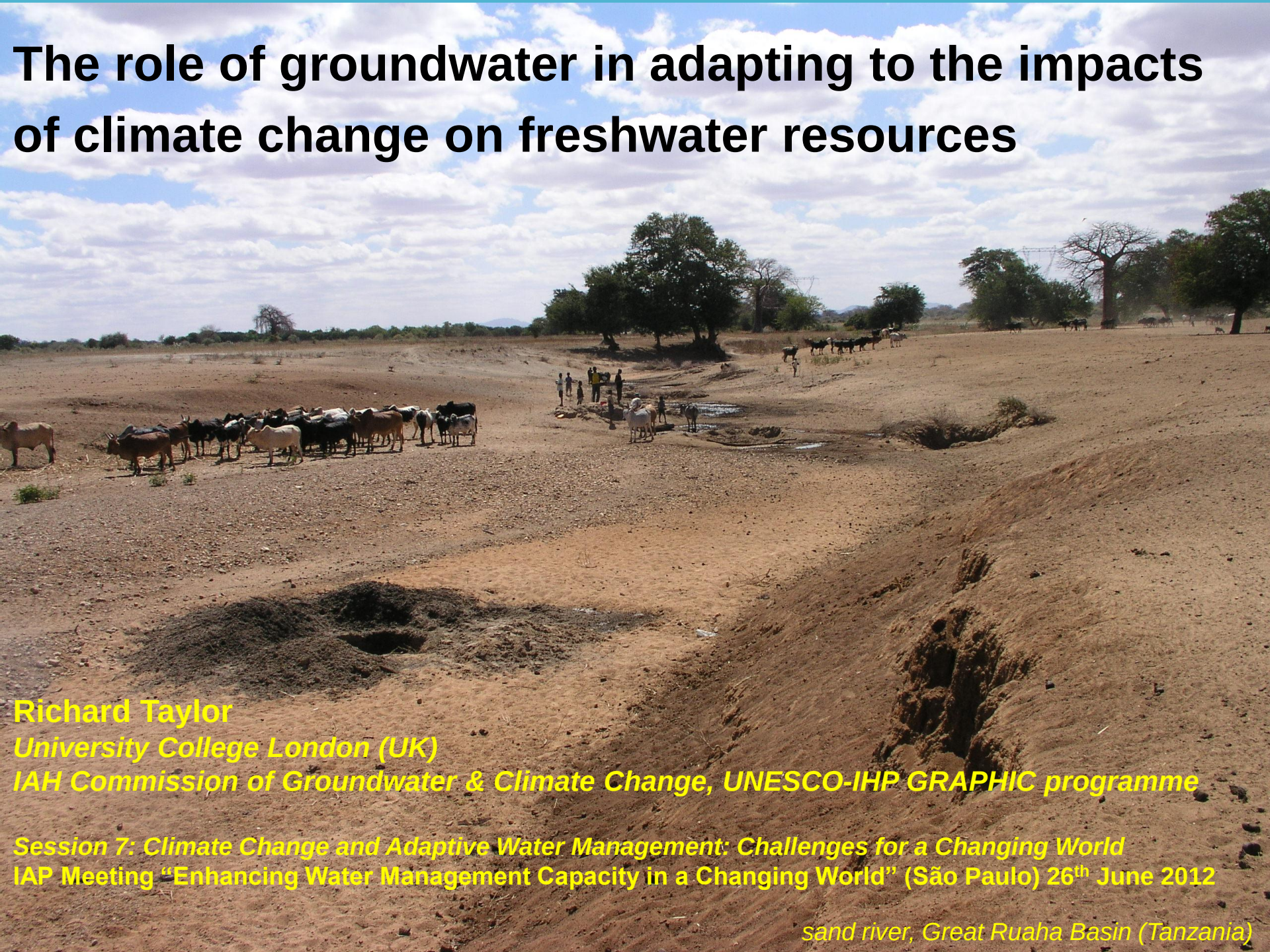
The role of groundwater in adapting to the impacts of climate change on freshwater resources



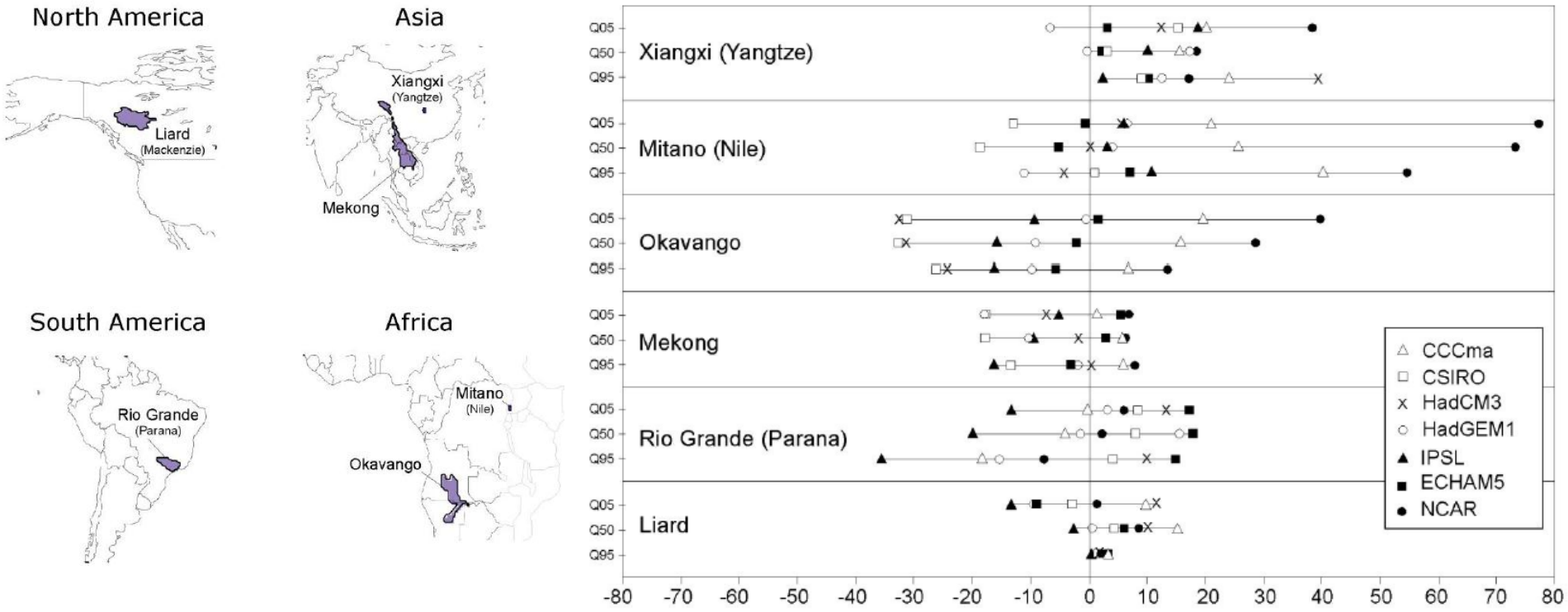
Richard Taylor
University College London (UK)
IAH Commission of Groundwater & Climate Change, UNESCO-IHP GRAPHIC programme

Session 7: Climate Change and Adaptive Water Management: Challenges for a Changing World
IAP Meeting "Enhancing Water Management Capacity in a Changing World" (São Paulo) 26th June 2012

sand river, Great Ruaha Basin (Tanzania)

uncertainty in water resources projections

- multi-model evaluations of climate change on river discharge reveal consensus in neither the magnitude nor direction of impacts



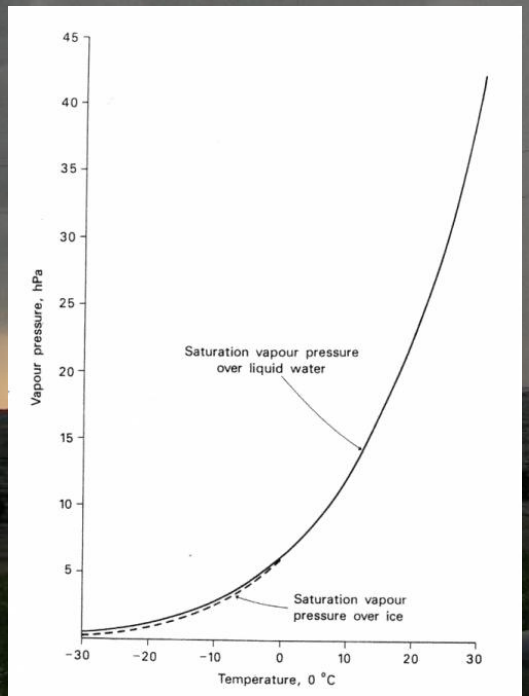
Todd et al., 2011. Hydrology and Earth System Sciences, Vol. 15, 1035-1046.

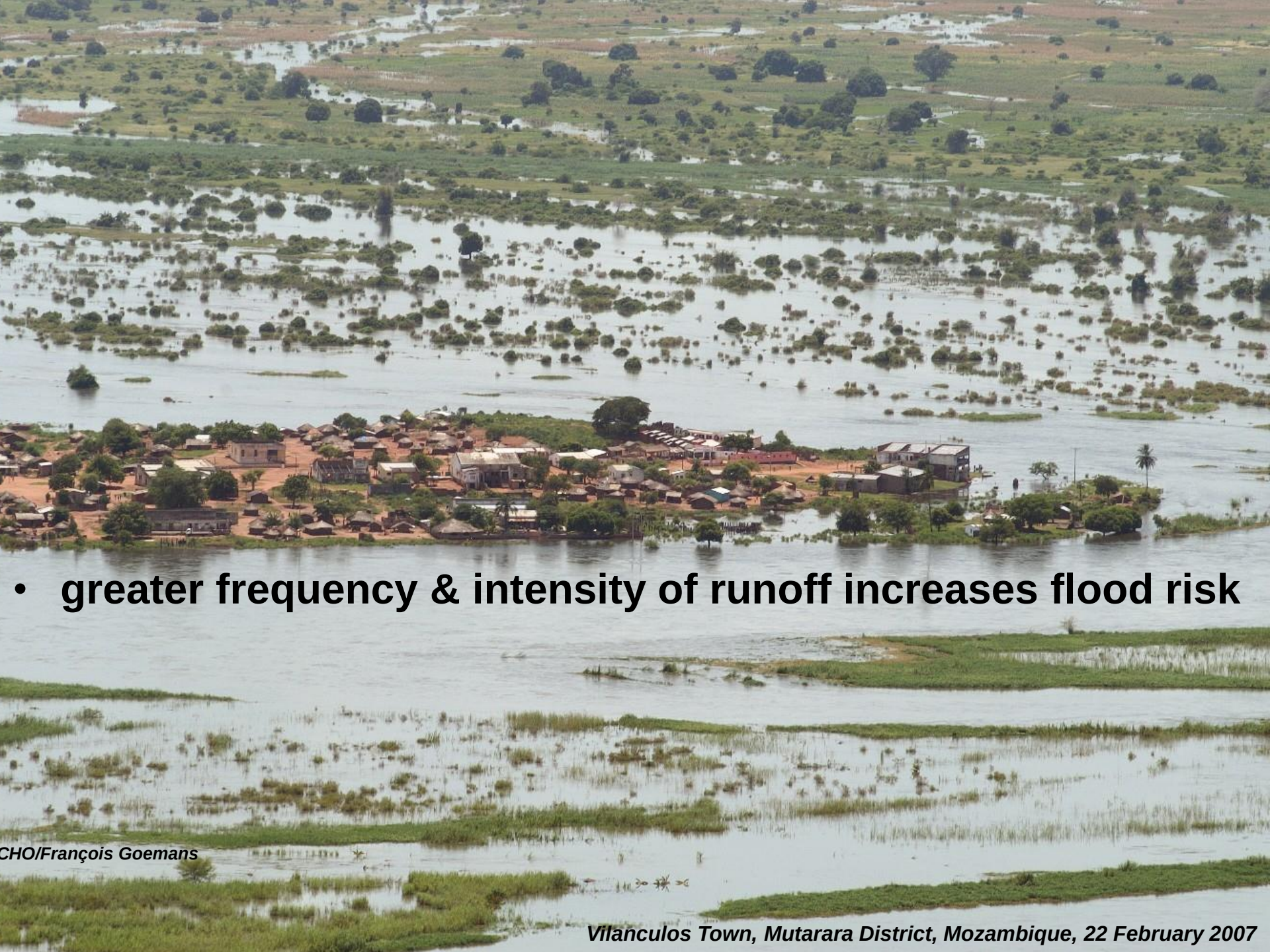
intensification of precipitation under climate change

- **fewer,** low and medium intensity precipitation events
- **more,** very heavy precipitation events (*i.e.*, "extreme events")

Allan & Soden, 2008. Science 321: 1481-1484.

"***It is likely that the frequency of heavy precipitation… will increase in the 21st century over many areas of the globe. This is particularly the case in… tropical regions***" *IPCC SREX (p. 10, 18 November 2011)*





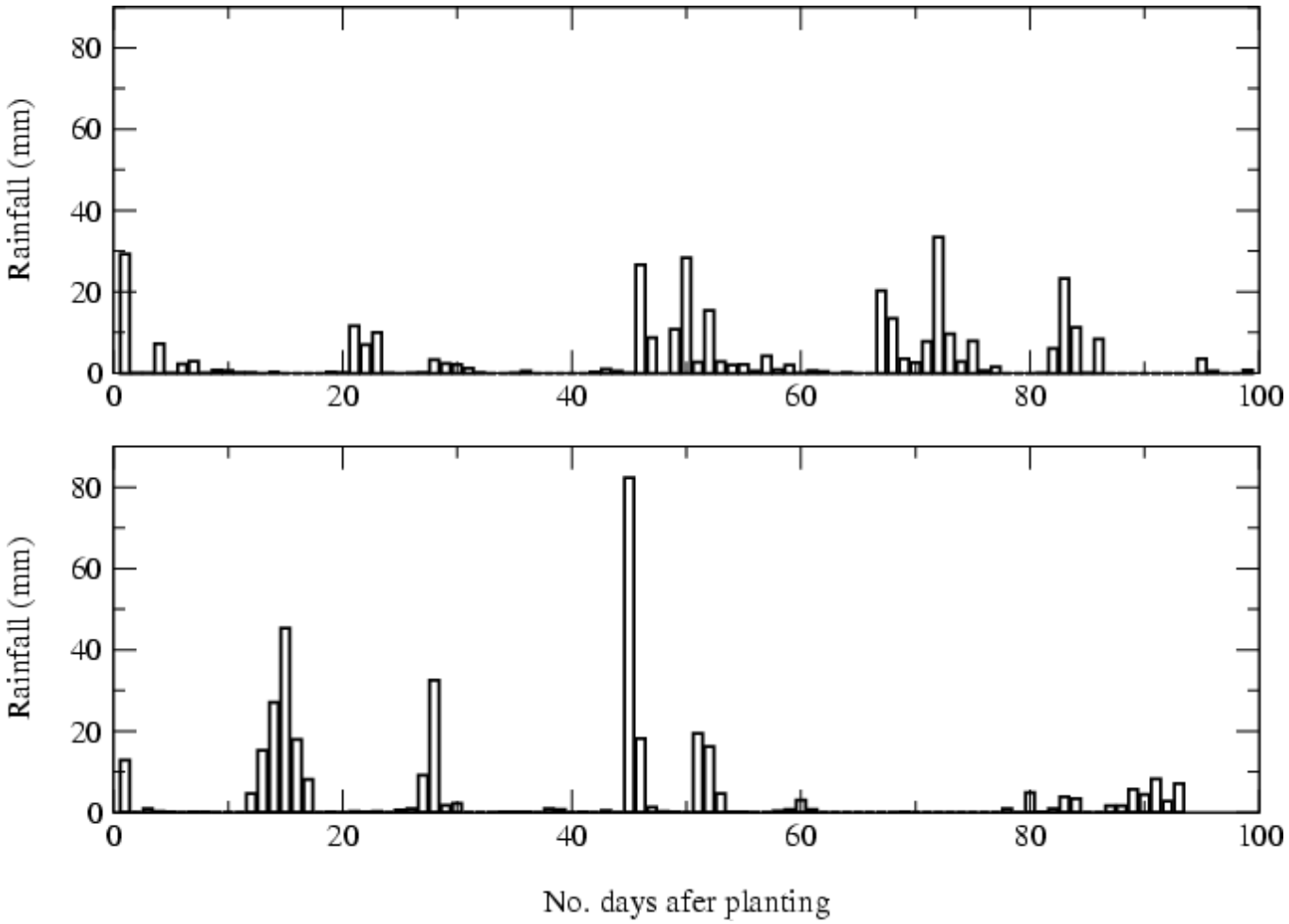
- **greater frequency & intensity of runoff increases flood risk**

CHO/François Goemans

Vilanculos Town, Mutarara District, Mozambique, 22 February 2007

intensification of rainfall & soil moisture

more variable precipitation lowers soil moisture reducing crop yields - *groundnut crop in Andhra Pradesh*



1975

Total rainfall: 394mm

Yield = 1360 kg/ha

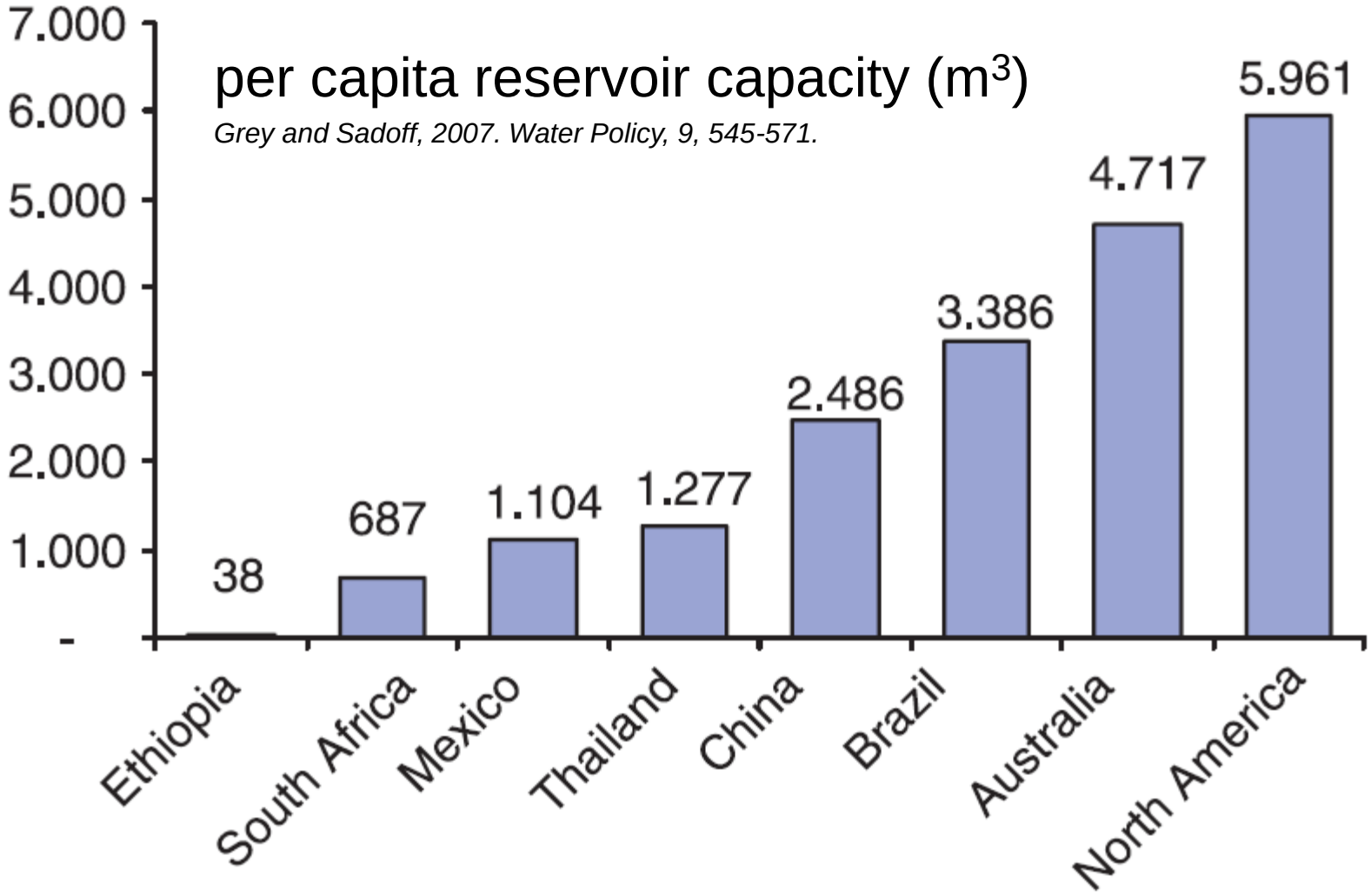
1981

Total rainfall 389mm

Yield = 901 kg/ha

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

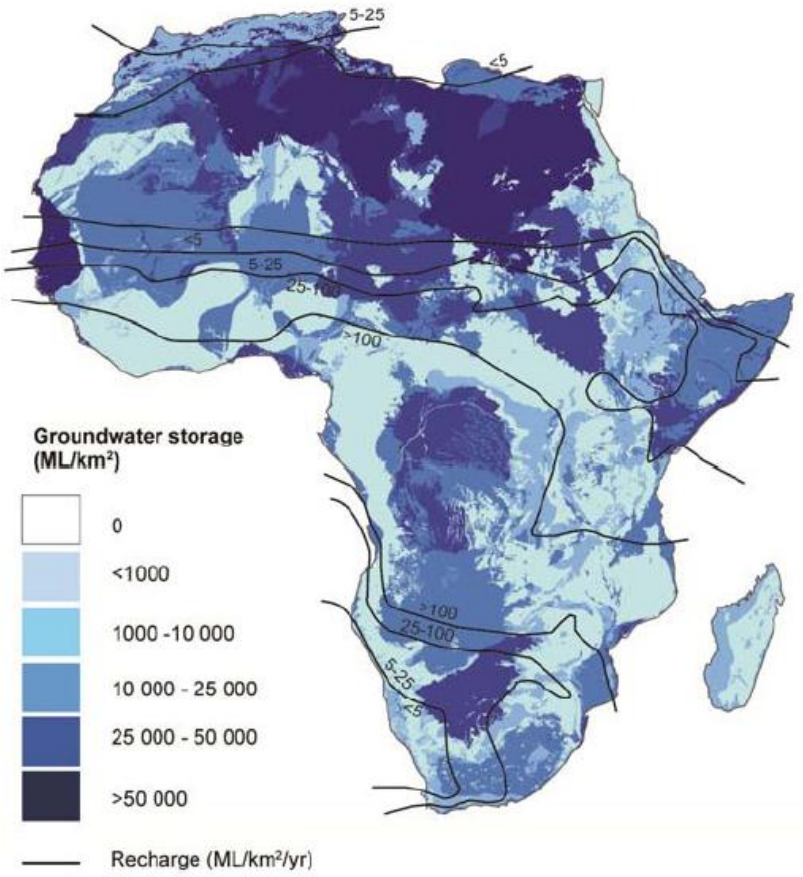
resilience and water storage

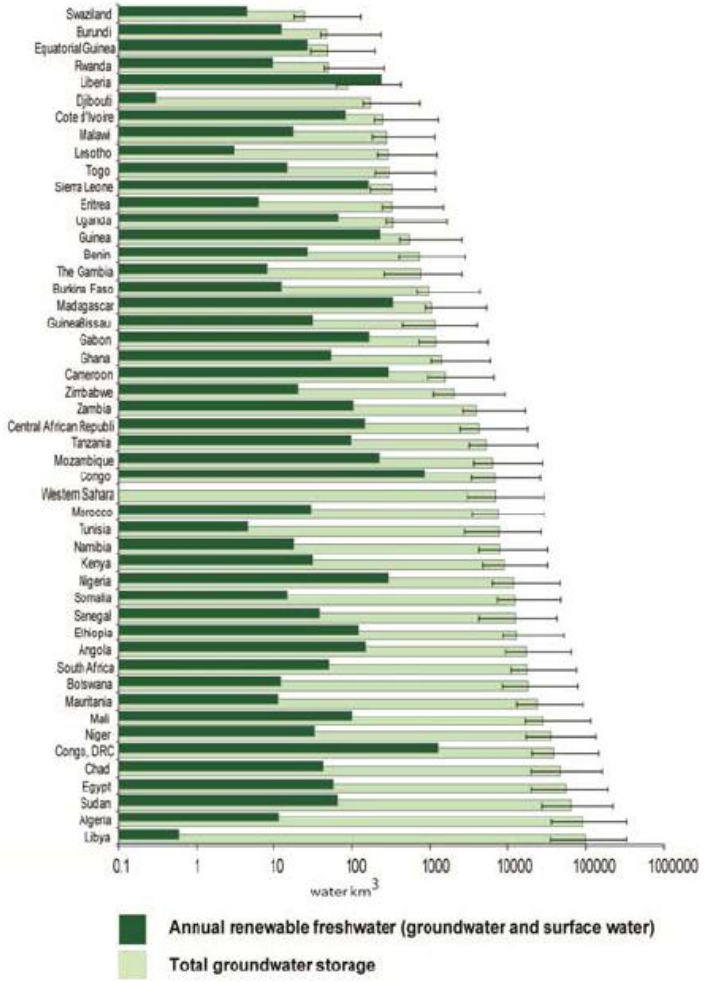


- resilience of nations to climate variability has been related to their capacity to store freshwater

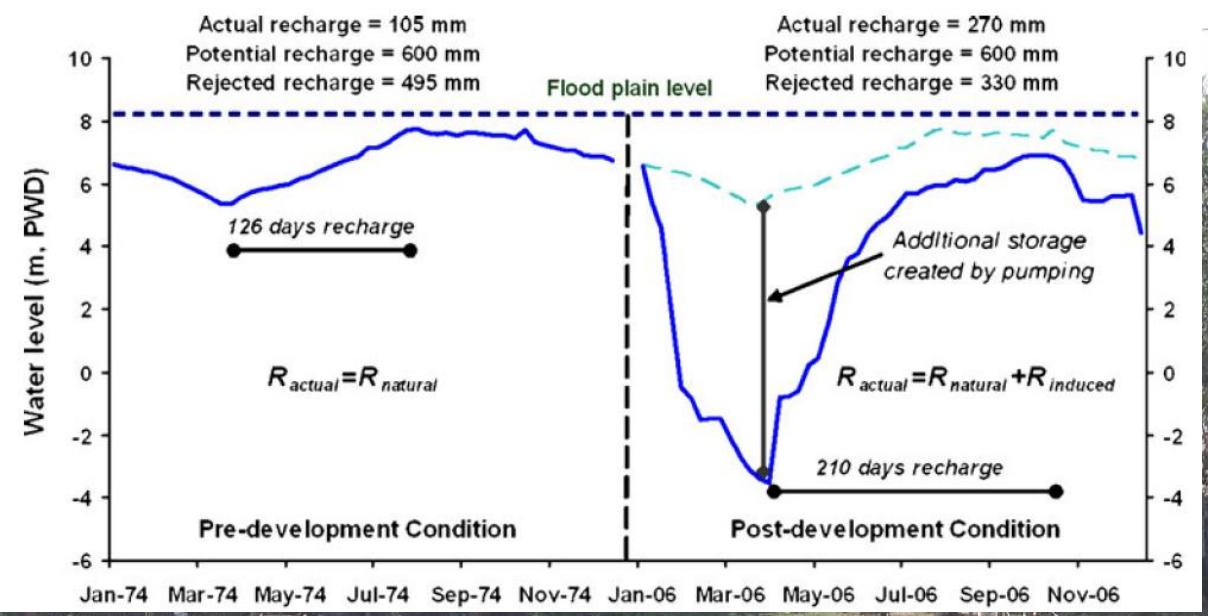
natural groundwater storage

- distributed nature of groundwater storage, *far in excess of river discharge in Africa,* provides resilience to variable and changing climates





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



Shamsudduha et al., 2011. Hydrogeology Journal, Vol. 19, 901-916.

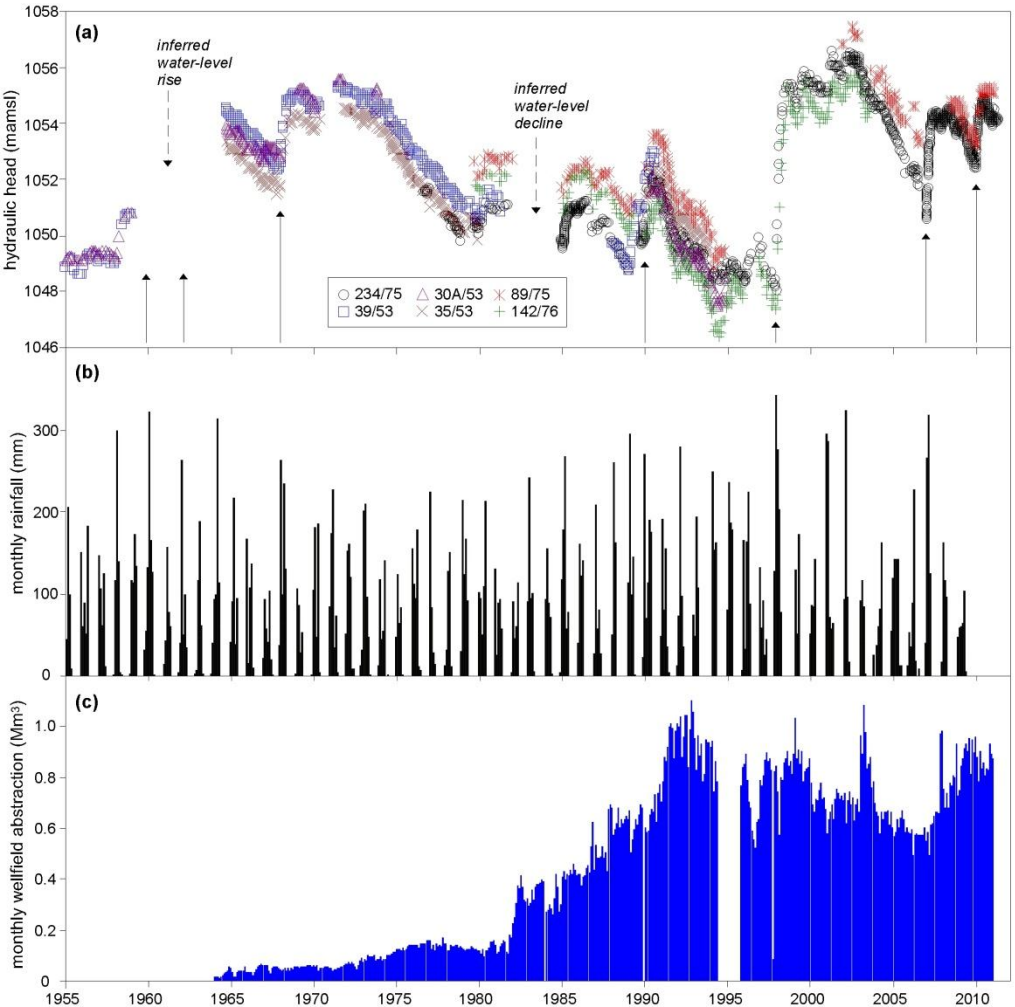
use of natural groundwater storage sustainably supports food security in South Asia

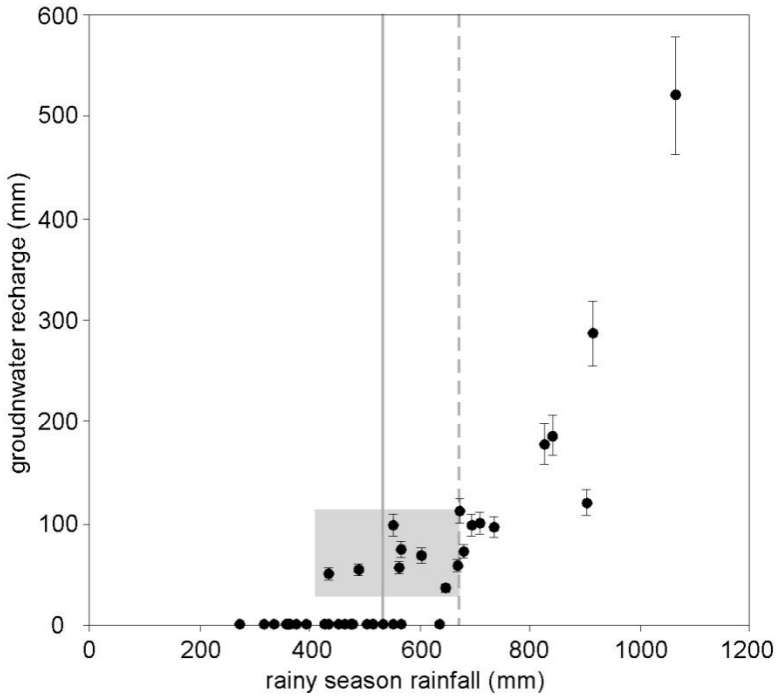
groundwater-fed irrigation of Boro rice (Bangladesh)

intensification of rainfall & recharge

- more intensive rainfall observed to favour groundwater recharge





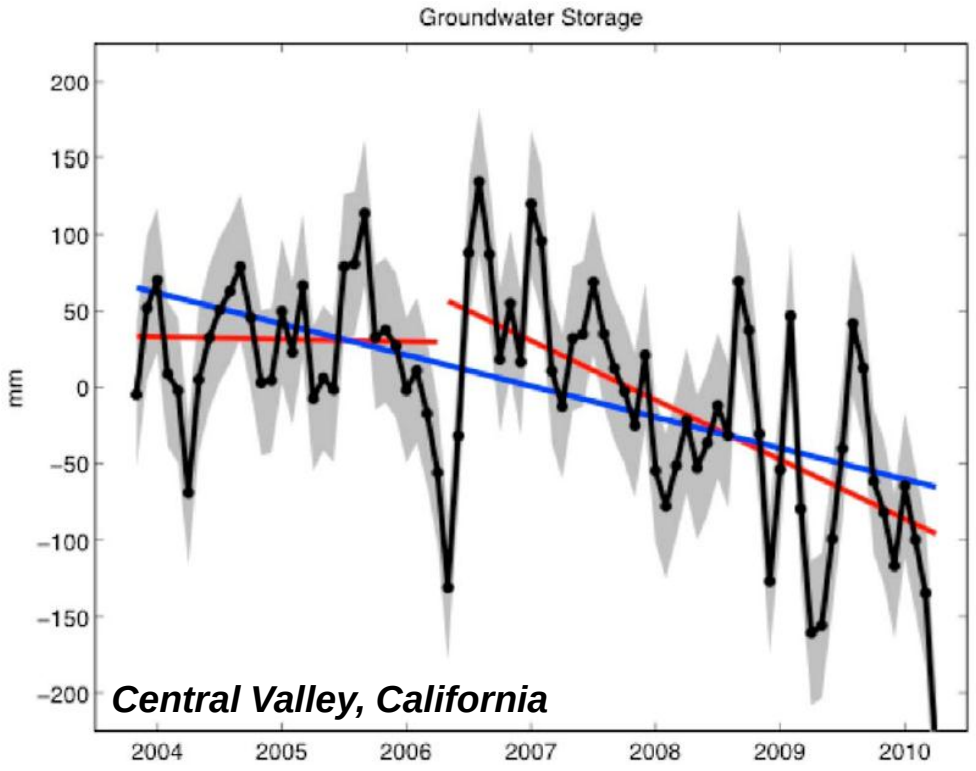


Taylor et al., in review. Nature Climate Change

groundwater depletion in some areas

- increased dependency upon groundwater is not a universal climate change adaptation strategy

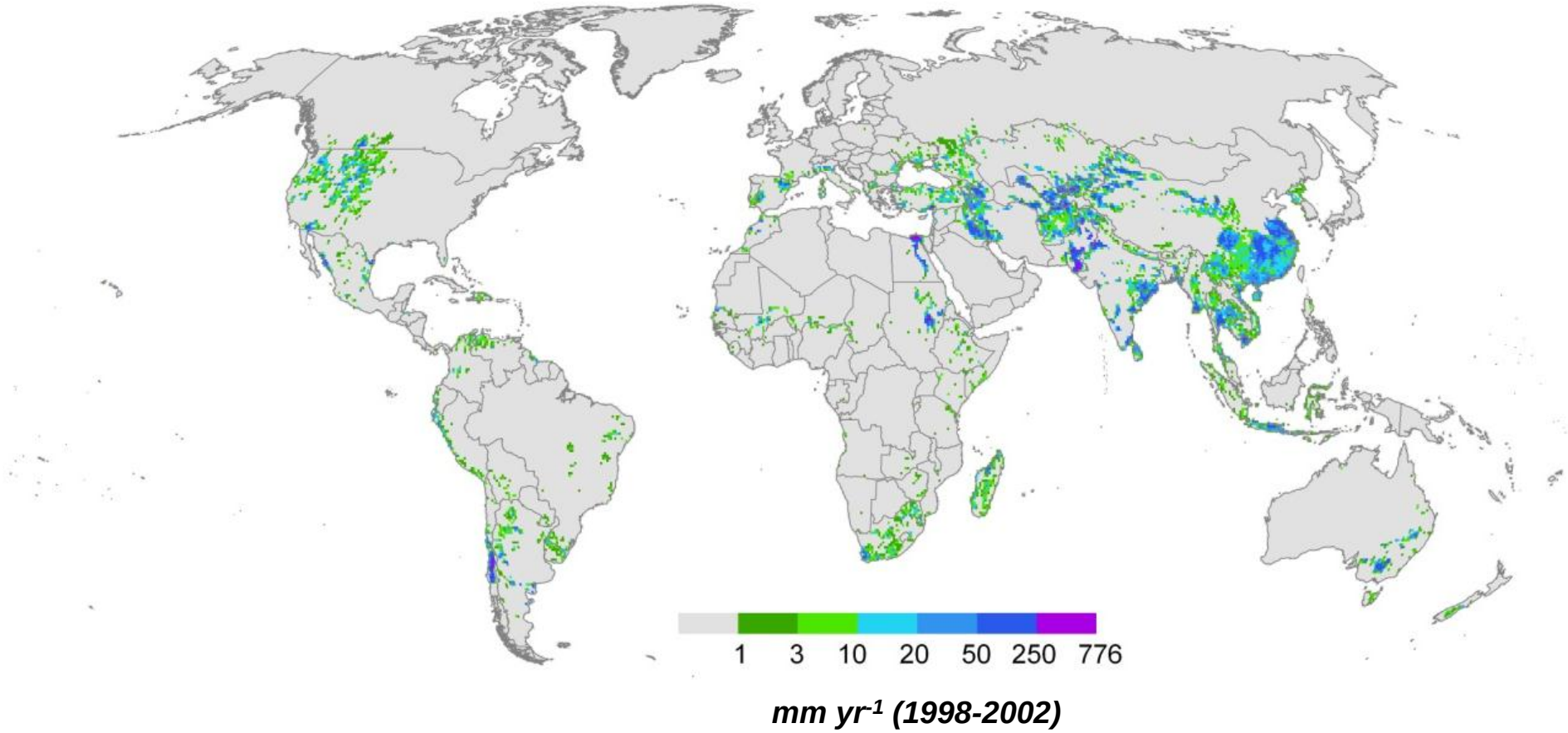
- groundwater depletion detected from satellite and *in situ* data in:
  - California (USA)
  - North China Plain
  - High Plains (USA)
  - Dhaka, Bangladesh



Famiglietti et al., 2011. Geophysical Research Letters Vol. 38, L03403.

groundwater accumulation in other areas

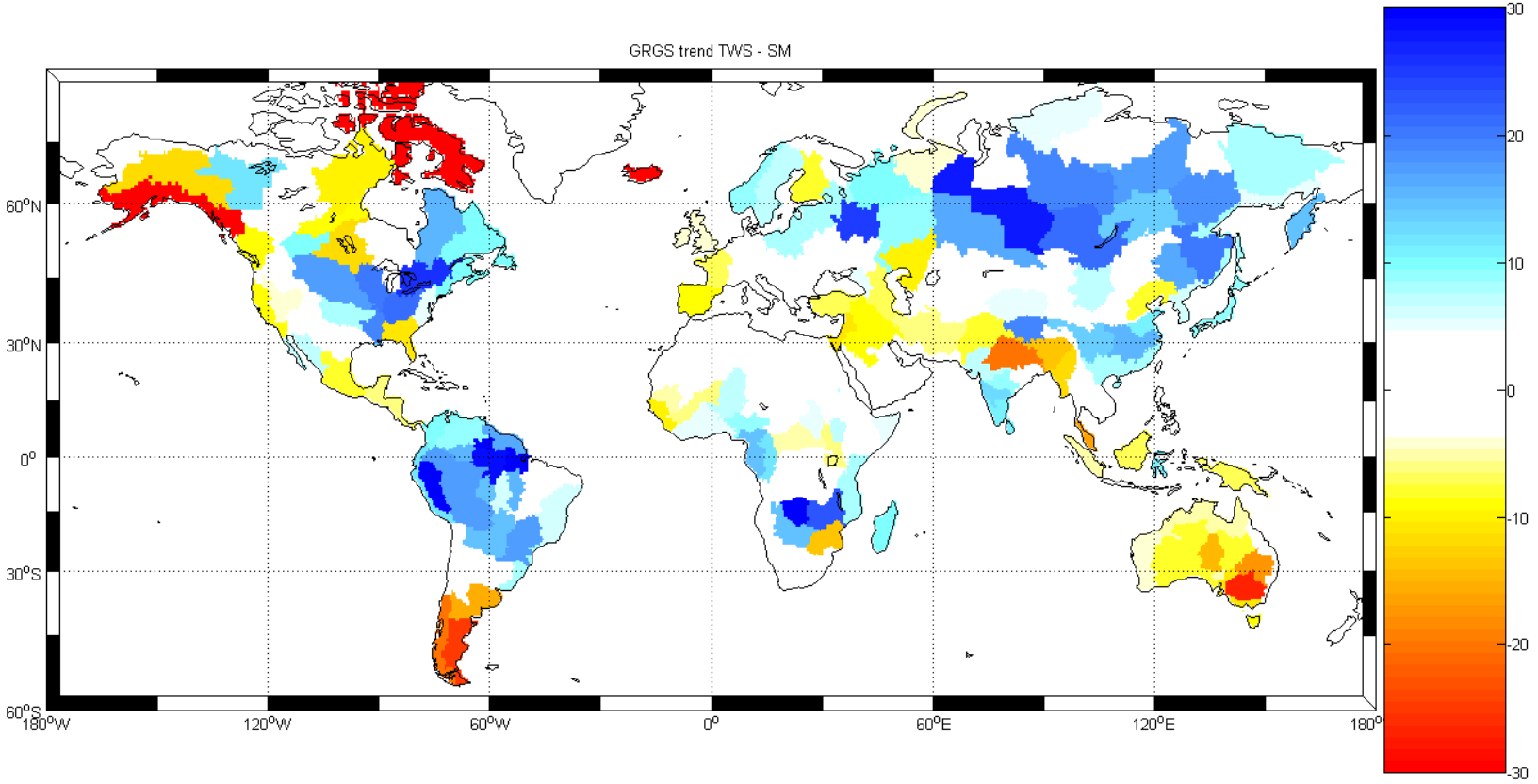
- return flows from irrigation water also estimated to exceed groundwater withdrawals in some areas increasing groundwater storage



Döll et al. (in press). Journal of Geodynamics

global trends in natural water storage

- satellite (GRACE) data provide large-scale, aggregate changes in terrestrial water storage but require in situ observations to constrain and resolve these

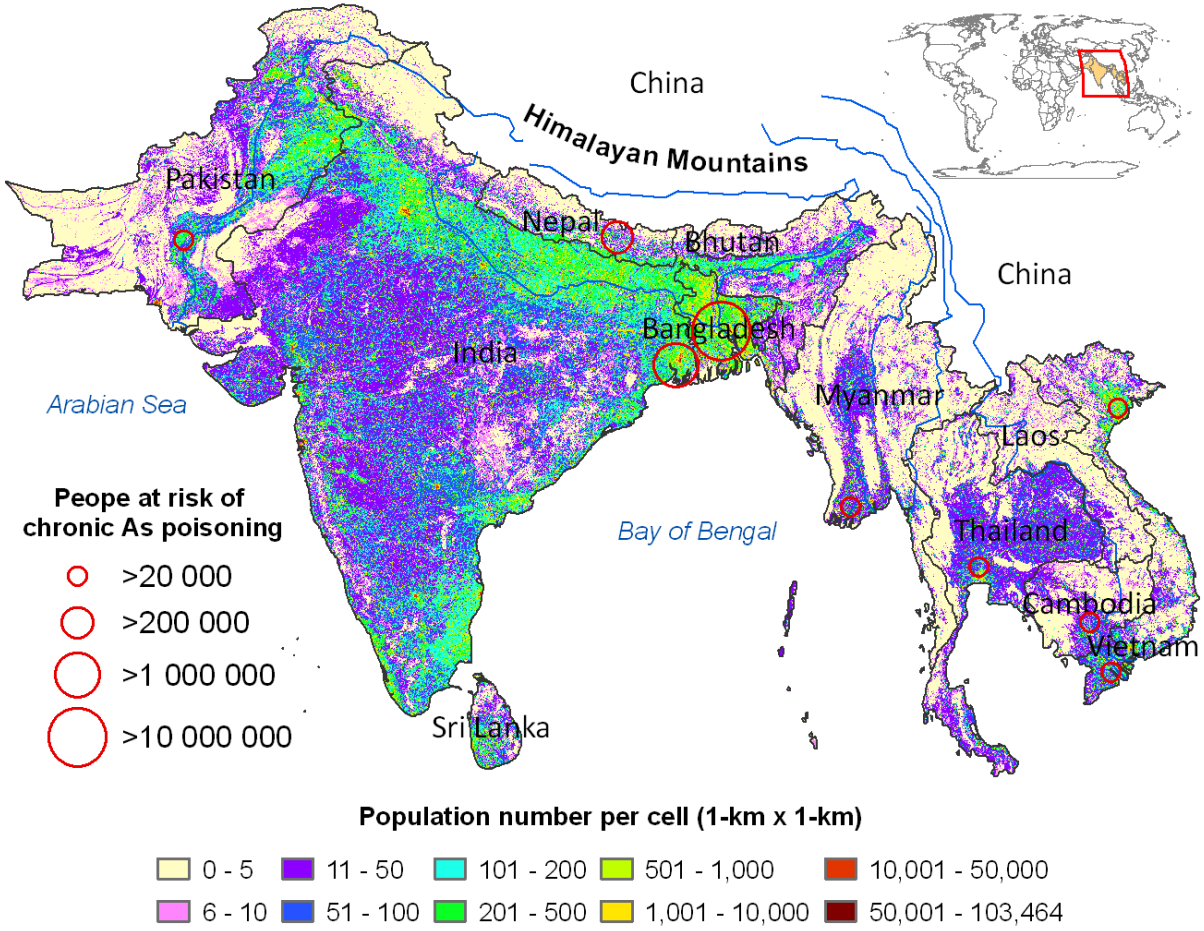


recent (2002-2008) mean trends in basin water storage (mm year^{-1}) in basin-scale groundwater, snow/ice and surface water

Taylor et al. (in preparation)

groundwater quality

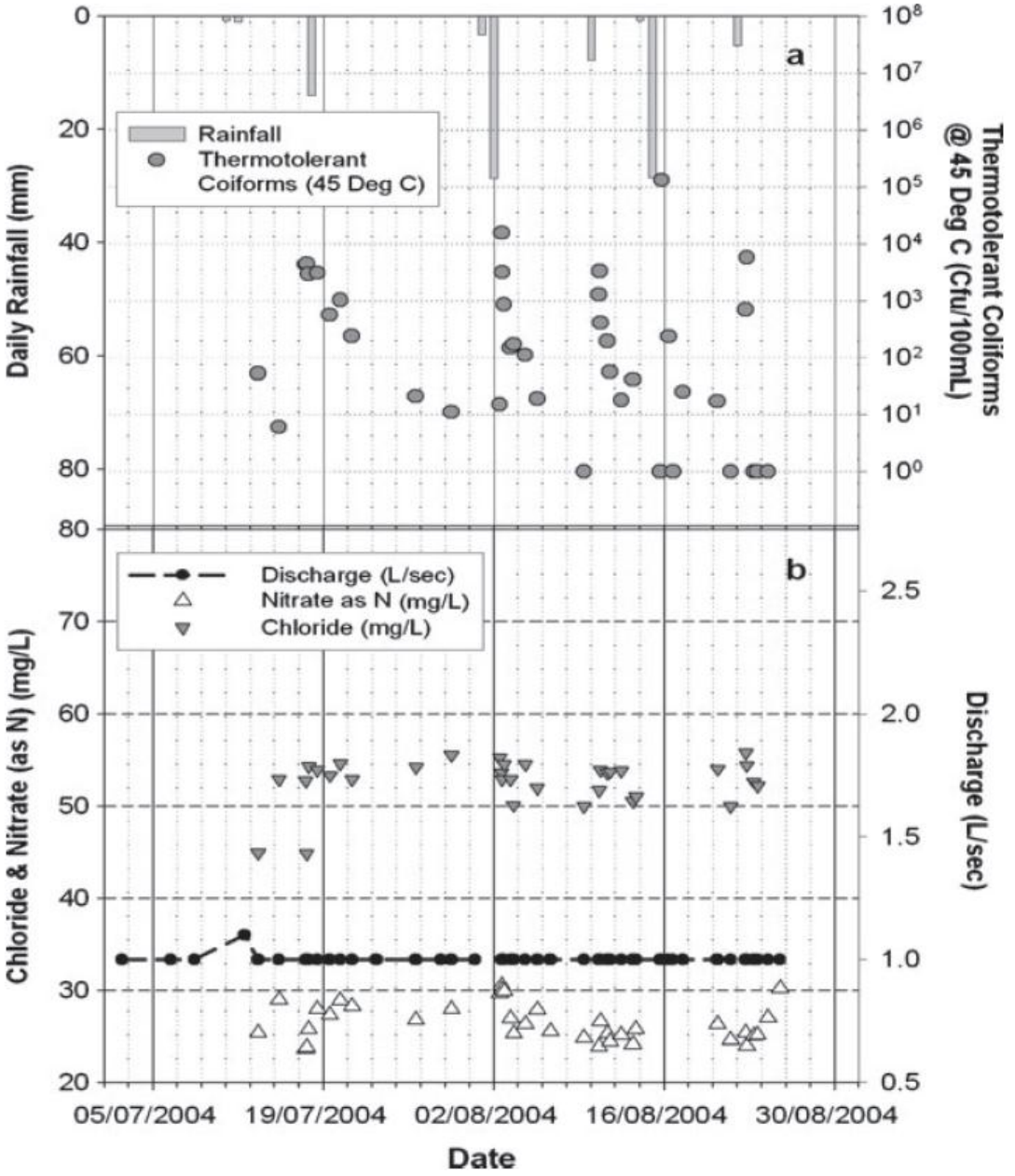
- chemical contamination (e.g. As, F) constrains groundwater use in some environments



Shamsudduha et al. (in review). Nature Geoscience

groundwater quality & climate change

- vulnerability of urban groundwater to episodic contamination from heavy rainfalls flushing inadequately contained faeces
- substantial nitrate contamination from sewage effluent



Flynn et al. (2012). Water, Air & Soil Poll., doi:10.1007/S11270-011-1033-0



- Groundwater supplies 50% of the world's drinking water *Kundzewicz & Döll, 2009. Hydrological Sciences Journal Vol. 54, 665-675.*

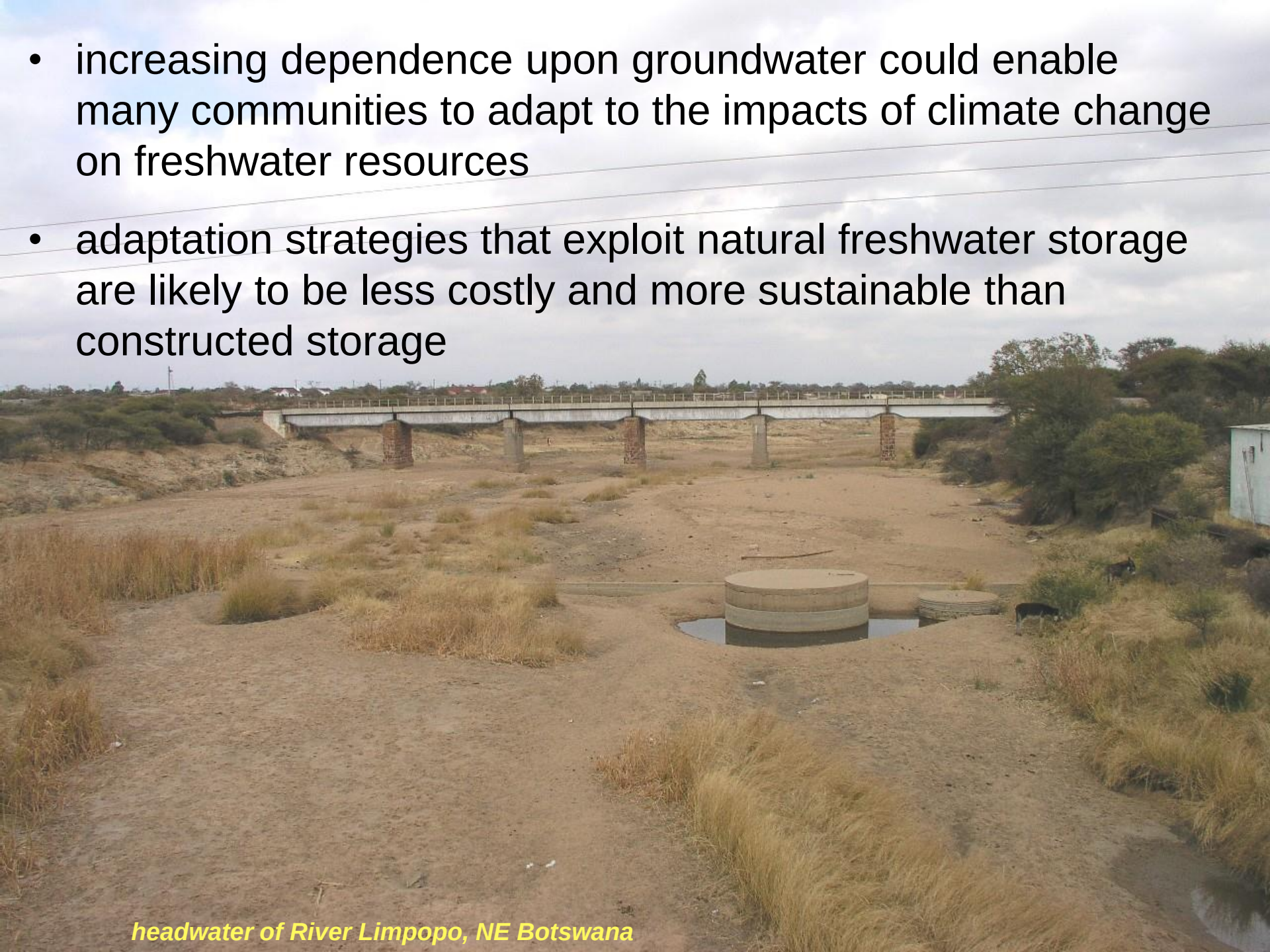
collecting water from a spring in Kampala



- groundwater supplies 42% of the water used globally in irrigation *Siebert et al., 2010. Hydrology & Earth System Sciences Vol. 14, 1863-1880.*

groundwater-fed pivots, Katwe (Zambia)

- increasing dependence upon groundwater could enable many communities to adapt to the impacts of climate change on freshwater resources
- adaptation strategies that exploit natural freshwater storage are likely to be less costly and more sustainable than constructed storage



headwater of River Limpopo, NE Botswana

groundwater for drinking

- despite the well-known potential of groundwater to increase access to safe water…



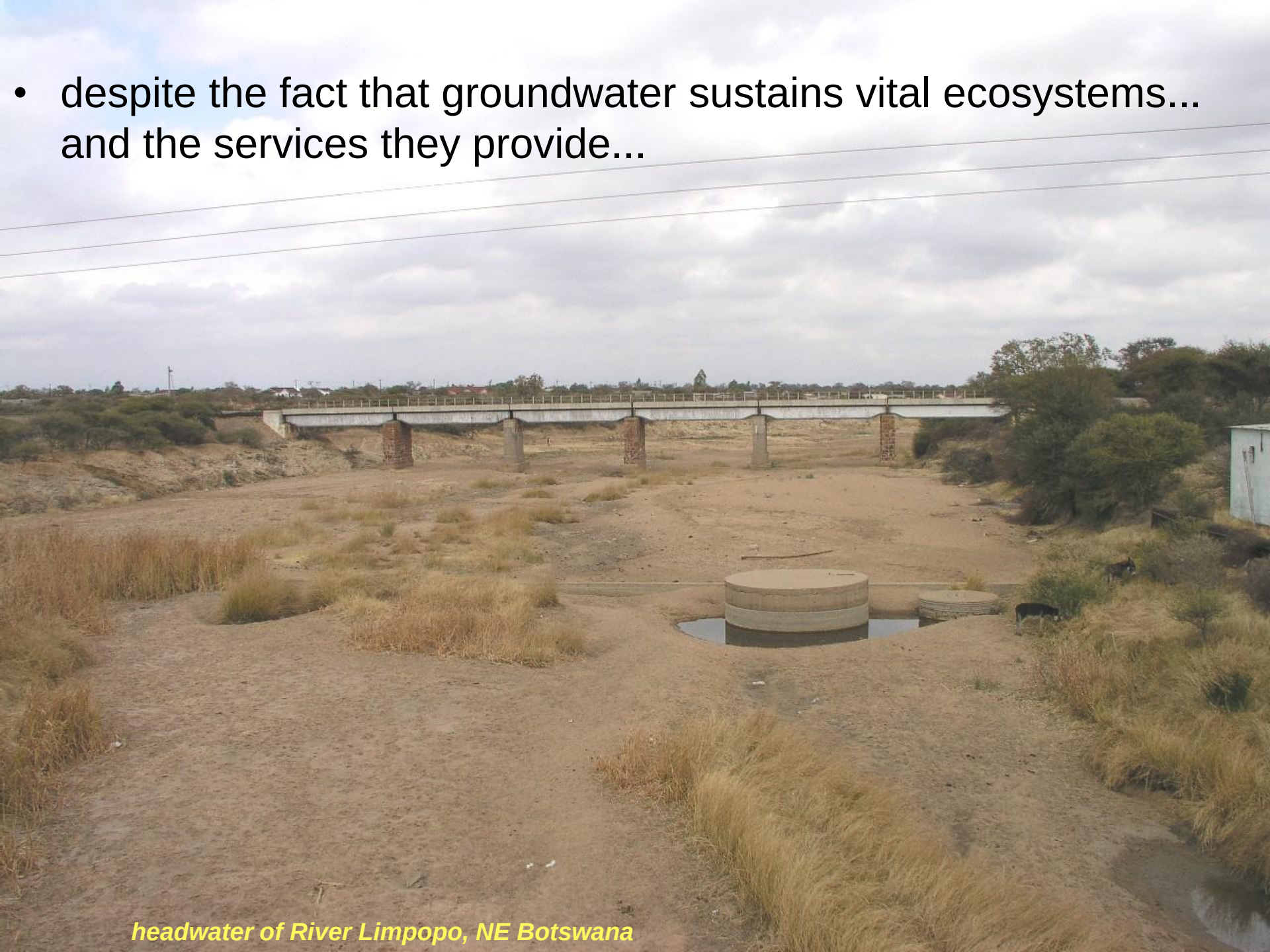
low-yielding well in Mbarara, Uganda

food security & poverty alleviation

- despite the potential of groundwater to sustain small-scale irrigation and thereby improve food security and household incomes… ("*The Kampala Statement*", **www.gwclim.org**)



- despite the fact that groundwater sustains vital ecosystems... and the services they provide...



headwater of River Limpopo, NE Botswana

- there is currently minimal investment in monitoring, data collation, and research to resolve the dimensions, characteristics and capacity of the groundwater store around the world



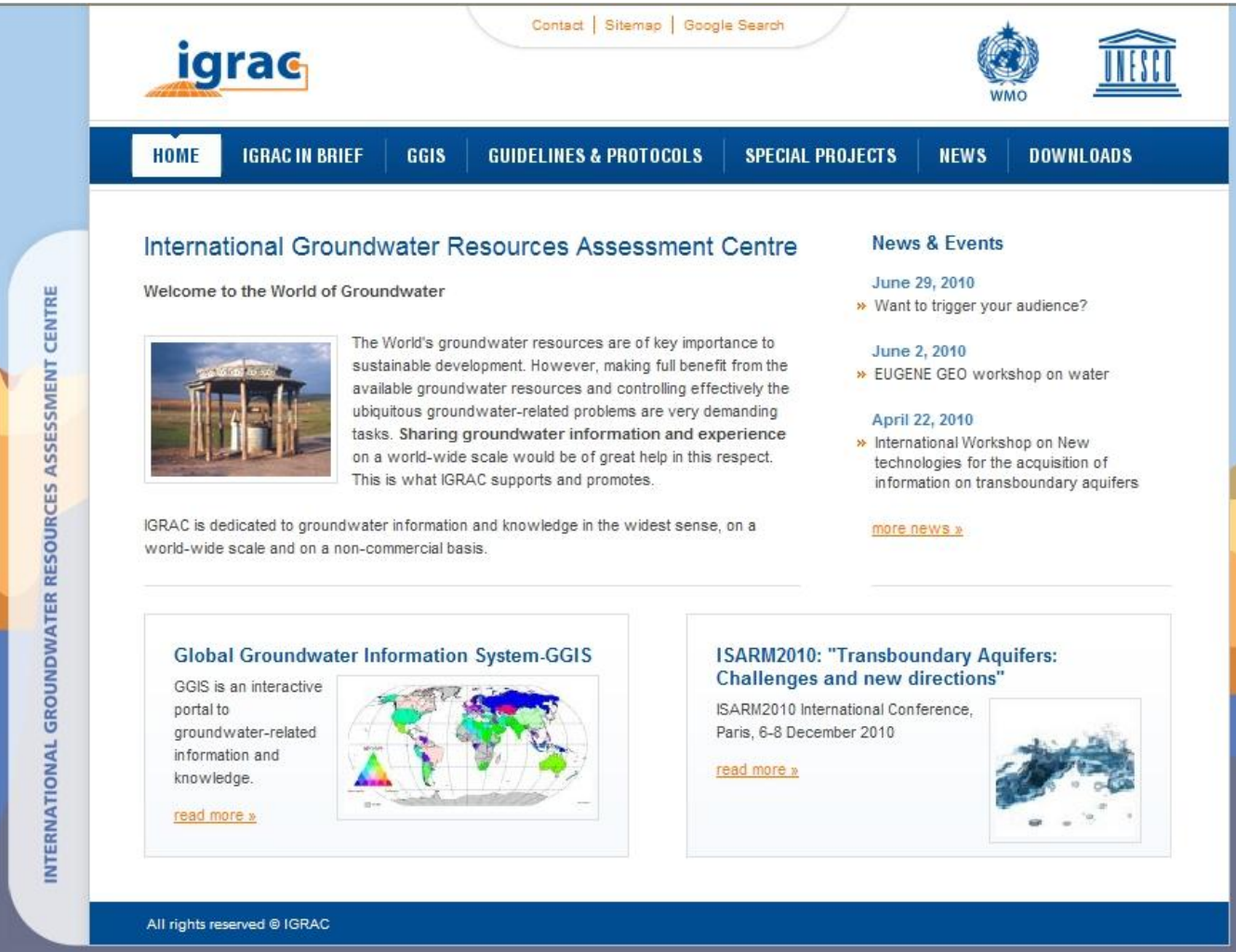
Makutapora Wellfield, Dodoma (Tanzania)

groundwater data

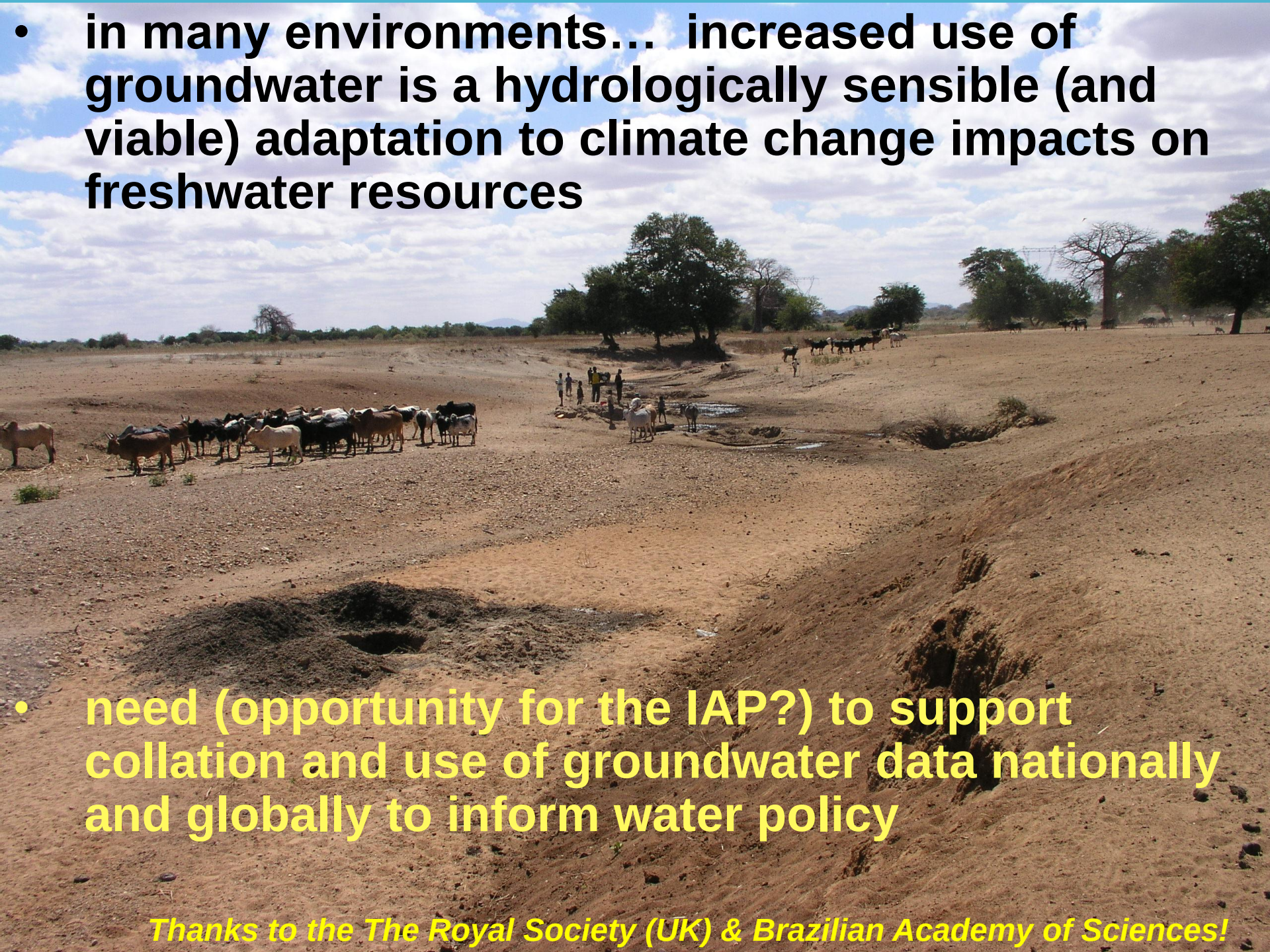
- data often exist yet there is no global programme (unlike precipitation and river flow) to colllate groundwater data



There is a global “bank” but very little income.



- **in many environments… increased use of groundwater is a hydrologically sensible (and viable) adaptation to climate change impacts on freshwater resources**

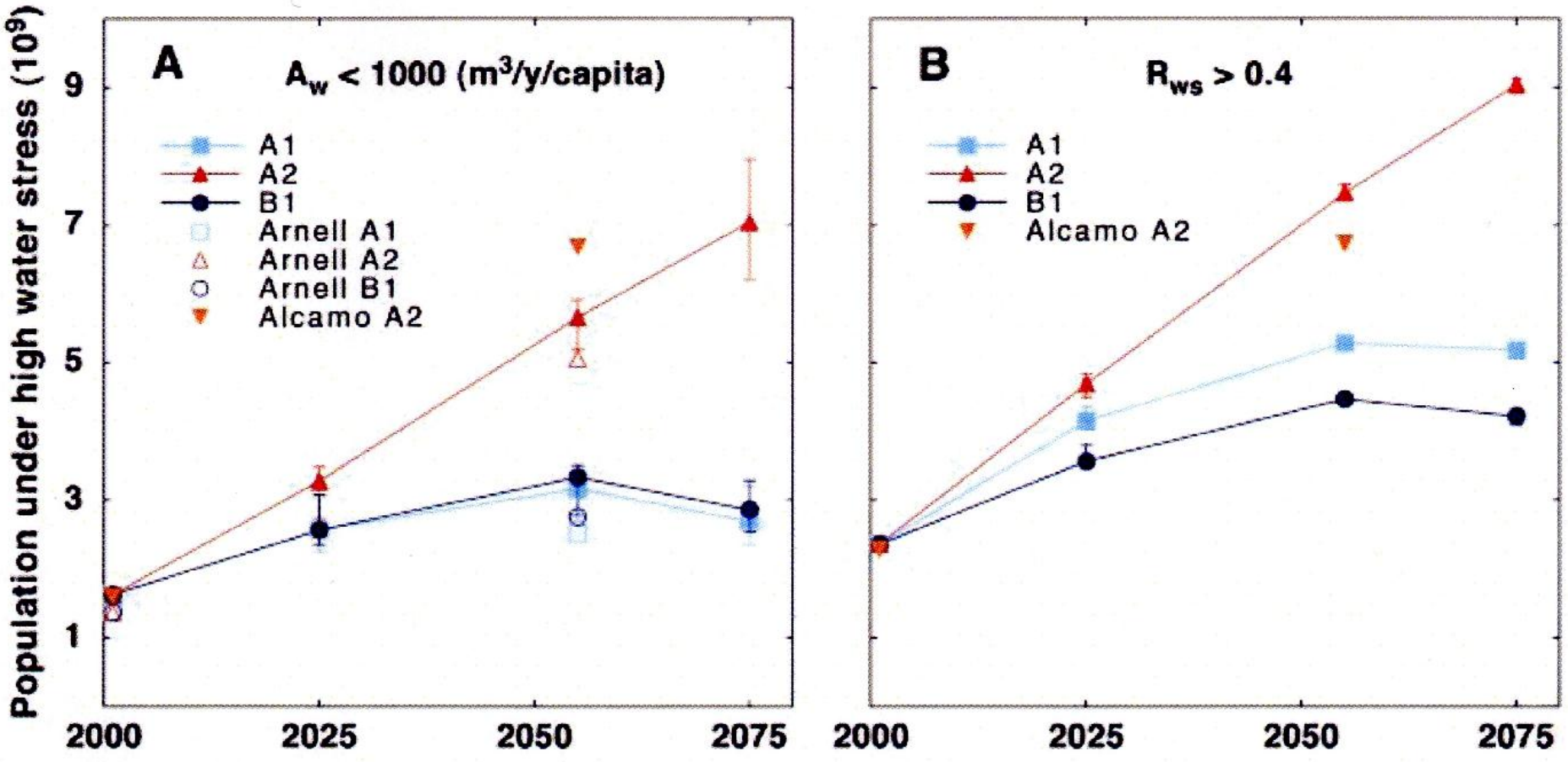


- **need (opportunity for the IAP?) to support collation and use of groundwater data nationally and globally to inform water policy**

Thanks to the The Royal Society (UK) & Brazilian Academy of Sciences!

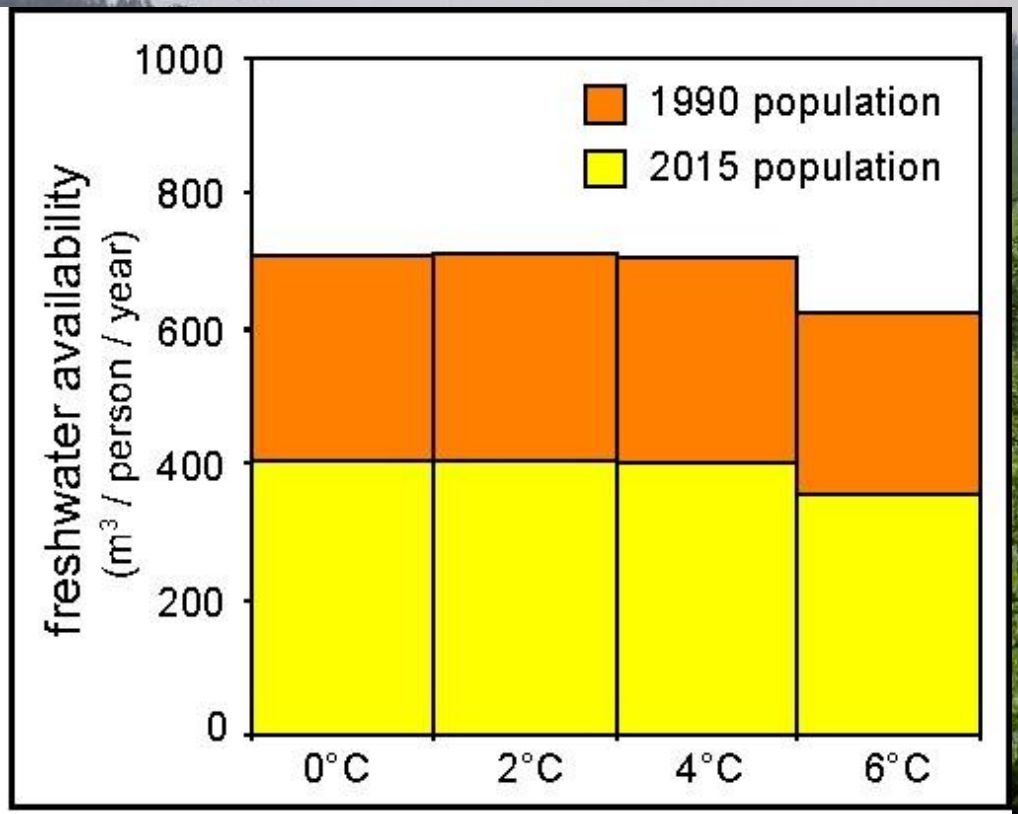
global water crisis (projected)

- projections of water scarcity defined in terms of mean annual river runoff and a fixed per capita demand



Oki & Kanae (2006) Science, 313, 1068-1072.

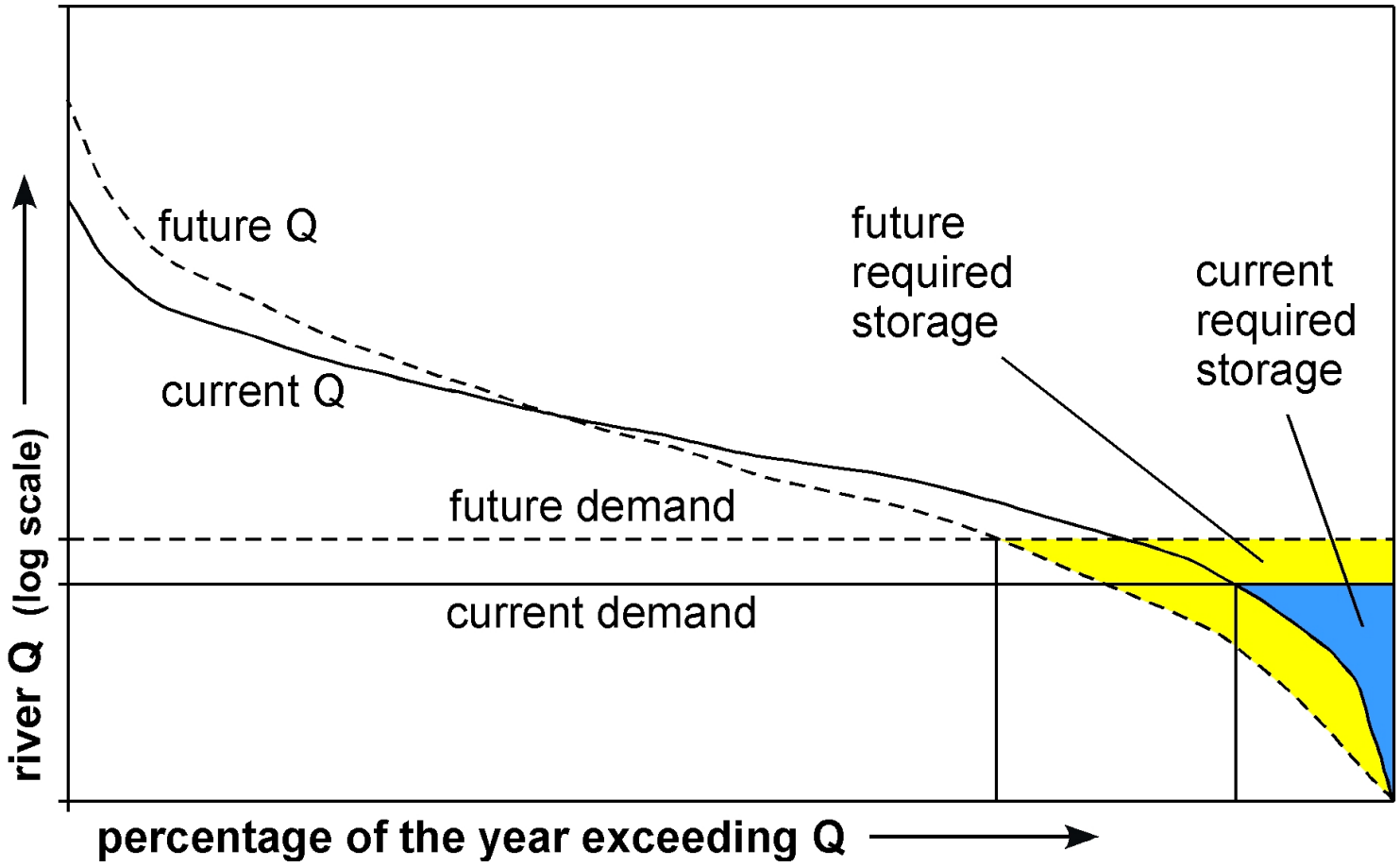
- fixed per capita demand of 1000 m^3 $year^{-1}$ (central to scarcity metrics) grossly misrepresents use in sub-Saharan Africa currently ranging from 20 to 30 m^3 $year^{-1}$ leading to pessimistic projections of water scarcity



matoke and tea growing in Bushenyi, Uganda

need to redefine water scarcity

- link water scarcity to resilience by defining storage requirements (natural and constructed) from river discharge data



Taylor (2009) EOS 90, 237-238.