Groundwater & Climate Change: opportunities and challenges for water science and adaptation policy

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Groundwater & Climate Change – comparative and international law and policy dimensions
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science overview

• substantial rise in research on direct and indirect impacts of climate forcing and feedbacks between groundwater and climate

• uncertainty
  – not just models but conceptual understanding

• complexity
  – diversity of groundwater-climate interactions

• intractability
  – indirect (climate change) vs direct human activity
palaeohydrological evidence

• “Much of the groundwater flowing in large sedimentary aquifers... was recharged by precipitation thousands of years ago.” deVries et al. (2000); Lehmann et al. (2003); Edmunds et al. (2003); McMahon et al. (2004)

• “…fossil aquifers (in arid environments) are storage dominated” – recharge independent

rock paintings from several thousand years BC in Ghat District of western Libya, within the Sahara Desert
groundwater storage

- low storage systems (e.g. deeply weathered crystalline rock aquifers) are especially climate dependent – requiring regular recharge
direct impacts - precipitation

- historically, timing of recharge related to modes of climate variability historically (e.g. ENSO, PDO)

Gurdak et al. (2012); Taylor et al. (2013)

- projections of diffuse recharge are highly uncertain due to choice of GCM, downscaling, emissions, and recharge model

Döll (2009); Allen et al. (2010); Holman et al. (2011); Stoll et al. (2011); Jackson et al. (2011); Crosbie et al. (2012); Hiscock et al. (2012)
intensification of precipitation under climate change

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


“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)
recharge and hydrological extremes

- in contrast to models, field observations suggest extreme (heavy) rainfall favours groundwater recharge
  - Owor et al. (2009); Favreau et al. (2009); Döll (2009);
  - Crosbie et al. (2012); Taylor et al. (2013)

- more intensive rainfall means longer droughts (more frequent floods) and more variable and lower soil moisture (food security?)

Taylor et al. (2013)
• heavy rainfall events have coincided with pathogenic contamination of groundwater & disease outbreaks

Taylor et al. (2009)
direct impacts – snow & ice

• “.. changes in snowmelt regimes tend to reduce the seasonal duration and magnitude of recharge”

Tague & Grant (2009); Sultana & Coulibaly (2010); Allen et al. (2010)
indirect impacts – land-use change

• “… Land-Use Change may exert a stronger influence on terrestrial hydrology than climate change.” Scanlon et al. (2006); Leblanc et al. (2008)

• “… recharge rates under cropland increased by one to two orders of magnitude compared with native perennial vegetation.” Cartwright et al. (2007); Scanlon et al. (2010); Leblanc et al. (2012)
• “… indirect effects of climate on groundwater through changes in irrigation demand and sources can be greater than direct impacts of climate on recharge.”
large increases in land under irrigation has led to:

(1) **groundwater depletion** in regions with primarily groundwater-fed irrigation;

(2) **groundwater accumulation** as a result of recharge from return flows from surface-water fed irrigation; and

(3) **changes in surface-energy budgets** associated with enhanced soil moisture from irrigation

*irrigated (pivot) farming in semi-arid Zambia*
• groundwater depletion detected from *in situ* and satellite data in California Central Valley, North China Plain, High Plains Aquifer, NW India and Bangladesh

Rodell et al. (2009); Chen et al. (2010); Longuevergne et al. (2010); Famiglietti et al. (2011); Scanlon et al. (2012); Shamsudduha et al. (2012)
• irrigation return flows from surface-water fed irrigation provide “anthropogenic recharge” to: Nile Basin, Tigris-Euphrates, lower Indus, and SE China

Döll et al. (2012)
• “… groundwater primarily influences climate through contributions to soil moisture. Irrigation can transform areas from moisture-limited to energy-limited evapotranspiration thereby influencing water and energy budgets.”

• increases downwind precipitation

Douglas et al. (2009); DeAngelis et al. (2010); Kustu et al. (2011); Lo & Famiglietti (in review)
• “The impacts of seawater intrusion have been observed most prominently in association with intensive groundwater abstraction around high population densities”  
  Taniguchi (2011)

• “Coastal aquifers under very low hydraulic gradients such as the Asian mega-deltas are theoretically sensitive to SLR but, in practice, are expected in coming decades to be more severely impacted by saltwater inundation from storm surges than SLR.”  
  Ferguson & Gleeson (2012)
groundwater depletion & SLR

• “Groundwater depletion contributes to SLR through a net transfer of freshwater from long-term terrestrial groundwater storage to active circulation near the earth’s surface and its eventual transfer to oceanic stores.”

• $204 \pm 30 \text{ km}^3/\text{year (0.57 \pm 0.09 mm/year)}$ flux-based method
  
  Wada et al. (2012)

• $145 \pm 39 \text{ km}^3/\text{year (0.4 \pm 0.1 mm/year)}$ volume-based method
  
  Konikow (2011)
legal and policy questions/challenges

• Groundwater represents an invaluable distributed store of freshwater to enable adaptation to climate variability and change… but for whom?

• Substantial uncertainty in predictive models – how to assess impact or assign responsibility?

• How to untangle direct impacts of human activity (over-abstraction, land-use change) from indirect (climate change) impacts on groundwater?
• increased dry-season groundwater abstraction induces greater recharge during the monsoon