Groundwater in the Indo-Gangetic Basin (IGB)

23/07/2024 IIT MANDI

DONALD JOHN MACALLISTER, BGS, UK AND MANY OTHERS

British Geological Survey

Overview

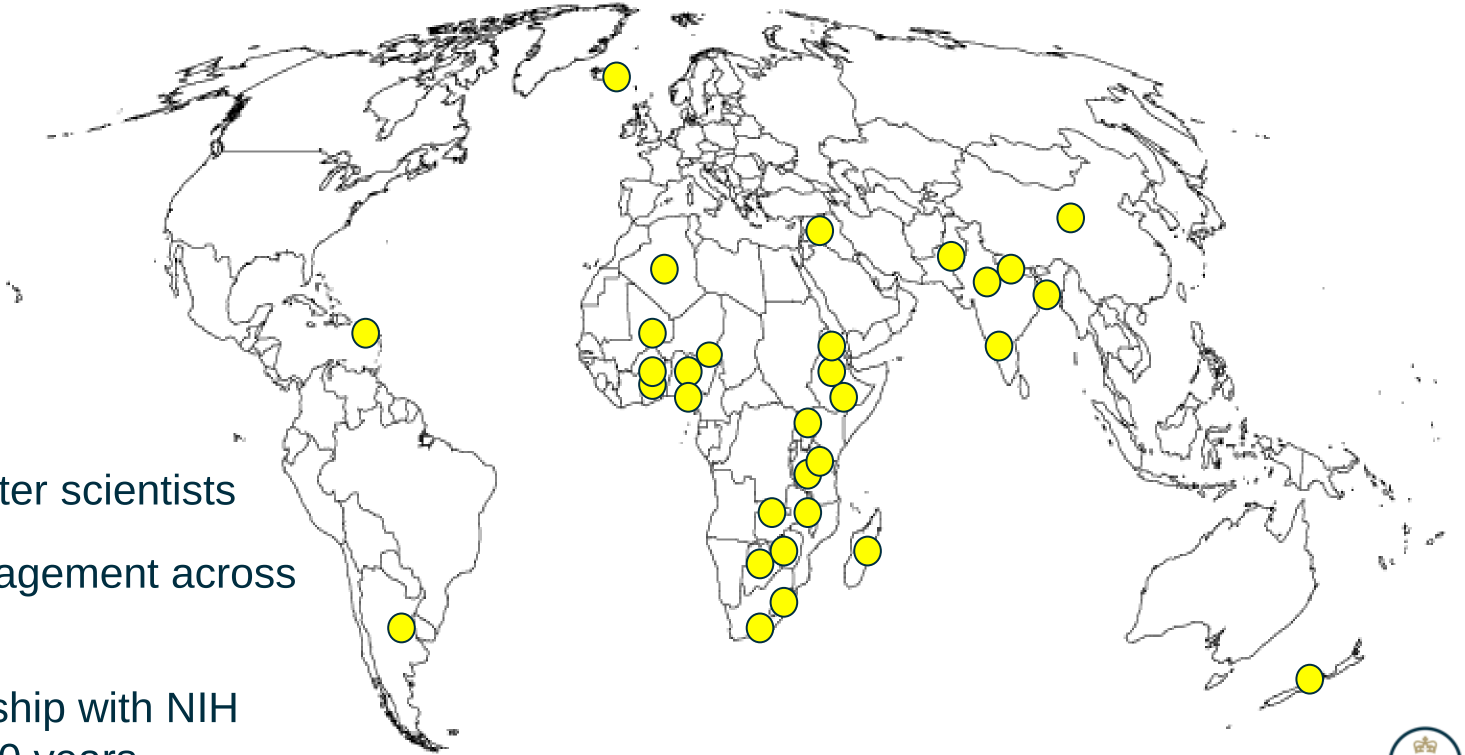
- Introduction to BGS and our groundwater work
- BGS work in India
- Groundwater in the IGB
- Long-term changes in groundwater in the north-western IGB aquifer
- Quantifying the relative influence of recharge sources in the north-western IGB aquifer

British Geological Survey

- A world-leading independent research organisation providing objective, expert geoscientific data, information and knowledge.

- www.bgs.ac.uk

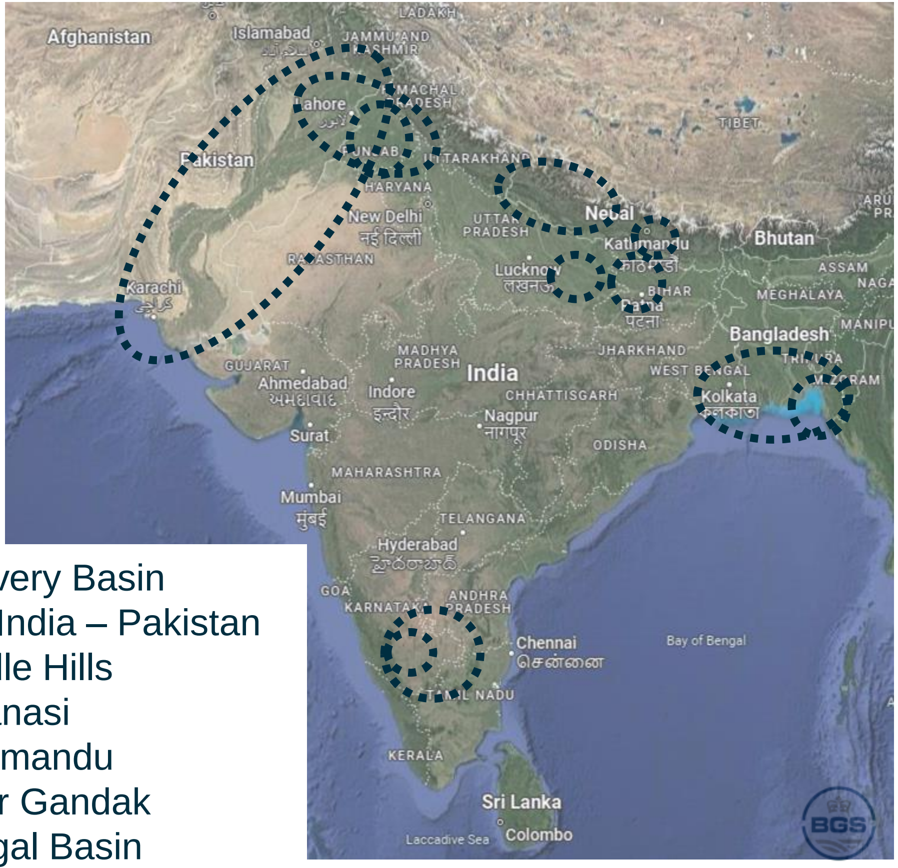
BGS Global Groundwater Science



- 40 + groundwater scientists
- Long-term engagement across India
- Strong partnership with NIH over the past 10 years

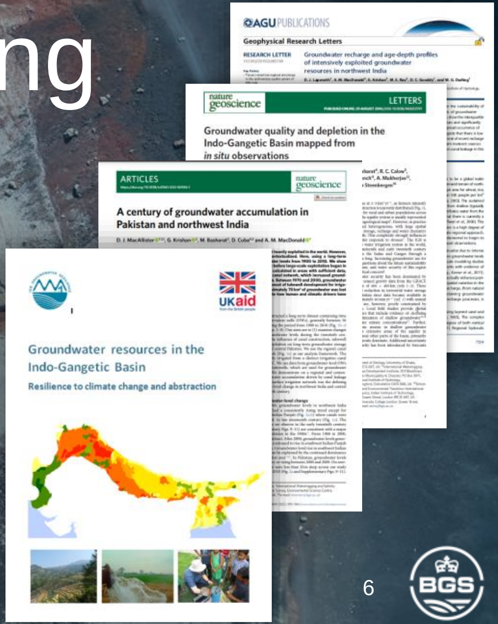
BGS Groundwater projects in India

- Hydrogeological typologies
- Mapping
- Modelling
- GW/SW interactions
- Recharge and residence times
- Water quality
- Long term GW levels



1. Cauvery Basin
2. NW India – Pakistan
3. Middle Hills
4. Varanasi
5. Kathmandu
6. River Gandak
7. Bengal Basin

Improving understanding of the IGB aquifer



Water use in the IGB

Water use approx 1000 km^3

Ganges/Indus/Brahmaputra flow 1200 km^3

Dam capacity approx 280 km^3

340 km^3 annual groundwater abstraction

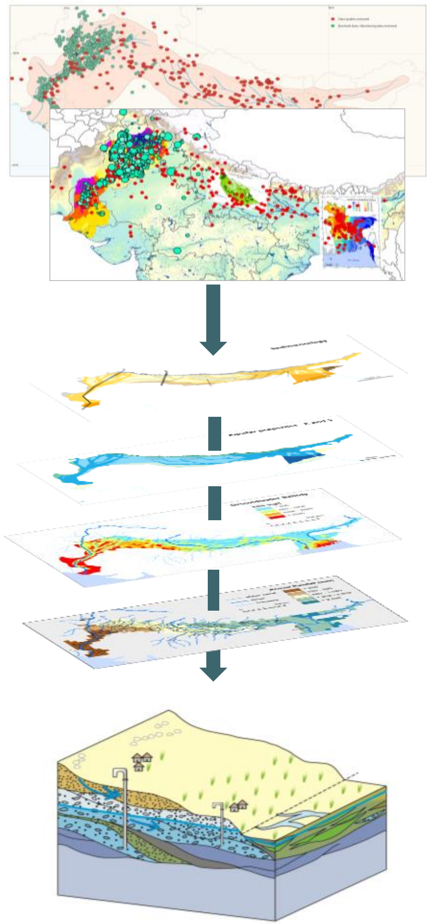
91% of water for irrigation

Methods

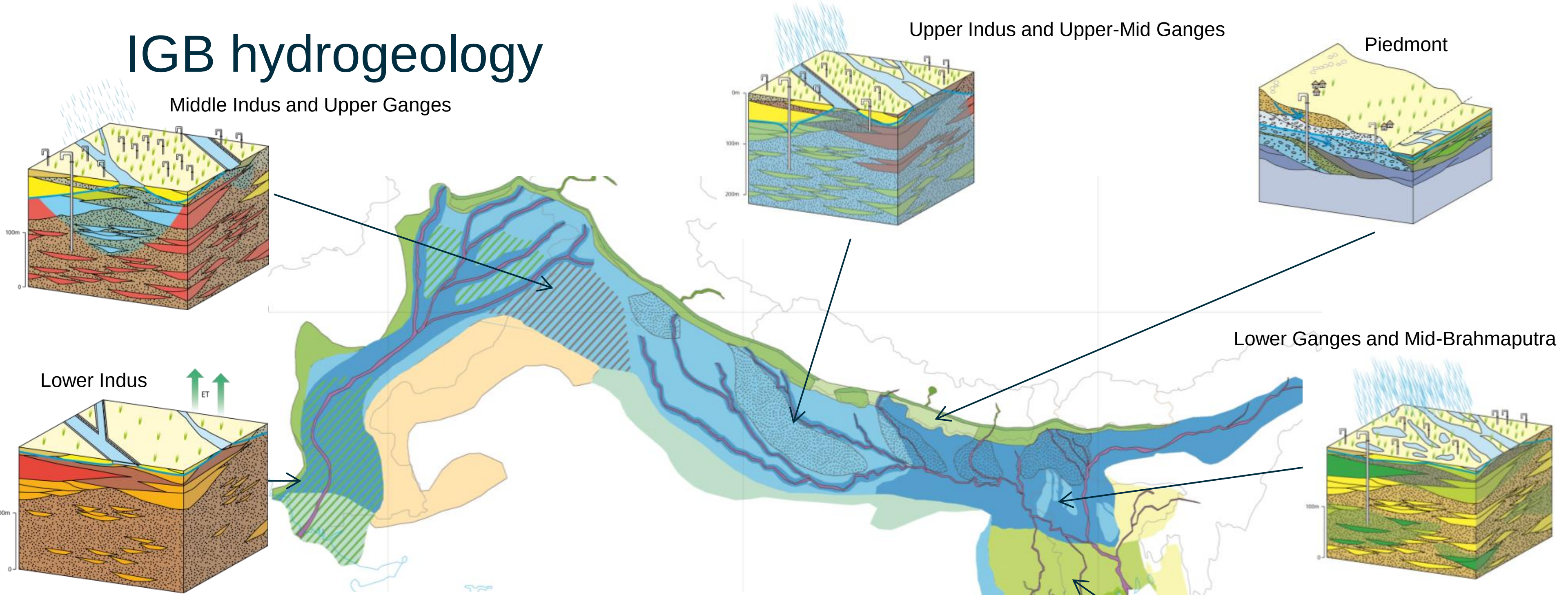
- Data collation and review – from the four countries: > 500 reports and datasets reviewed

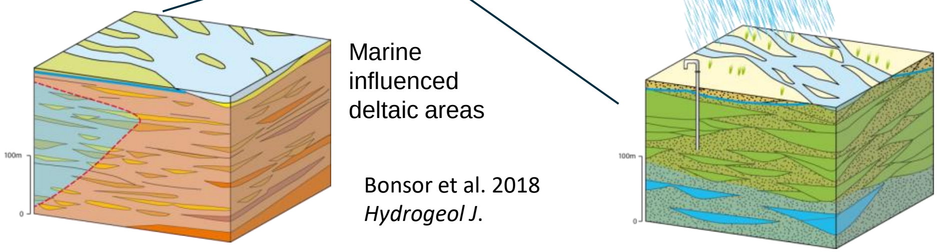
- New basin-scale data maps of key groundwater parameters: alluvial geology, abstraction, groundwater quality, water level trends, aquifer properties

- Delineation into 7 main typologies and 3 minor: 3D characterisation related to the resilience to change



IGB hydrogeology





Bonsor et al. 2018
Hydrogeol J.

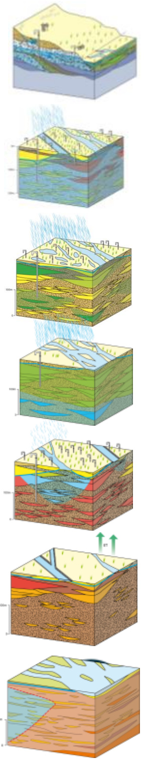
1. GW **storage 30,000 km^3** 20 times the annual flow in the GMB + Indus, 100 x storage in dams
2. Yields > 20 l/s
3. Large **systematic variations in aquifer**: permeability, storage and anisotropy

IGB hydrogeology

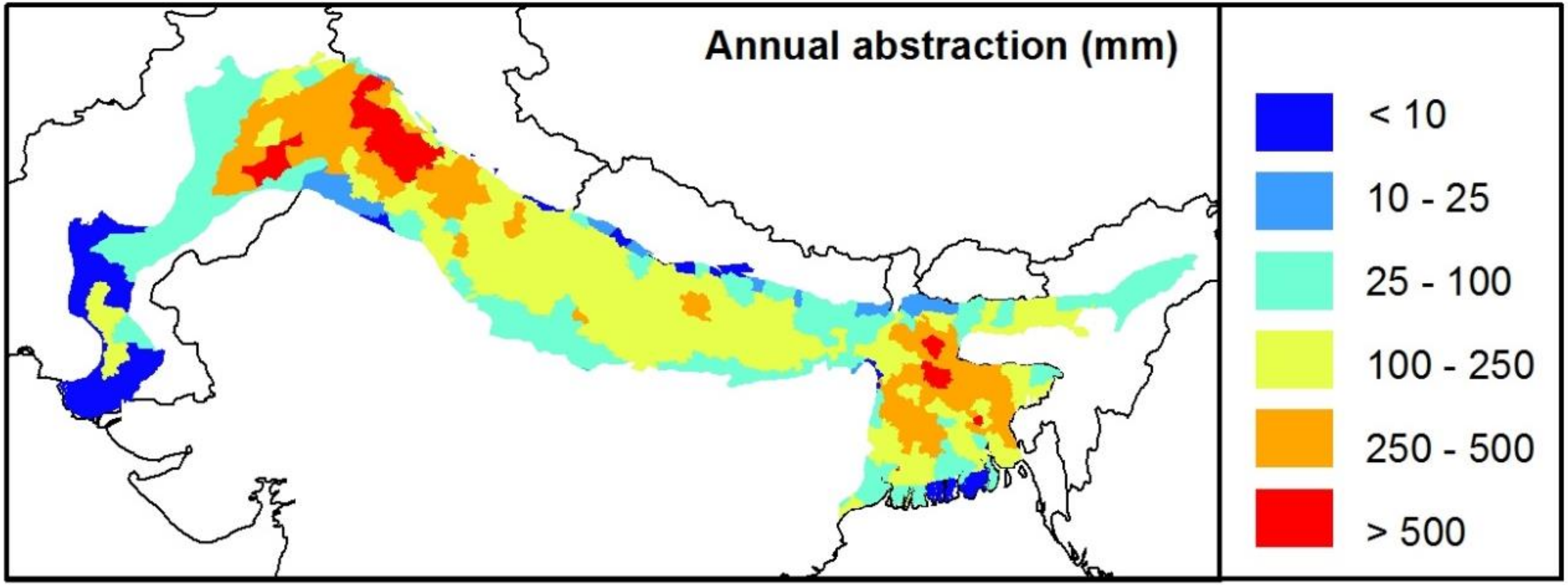
- Different characteristics
- Different symptoms
- Different response to pressures
- May need different strategies

Sources MacDonald et al 2015

	permeability	storage (Sy)	thickness (m)	Salinity	arsenic	Recharge mechanism	abstraction	Water-levels
Piedmont margin	High	V High	<100	No	local	High rainfall	Mod	stable
Upper Indus and Upper-Mid Ganges	V High	High	>200	local	local	High rainfall canals	V High	Variable mostly falling
Lower Ganges and Mid-Brahmaputra	V High	High	>200	No	local	High rainfall & rivers	Variable	Shallow mostly stable
The fluvial influenced deltaic area of the Bengal basin	High	Mod	>350	No	V High Low at depth	High rainfall	High	Shallow mostly stable
Middle Indus and Upper Ganges	High	High	200	Yes	local	Moderate canals & irrigation	High	Mostly falling rapidly
The Lower Indus	Mod	Mod	200	Extensive	local	Moderate canals & irrigation	Low	Rising
The marine influenced deltaic areas	Mod - Low	Low	350	Extensive	local	variable	at depth Bangladesh	Shallow and Variable



Groundwater abstraction in the IGB



Abstraction high – 205 km^3 **25% global abstraction**;

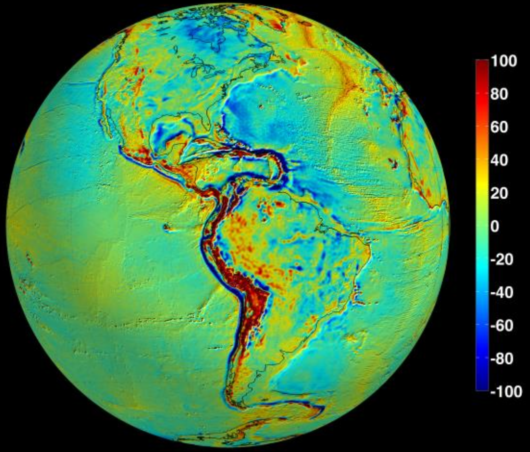
Bonsor et al. 2018 *Hydrogeol J.*

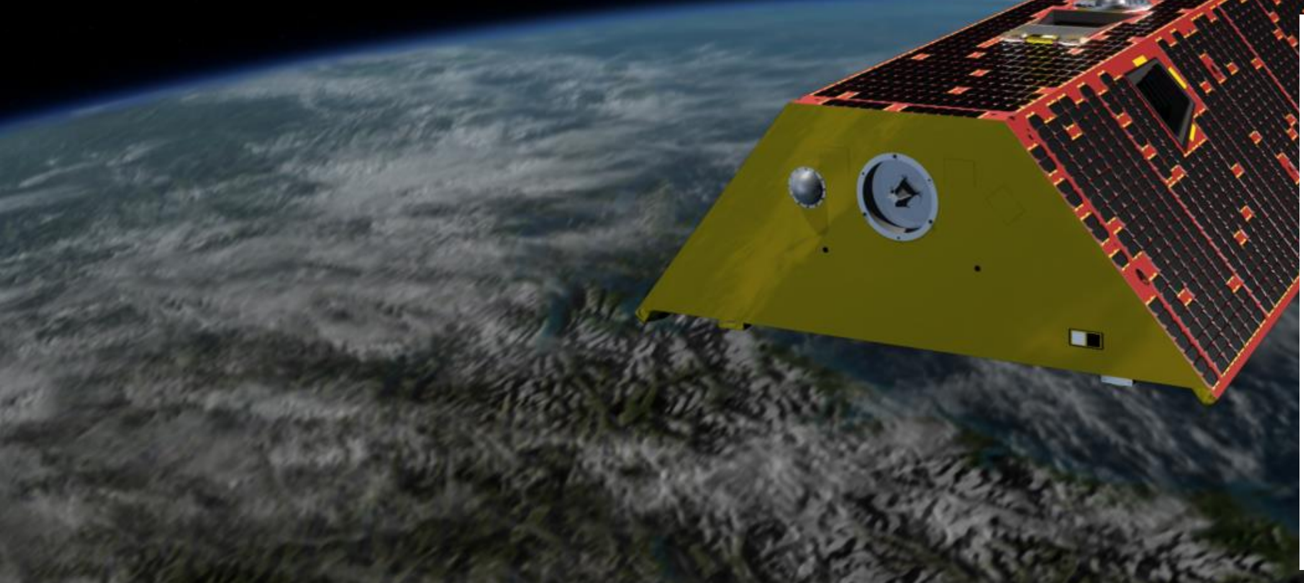
GRACE / GRACE-FO

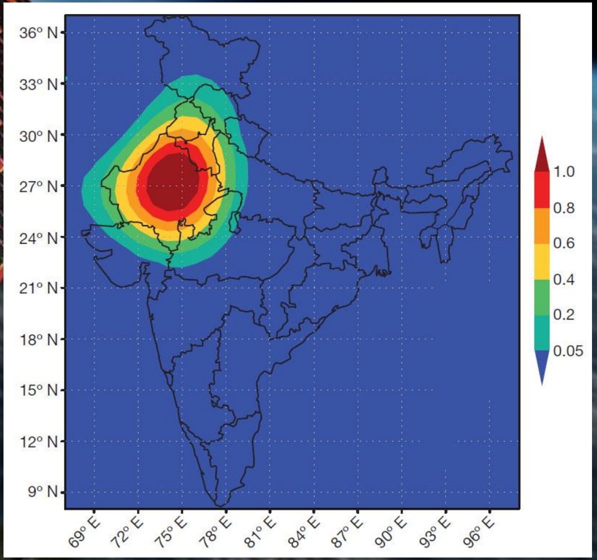
Large footprint – 400 x 400 km

Monthly return

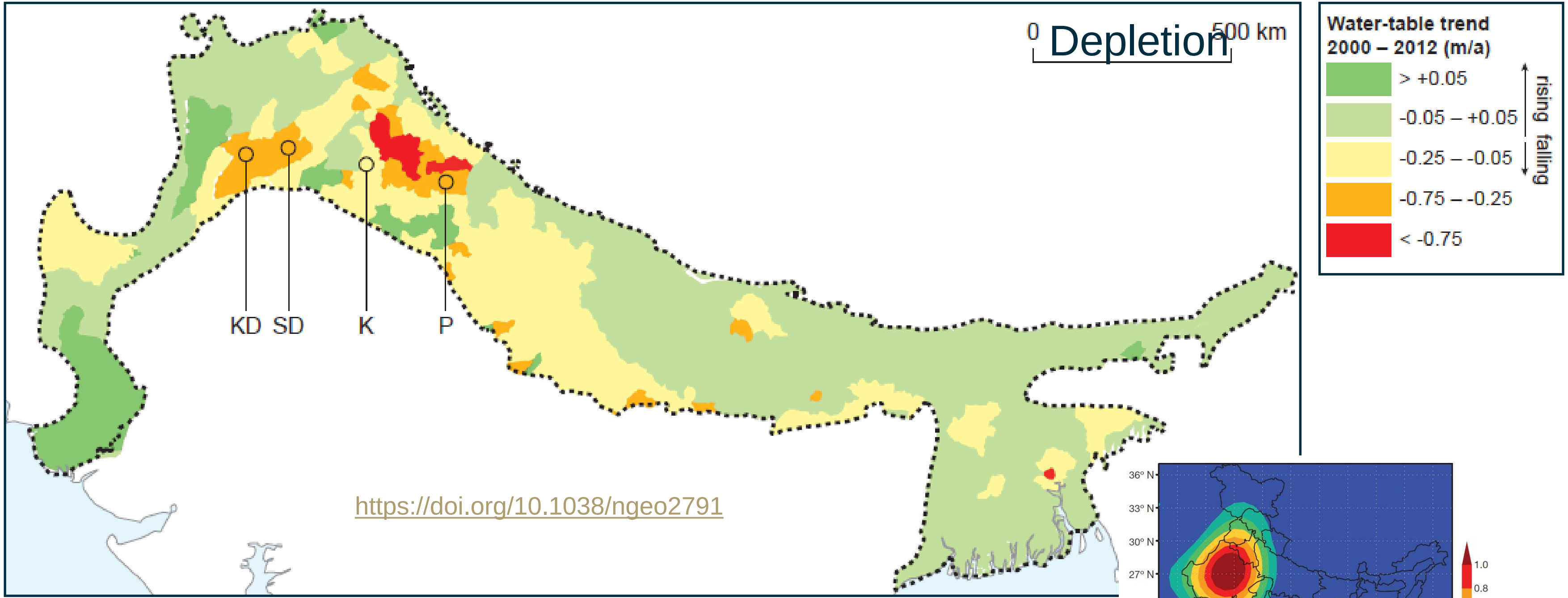
Much modelling and corrections



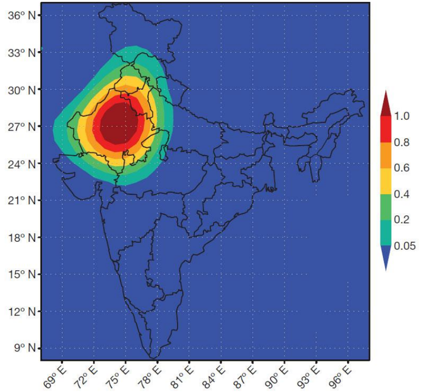




Groundwater depletion in the IGB

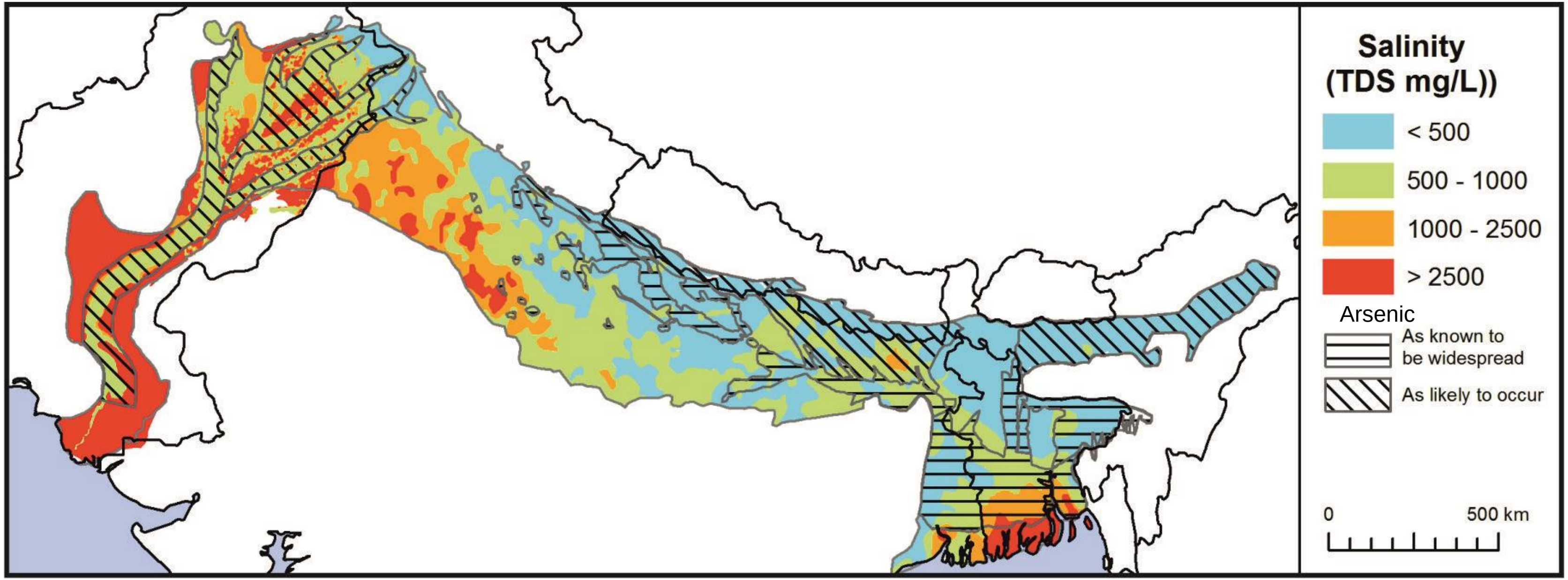


https://doi.org/10.1038/ngeo2791



MacDonald et al. (2016) *Nature Geoscience*

Groundwater salinity and arsenic



Salinity or arsenic impacts up to 60% of the aquifer area

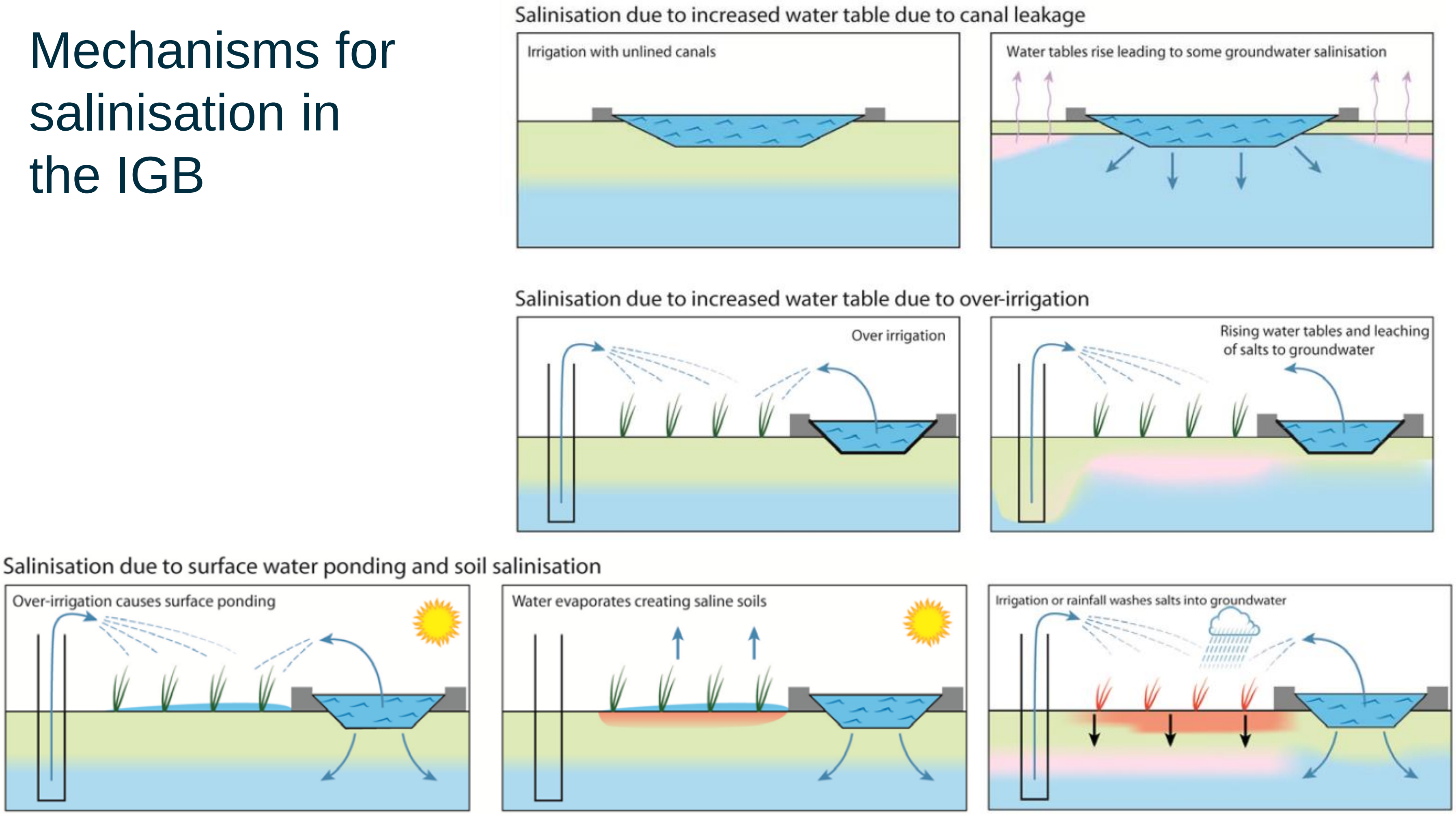
Salinity is both natural and man made

Arsenic natural and associated with Holocene deposits and organic soils

Other quality problems poorly constrained

MacDonald et al. (2016) *Nature Geoscience*

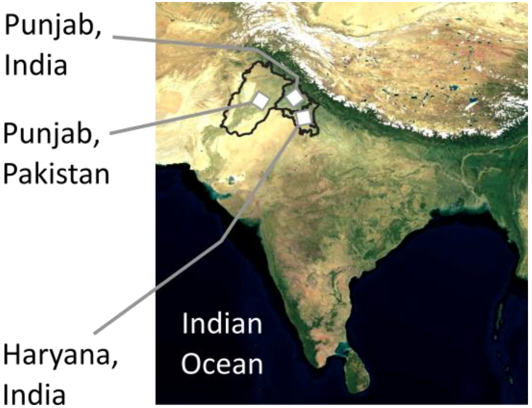
Mechanisms for salinisation in the IGB

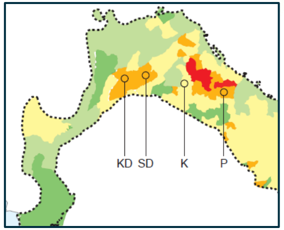


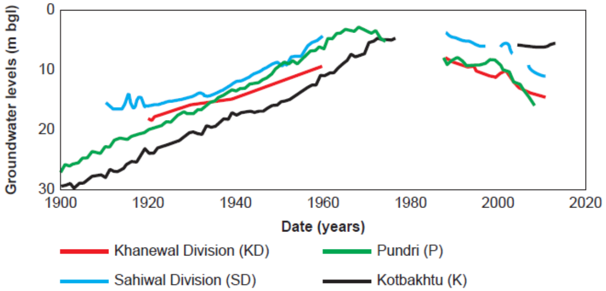
A century of groundwater level change

Long-term groundwater level change in the IGB

- Groundwater depletion is a major concern.
- Groundwater used for > 100 years.
- Groundwater level change since 1900?
- 4028 observation wells from 1900 – 2010.







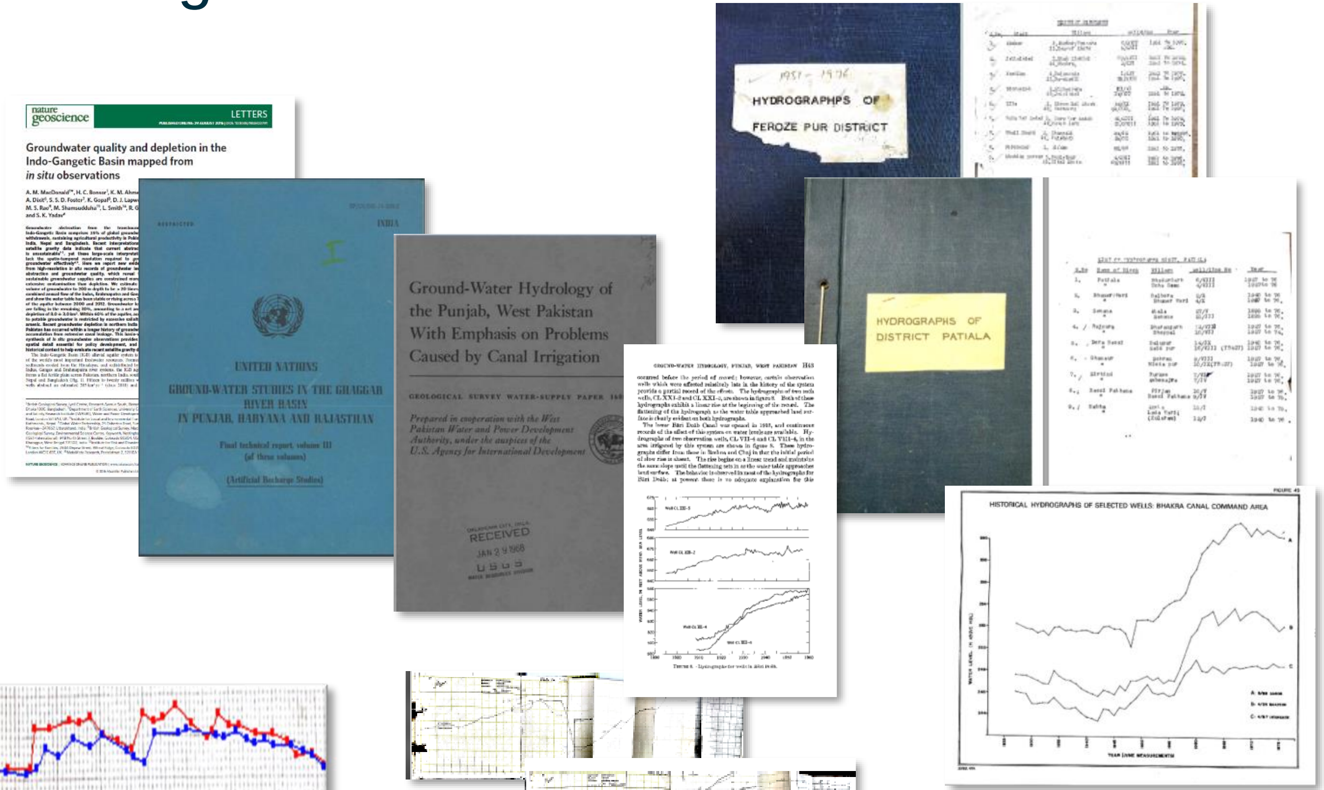
Pre1857

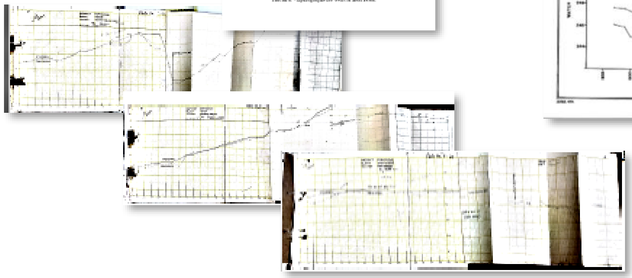
1800s - 1947

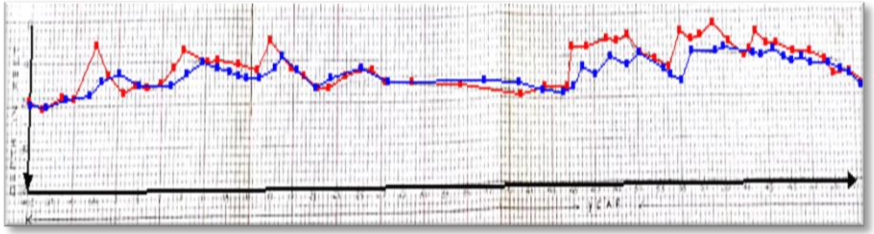
Post 1947

Compilation of historic groundwater data

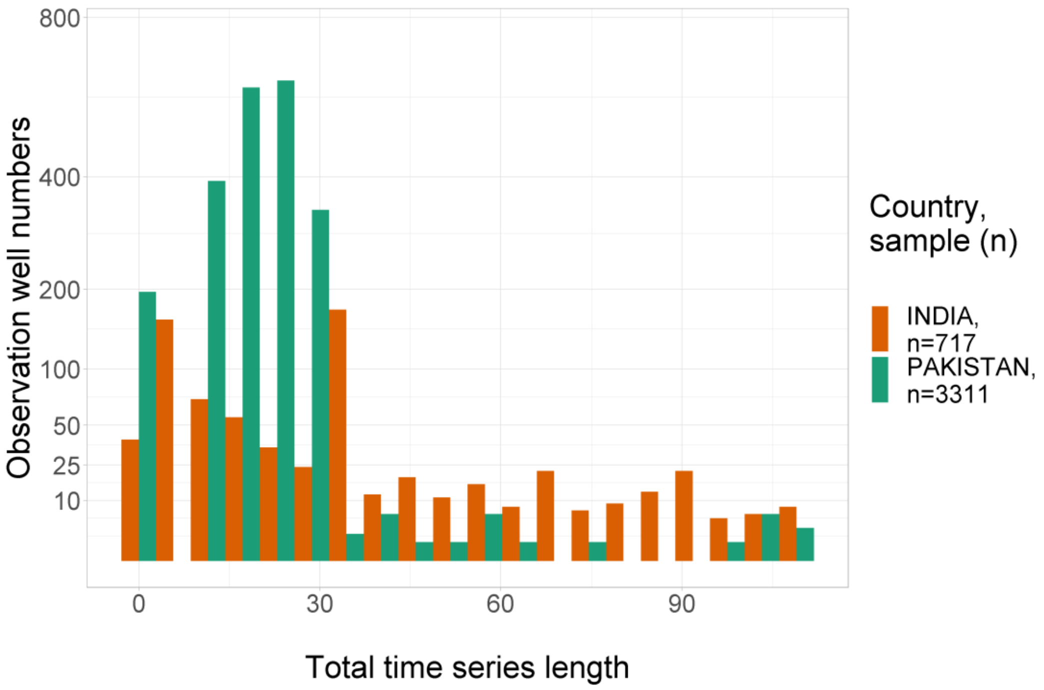
- > 100 hydrographs scans:
  - old reports
  - books
  - government archives
  - digital and hard copy

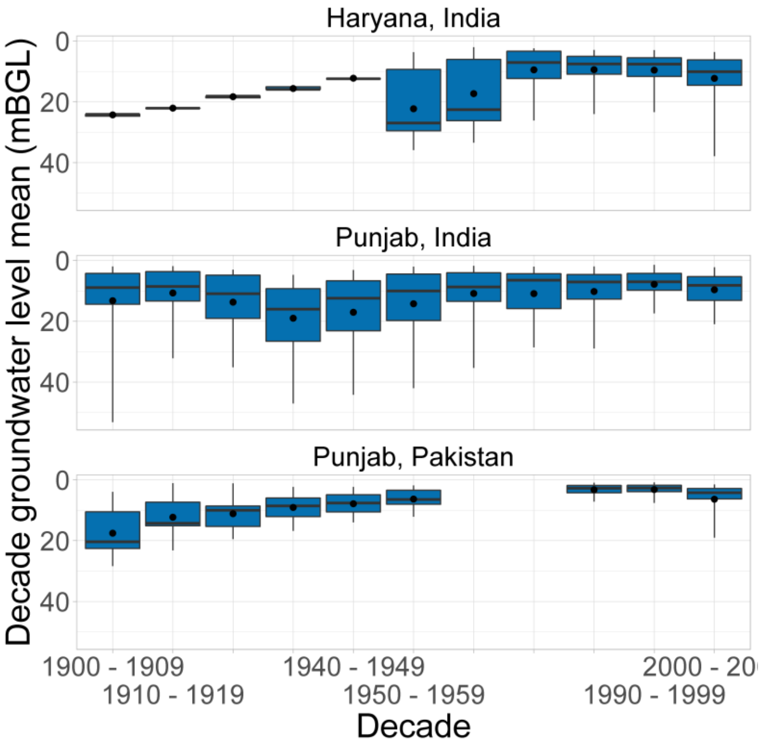




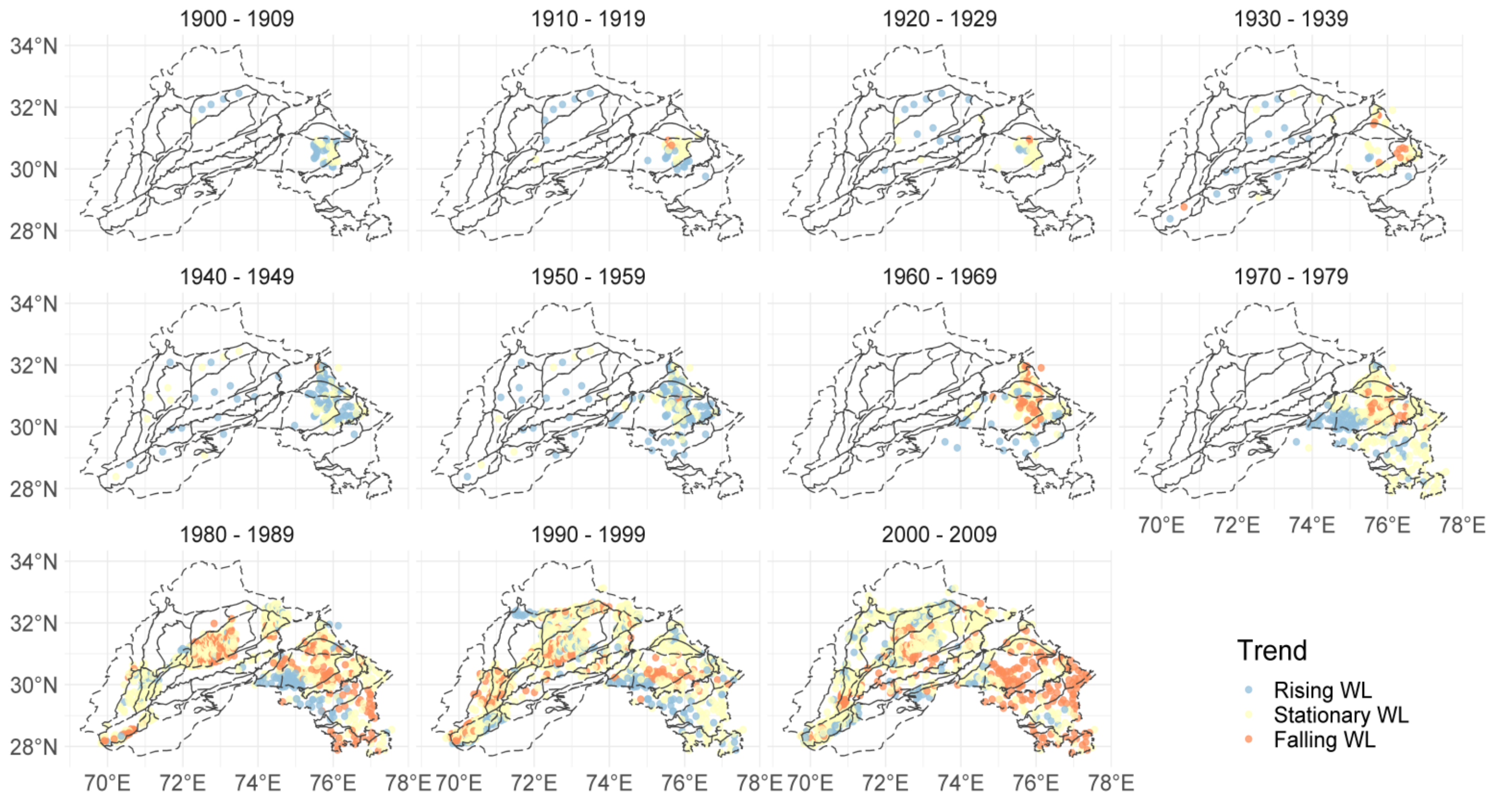


Tubewell numbers and groundwater levels

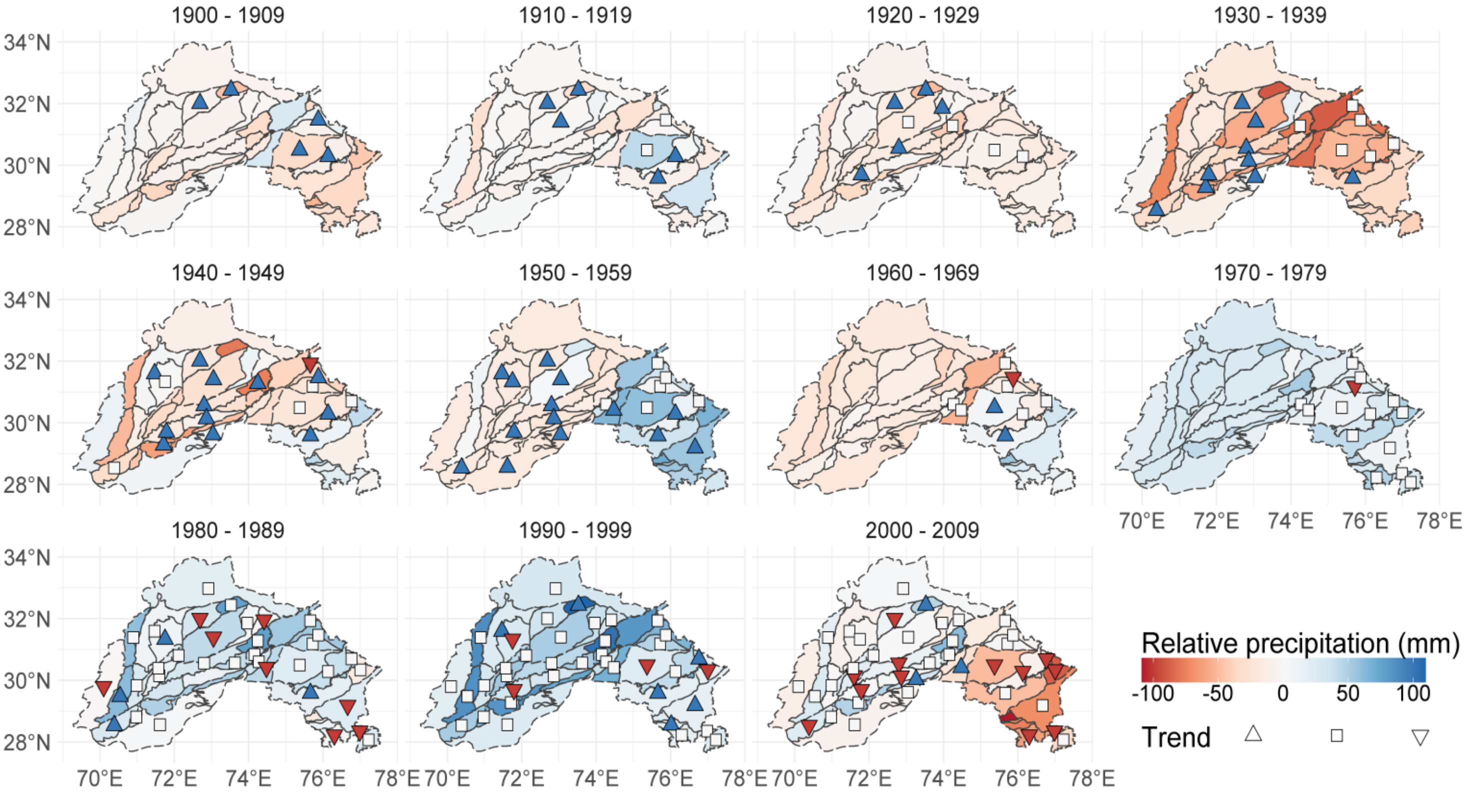




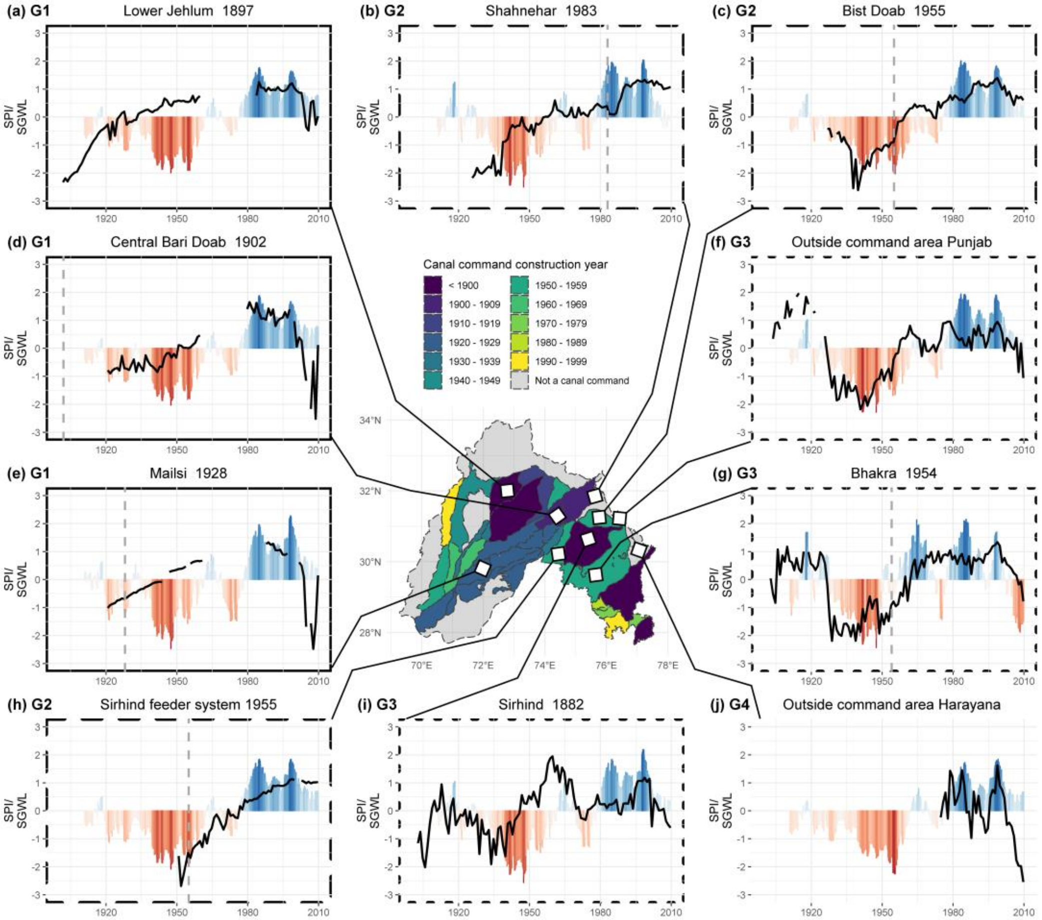
Groundwater level decadal trend



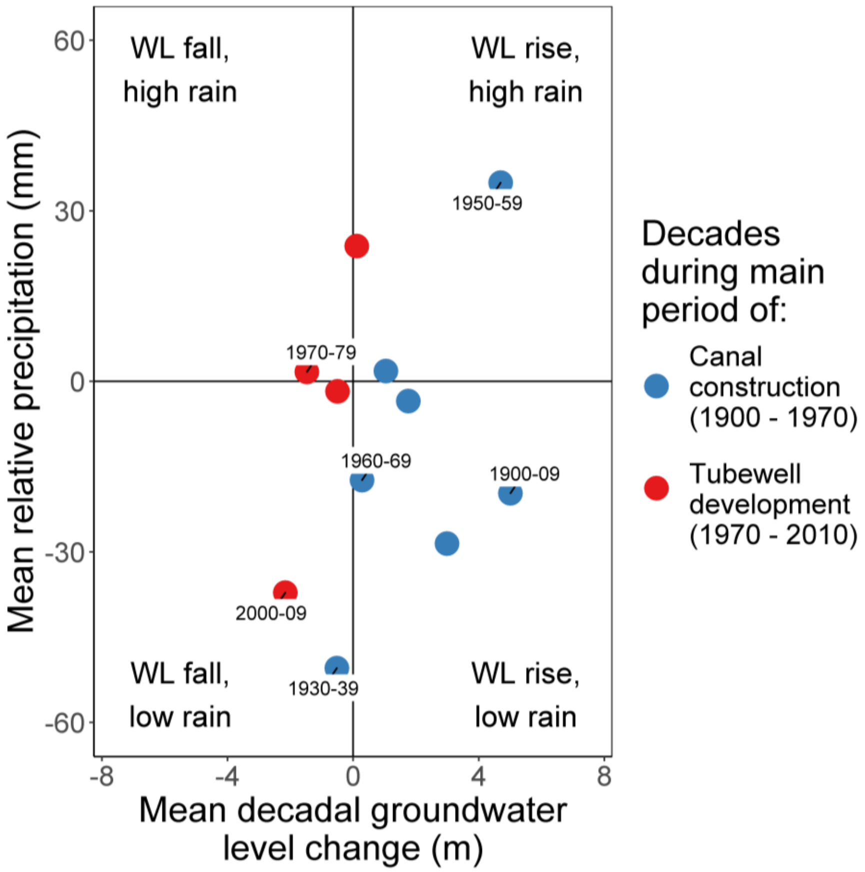
Groundwater level and precipitation trend



Regional groundwater level trends

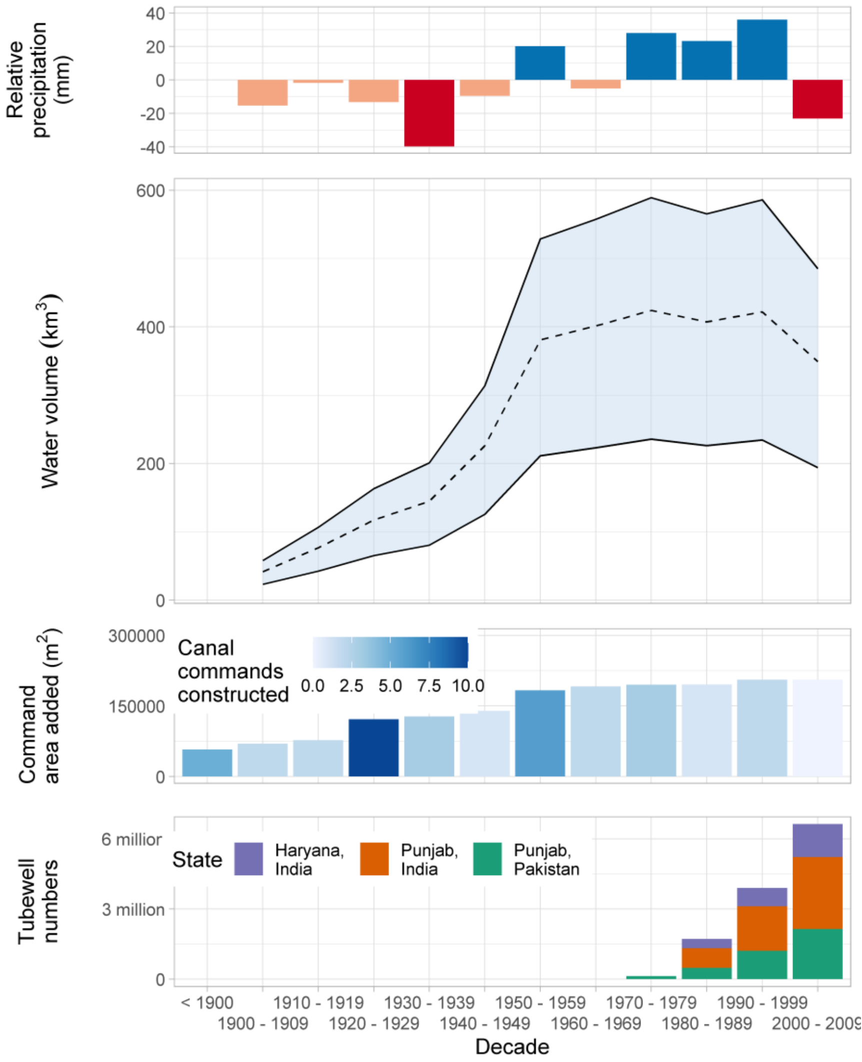


Influence of canals and tubewells on decadal trend



A century of accumulation

- 1900 – 1960:
  - Rainfall below period mean.
  - **125,000 km²** of canal area added.
  - Net groundwater accumulation: **350 km³** (range: 150-450 km³)
- 1960 – 1990:
  - Rainfall above period mean.
  - Little additional canal area added.
  - Tubewell development began.
  - Groundwater stabilised.
- 1990 – 2010:
  - Rainfall below period mean.
  - Groundwater depletion **75 km³** (range: 25-100 km³)



Groundwater in its recent historic context in the IGB

- For the majority of the last century groundwater levels were rising, net groundwater accumulation was c.350 km^3.
- Large scale irrigation development via canal construction played a defining role in groundwater accumulation.
- More recent groundwater depletion was driven by the superimposed effects of low average rainfall and large scale tubewell development.
- **Human activity in the early 20th century increased the total volume of groundwater available prior to large scale exploitation in the late 20th century.**

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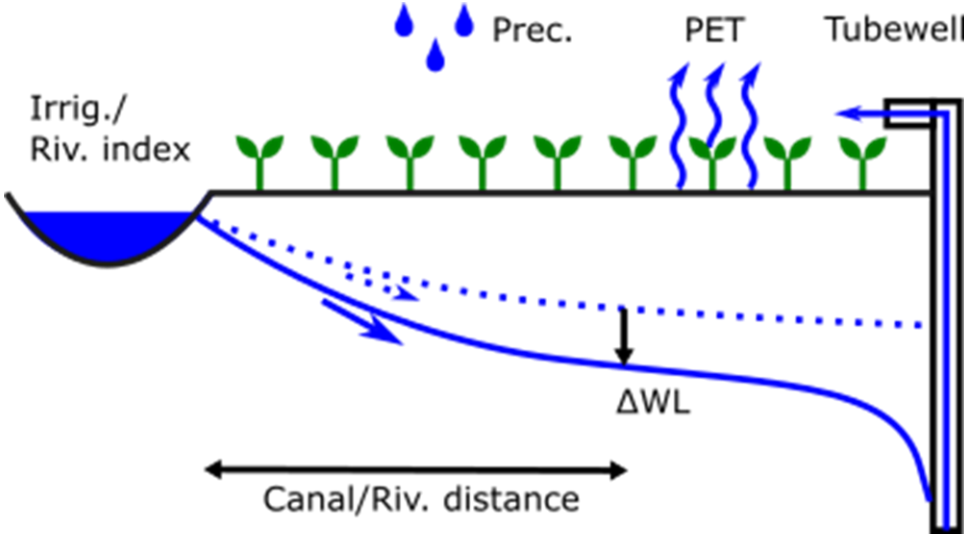
Quantifying relative importance of recharge sources

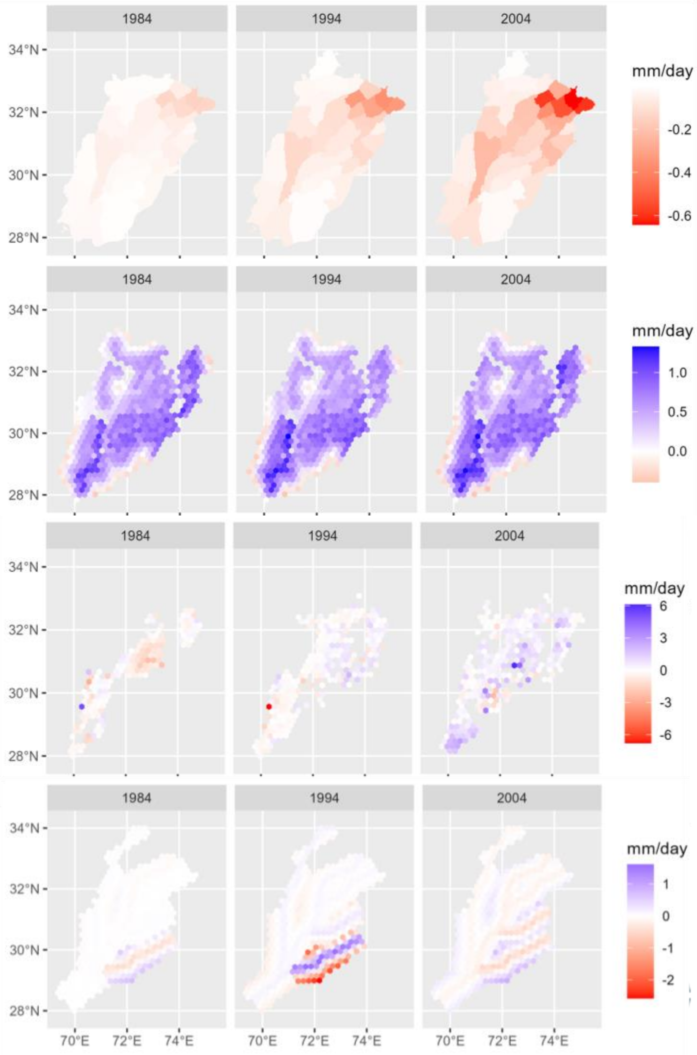
Quantifying recharge sources in the IGB

- Developed a spatially correlated linear model for Punjab in Pakistan, the model:
  - considers groundwater levels' daily rates of change over the monsoon.
  - examines first-order marginal effects of potential influences on groundwater recharge.
  - uses a linear approximation for distance's moderating effect on river/canal leakage.

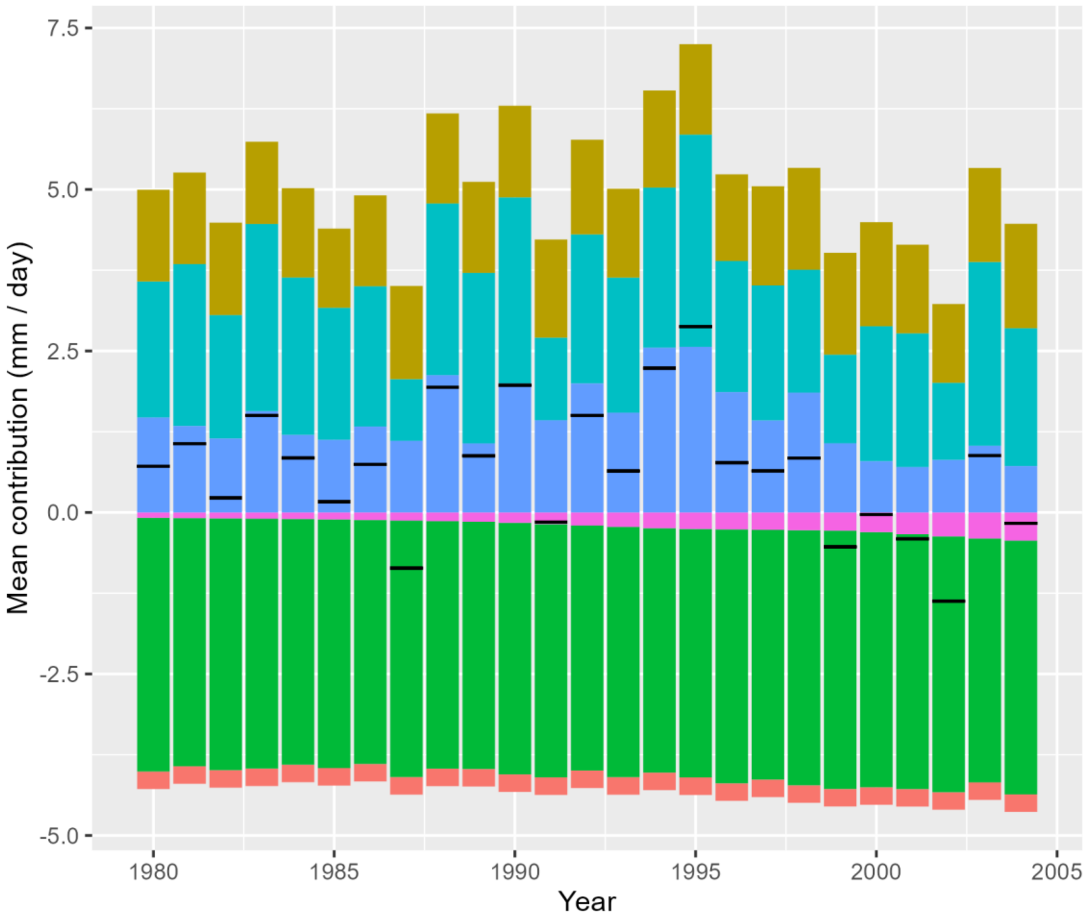


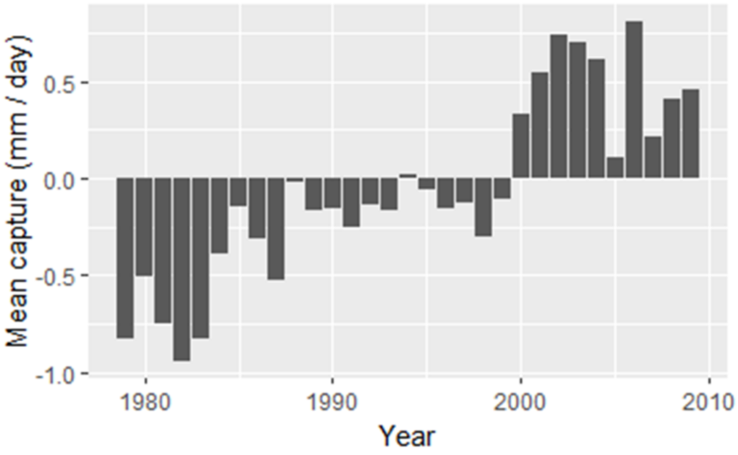
Quantifying recharge sources in the IGB

- **Tubewell effects**: the increasing importance of tubewell abstraction as more and more wells were drilled for irrigation
- **Canal irrigation effects**: The effect of high or low river/canal flows, decreasing with distance from each canal
- **Groundwater capture effects**: Increasing groundwater capture due to the slightly lower pre-monsoon water levels in 2000’s than 1990’s and in 1990’s than 1980’s.
- **River inflow effects**: decreasing effects with distance from rivers



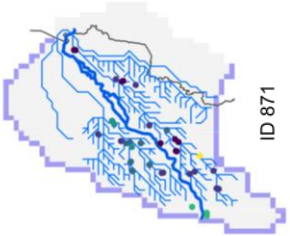
Quantifying recharge sources in the IGB

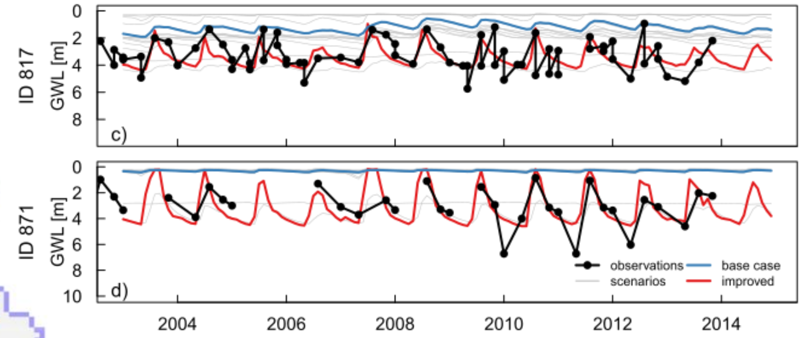


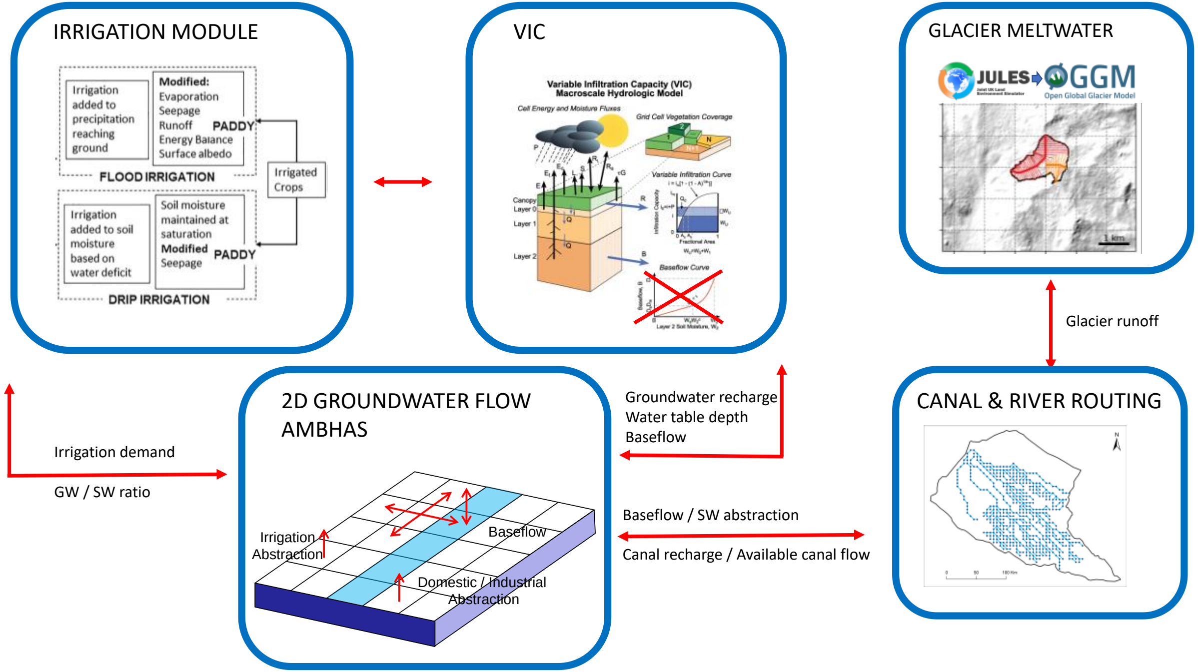


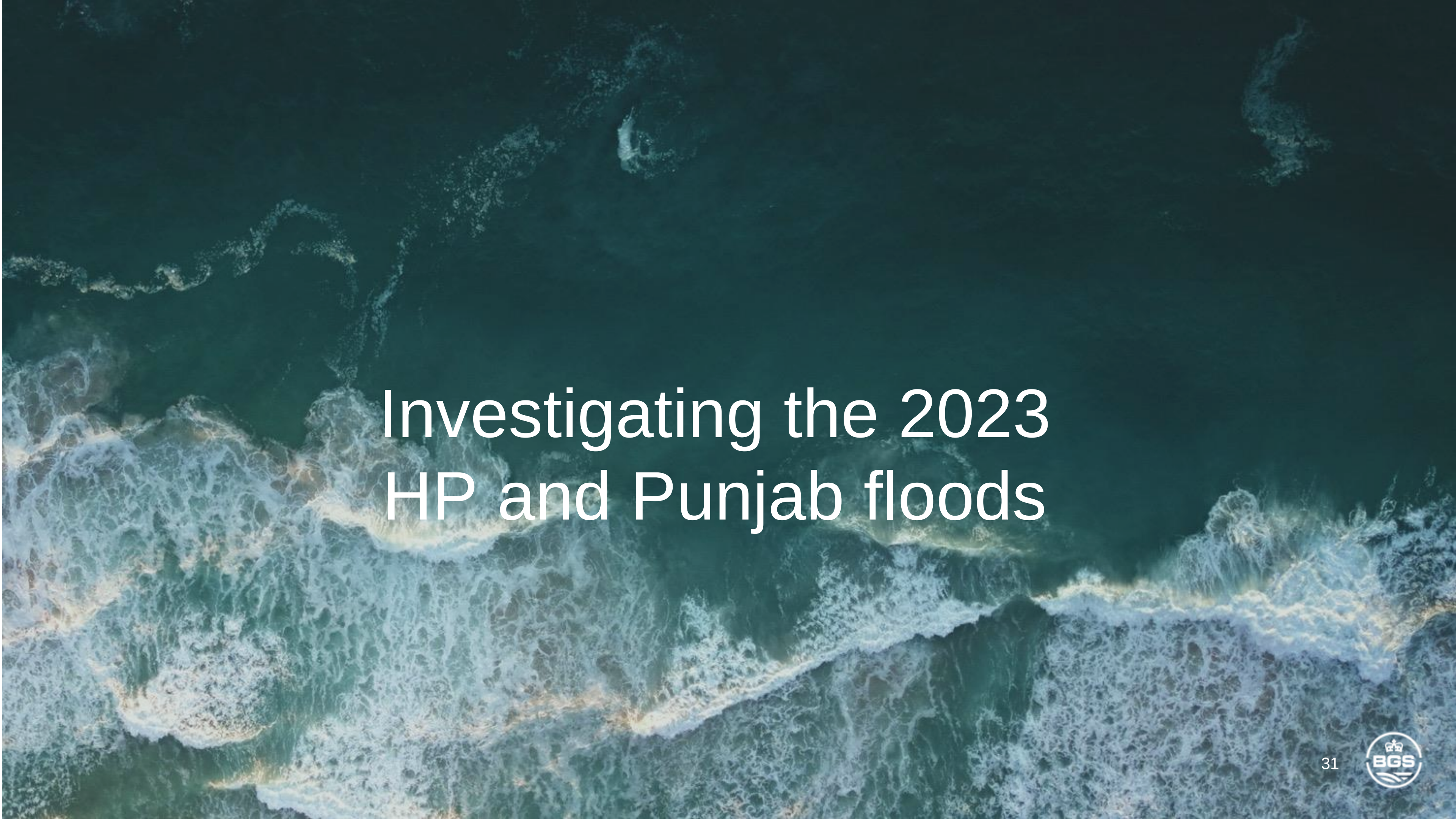
IGB hydrological modelling

- Adding irrigation and surface water routing to VIC, a large-scale, semi-distributed hydrological model.
- VIC linked to a 2D groundwater model adding lateral flow, and tested in the Gandak, Bihar.
- Explore glacier runoff and other future impacts on downstream water use/vulnerabilities in the IGB by linking JULES-OGGM with VIC.









Investigating the 2023 HP and Punjab floods

Aim

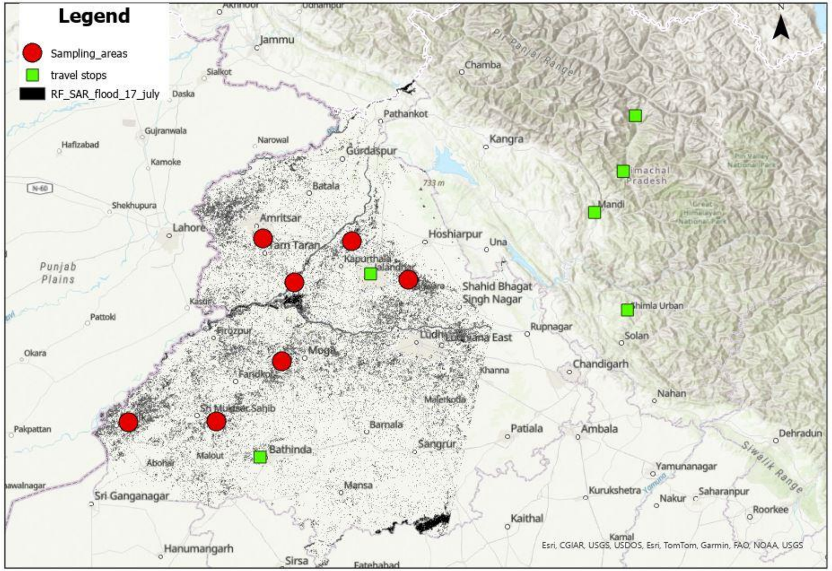
- **To constrain the scale of the extreme flood event in HP and Punjab in July 2023 and assess the cumulative impact of continued heavy rain and flooding, focusing on groundwater recharge and contamination, during the 2023 monsoon.**

Objectives

- Characterise initial flood characteristics and cumulative impacts of persistent rain to estimate flood inundation, peak flow, magnitude, and return period in the mountains and plains.

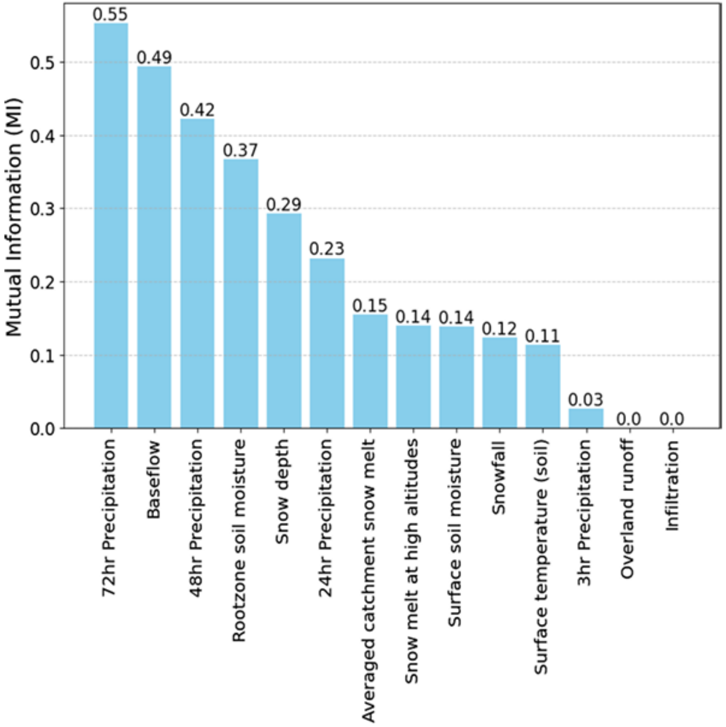
- Collect and interpret groundwater level and natural tracer data to quantify the impacts of floods on groundwater levels and recharge in the Punjab plains and relate this to upstream and downstream flood characteristics.

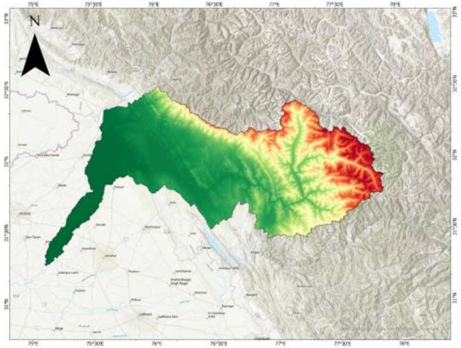
- Quantify flood impacts on water quality by collating baseline data and conducting new groundwater quality sampling and analysis.



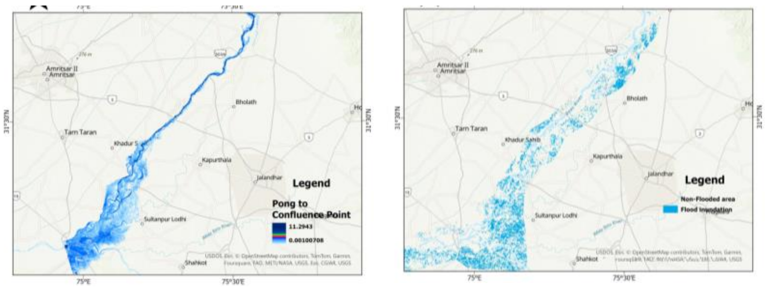
Flood characterisation

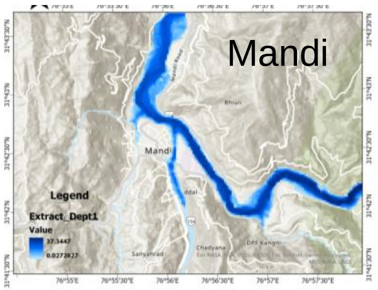
- Investigating the relative contribution of different factors to the flood intensity.
- Developing 1D and 2D models of the flood in HP and Punjab.
- Relating the upstream flows to downstream river flow and subsequent groundwater recharge and contamination.





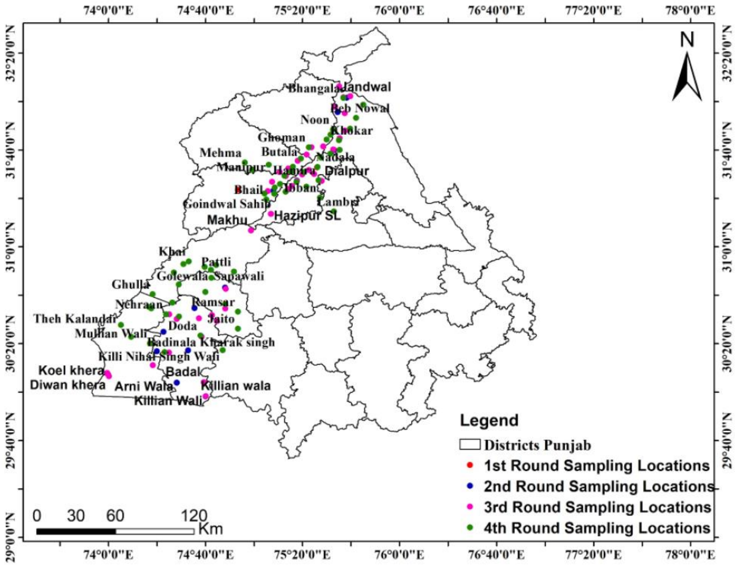
Punjab

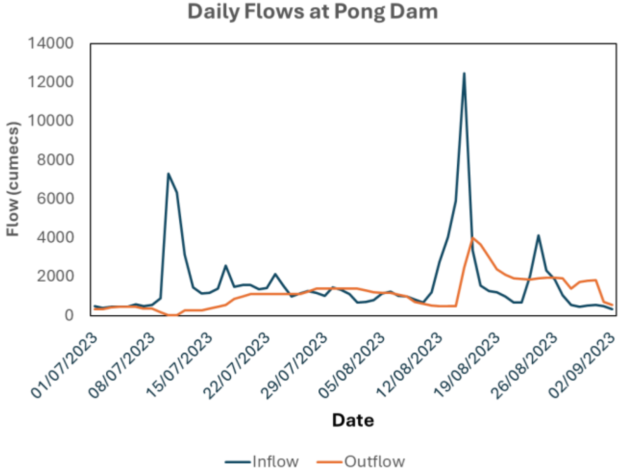




Investigating floods impact on groundwater in Punjab

- Collected 126 records of groundwater levels from the 5 worst affected districts
- Almost 200 samples collected in Punjab:
  - Stable isotopes, Natural tracers (CFC, SF6), Pesticides/fungicides, Major ions, Metals
- Once analytical analysis is complete, we will examine how the flood water from HP influenced groundwater in Punjab.
- Initial indications suggest dams were crucial in limiting flow to Punjab, Pong **dam restricted outflows from HP** to **over 99%** of the incoming floodwater, likely also limiting recharge potential.

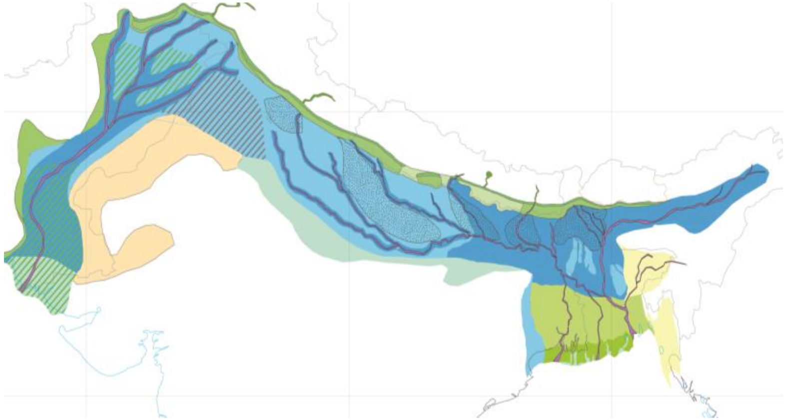




Groundwater in the IGB

Summary and conclusions

- The IGB aquifer is an excellent buffer to human and climatic change.
- It has been changing for more than 150 years and has been altered by human activity throughout this period.
- Groundwater is more vulnerable to abstraction than climate change.
- Degradation in groundwater quality is arguably a greater concern than depletion.
- The aquifer properties and status vary considerably and need targeted governance.
- Groundwater and surface water are linked – one resource.



THANK YOU

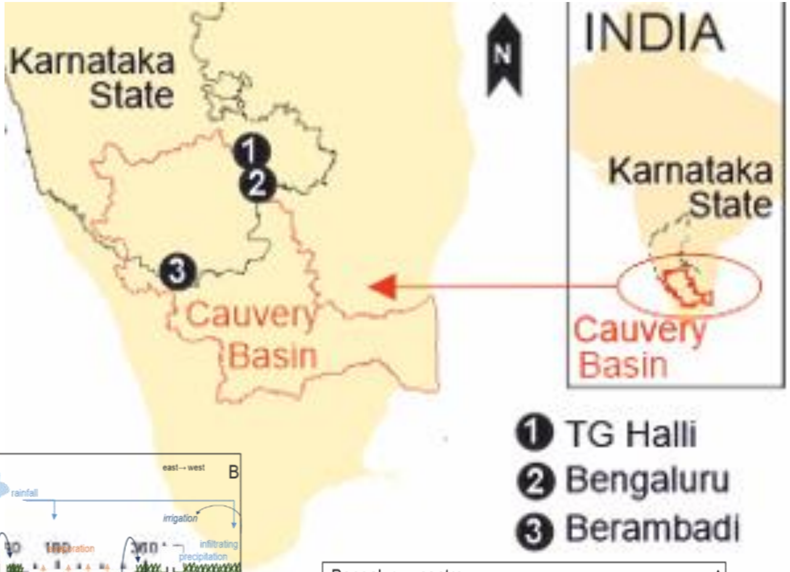
Any questions?

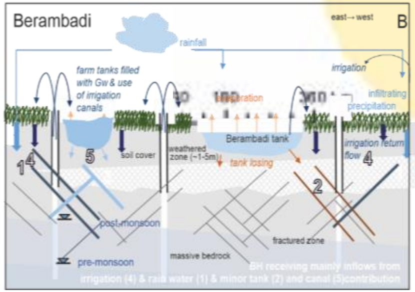
Groundwater in South India

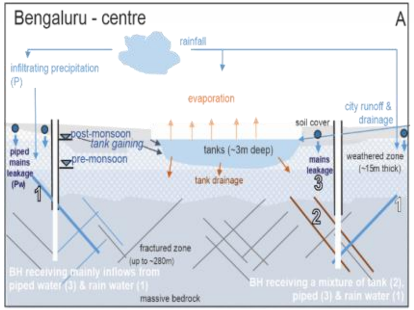
Groundwater in the Cauvery

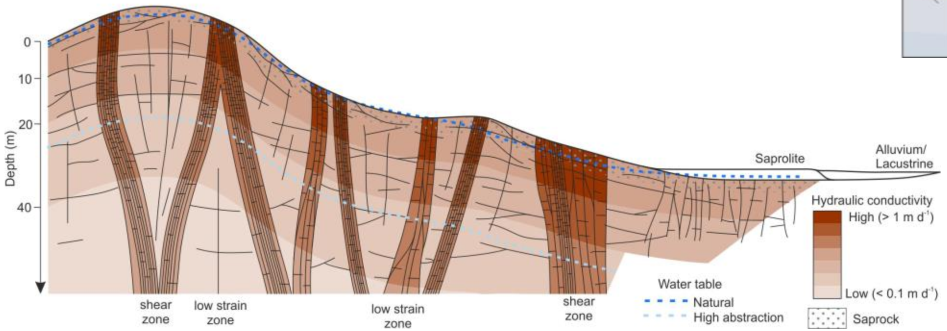
- Understanding groundwater connectivity of a sheared gneiss aquifer.

- Assessing the role of tanks in groundwater recharge.









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