The evolution of long-term groundwater storage and recharge in the Indus Basin

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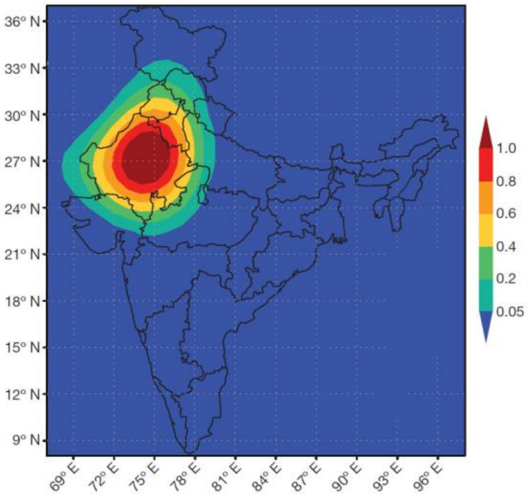
Overview

- How has groundwater storage changed over the last 150 years of intensive water resource developments in the Indus basin?
- What is the relative contribution of human vs climatic factors on long-term groundwater storage?
- Can we quantify the contribution of different sources of groundwater over this period?
- Long-term changes in groundwater in the Indus Basin.
- Quantifying relative influence of recharge sources in the Western Indus Basin.

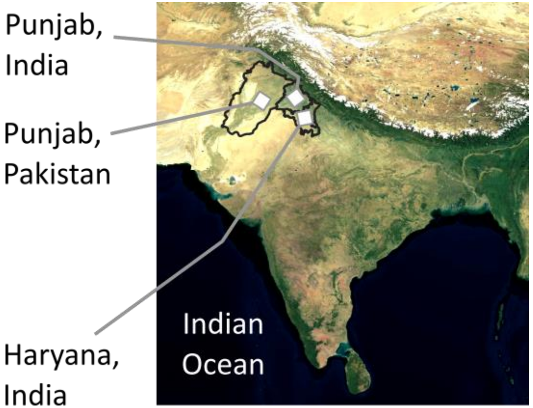
A century of groundwater level change

Background

- Groundwater depletion is a major concern in the 21st century.
- Long-history of water resource development in the Indus basin.
- Large-scale groundwater use is relatively recent.
- How has groundwater storage changed in the past century?



Rodell et. al. 2009, Nature

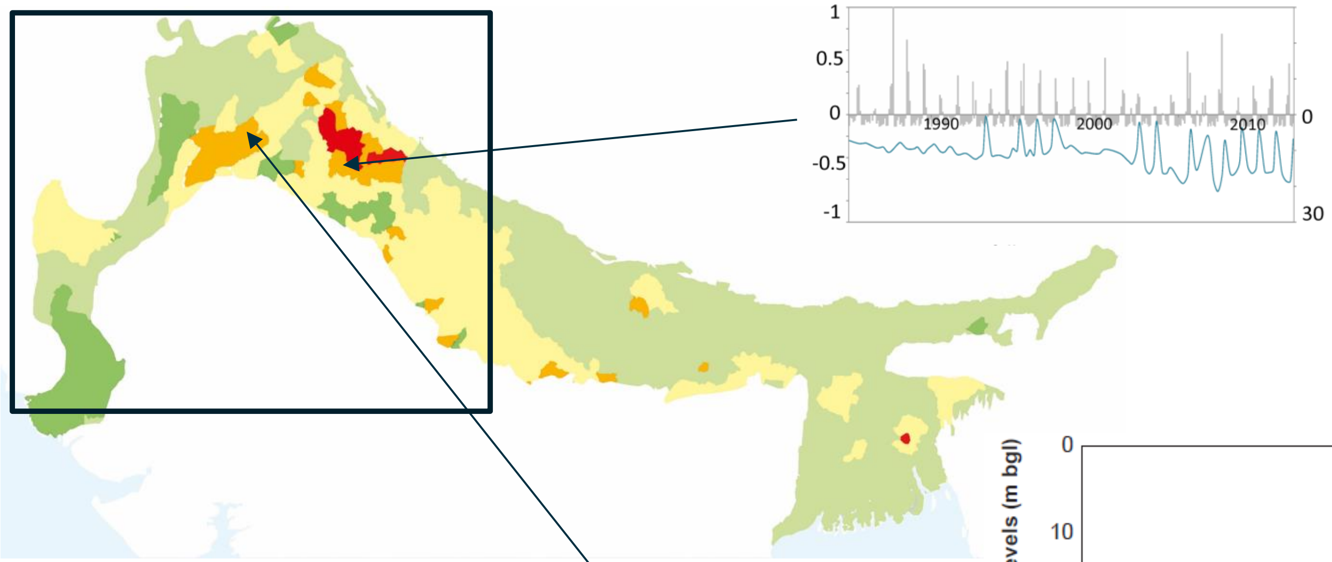


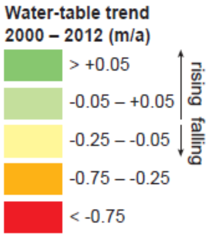
Pre1800s

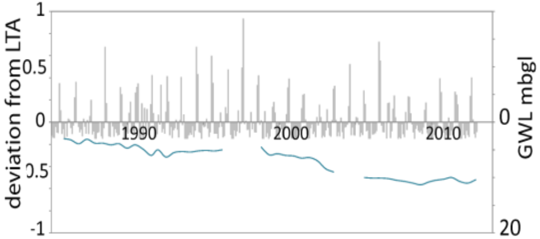
1800s - 1947

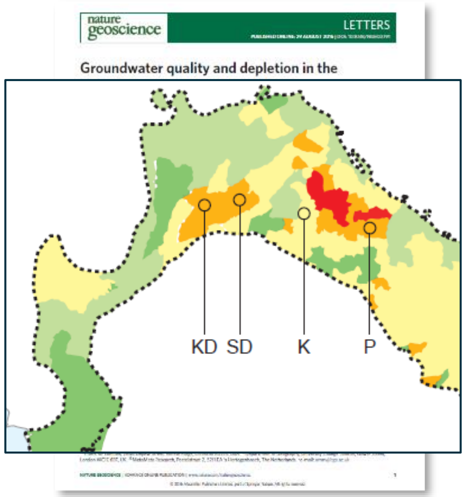
Post 1947

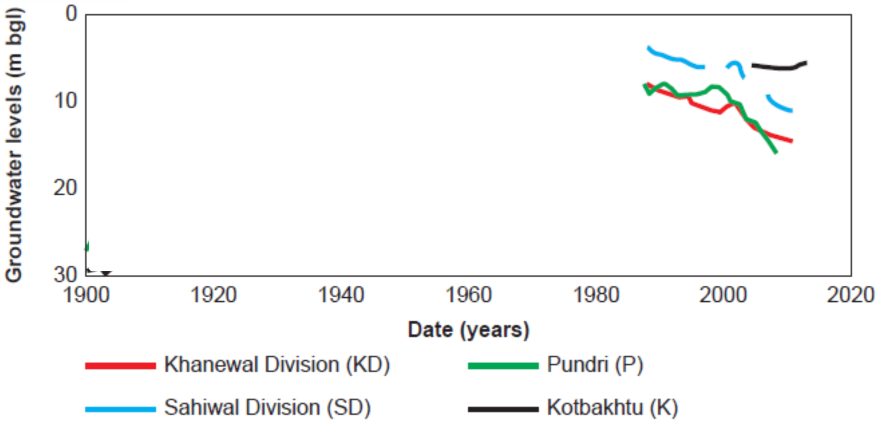
Motivation





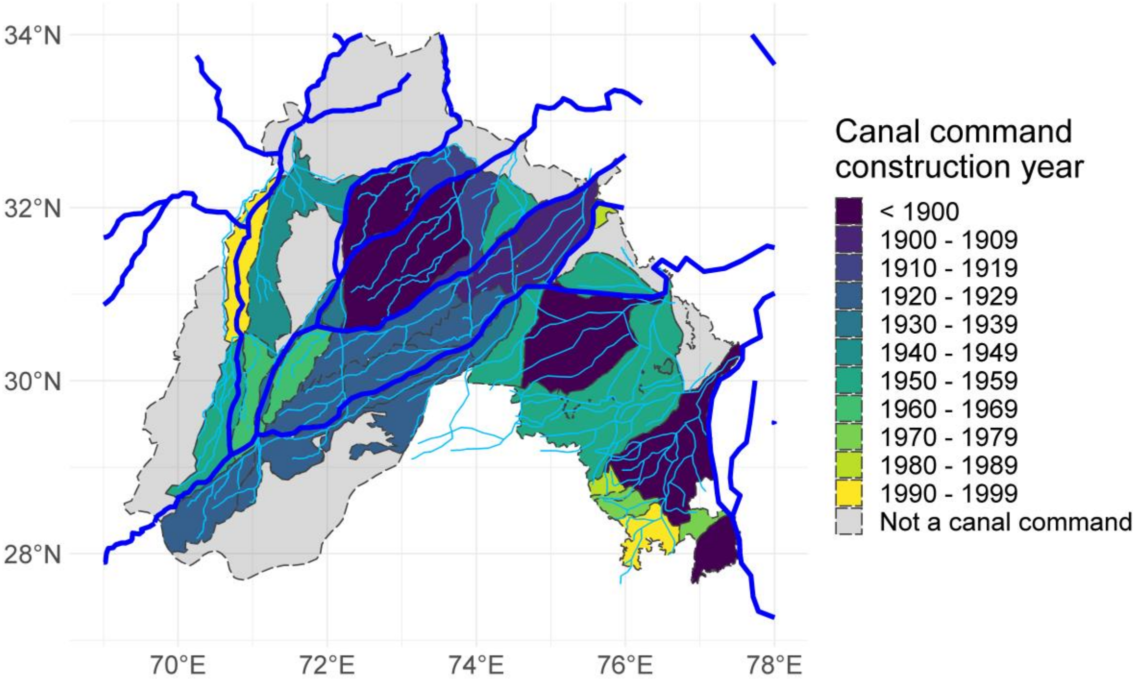


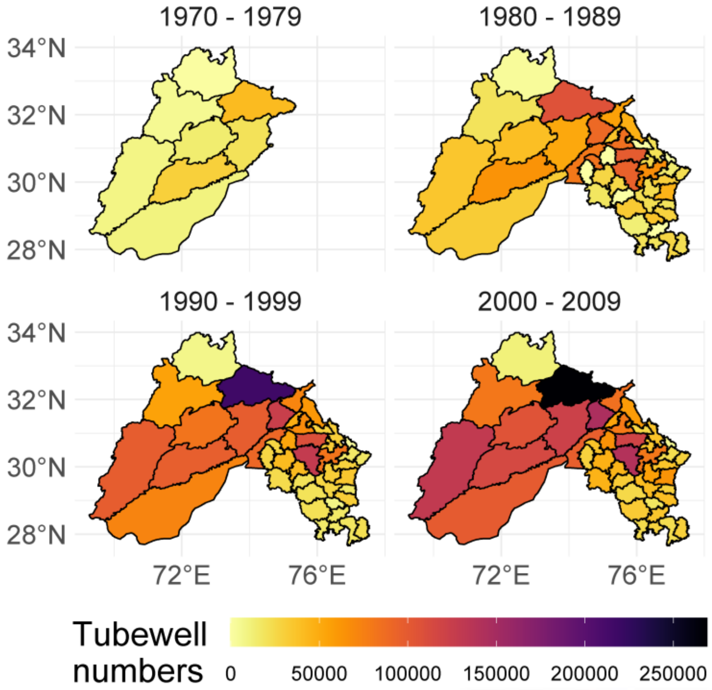




MacDonald et. al. 2016, Nat Geoscience

A century of water resource development

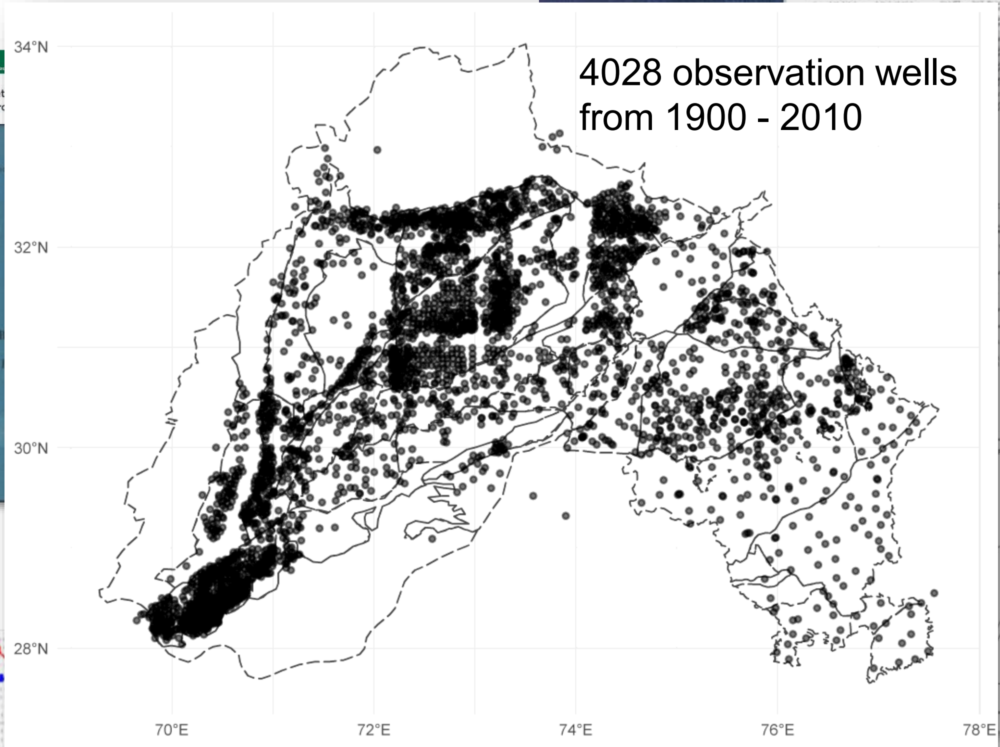


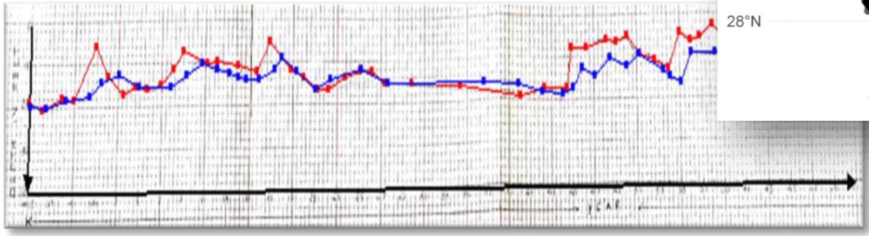


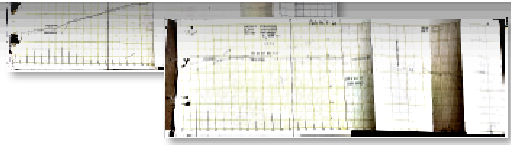
MacAllister et. al. 2022, Nat Geoscience

Compilation of historic groundwater data

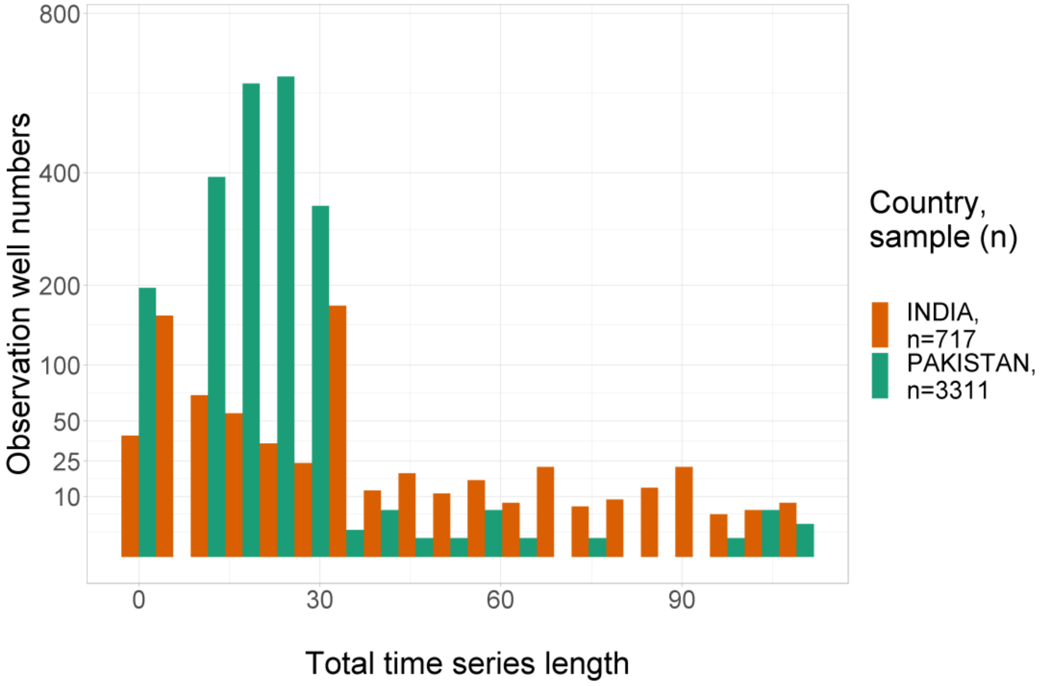
- > 100 scans:
  - old reports
  - books
  - government archives
  - digital and hard copy
  - Ex-director agricultural Punjab

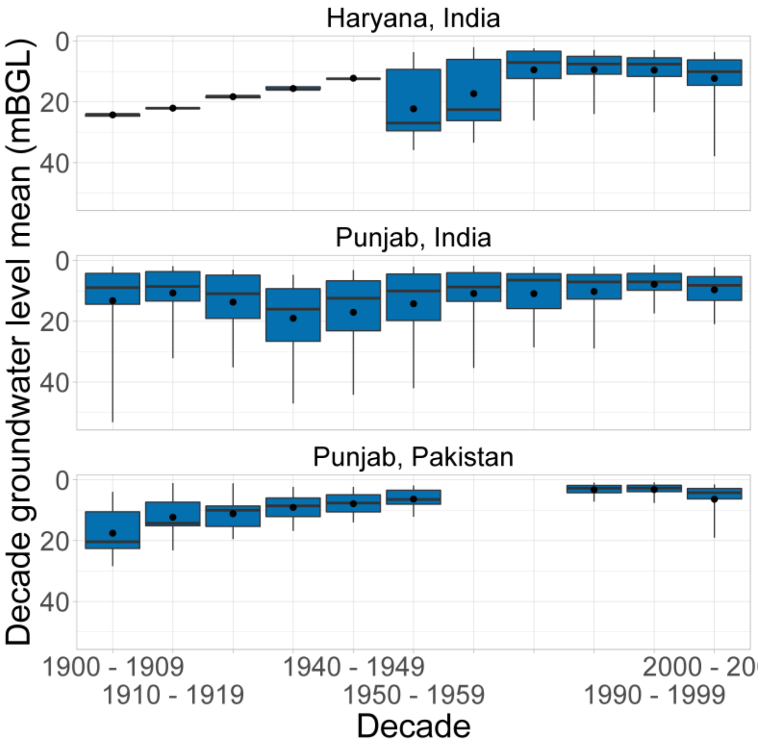






Tubewell numbers and groundwater levels





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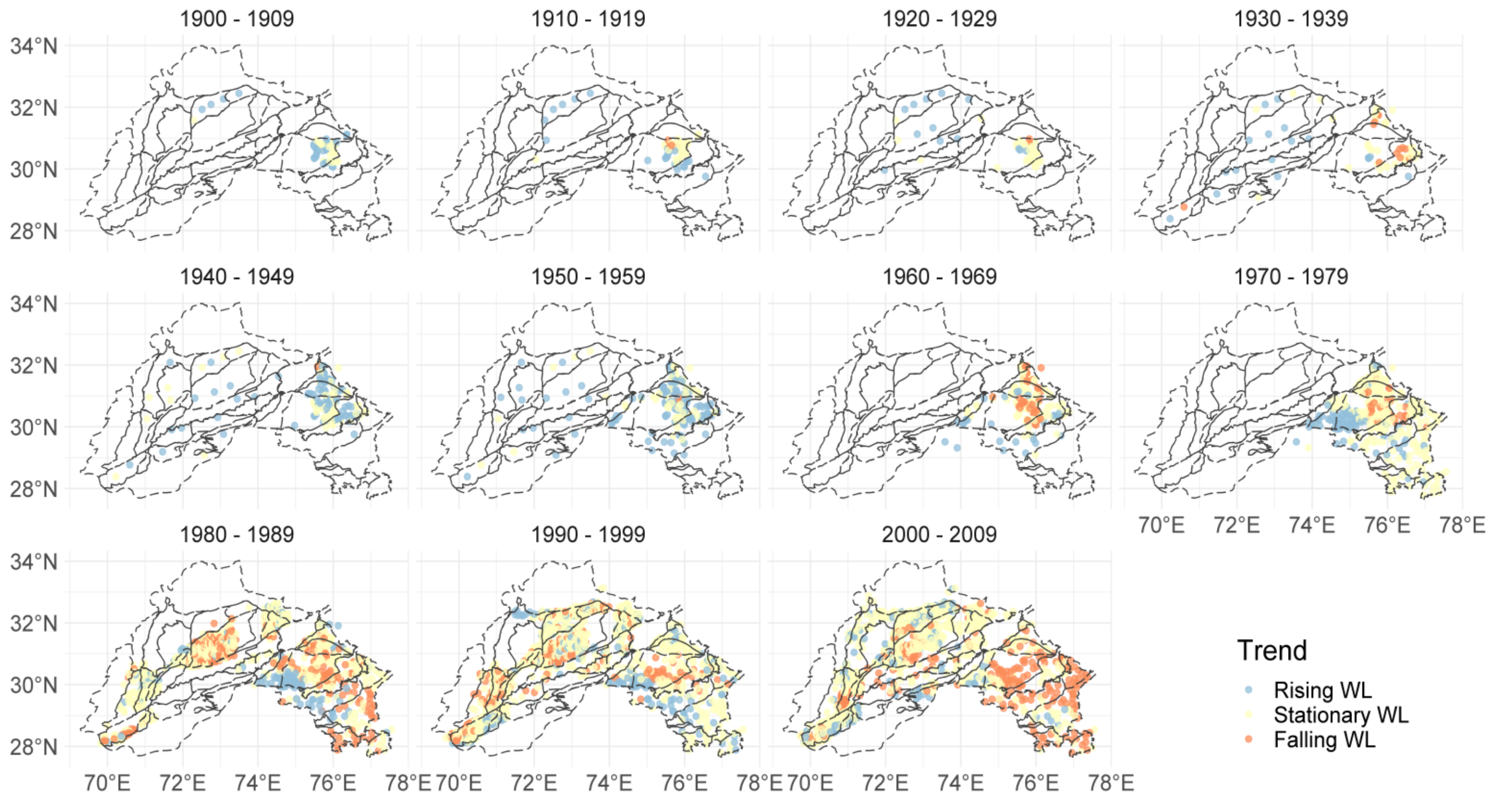
Groundwater level decadal trend



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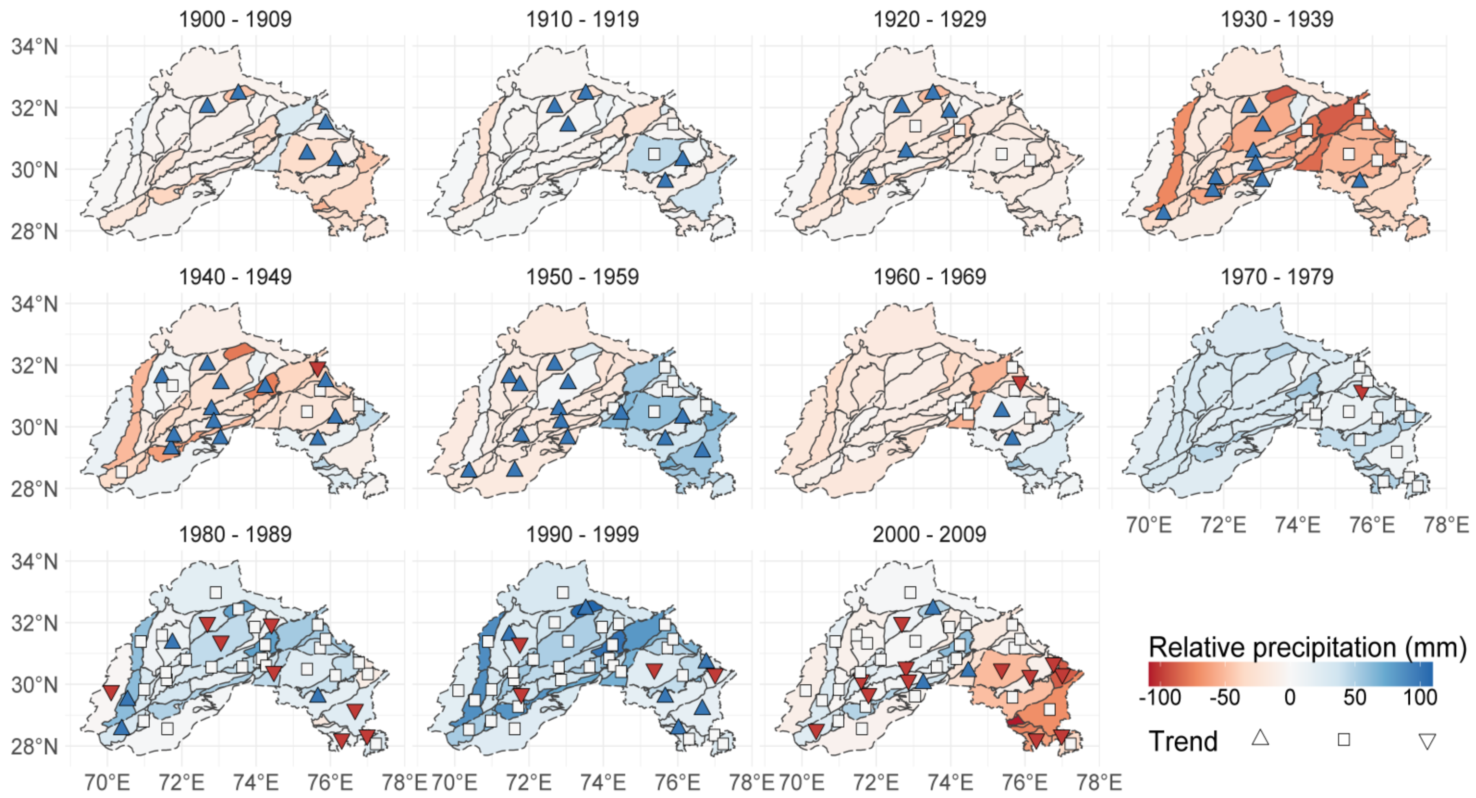
Groundwater level and precipitation trend



Climatic Research Unit gridded Time Series (CRUTS) precipitation data

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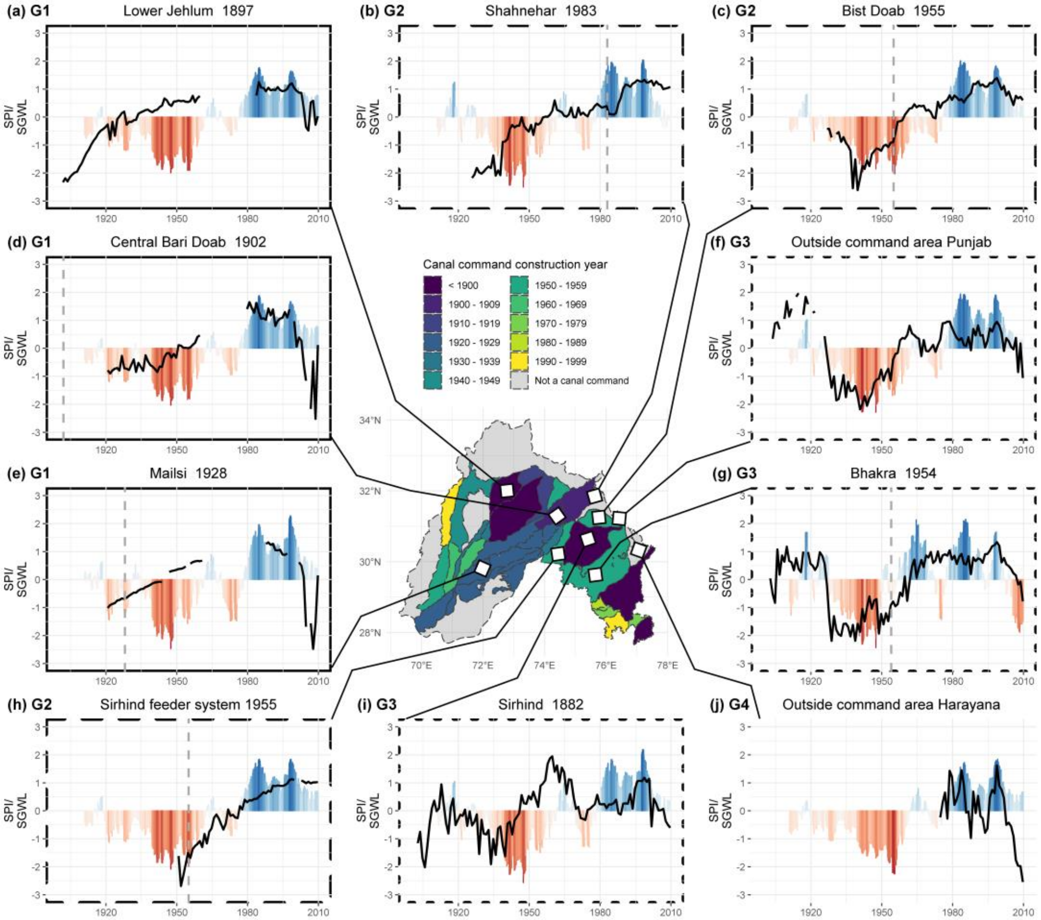
Regional groundwater level trends



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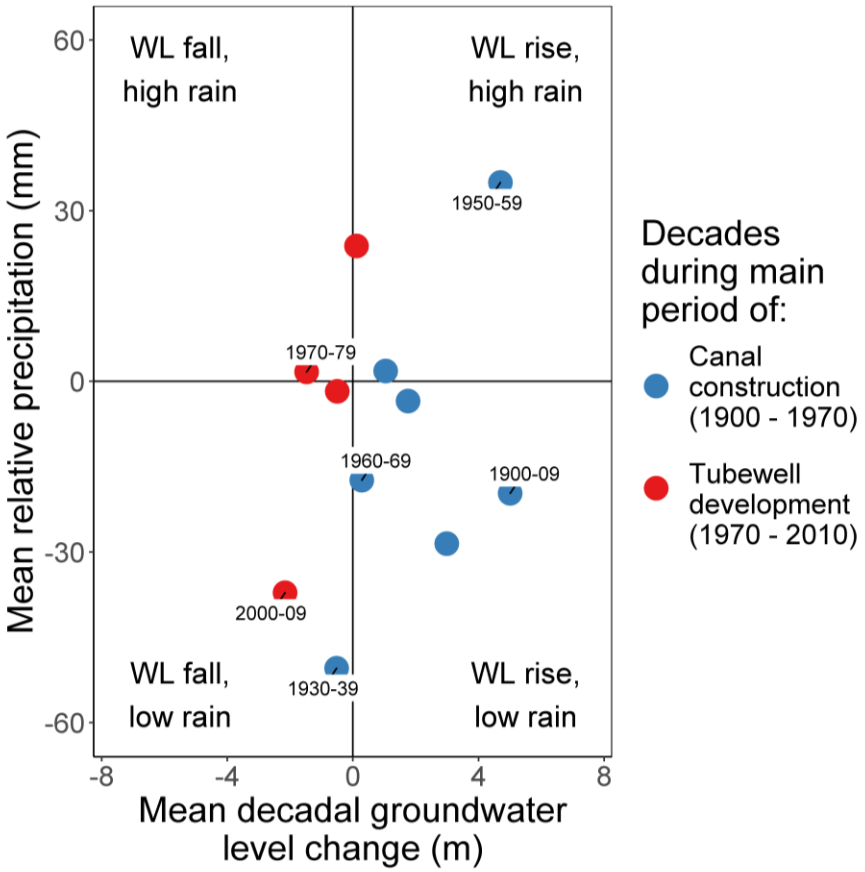
Influence of canals and tubewells on decadal trend



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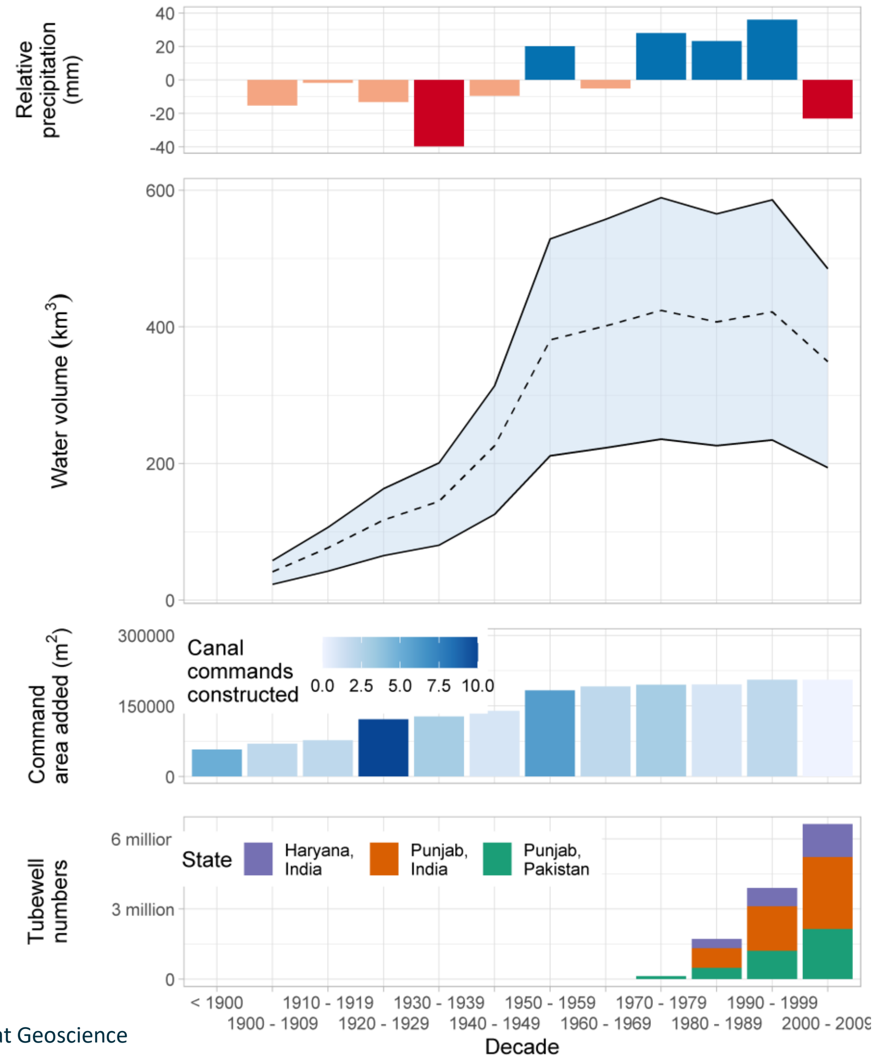
A century of accumulation

- 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)



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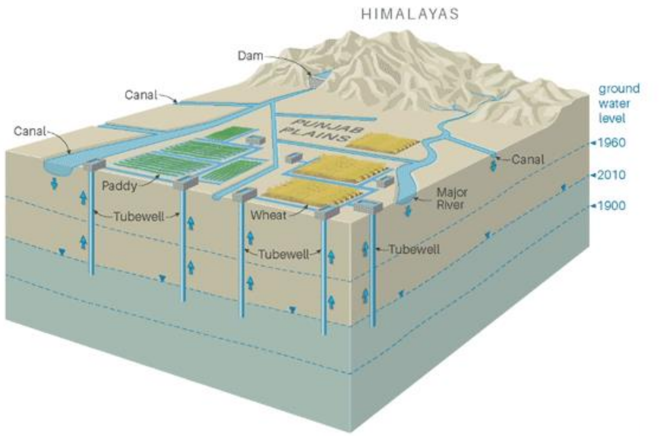
Quantifying relative importance of recharge sources

Quantifying recharge contributions in the western Indus

- Using this long-term dataset, can we quantify the contribution of different recharge sources?

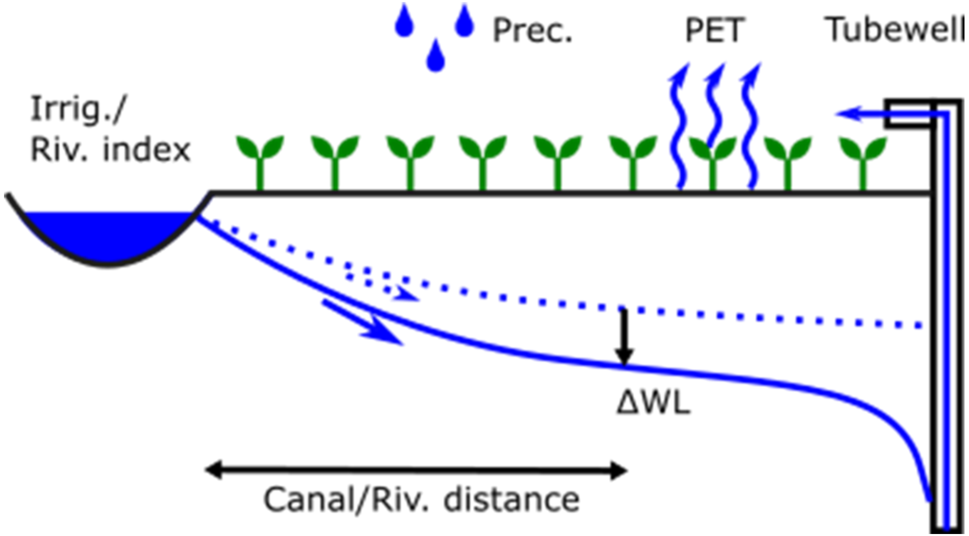
- Analysis of higher spatial and temporal resolution data in Pakistan (1980 – 2010) to investigate:
  – Seasonal & spatiotemporal response of GW to climate, abstraction, canal/river leakage.
  – Evidence of groundwater 'capture'?

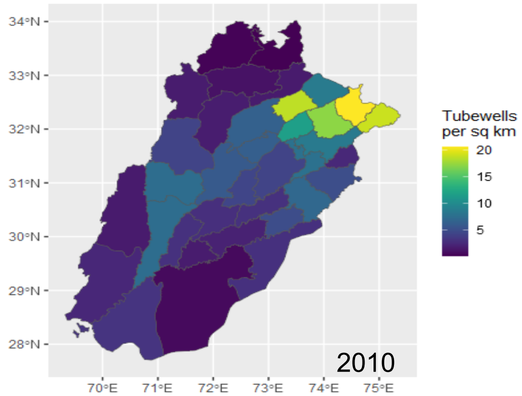
- Water and Power Development Authority (WAPDA), 91,068 records at 3,385 locations from 1979 – 2009:
  – After cleaning and QA: 78,878 digitised groundwater records at 2,968 wells
  – Most records biannual, before & after the monsoon.



Linear model

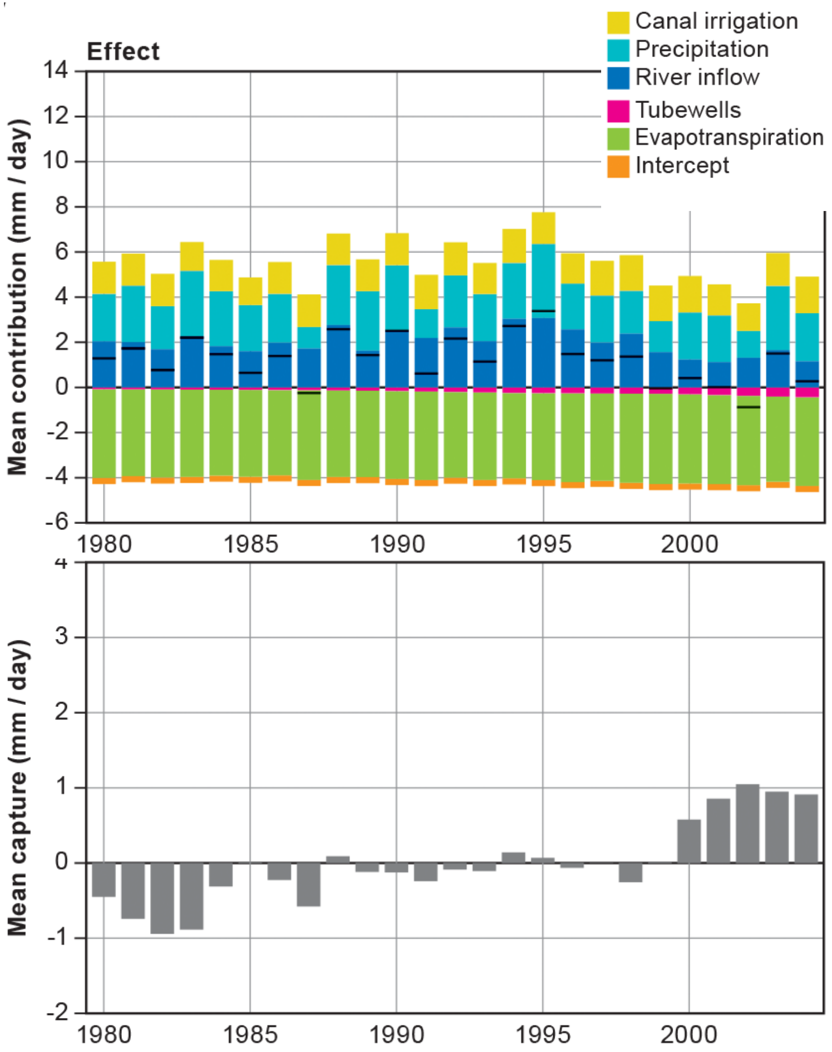
- Developed a spatially correlated linear model for Punjab in Pakistan, the model:
  - considers groundwater levels' daily rates of change over the monsoon.
  - examines first-order marginal effects of potential influences on groundwater recharge.
  - uses a linear approximation for distance's moderating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





Quantifying recharge sources

- **Precipitation:** provides the single largest contribution to recharge.
- **Canals**: provide a reliable source of groundwater recharge. Effect decreasing with distance from each canal.
- **River inflow**: more variable source of groundwater recharge. Effect decreasing with distance from rivers.
- **GW abstraction**: increasing importance as more and more irrigation wells were drilled.
- **GW capture**: increasing groundwater capture. More tubewells => more extraction, lower water tables, but more recharge!

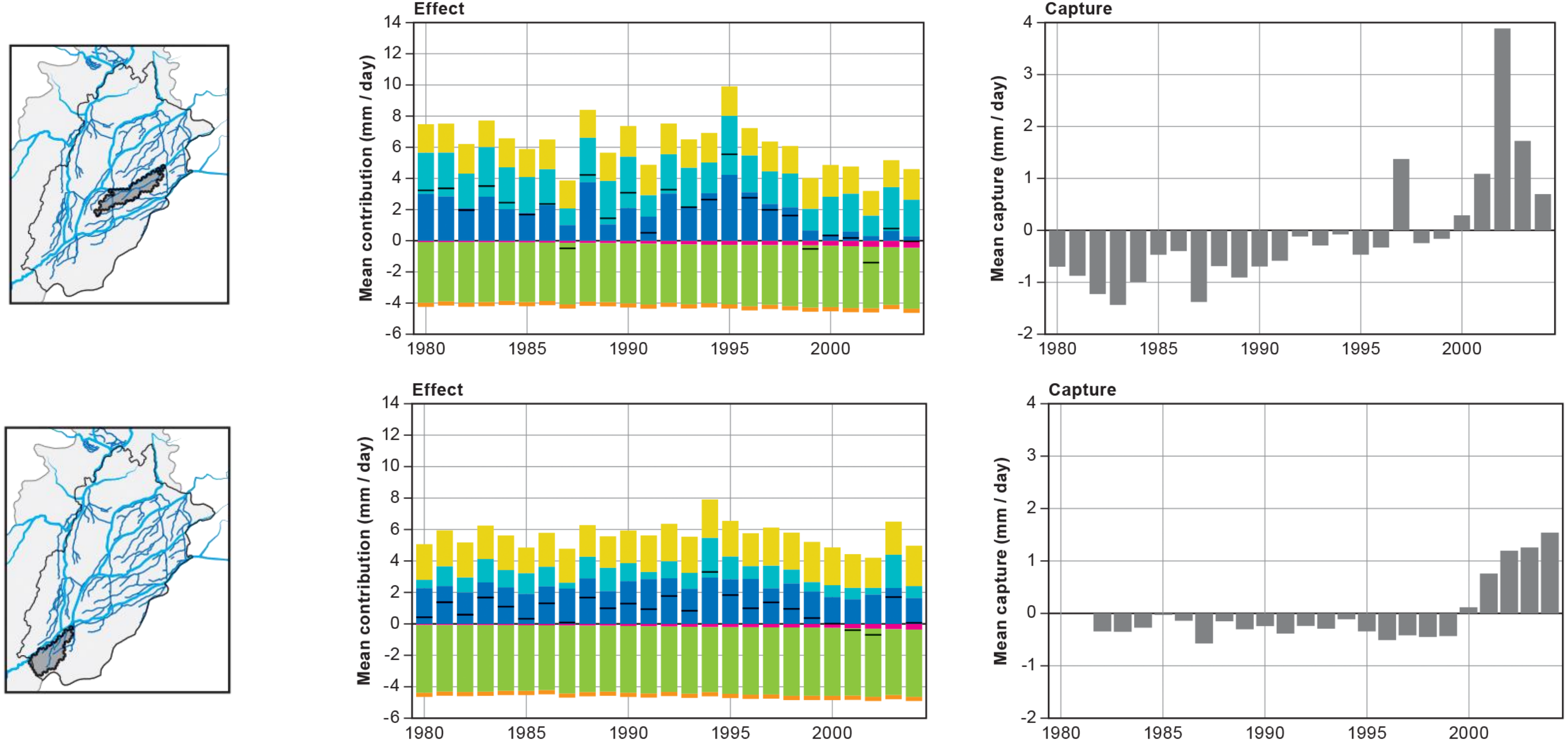


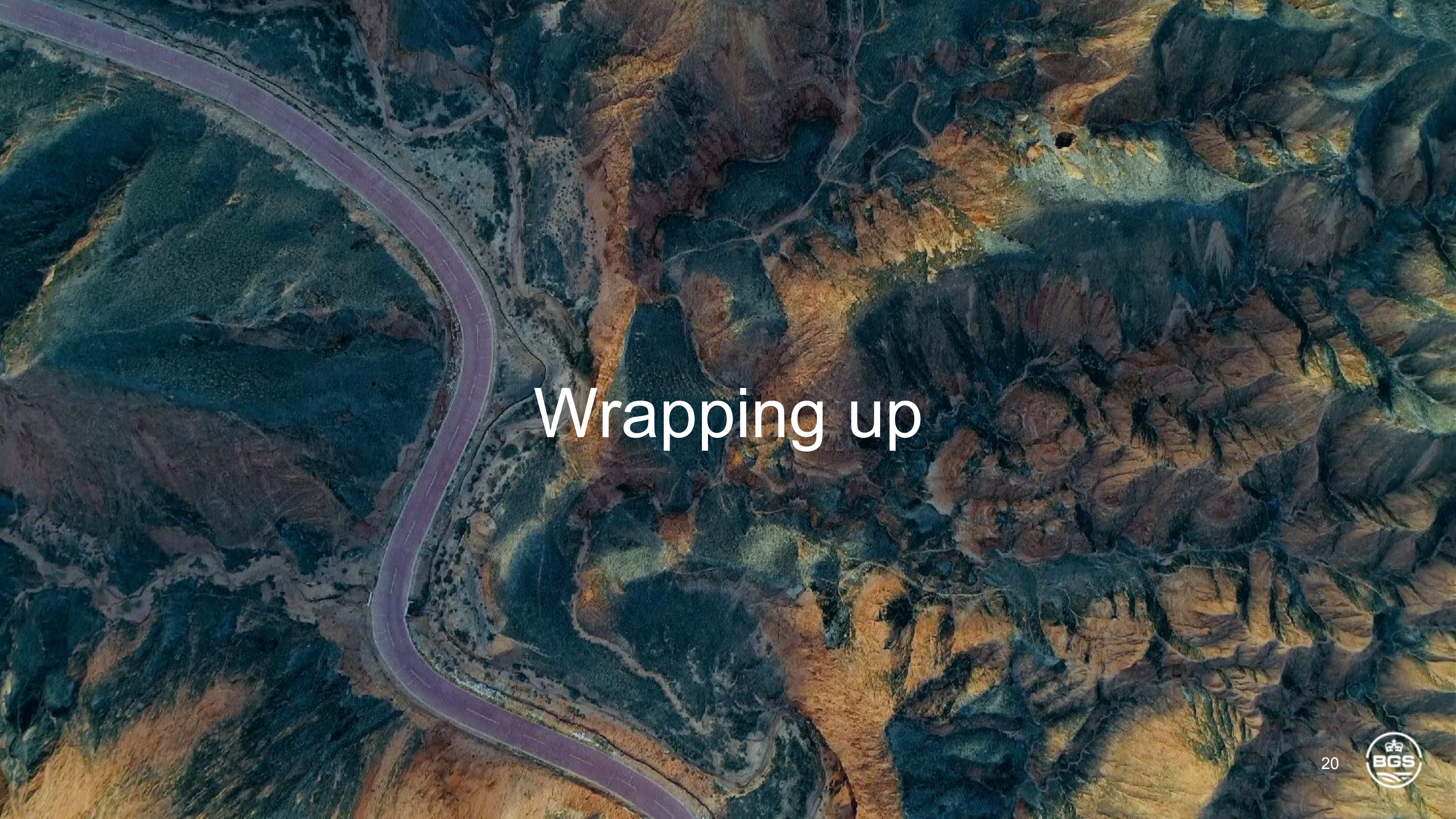
Model coefficients

- Best-fit linear model for monsoonal rates of recharge:
  - +1 mm / day rainfall ⇒ 0.7 mm / day (~ 20% seepage)
  - +1 mm / day PET ⇒ - 0.2 mm / day (~ 30% of PET realised)
  - +1 tubewell / km^2 ⇒ - 0.02 mm / day (~ 6 m^3 / day extraction)
  - +1 mm / day supply to canal command
    ⇒ 0.4 mm / day next to mapped canal, decreasing to 0 mm / day at 50 km
  - River flow 10% above long-term mean
    ⇒ 0.06 mm / day next to river, decreasing to 0 mm / day at 20 km
  - 1 m lower water table (groundwater capture)
    ⇒ 0.8 mm / day next to mapped canal, decreasing to 0 mm / day at 40 km

Spatial and temporal recharge contributions

- Significant spatial and temporal variation in contribution of recharge sources across the study area.

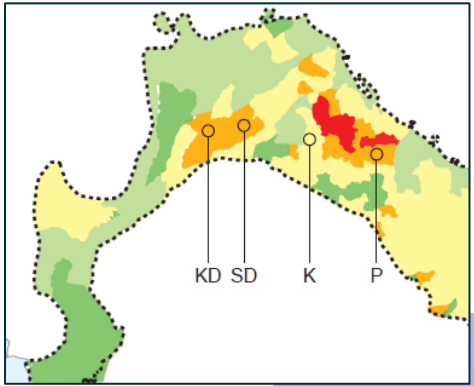


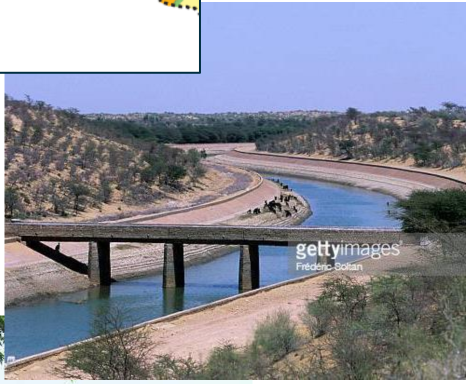


Wrapping up

Summary

- Groundwater in the Indus basin has been changing for more than 150 years.
- Groundwater is influenced more by human activity than climate change.
- Human activity in the early 20th century increased the total volume of groundwater available prior to large scale exploitation in the late 20th century.
- Canals continue to provide an important source of groundwater recharge and pumping has allowed ‘capture’ of additional recharge.
- Groundwater and surface water are linked and should be managed as one resource.





THANK YOU

Any questions?

Conclusions

- During the monsoon season from 1979 – 2010:
  - Precipitation provided the single largest contribution to recharge.
  - Canals provided a consistent rate of recharge throughout.
  - The contribution of rivers to recharge is variable.
  - We find evidence of groundwater capture, with mean capture increasing. More tubewells => more extraction, lower water tables, but more recharge!

Improving understanding of the IGB aquifer