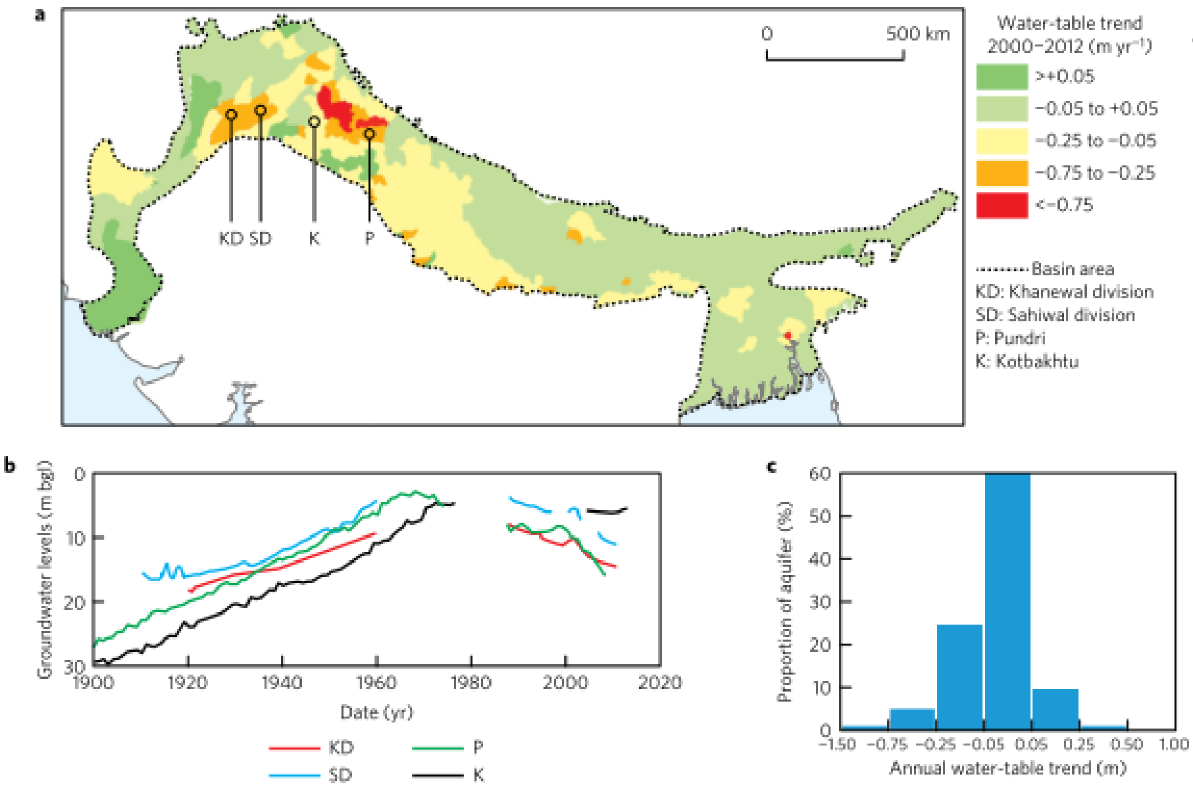


World Bank

human imprint on terrestrial water cycle

- redistribute water from rivers and aquifers to the land and atmosphere through irrigation and dams (energy production & low-flow regulation)

Taylor et al. (2013) Nat. Clim. Change Vol. 3, 322-329.
Jaramillo and Destouni (2015) Science Vol. 350, 1248-1251.

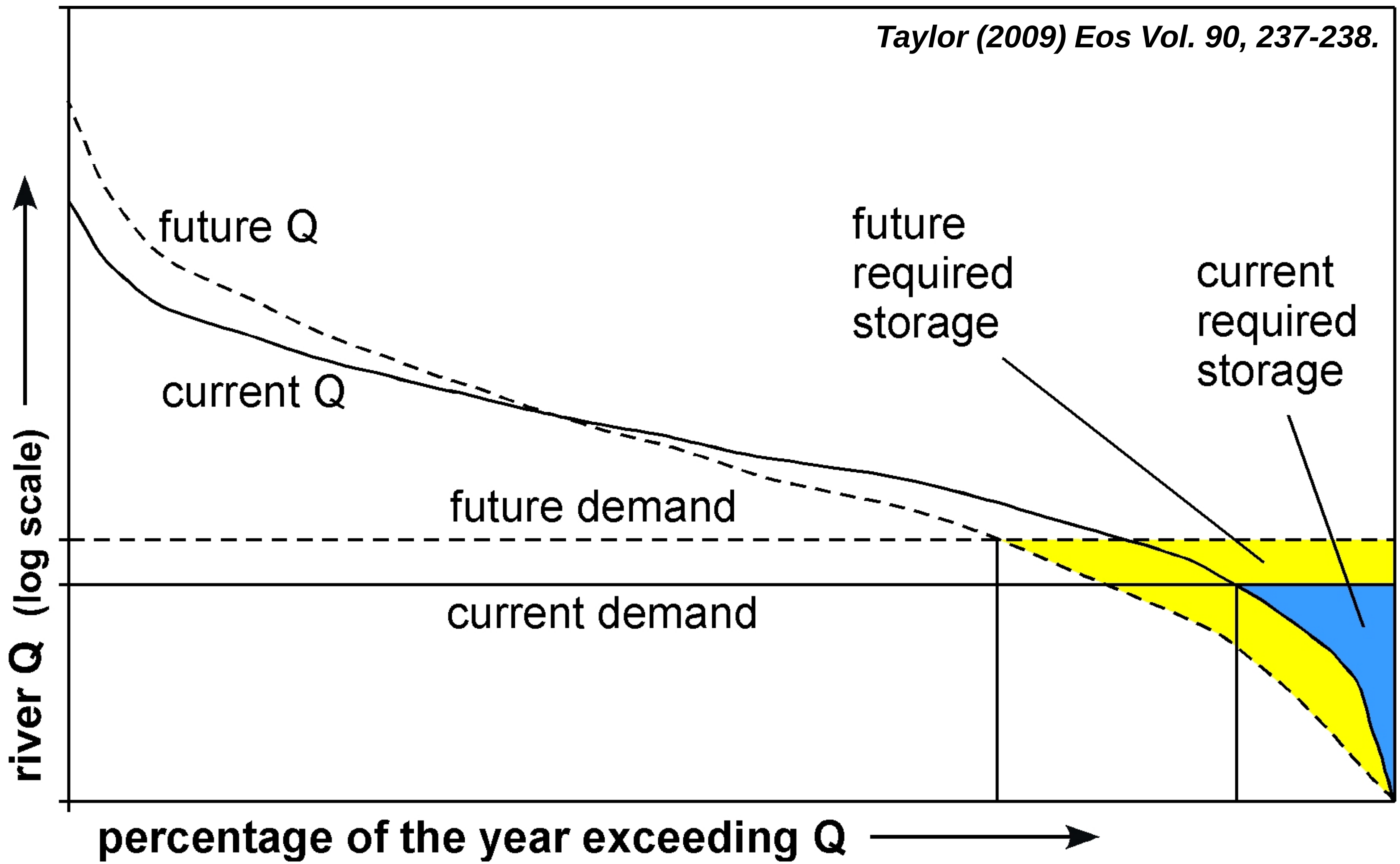


- constrain use of groundwater due to contamination – more so than depletion in IGB

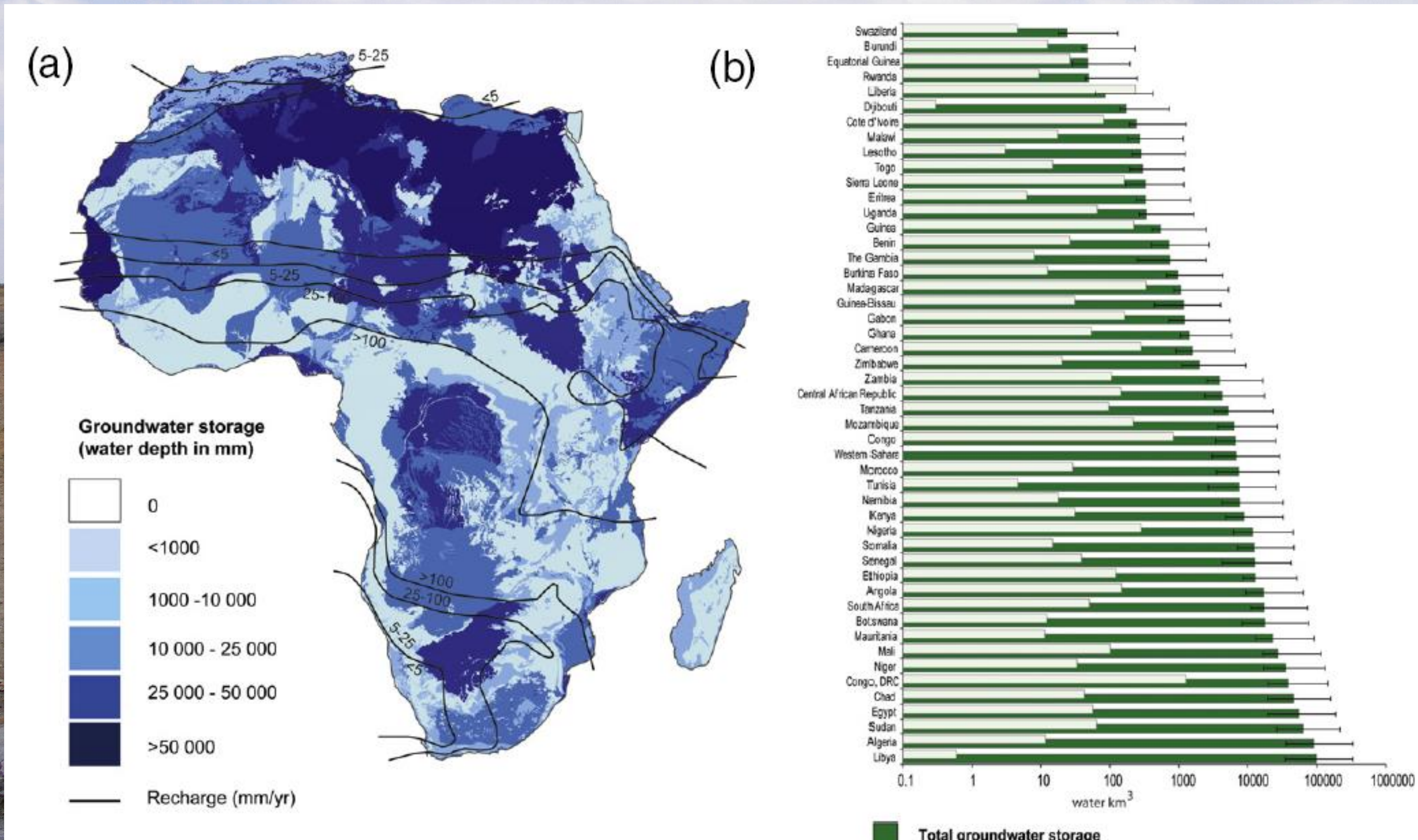
MacDonald, A. et al. 2016. Nat. Geosci. Vol. 9, 762-766.

redefine freshwater availability: storage

- extent to which available storage, natural and constructed, can address imbalances in water flows



beyond reservoirs: substantial, distributed, natural groundwater storage exists but… is it sustainable?



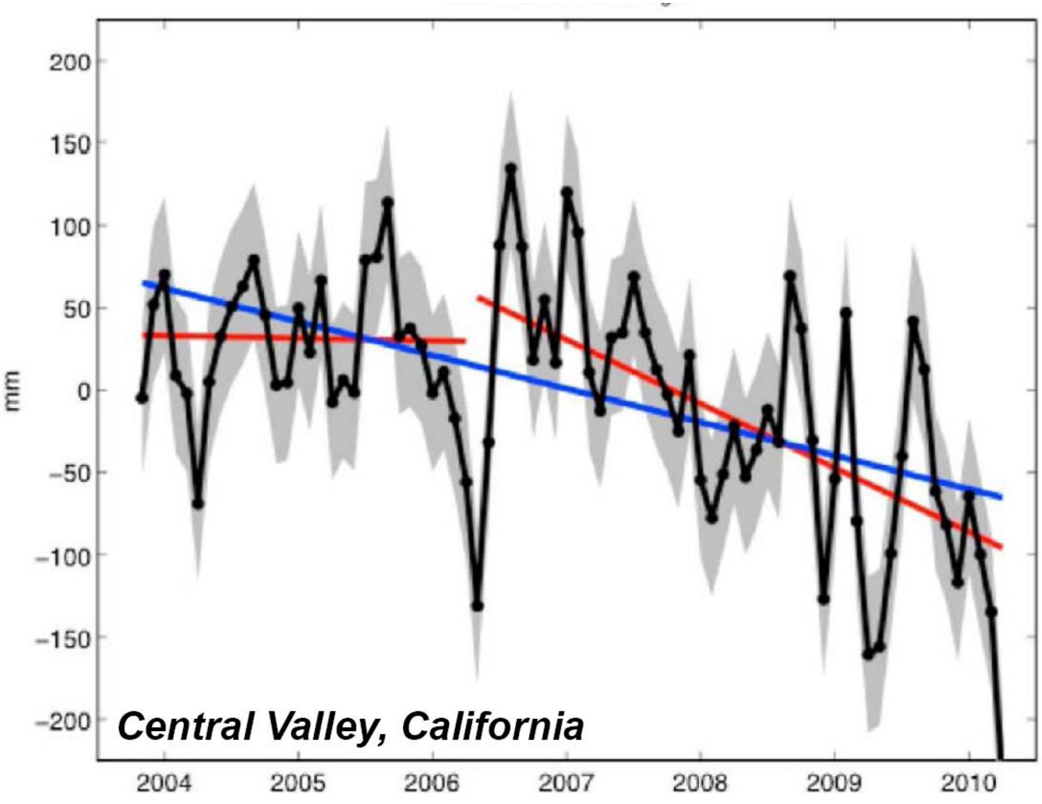
MacDonald et al. (2012) Environ. Res. Lett. 7: 024009.

artesian borehole, Singhida (central Tanzania)

groundwater depletion and irrigation

- groundwater depletion observed in California Central Valley, North China Plain, High Plains Aquifer, NW India & Bangladesh – ***these storage declines threaten global food security***

Chen (2010) Environ. Earth Sci. Vol. 61, 1037–1047.
Longuevergne et al. (2010) Wat. Resour. Res. Vol. 46, W11517.
MacDonald et al. (2016) Nat. Geosci. Vol. 9, 762-766.
Scanlon et al. (2012) Wat. Resour. Res. Vol. 48, W04520.
Shamsudduha et al. (2012) Wat. Resour. Res. Vol. 48, W02508.



HYDROLOGY

When wells run dry

A global analysis reveals growing societal dependence on the use of non-renewable freshwater resources that depletes groundwater reserves and undermines human resilience to water scarcity in a warming world.

RICHARD TAYLOR

That freshwater reserves are in decline in many parts of the world is not only of great scientific interest, but of profound societal concern. Reports of groundwater depletion[1,2] and declining river and lake levels[3] provide compelling evidence of regional freshwater use exceeding its renewable supply. Quantifying freshwater supply and use around the world is, however, a substantial technical challenge. In one of the most comprehensive analyses so far, published in *Environmental Research Letters*, Wada and Bierkens[4] estimate the supply and use of fresh water from 1960 to 2099. They use both historical records and future projections that include substantial demographic and climate-related changes expected this century. Their analyses reveal a steady rise in the non-renewable use of fresh water in many parts of the world that should be of global concern.

Irrigation currently accounts for 70% of global freshwater withdrawals[4]. The green revolutions of the past half century which dramatically increased food production, most notably in the United States and Asia, were driven primarily by the expansion of cultivated land under irrigation. Because irrigation redistributes fresh water withdrawn from aquifers, rivers and lakes to the land, it changes regional water balances by increasing consumptive use of fresh water through evapotranspiration.

Intensive irrigation can deplete freshwater sources. For rivers and lakes that are being replenished through present-day precipitation, the magnitude of their depletion is constrained by their limited total volume[5] (about 93,000 cubic kilometres worldwide) and the very visible impacts of overuse. By contrast, groundwater resources derived from precipitation over years to decades and, in some cases, millennia, enable substantial non-renewable use on account of their vast, distributed

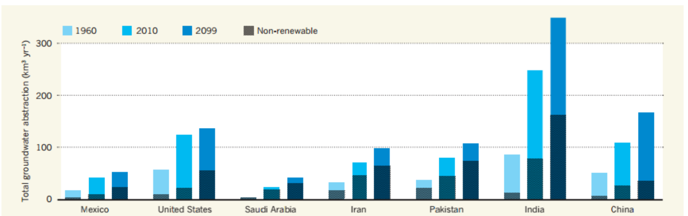


Figure 1 | Historical and projected groundwater withdrawals in the world's major irrigating countries. The chart shows total and non-renewable groundwater abstraction in India, the United States, China, Pakistan, Iran, Mexico and Saudi Arabia, as estimated by Wada and Bierkens[4], for 1960, 2010 and 2099; these countries accounted for 74% of global groundwater withdrawals in 2010. From 1960 to 2010, the estimated proportion of non-renewable groundwater withdrawals increases for all of these countries except Pakistan, where it remains stable but high at 58%.

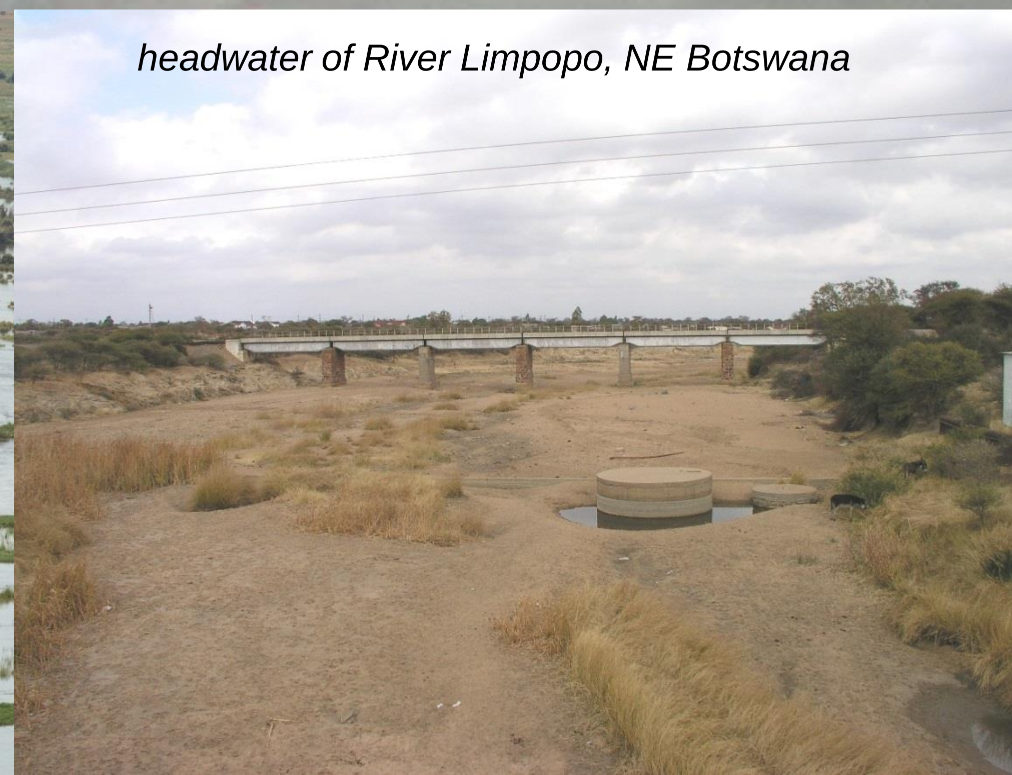
Climate change intensifies global hydrological system

- more frequent, very heavy precipitation
- fewer, light and medium precipitation events

Allan & Soden (2008) Science Vol. 321, 1481-1484.
Allan et al. (2010) Environ. Res. Lett. Vol. 5, 025205.
O’Gorman (2012) Nat. Geosci. Vol. 5, 697-700.

- **more frequent and intense floods & longer droughts will intensify freshwater storage requirements and thus groundwater…**

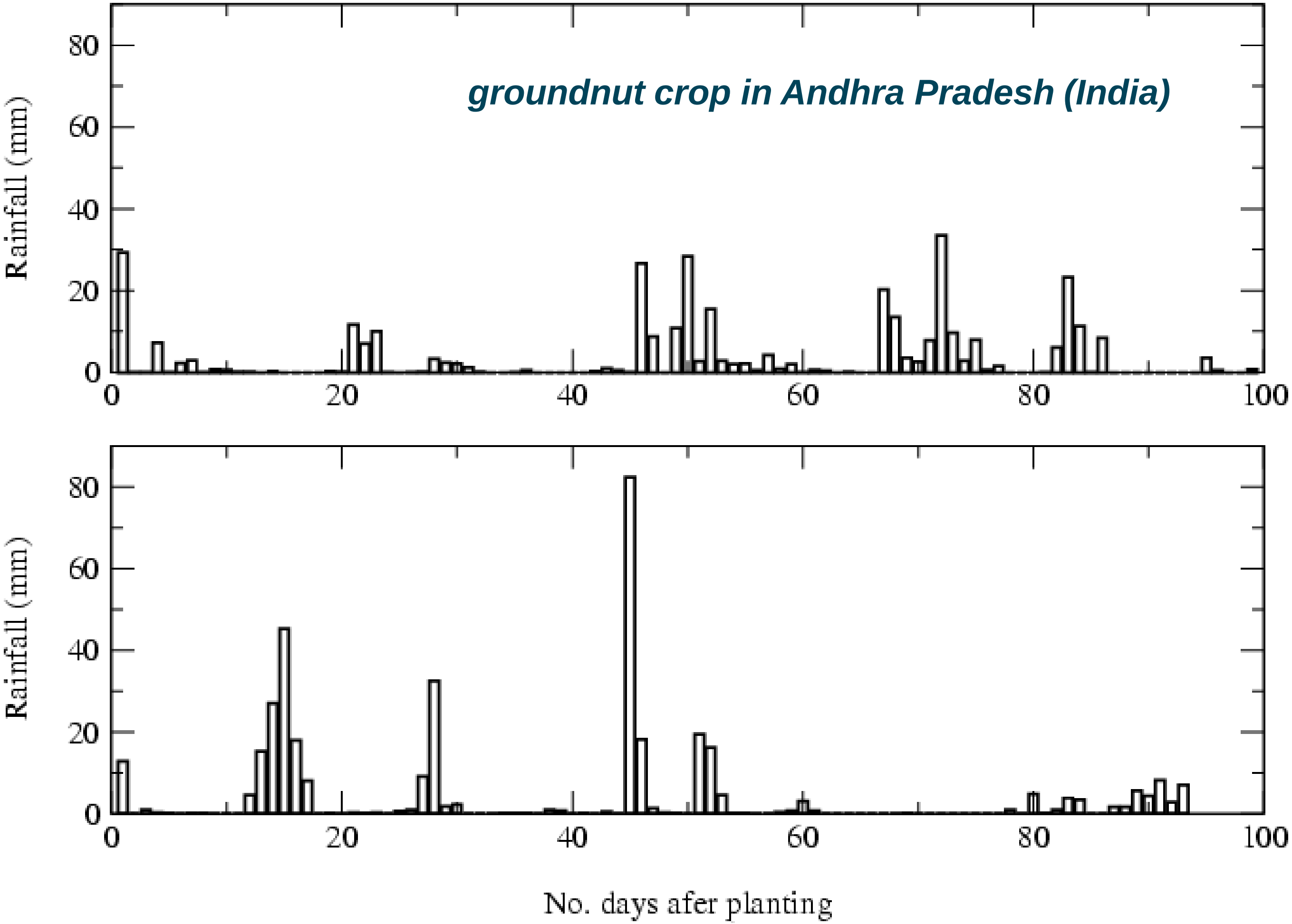
Mutarara District, Mozambique, 22 February 2007



headwater of River Limpopo, NE Botswana

crop productivity & soil moisture

- more variable rainfall leads to more variable soil moisture reducing crop yields and/or increasing irrigation requirements



1975
Total rainfall: 394mm
Yield = 1360 kg/ha

1981
Total rainfall 389mm
Yield = 901 kg/ha

Challinor et al. 2006. "Avoiding Dangerous Climate Change", pp. 187-194.

- **intensification of precipitation as a result of global warming favours groundwater recharge in the tropics**

Taylor and Howard (1996) J. Hydrol. Vol. 180, 31-53.
Owor et al. (2009) Environ. Res. Lett. Vol. 4, 035009.
Taylor et al. (2013) Nat. Clim. Change 3: 374-378.
Jasechko and Taylor (2015) Environ. Res. Lett. Vol. 10, 124015.

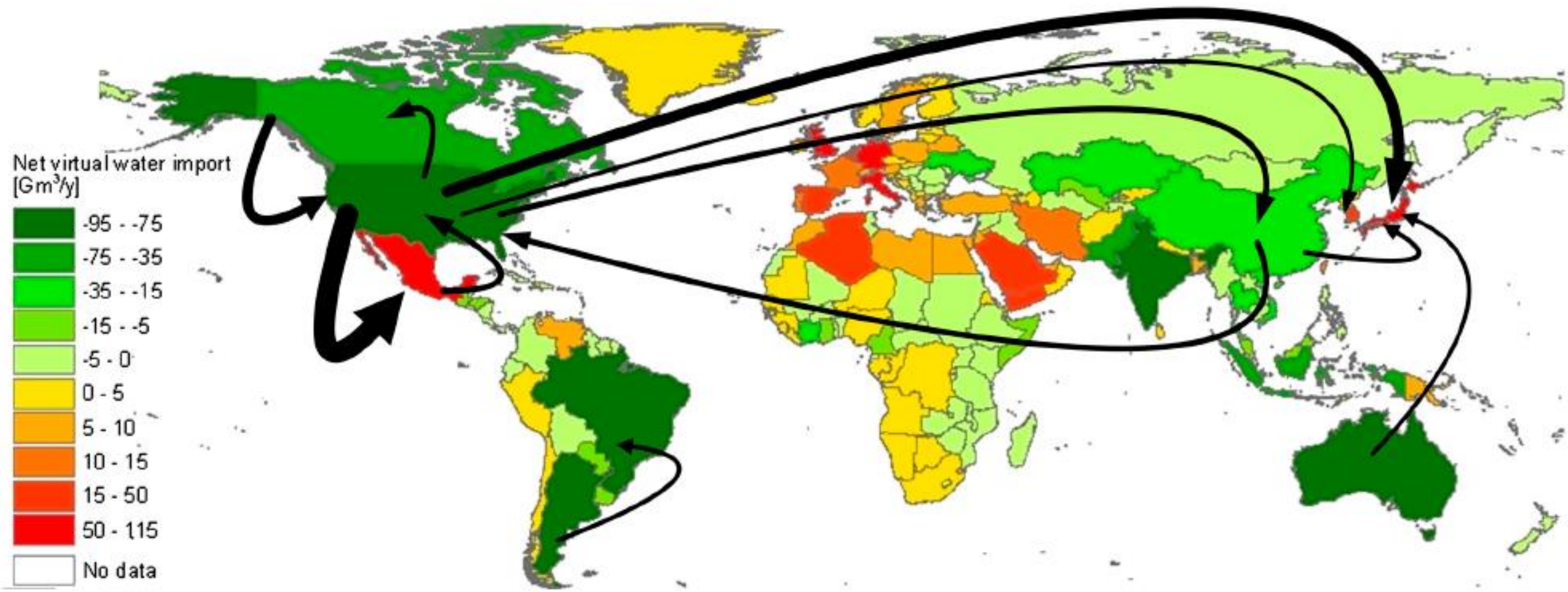
irrigation of Boro rice (Bangladesh)

“Virtual Water” trade?

- water embedded in food (& other commodities)
  kilo of wheat: 1100 litres
  kilo of rice: 2300 litres
  kilo of maize: 900 litres

- address water scarcity through the importation of food from “**water-sufficient**” countries to “**water-scarce**” countries?

global *virtual water* trade flows



Hoekstra and Mekonnen (2012) Proc. Nat Acad. Sci. Vol. 109, 3232-3237.

- **green:** (net) virtual water flows out
- **red:** (net) virtual water flows in
- trade often from ‘water-scarce’ to ‘water-sufficient’

Concluding messages:

- global water crisis is inadequately defined by both models and metrics
- ‘water scarcity’ is unrelated to ‘access to safe water’
- groundwater represents both a key constraint to global food production (depletion, quality) and a key opportunity to adapt to climate change
- addressing water scarcity through trade in ‘virtual water’ not yet realised


Thanks for listening!
Victoria Falls