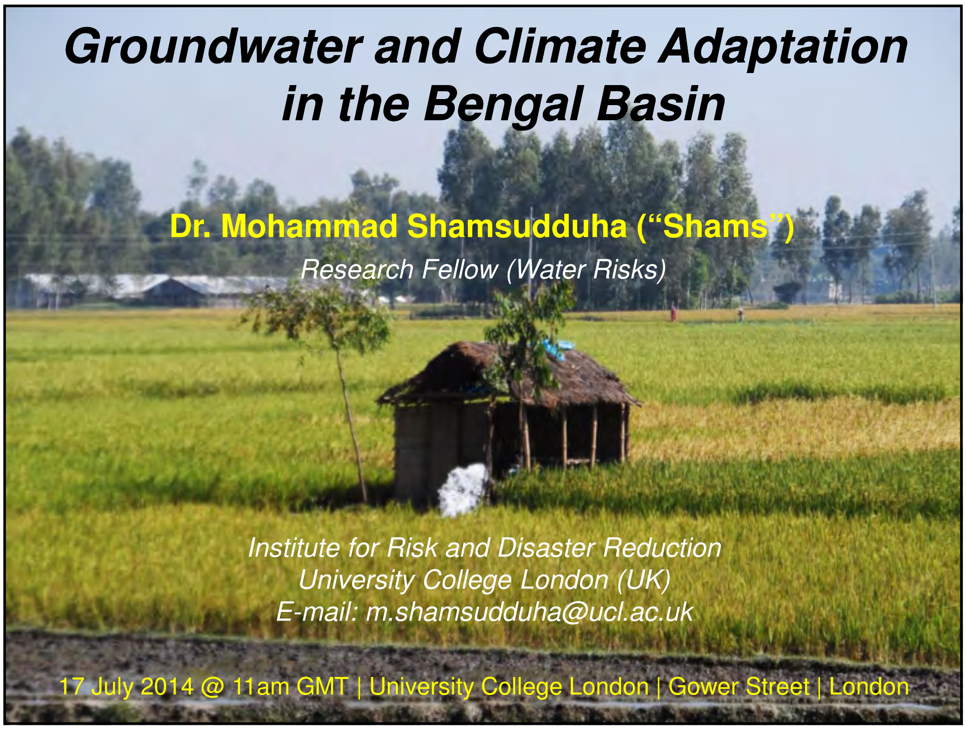

Groundwater and Climate Adaptation in the Bengal Basin

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17 July 2014 @ 11am GMT | University College London | Gower Street | London

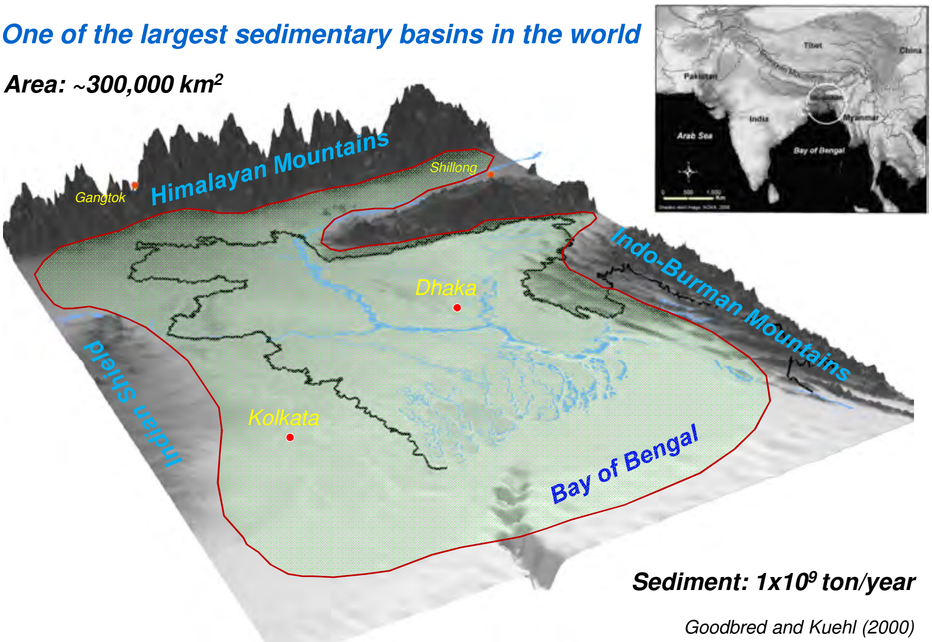
Webinar outline

- Bengal Basin: location, hydrology & climate
- Groundwater-fed irrigation and food security
- Impacts of long-term pumping on groundwater
- Impacts of climate change on groundwater
- Way foreword: adaptation

Bengal Basin: location and topography

One of the largest sedimentary basins in the world

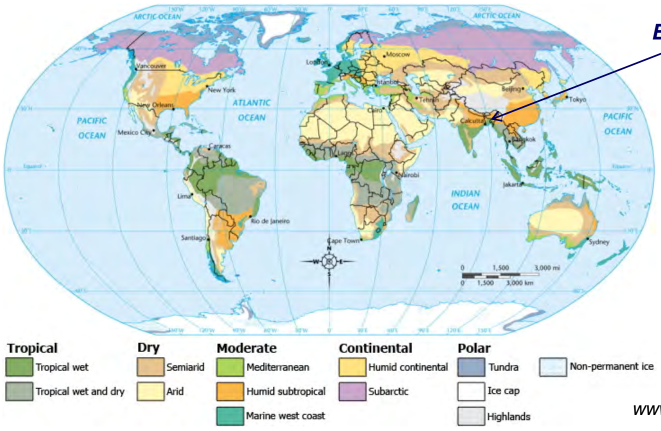
Area: ~300,000 km^2



Sediment: 1x10^9 ton/year

Goodbred and Kuehl (2000)

Bengal Basin: climatic zone

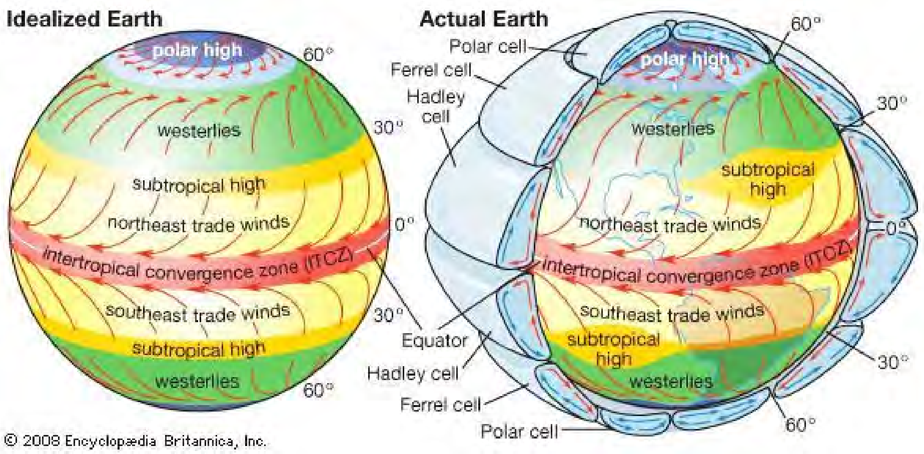


www.wikipedia.org

- Monsoon climate is characterised by heavy rainfall (annual range: 1,500 to 5,000 mm), high temperature and humidity during the summer months
- Three distinct seasons: a hot, humid summer (Mar to Jun); a wet, rainy monsoon season (Jun to Oct); and a cool, dry winter (Oct to Mar)
- April/May is the warmest month; January is the coldest month

Bengal Basin: climatic conditions

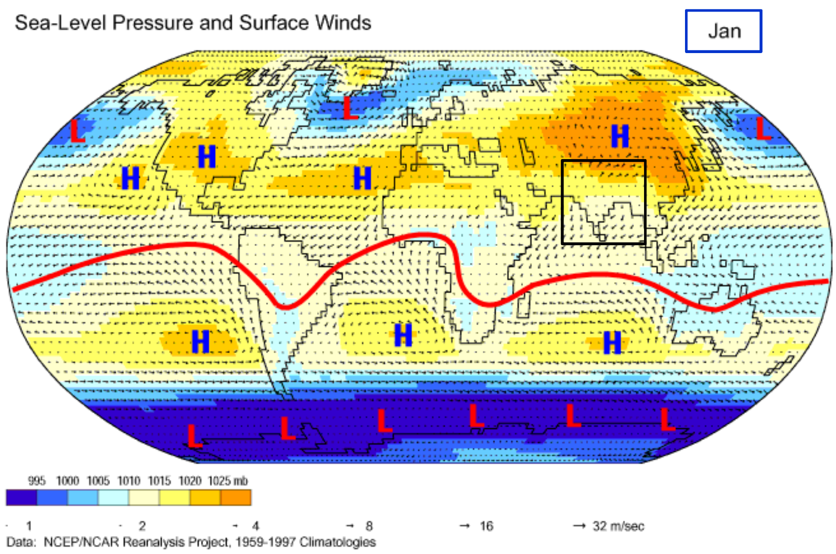
Global Scale Circulation of the Atmosphere



Encyclopaedia Britannica

Bengal Basin: monsoon climate

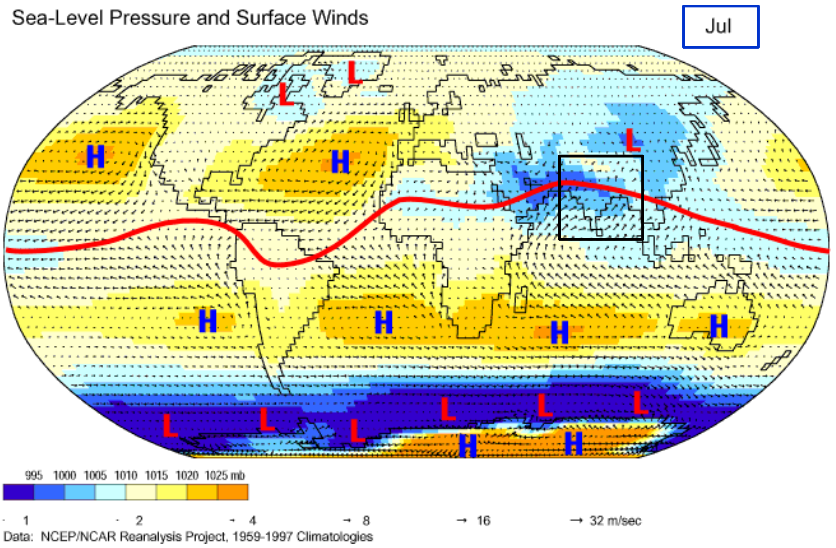
Asian Monsoon associated with the movement of the ITCZ



www.physicalgeography.net

Bengal Basin: monsoon climate

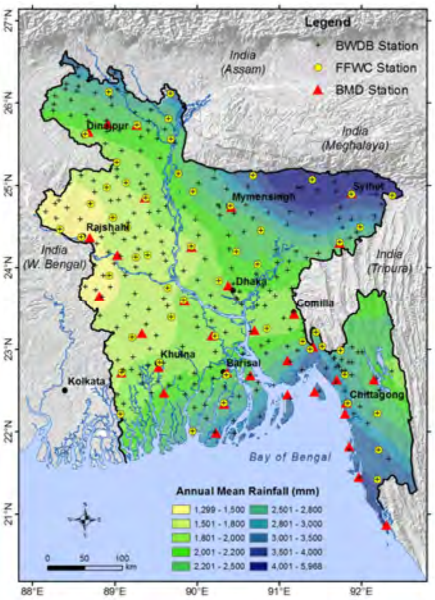
Asian Monsoon associated with the movement of the ITCZ



www.physicalgeography.net

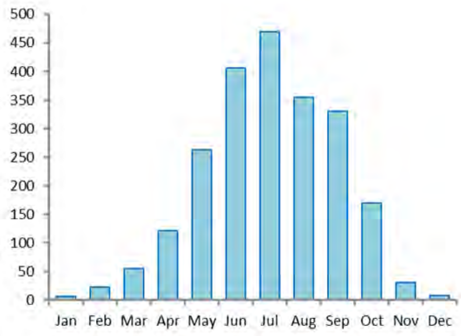
Bengal Basin: rainfall pattern in Bangladesh

> 85% of annual rainfall occurs between May and October



Monthly rainfall

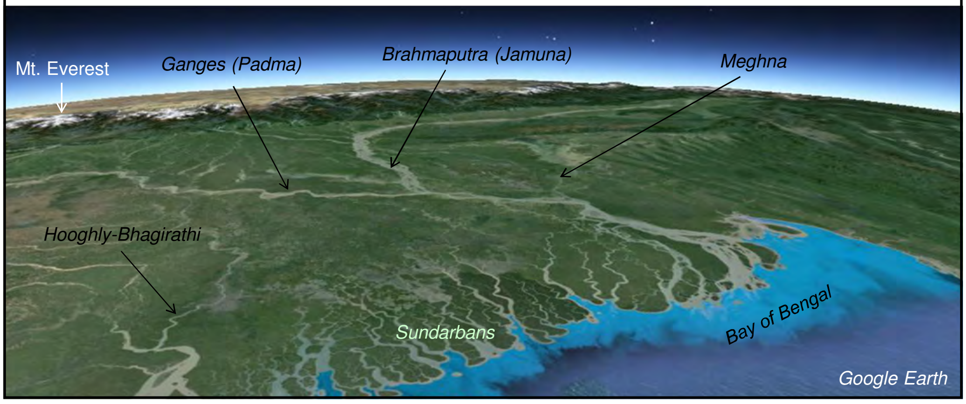
Averaged over 250 stations



Data source: BWDB

Hydrology of the Bengal Basin

- Bengal Basin includes nearly whole of Bangladesh (~140,000 km^2) and a major part of West Bengal and Assam (India)
- Alpine glaciers on the Himalayas form headwaters of the Ganges and Brahmaputra Rivers
- The confluence of 3 major rivers – Ganges (Padma), Brahmaputra (Jamuna) and Meghna is a major hydrological feature of the basin
- GBM Delta – a major feature of the basin, is the largest delta in the world



Bengal Basin: irrigation and food security

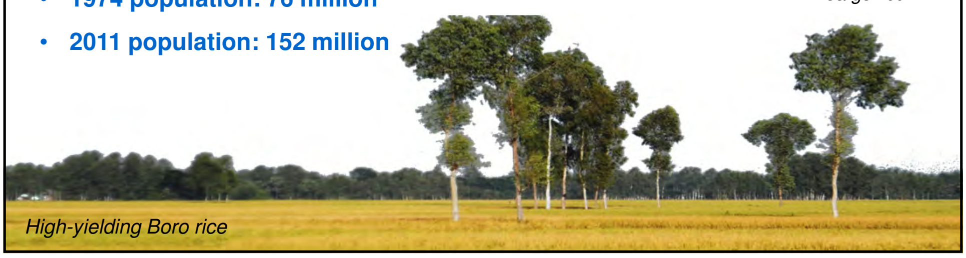
- **Food security in the Bengal Basin, Bangladesh:**

Dramatic improvement in food production in Bangladesh: worst famines (1943 and 1974) to near self-sufficiency in food grains in less than 4 decades

Cultivable land	8.52 million hectare (57% of total land area)
Cropping intensity	191%
Single cropped area	2.24 million hectare (29% of net crop area)
Double cropped area	4.11 million hectare (52% of net crop area)
Triple cropped area	1.49 million hectare (19% of net crop area)
Contribution of agriculture sector to GDP	19.3%
Total food crop production	37.3 million metric ton

www.moa.gov.bd

- **1974 population: 76 million**
- **2011 population: 152 million**

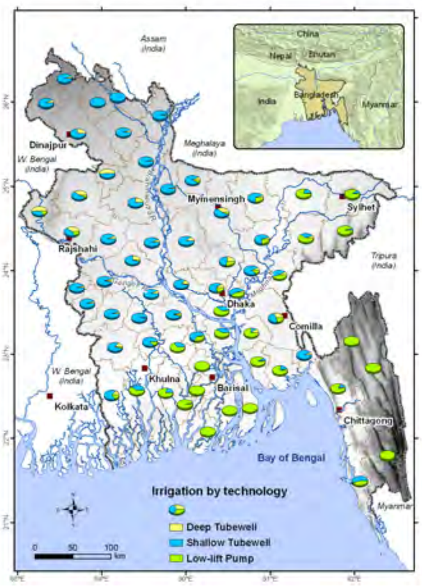


High-yielding Boro rice

Groundwater irrigation and food security

- Dramatic increases in cultivated land under irrigation over the last 40 years
- Production of high-yielding, “Boro” rice during the dry season (December – May)

Distribution of irrigation methods in Bangladesh



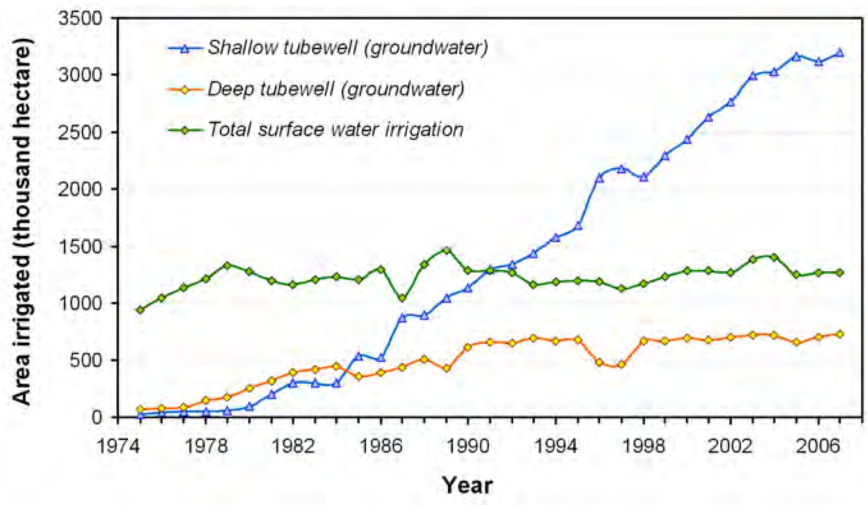
Shamsudduha et al. (2011) Hydrogeol. J.

FAO (2007)

www.nationalgeographic.com

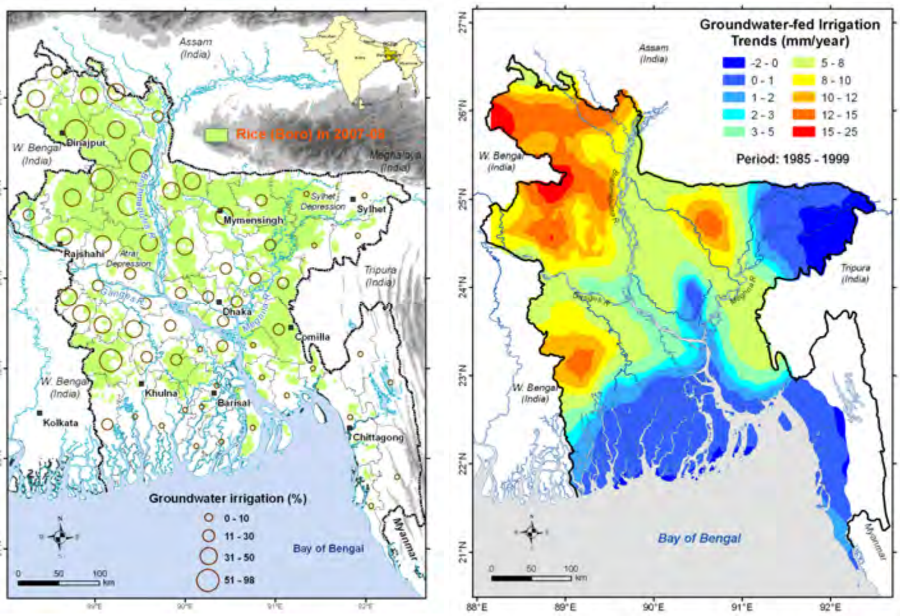
Trends in irrigation methods in Bangladesh

- *Number of shallow irrigation wells in Bangladesh: 1.2 million (2006-07)*
- *Number of deep irrigation wells in Bangladesh: 29,350 (2006-07)*



Shamsudduha et al. (2011) Hydrogeol. J.

Dry-season rice and groundwater-fed irrigation



Shamsudduha et al. (2012), Water Resour. Res.

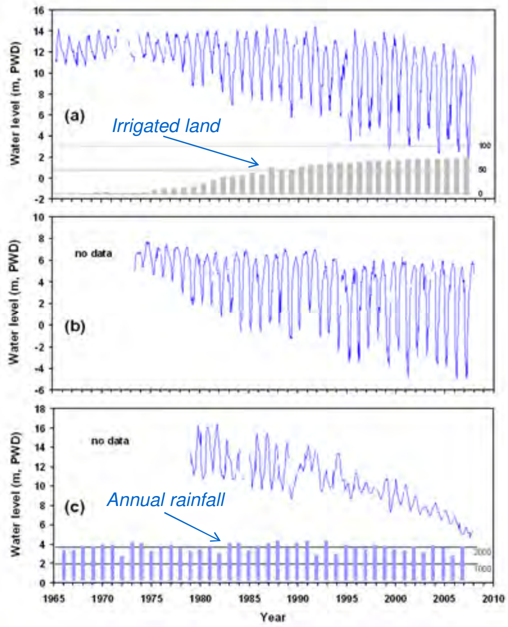
Impact of increased groundwater abstraction

Evidence from in situ (ground-based) monitoring

<u>Increased seasonality</u>

- *declining trends in dry season groundwater levels*
- *little or no trend in wet season groundwater levels*

<u>Reduced seasonality</u> and steady declining trends



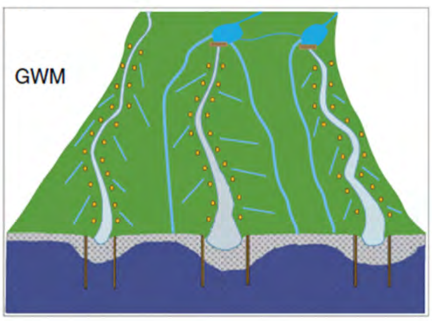
Shamsudduha et al. (2009) Hydrogeol. J.

Capture of runoff by induced recharge

"The Ganges Water Machine"

The idea was first proposed in 1975 by Revelle and Lakshminarayana who recognised:

- *Access rainfall during monsoon and need for storage to increase year-round water availability*
- *Difficulty and cost of building reservoir or dam*
- *Permeability of alluvial deposits (shallow aquifers) along the Ganges River*

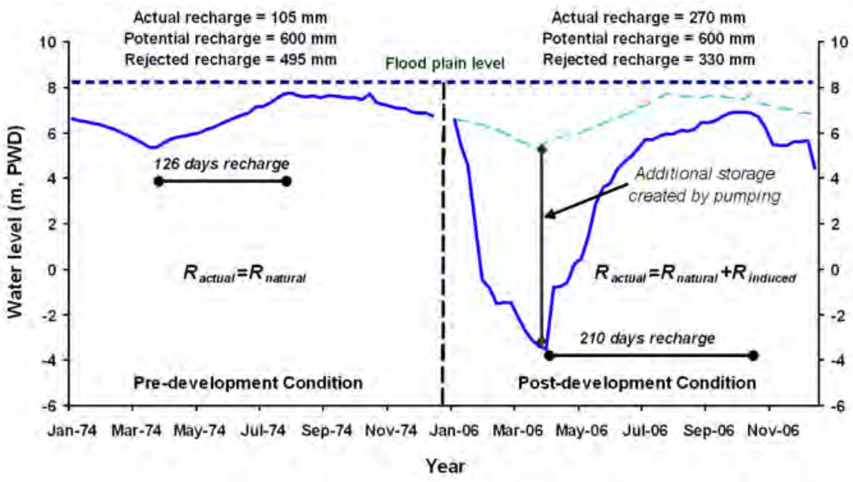


Khan et al. (2014) Water Resour. Manage.

Induced groundwater recharge

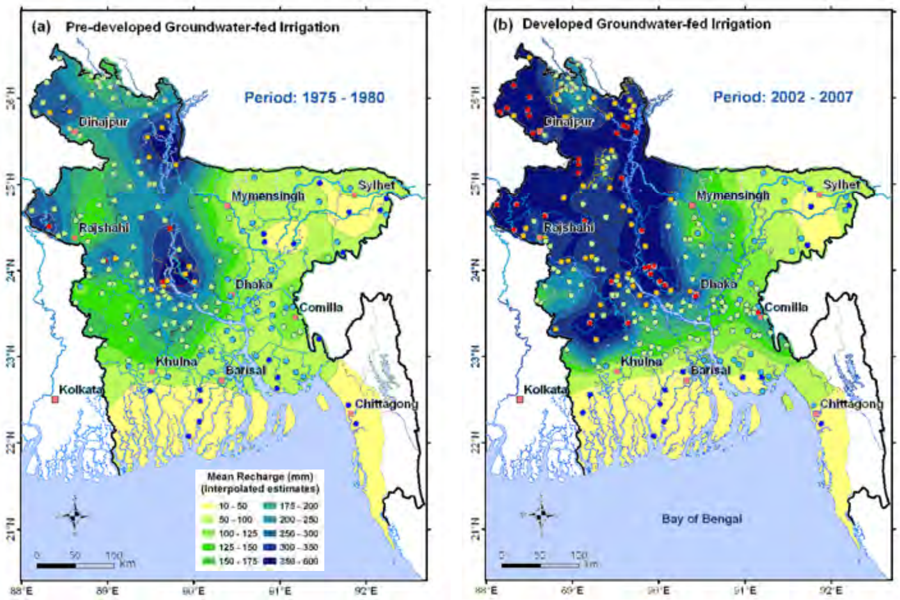
Increased recharge occurs as a result of reduced surface runoff ("rejected recharge")

"The Ganges Water Machine"



Shamsudduha et al. (2011) Hydrogeol. J.

Induced groundwater recharge



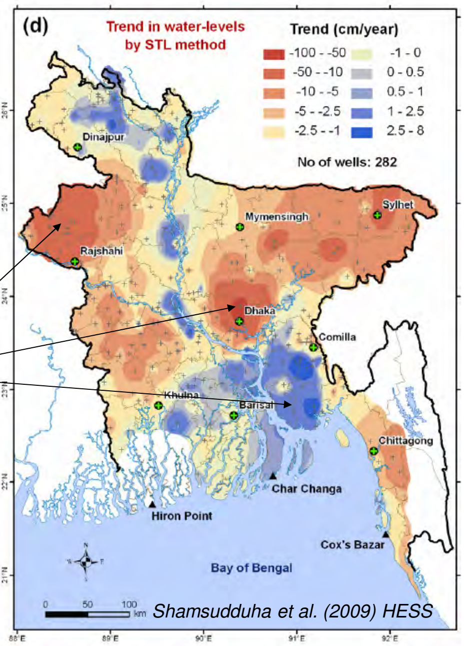
Shamsudduha et al. (2011) Hydrogeol. J.

Over-abstraction of groundwater

Trends in groundwater levels resolved after decomposing seasonal and trend components in observations from 1985 to 2005

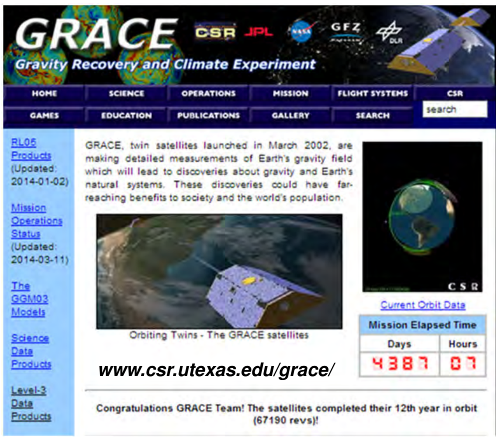
- **Note spatial characteristics in groundwater-level trends**

Supported by satellite observations?



Shamsudduha et al. (2009) HESS

Gravity Recovery and Climate Experiment



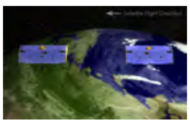
www.csr.utexas.edu/grace/

- **Gravity variations represent fluid mass changes over time**

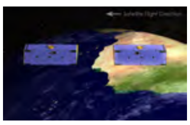
∆Terrestrial water mass =
∆Groundwater storage +
∆Soil moisture storage +
∆Surface water storage +
∆Ice & snow water storage

Over ocean

approaching land

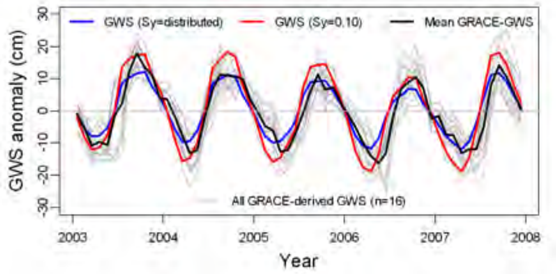


leaving land



http://earthobservatory.nasa.gov/

Validation of GRACE-derived ∆GWS

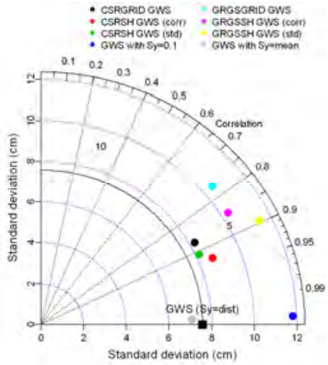


GRACE data: CSR and GRGS

SMS data: NOAH, VIC, CLM

SWS data: observational

GWS data: observational



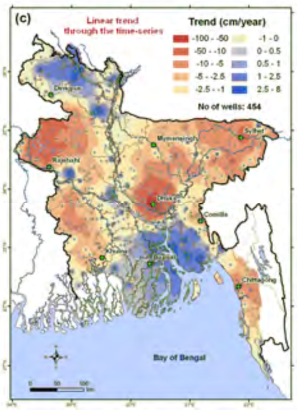
Strong correlations observed between GRACE satellite and *in situ* observations in the Bengal Basin

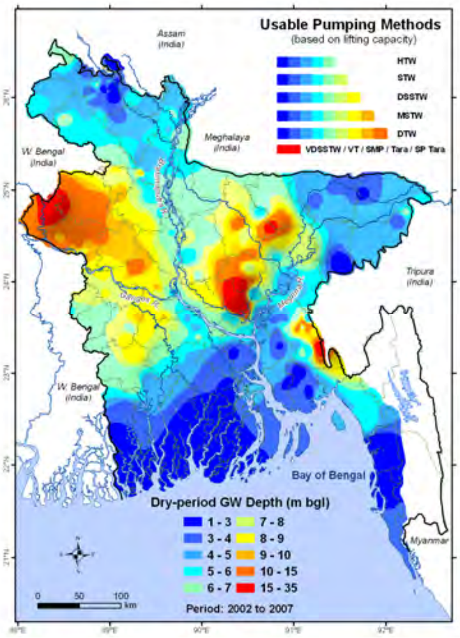
Shamsudduha et al. (2012) Water Resour. Res.

Negative impacts of GW-level decline

Groundwater-level declines have, in some areas, rendered pumping technologies inoperable

> issues of equity?



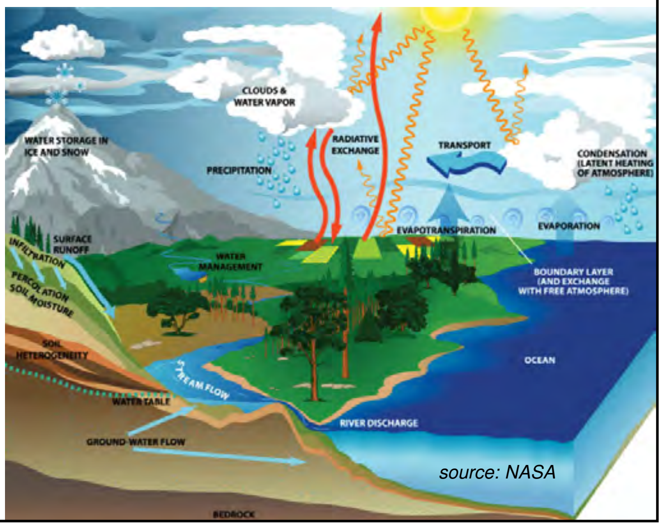


Climate change: impacts on groundwater

Climate change manifests itself mainly through changes in the Earth's hydrological systems

- Higher Temperatures
- Changing Rain and Snow Patterns
- More Droughts
- Warmer Oceans
- Rising Sea Level
- Wilder Weather
- Increased Ocean Acidity
- Shrinking Sea Ice
- Melting Glaciers
- Less Snowpack
- Thawing Permafrost

US EPA (2013)

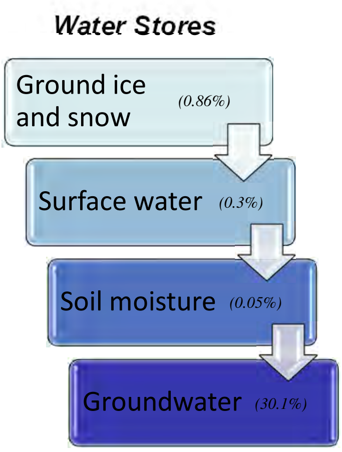


source: NASA

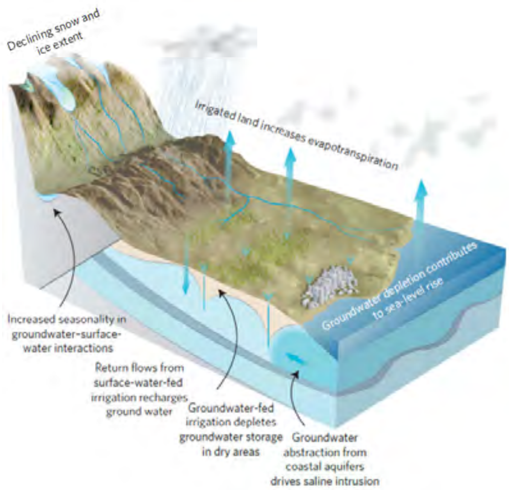
Climate change impacts on water stores

Global warming intensifies the hydrological system through:

- *Net transfer of freshwater from ice and snow*
- *Higher saturation vapour pressures that enhance precipitation and evapotranspiration*



Note: % of total freshwater

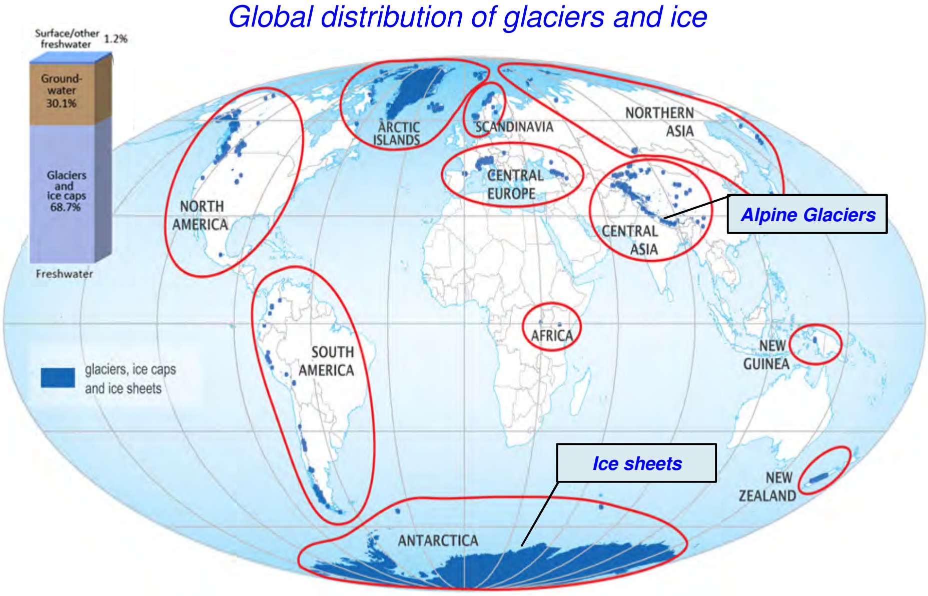


Taylor et al. (2013), Nature Climate Change 3, 322–329

• *Net transfer of freshwater from ice and snow*

UCL

Global distribution of glaciers and ice



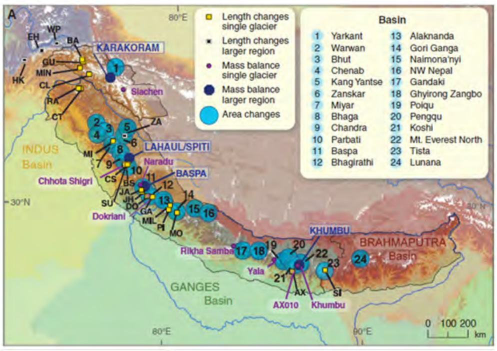
http://www.grid.unep.ch/glaciers/img/6-1.jpg

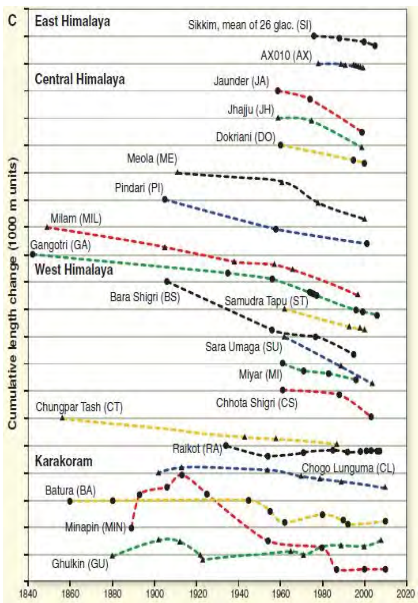
Recent alpine glacial recession in the Himalaya

UCL

	Total	*Fresh*
Ice sheets and glaciers	**1.74%**	**68.7%**
Antarctic ice sheet	1.62%	64.2%
Greenland ice sheet	0.17%	6.70%
Glaciers	0.02%	0.69%

http://en.wikipedia.org/

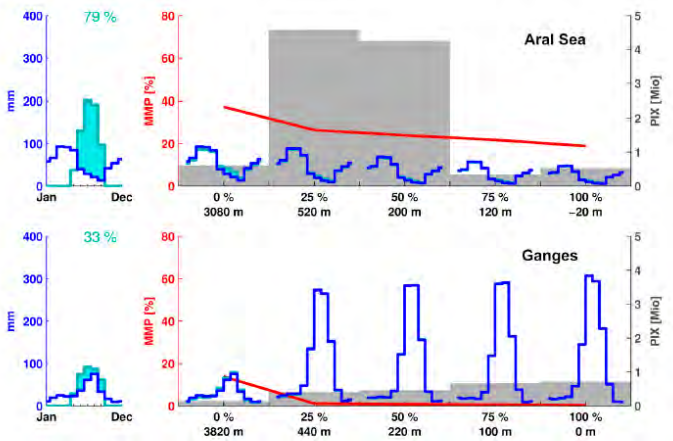




Bolch et al. (2012), Science

Glacial recession and river flow

Contribution of melt-water discharges from snow and alpine glaciers to river flow is major in very dry basins, moderate in most mid-latitude basins, and minor in monsoon climates



Kaser et al. (2010), PNAS

- ***Higher vapour pressure enhances precipitation***

Warmer air holds more moisture…

The increased moisture in the atmosphere is driving the shift to heavier but less frequent rains — "when it rains, it pours."

www.cksimpsonwx.blogspot.co.uk/ and www.climatecommunication.org/

Theoretical basis for the intensification of rainfall

1. Warmer air holds more water
   – *amount rises exponentially with temperature*

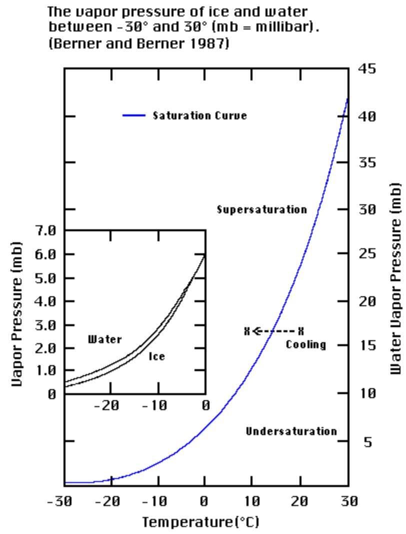
   4.5 g·m^{-3} @ 0℃

   30 g·m^{-3} @ 30℃

2. *Heavy rainfalls tend to deplete the available moisture in air*

As air temperature rises in the tropics it leads to greater increases in water-holding capacity so in the tropics intensification of rainfall is projected to be greatest under a warmer climate

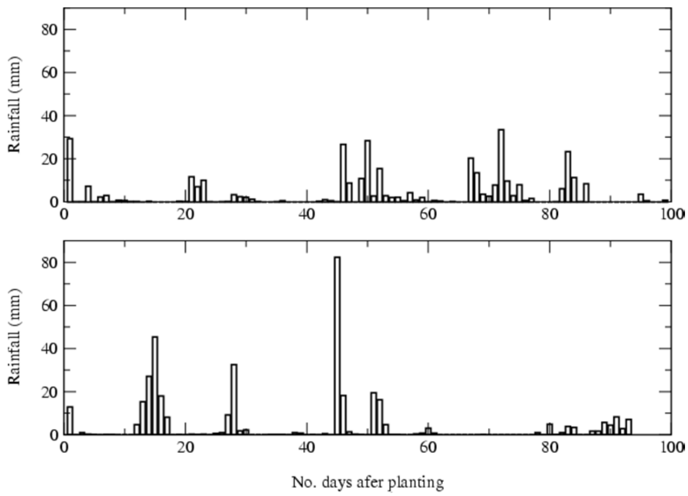
Clausius-Clapeyron relation



Negative effect of rainfall intensity on crop

More variable precipitation (soil moisture) reduces crop yields

Example: groundnut crop in Andhra Pradesh (India)



1975:

Total rainfall: 394 mm

Yield = 1360 kg/ha

1981:

Total rainfall: 389 mm

Yield = 901 kg/ha

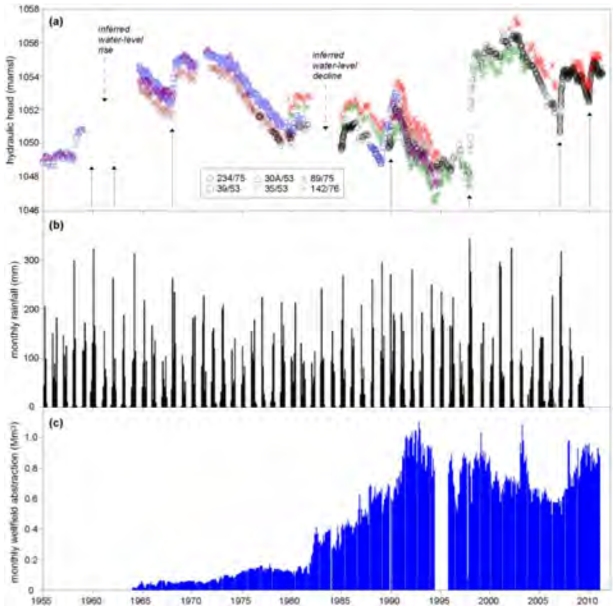
Challinor et al. (2006), "Avoiding Dangerous Climate Change"

Positive effect of rainfall intensity on groundwater

Longest, observed record of groundwater levels in the tropics:

Makutapora well field in Tanzania

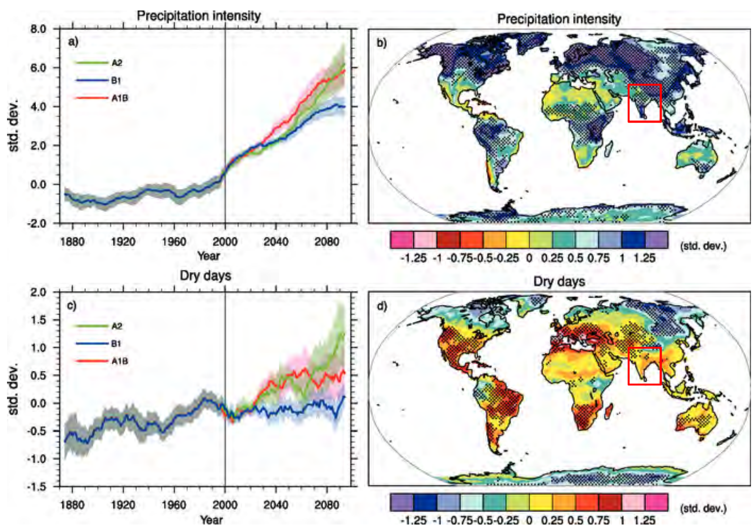
Groundwater recharge results disproportionately from very intense, extreme seasonal rainfalls



Taylor et al. (2013b), Nature Climate Change

Projected changes in precipitation intensity

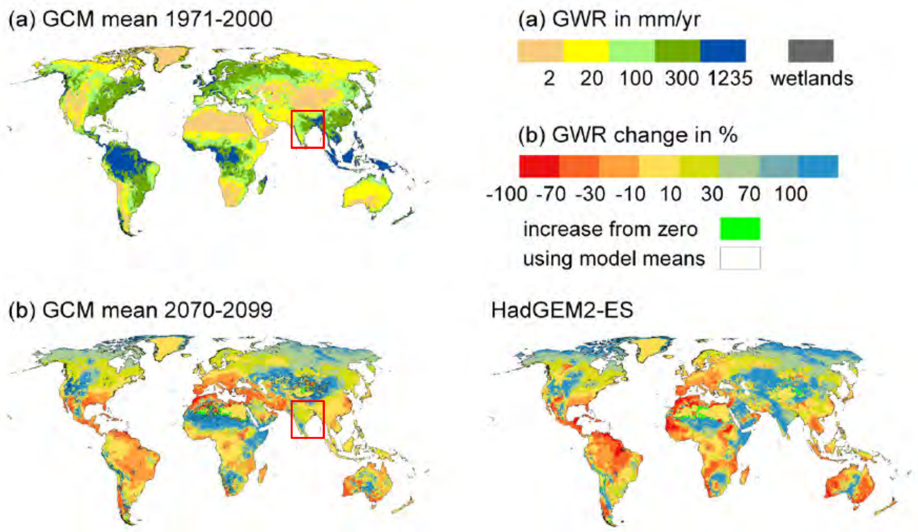
More variable & intensive rainfall – widespread signal



IPCC AR4 (2007)

Climate change and groundwater recharge

IPCC 5th AR - Coupled Model Intercomparison Project (CMIP5), RCP 8.5

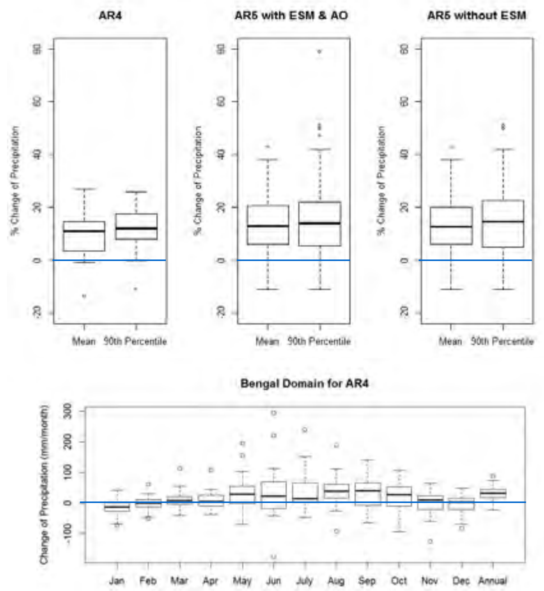


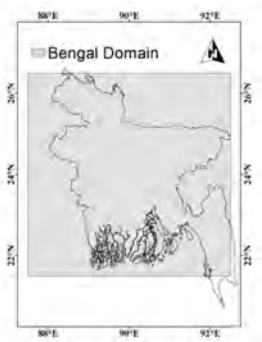
Debate on focused versus diffuse recharge

Portmann et al. (2013), Environ. Res. Lett.

Climate change projection on rainfall

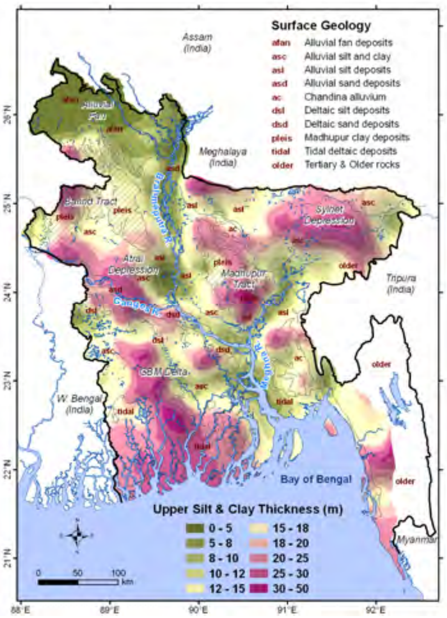
Climate change projected to intensify seasonality in rainfall over the Bengal Basin





Courtesy: Sara Nowreen (BUET)

Basin response to the Asian Monsoon

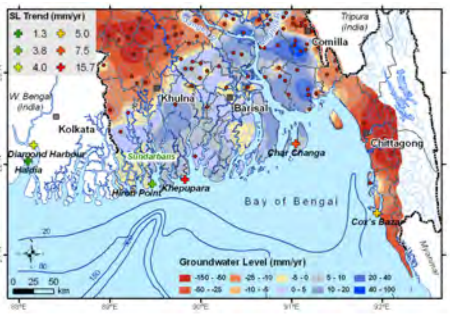


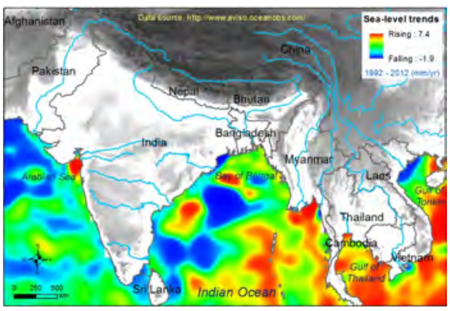
Groundwater recharge and surface geology:

- Areas of surficial clay cover give rise to overland flow (increased runoff)
- Areas of sandy soils with shallow aquifers get more recharge through diffuse as well as focused groundwater recharge

Shamsudduha et al. (2011) Hydrogeol. J.

Groundwater responses to sea-level rise?



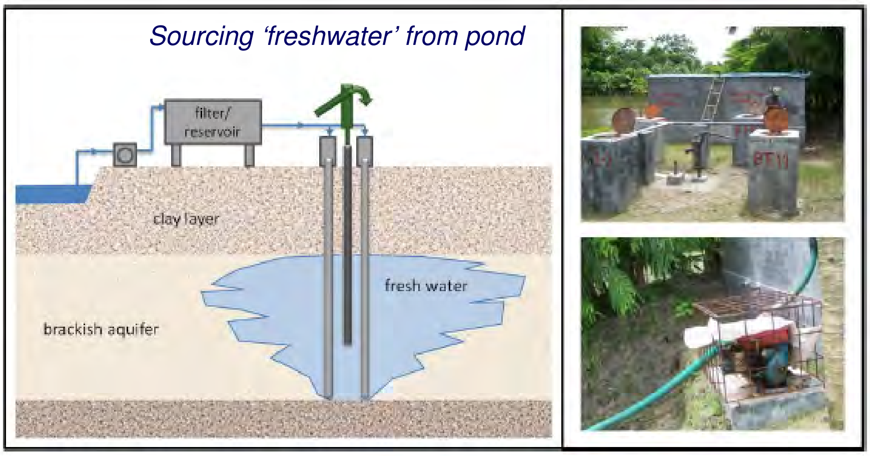


Shallow groundwater levels and rising sea levels:

- Analysis of long-term time series records reveals rising groundwater levels in coastal region of the basin
- Rising groundwater levels commensurate with long-term trends in tidal levels
- Sea levels in the Bay of Bengal are generally rising – this will further raise shallow groundwater levels

Way foreword: adaptation

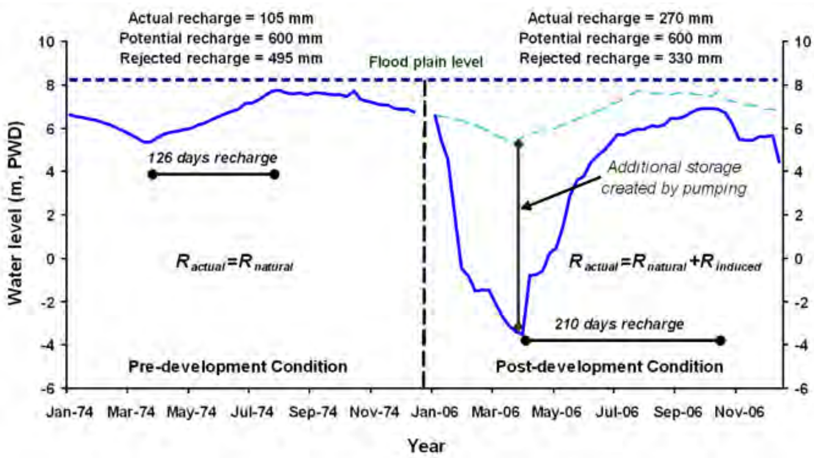
- Groundwater levels are declining in several areas of the basin due to intensive pumping for irrigation and public water supplies – *less (ground)water intensive crops should be grown during dry season; conjunctive use of water resources is needed; Managed Aquifer Recharge (MAR) should be engineered*



Courtesy: Professor Kazi Matin Ahmed (Dhaka University)

Way foreword: adaptation

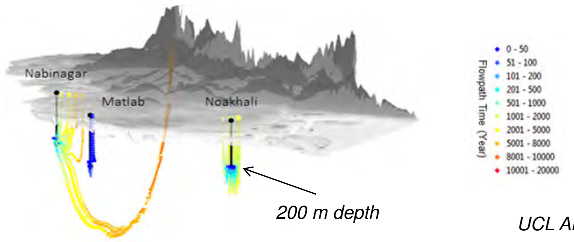
- Induced groundwater recharge is taking place over many parts of the basin under permeable surface geology due to increased storage in shallow aquifers as a result of pumping – *monitoring of groundwater levels is needed to ensure that the actual recharge rates do not exceed the potential recharge*



Shamsudduha et al. (2011) Hydrogeol. J.

Way foreword: adaptation

- Recharge to shallow aquifers takes place primarily through (i) diffuse (monsoon rainfall) and (ii) focused (river water, flood water) recharge processes – *further research is needed to establish relationships between rainfall intensity and groundwater recharge in different geological conditions*
- Under projected climate change scenarios (IPCC AR5 models) monsoon rainfall is going to be intensified (i.e. increased magnitude and intensity) in the basin – *impacts on hydro-ecological environments are currently unknown*
- Rising sea level and coastal storms will impact shallow groundwater – *careful development of deep groundwater (>150 mbgl) with monitoring is critical for future 'fresh & safe' water supply in order to safeguard against arsenic and saltwater intrusion under rising sea levels*



UCL Arsenic Project (2013)

Institute for Risk and Disaster Reduction

Thanks to MetaMeta Communications and the Water Channel

Acknowledgements

- *Professor Richard Taylor (UCL Department of Geography)*
- *Dr. William Burgess (UCL Department of Earth Sciences)*
- *Dr. Alan MacDonald (British Geological Survey)*
- *Professor Kazi Matin Ahmed (University of Dhaka)*
- *Dr. Anwar Zahid (Bangladesh Water Development Board)*

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