British Geological Survey

Gateway to the Earth

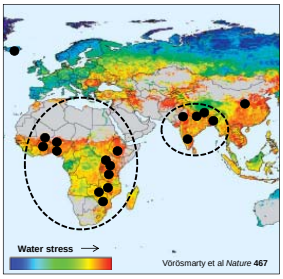
Groundwater and climate resilience

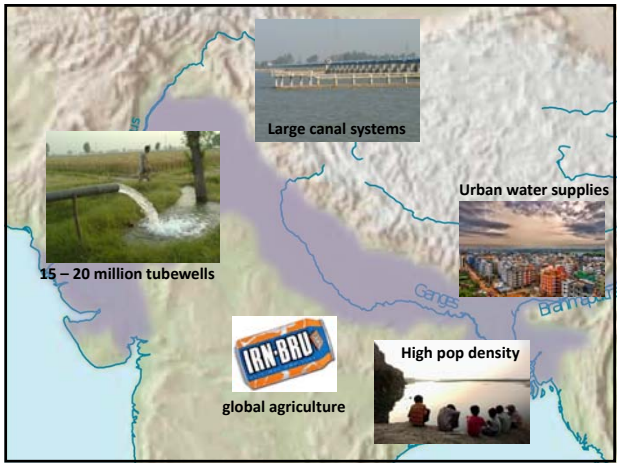
W. Mike Edmunds Memorial Lecture

Prof Alan MacDonald
3 Nov 2016, Oxford

The tale of two continents

Water stressed areas





South Asia in rough numbers

Water use approx. 1000 km^3

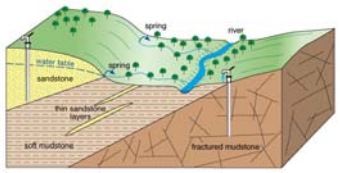
Ganges/Indus/Brahmaputra flow 1200 km^3

Dam capacity approx 280 km^3

91% of water for irrigation

340 km^3 annual groundwater abstraction

So groundwater: a AAA reserve ?

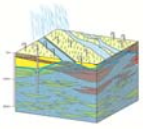


- Natural storage: large volume, widely distributed, generally good quality
- accounts for a third of global abstraction (800 - 1000 km^3)

Vital for adaptation to climate change

However: how will groundwater respond to climate variability and increasing abstraction ?

Simple resilience framework



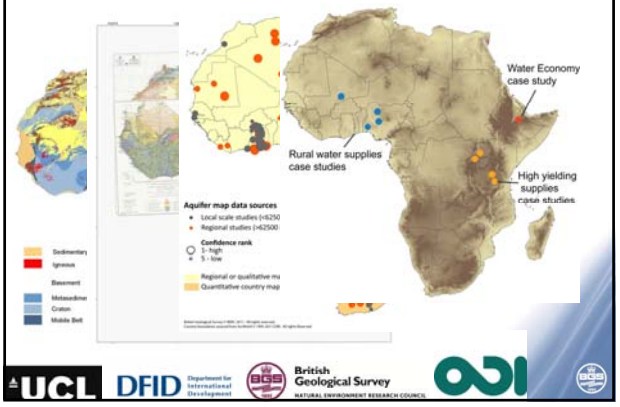
Aquifer Volume

Short term OK - Long term unsustainable	Sustainable
unsustainable	Susceptible to drought

Long term recharge

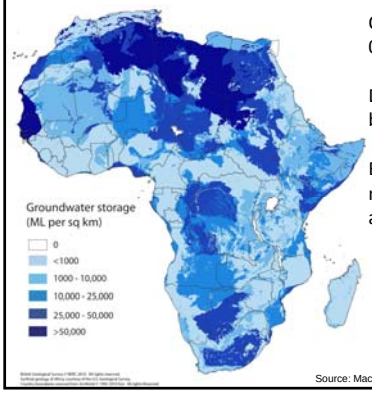
Foster and MacDonald, Hydrogeology Journal 2014, Cook 2015

Mapping Africa's groundwater storage



UCL DFID Department for International Development BGS British Geological Survey NATURAL ENVIRONMENT RESEARCH COUNCIL

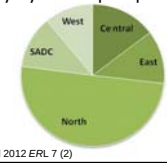
Volume of groundwater storage



Overall storage high: 0.5 - 1 million km^3

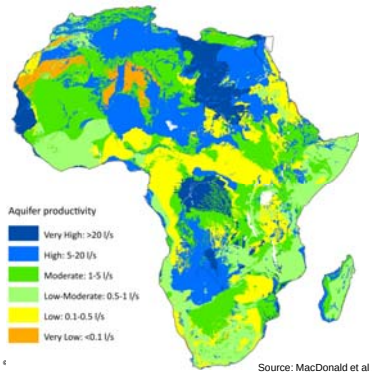
Dominated by north African basins

But elsewhere still 5 times more storage than used annually by a handpump

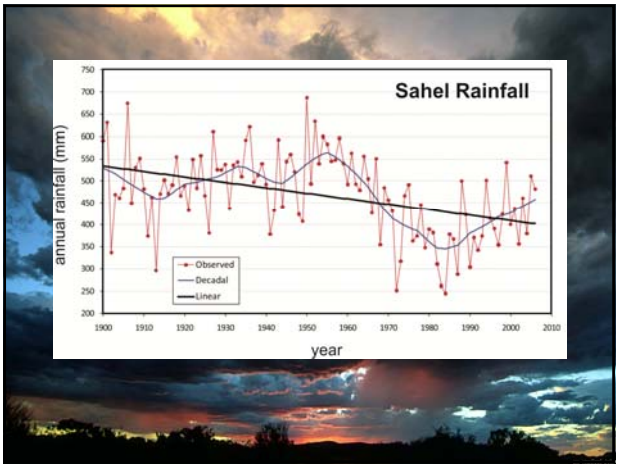


Source: MacDonald et al 2012 *ERL* 7 (2)

Potential borehole yields

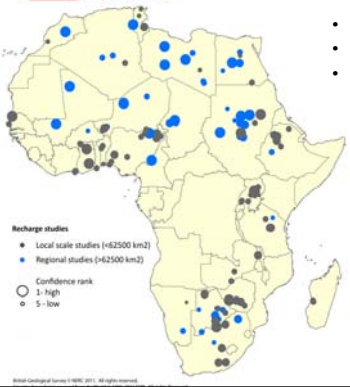


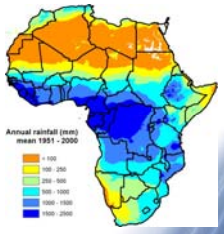
Source: MacDonald et al 2012 *ERL* 7



Analysis of recharge studies

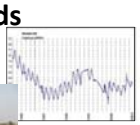
- > 200 studies
- Systematic review of studies
- different techniques and methods





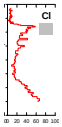
Recharge measurement methods

Physical methods – changes in the water table



stable isotopes, CFC, SF6, tritium

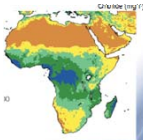
Chloride – diffuse recharge



Modelling methods – measure rainfall etc.. Penman

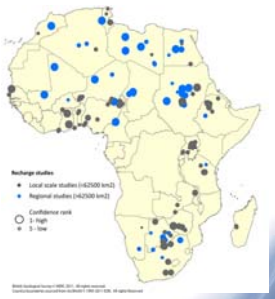
Direct soil physics measurements

Water balance methods, base flow analysis



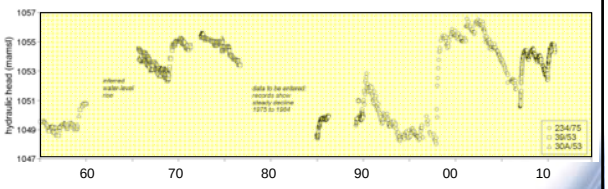
Results: long term average recharge

- No bias from different methods
- recharge rarely > 10 mm when rainfall < 250 mm
- Recharge rarely <10 mm when rainfall > 500 mm
- Widespread evidence of bypass recharge from difference between UZ and SZ methods.



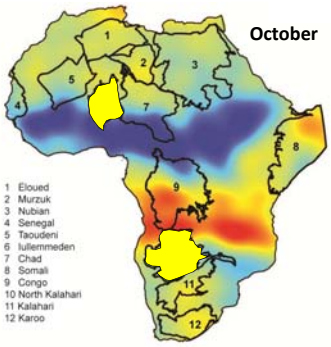
Example: Makutapora wellfield

Recharge is indirect and episodic



Taylor et al *Nature Climate Change* 2013

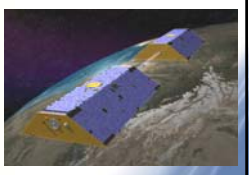
Example 2: GRACE



Monthly estimates of changes in terrestrial water storage

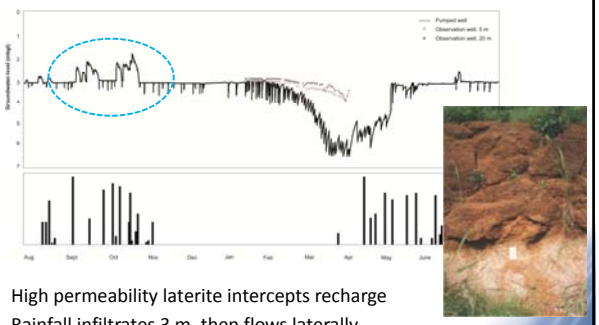
Resolution – approx 5 mm

Large footprint - 400 x 400 km



Source Bonsor et al.- in preperation

Example 3 - humid Nigeria



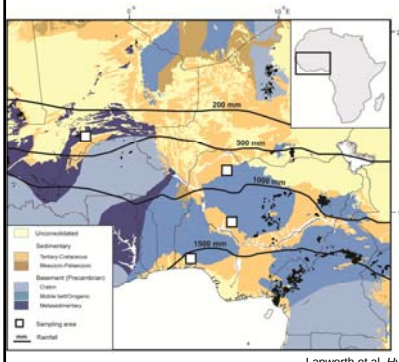
High permeability laterite intercepts recharge
Rainfall infiltrates 3 m, then flows laterally
= recharge does not always reach aquifer

Bonsor et al Hyd Proc. 2014

Example 4: Mean residence times…

Sampling…

West African transect



Humid to semi-arid

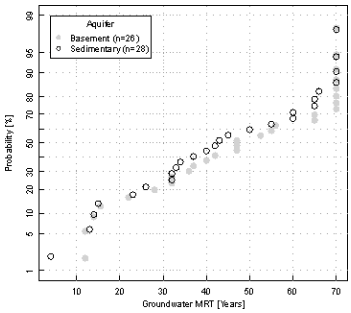
Shallow groundwater

60 Hand Pumps

High and low storage aquifers

Lapworth et al. *Hydrogeology Journal* 2013

West African transect



Shallow GW 30 – 60 years MRT

No significant difference between aquifers and climate zones…

Lapworth et al. *Hydrogeology Journal* 2013

Africa Summary

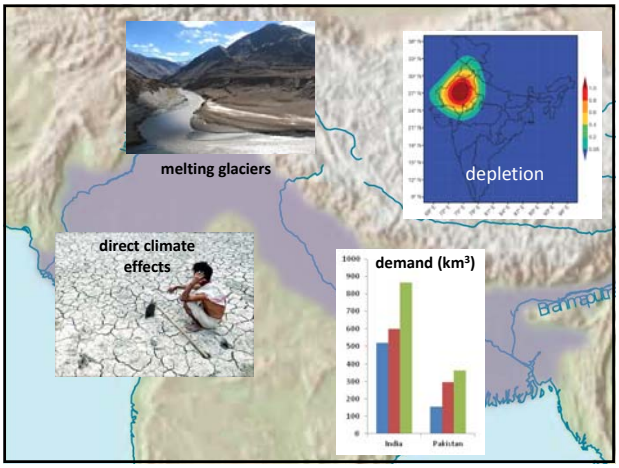
Groundwater is fundamental to adapting to climate variability

Generally resilient to current abstraction

Under developed in many areas

Higher yields for intensive agriculture - patchy

Quantifying recharge processes which include bypass and indirect flow increasingly important

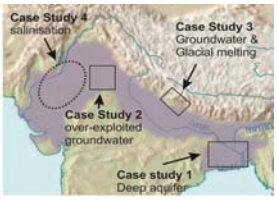


IGB groundwater resilience

UKaid

1. Provide an overview of groundwater resilience to change in the IGB

2. Four case studies of under researched issues



MacDonald AM, Bonsor HC, Taylor R, Shamsudduha M, Burgess WG, Ahmed KM, Mukherjee A, Zahid A, Lapworth D, Rao MS, Gopal K, Moench M, Bricker SH, Yadav SK, Satyal Y, Smith L, Dixit A, Bell R, van Steenbergen F, Basharat M, Gohar MS, Tucker J, Calow RC and Maurice L

British Geological Survey, University College London, National Institute of Hydrology (Roorkee), University of Dhaka, IIT Kharagpur, ISET, MetaMeta, Overseas Development Institute, Bangladesh Water Development Board

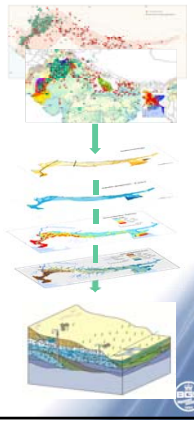
Groundwater in the IGB

Data collation and review – from the four countries:
> 500 reports and datasets reviewed

New basin-scale data maps of key groundwater parameters:
alluvial geology, abstraction, groundwater quality, water level trends, aquifer properties

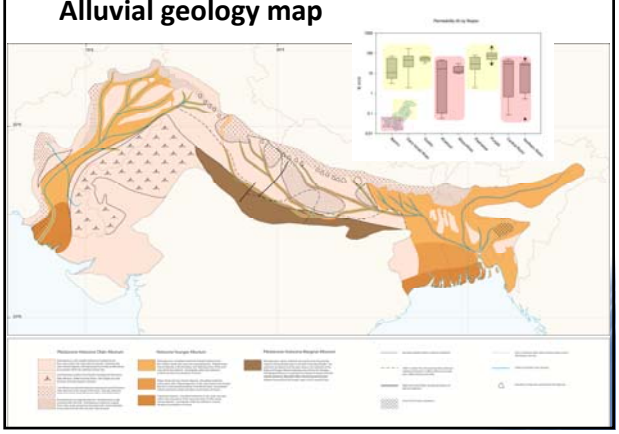
3D characterisation related to the resilience to change

Also enough data to look at symptoms of stress

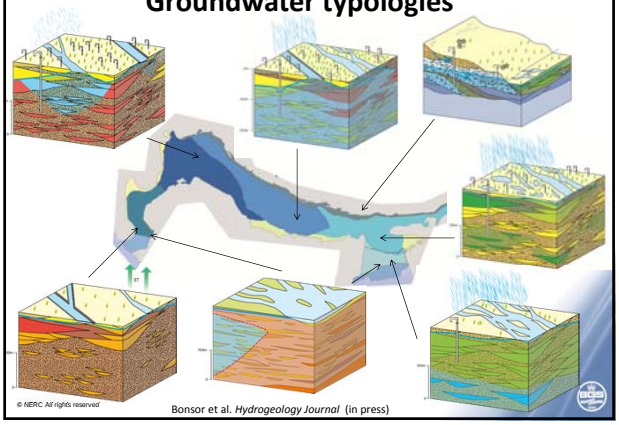


Bonsor et al. *Hydrogeology Journal* (in press)

Alluvial geology map

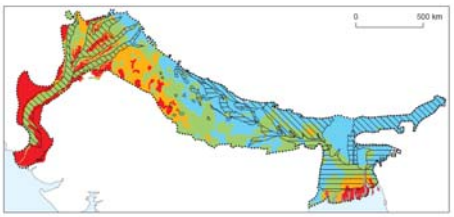


Groundwater typologies



Bonsor et al. *Hydrogeology Journal* (in press)

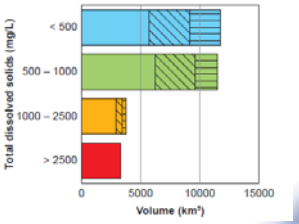
Groundwater quality



MacDonald et al.) *Nature Geoscience* 2016

IGB groundwater volume

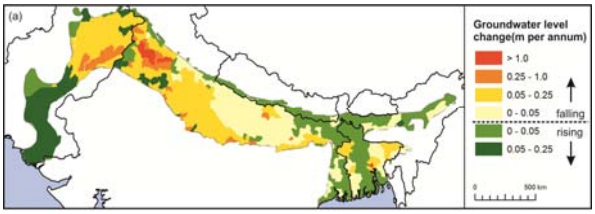
1. GW **storage 30,000 km³** 20 times the annual flow in the GMB + Indus, 100 x storage in dams
2. Yields often > 20 l/s
3. Abstraction high – 205 km³ **25% global abstraction**;



High storage aquifer – but problems of quality

MacDonald et al. (2016) *Nature Geoscience*

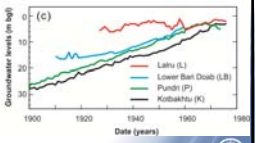
Groundwater depletion



Water table is near stable across 60% of the aquifer, falling in 33%

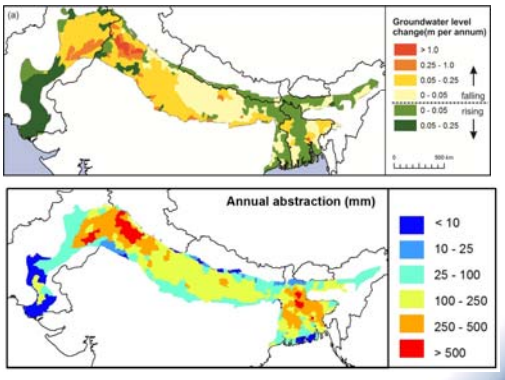
Complex pattern

Long term history of *accumulation*



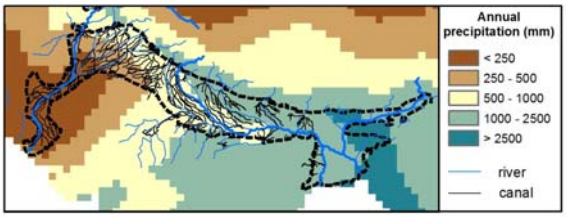
MacDonald et al. *Nature Geoscience* 2016

Depletion and abstraction



MacDonald et al. *Nature Geoscience* 2016

Recharge



Rainfall

Importance of canal leakage

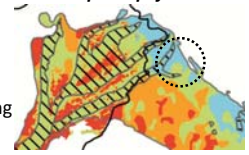
Abstraction changes recharge

MacDonald et al. *Nature Geoscience* 2016

Example Punjab, India

What are the dominant recharge mechanisms?

How connected are the shallow and deeper aquifers?

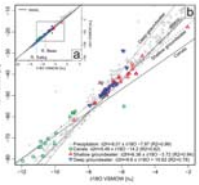


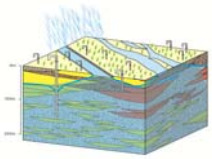
Bist Doab

- Analysis of 20 year groundwater level monitoring
- Tracer tests and noble gases in 19 shallow/deep piezometer pairs
- Widespread sampling for stable isotopes

Example Punjab India

Recharge is primarily rainfall in Bist Doab: local meteoric recharge sources dominate both shallow and deep aquifers.



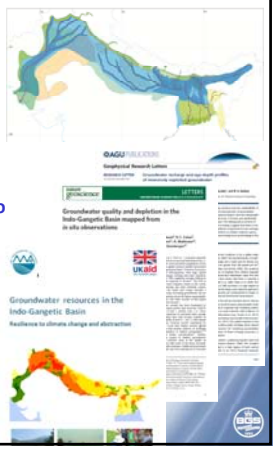


Deep and shallow groundwater strongly connected: modern water is being drawn into deeper aquifers by intensive abstraction and growing contamination

Lapworth et al. *GRL* 2016

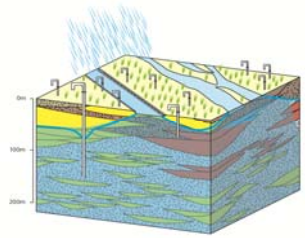
Summary for IGB

- The IGB aquifer already offers an **excellent buffer to change**
- Degradation in **groundwater quality** is arguably a greater concern than depletion.
- Groundwater is more **vulnerable to abstraction** than climate change.
- The resilience varies across the aquifer and needs **targeted governance**
- Groundwater and surface water clearly linked – one resource



Getting the most from groundwater

- Understanding
- Think long term
- Multi-dimensional
- Dynamic



With appropriate governance groundwater can offer a high resilience to climate change