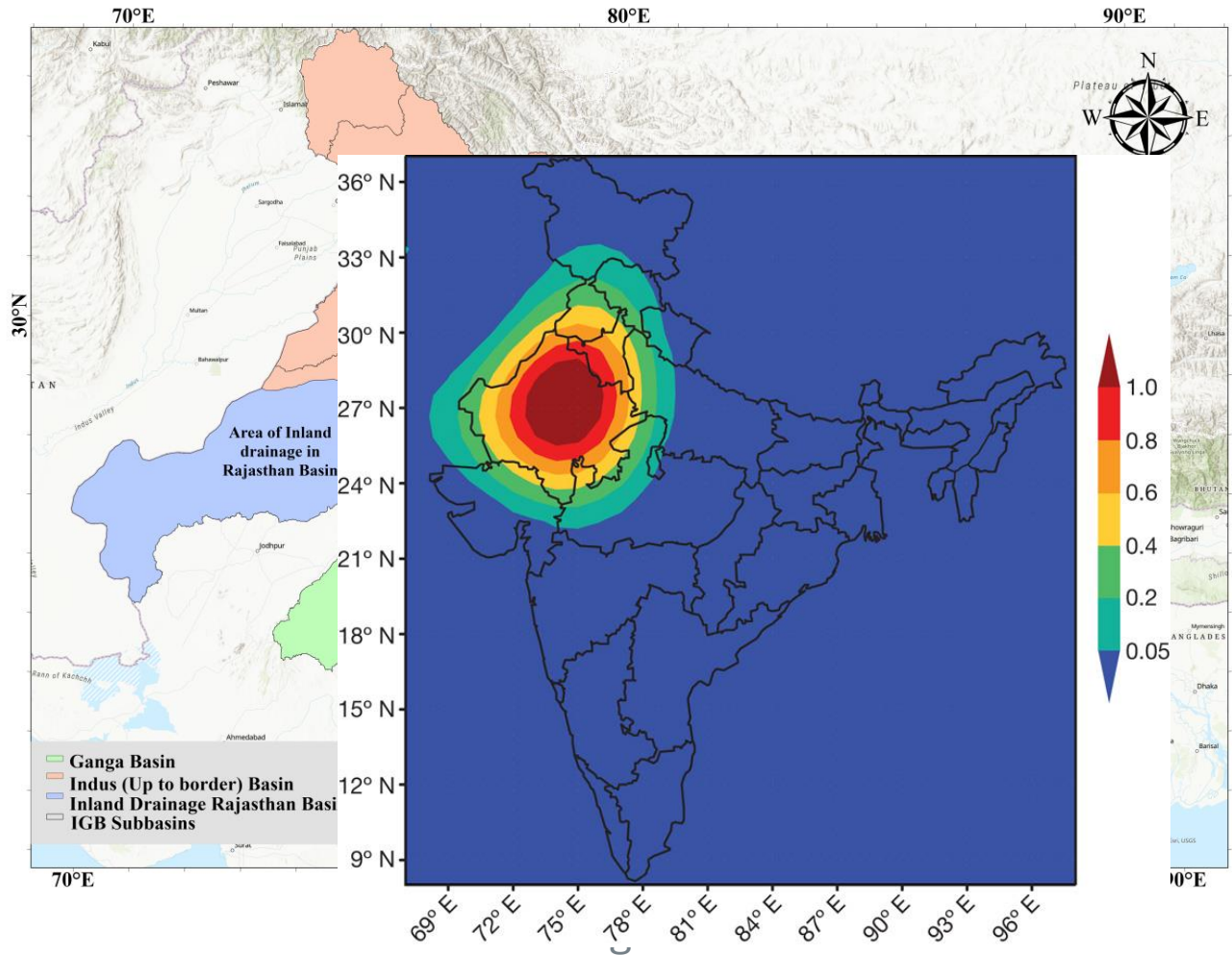


Are Groundwater levels recovering in IGB?

Patterns, trends and drivers across the Indo-Gangetic Basin

Pratibha Mishra | PhD Researcher (III Year) University of Edinburgh | 15/09/2026

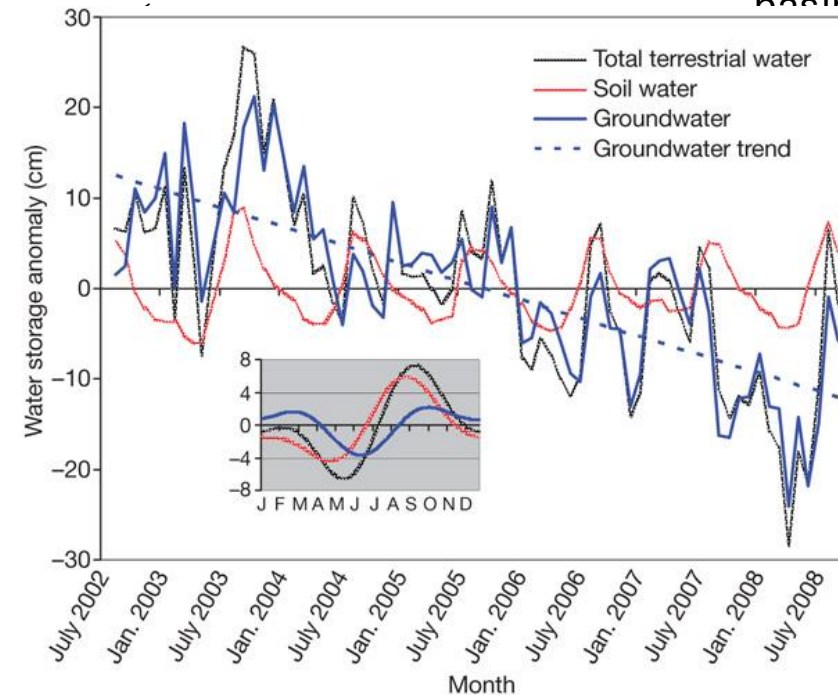
The beginning of the story of groundwater decline in IGB



The Indo-Gangetic Basin can be divided into 3 major :

- ✓ The Indus Basin
- ✓ Ganga Basin

Covering regions of fertile Indo-Gangetic Plains (IGP) and larger basin area



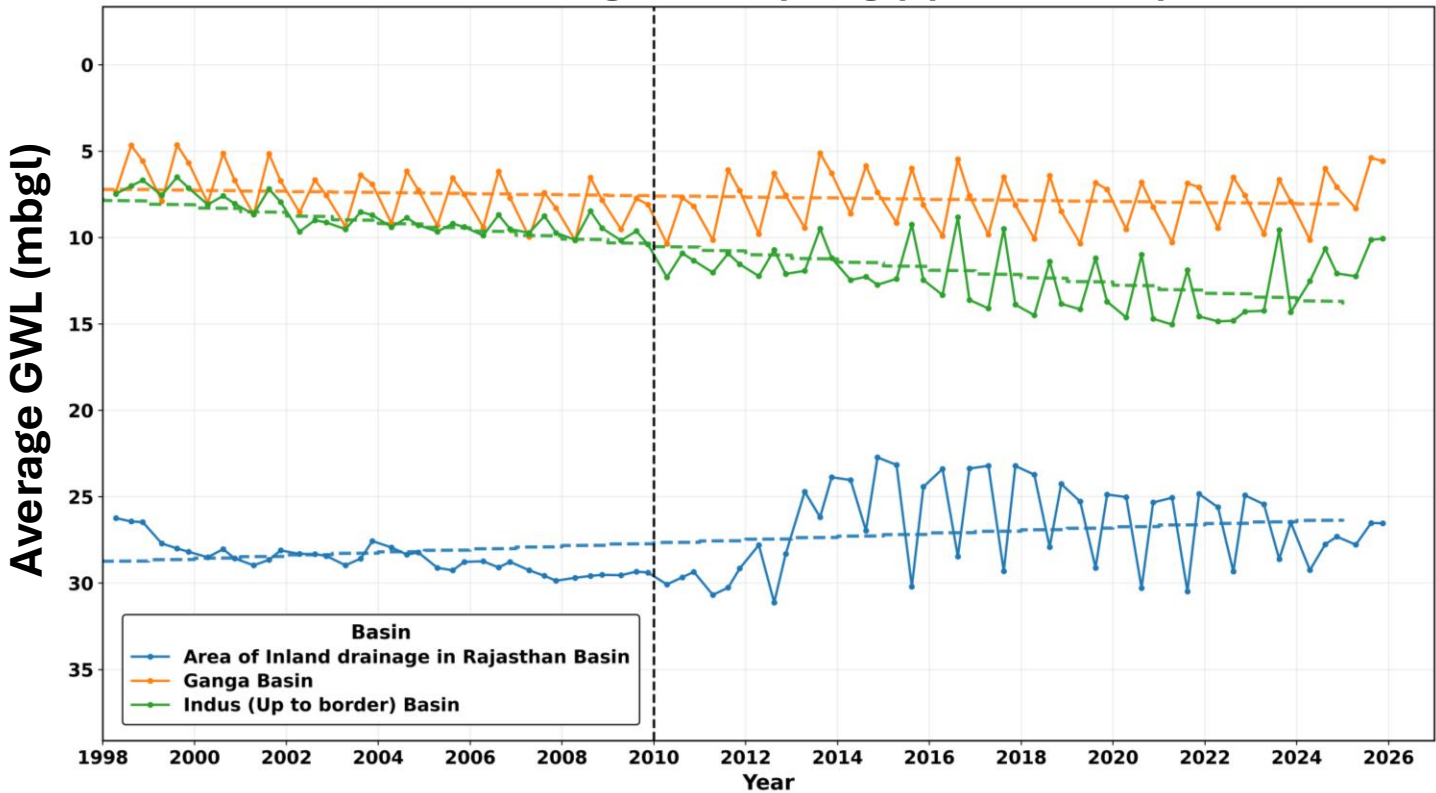
M Rodell *et al.* *Nature* **460**, 999-1002 (2009)
doi:10.1038/nature08238

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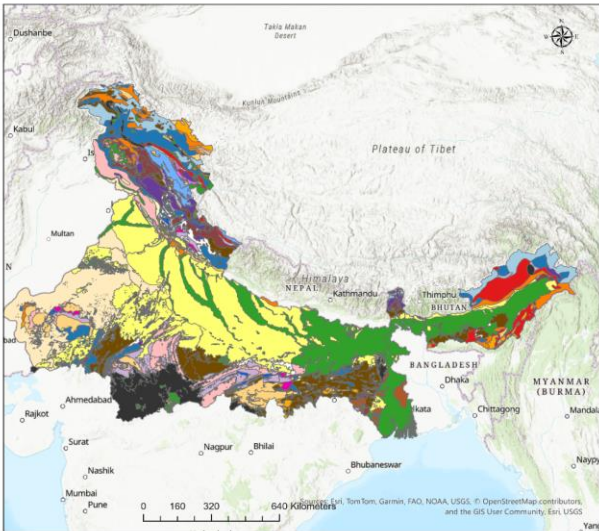
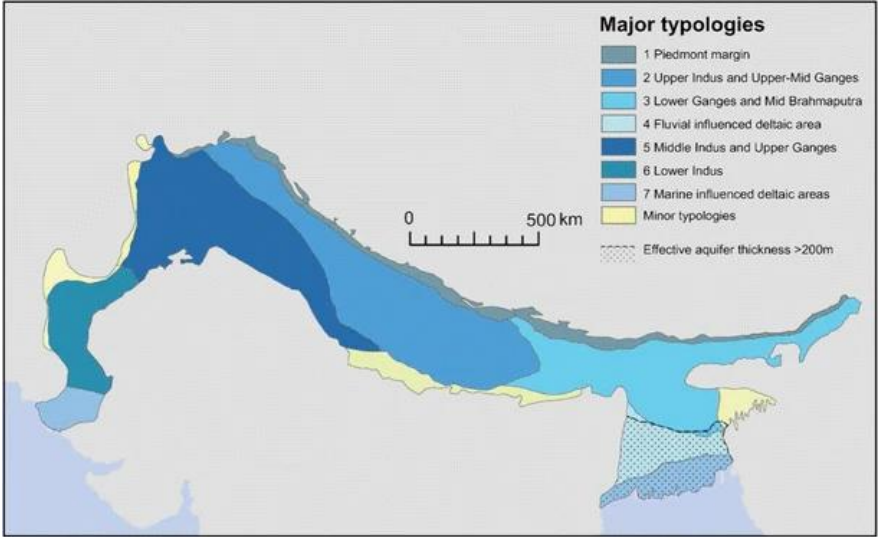
Is groundwater decline really happening everywhere in the same way across the IGB?

The basin average hides spatial heterogeneity

Basin Average GWL (mbgl) (1998-2025)



7 Major Typologies of IGP
(Bonsor et al., 2017; MacDonald et al., 2015)



Aquifer geology Map
(Courtesy: CGWB, India)

The Study System and Questions

OBSERVE

Understanding
Groundwater level
trends and Patterns



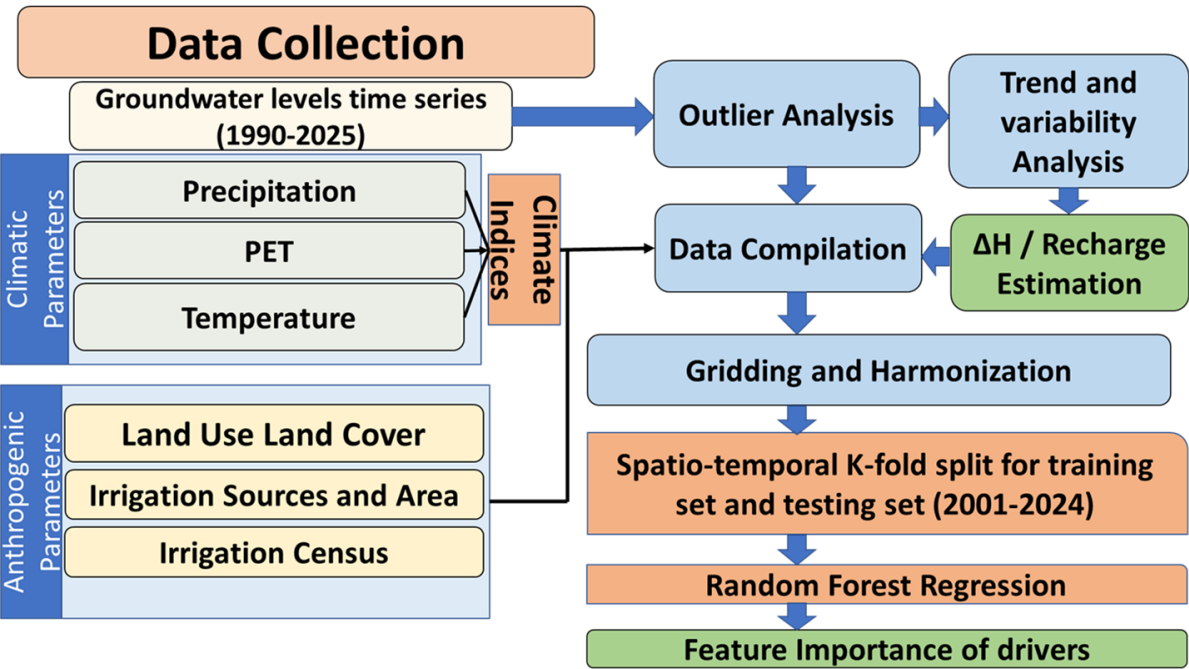
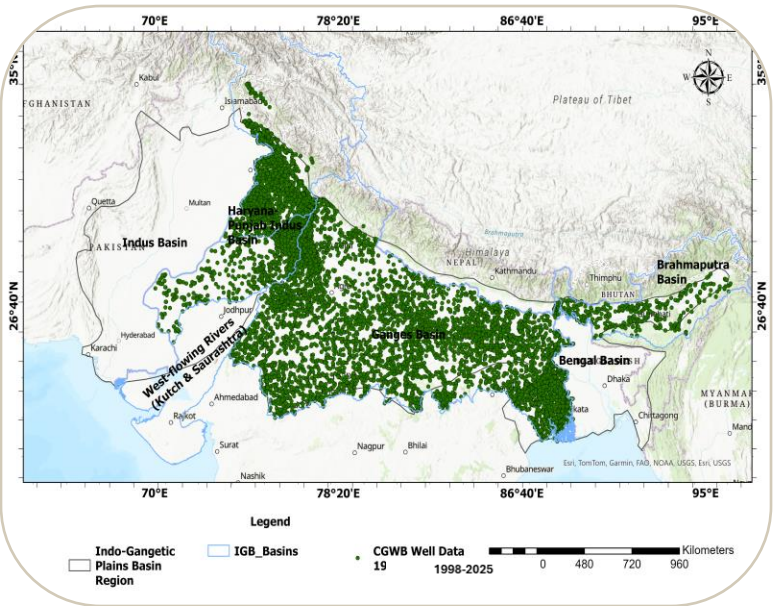
COMPARE

How has the
relationship
changed across
decades?



EXPLAIN

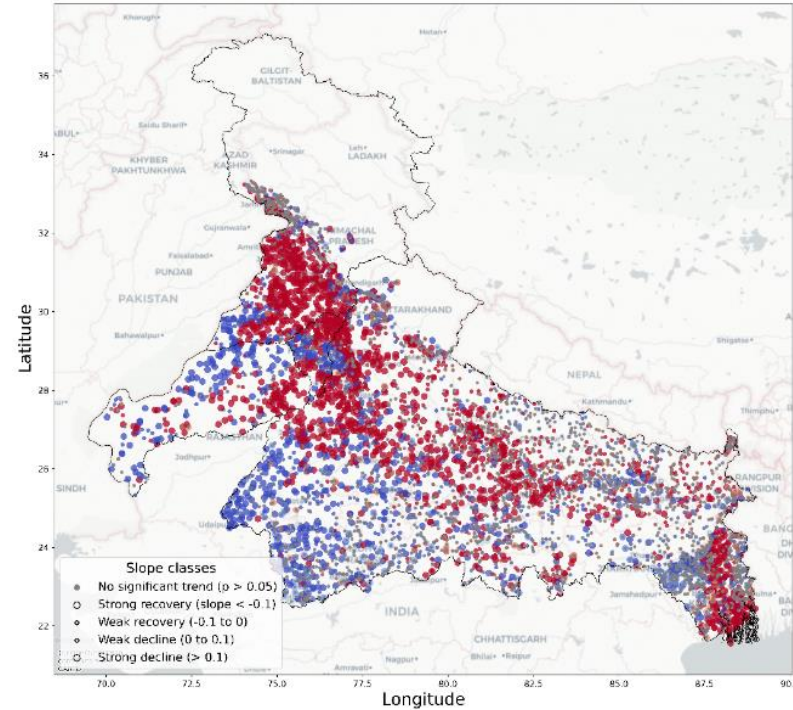
What are the main
drivers of groundwater
variability in the
region?



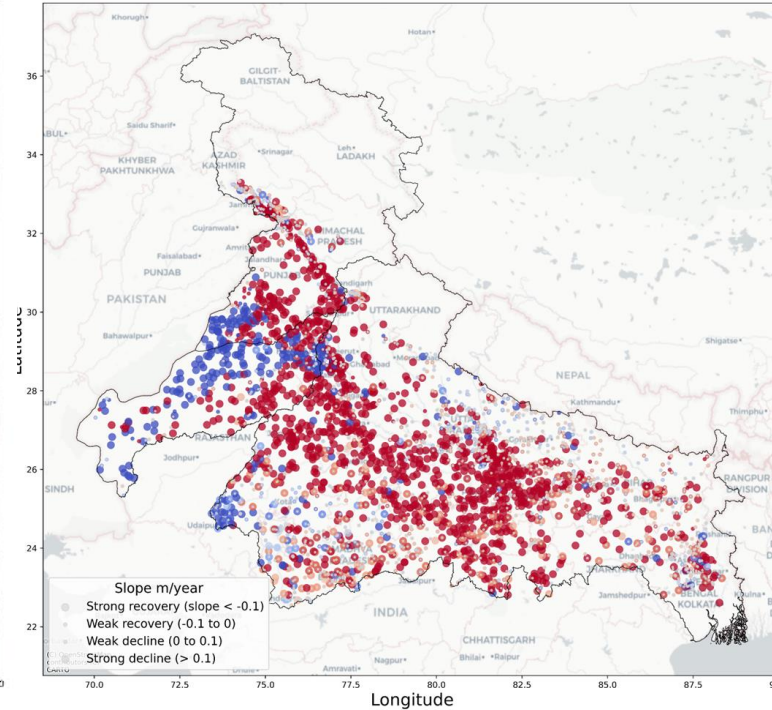
What is changing?

MK-Trend and Slope for GWL (mbgl)

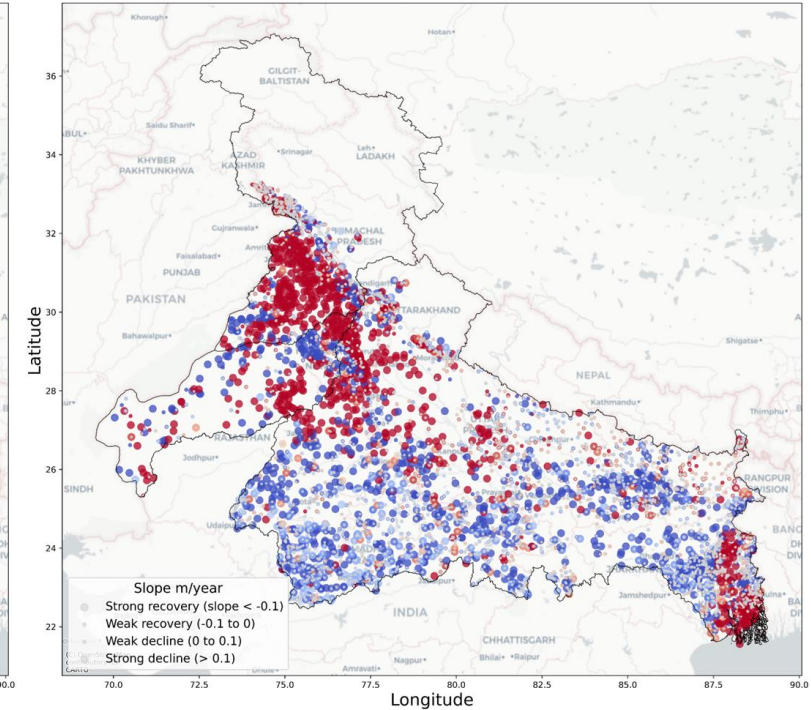
1998-2025



1998-2010



2010-2025



GWL Declining
($Z > 1.96$)

No Trend

GWL Rising
($Z > -1.96$)

The basin average hides spatial heterogeneity

The dominant signal is not uniform.

Different parts of the IGB show contrasting groundwater behavior.

Post-2010, large parts of central Ganga basin show recovery

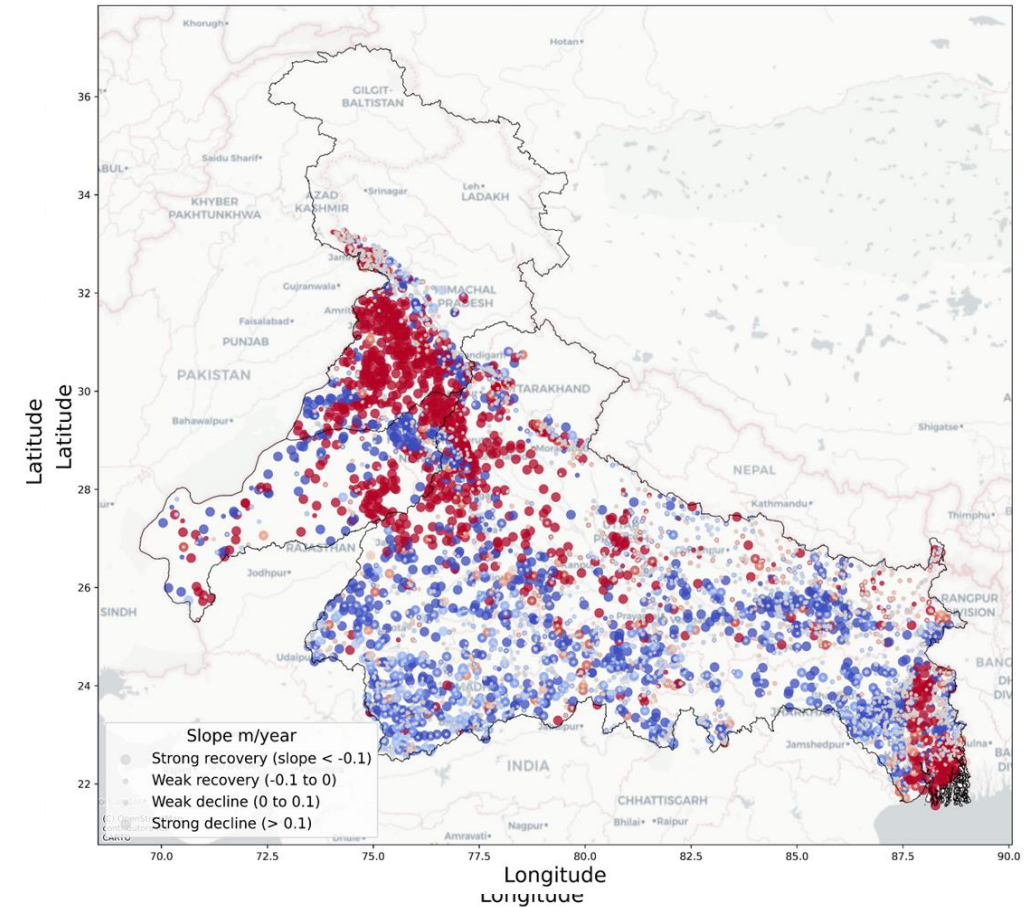
(n=5788 unique well records)

GROUNDWATER • IGB

What is changing?

Spatial Patterns at basin and sub-basin scale

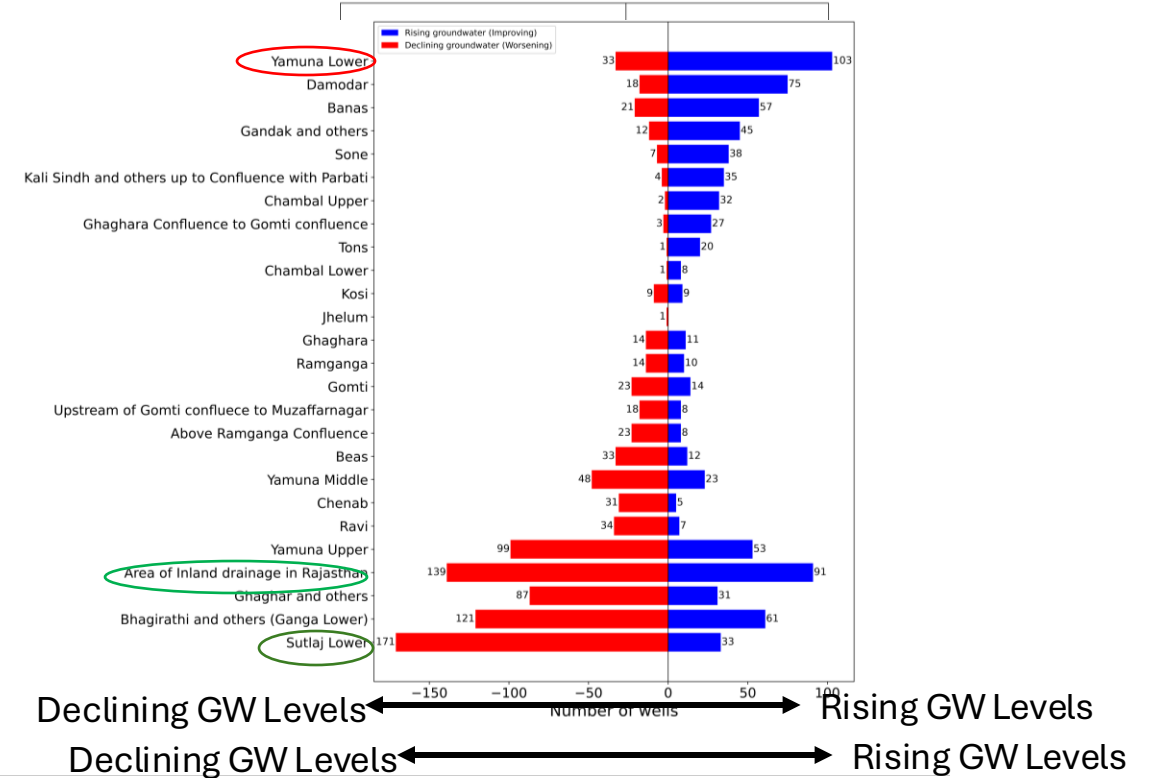
Subbasin-wise Net Stress 2008-2010



GWL Declining
($Z > 1.96$)

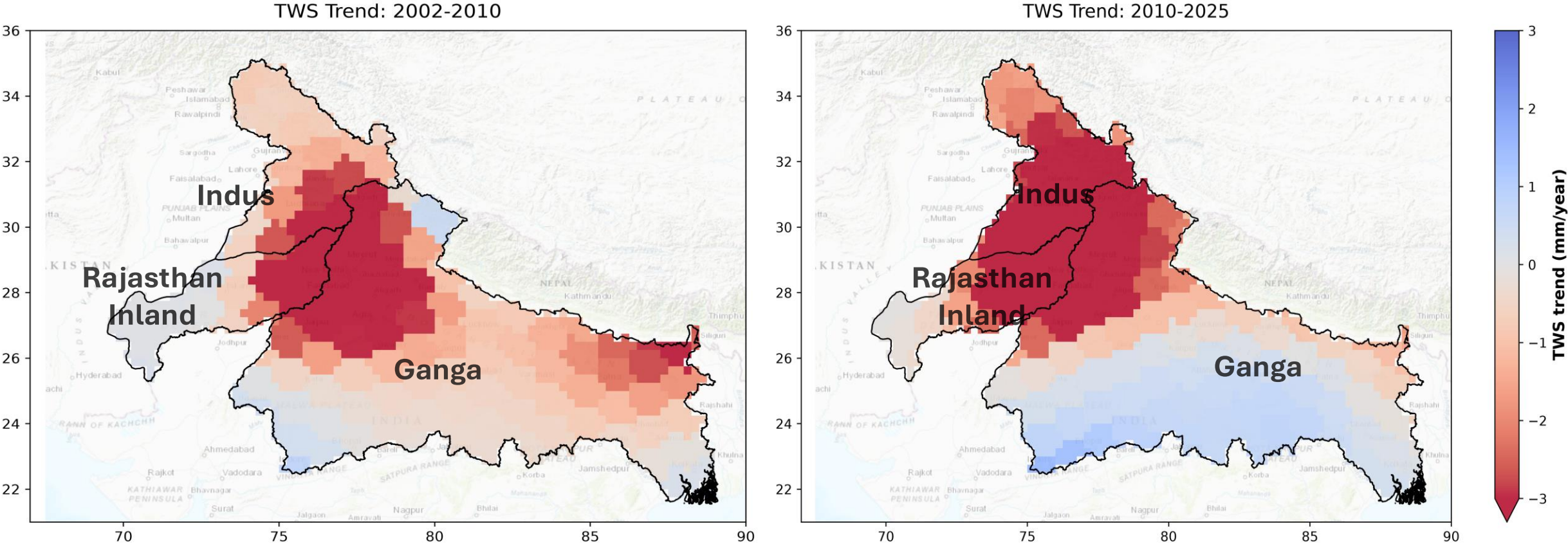
No Trend

GWL Rising
($Z > -1.96$)



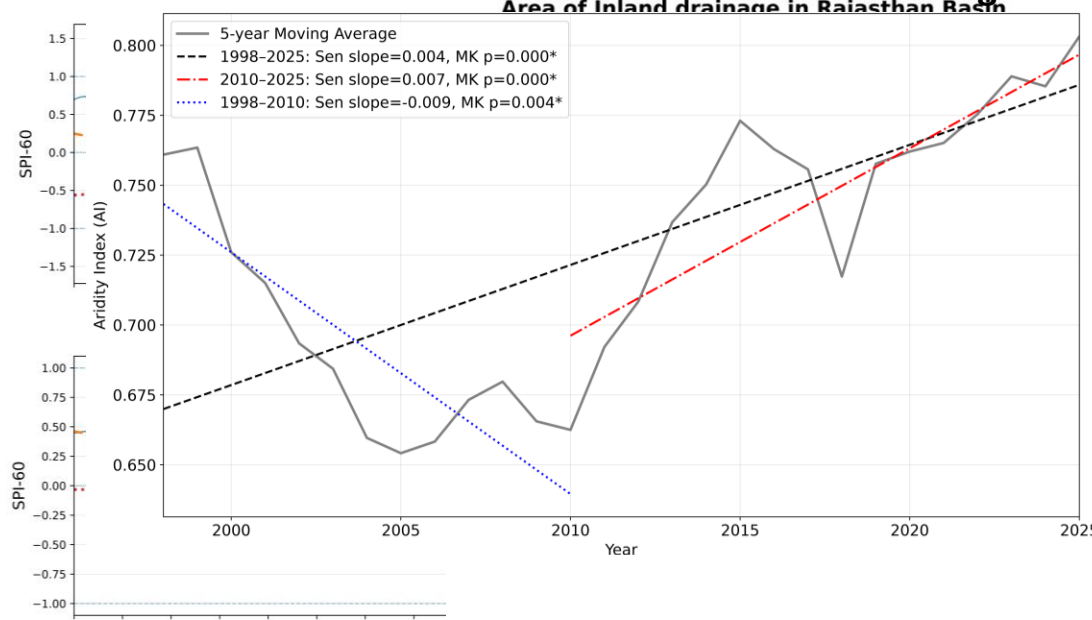
- Wells with no long-term trends increased Post-2010
- Increased year to year variability
- Indus basin shows continued decline

GRACE-GRACE FO Terrestrial Water Storage Anomaly Trends

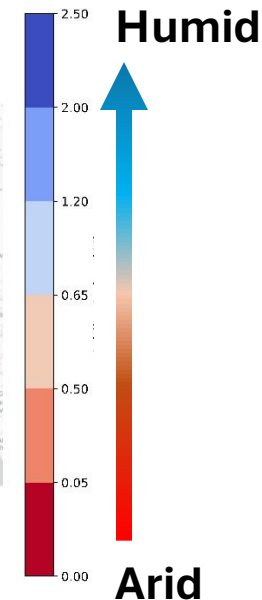
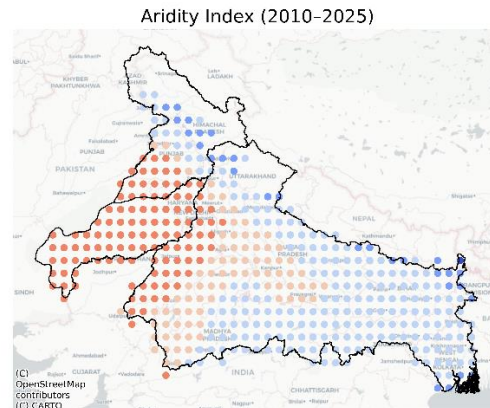
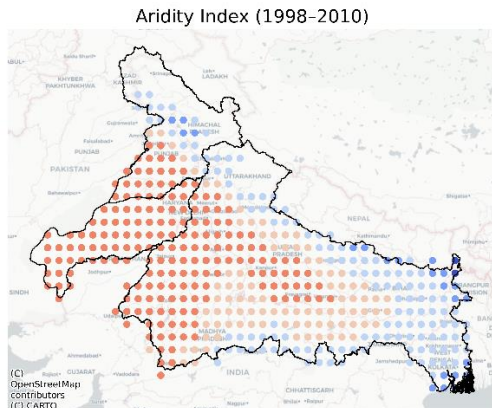
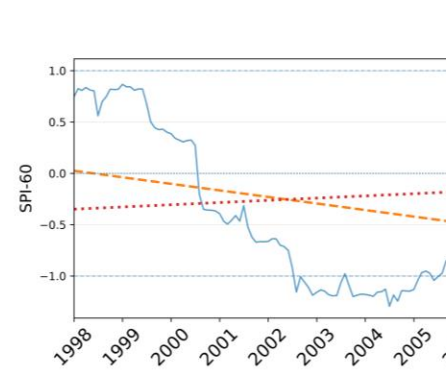
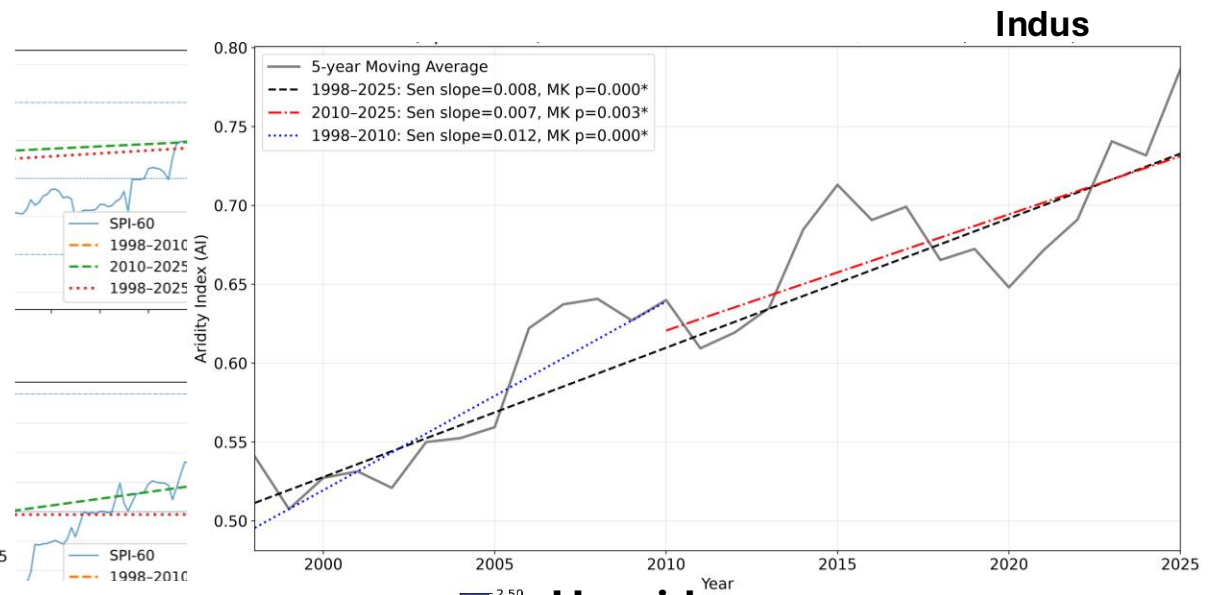


How have the climatic factors changed?

Standard Precipitation Index –SPI 60 (1998-2025)

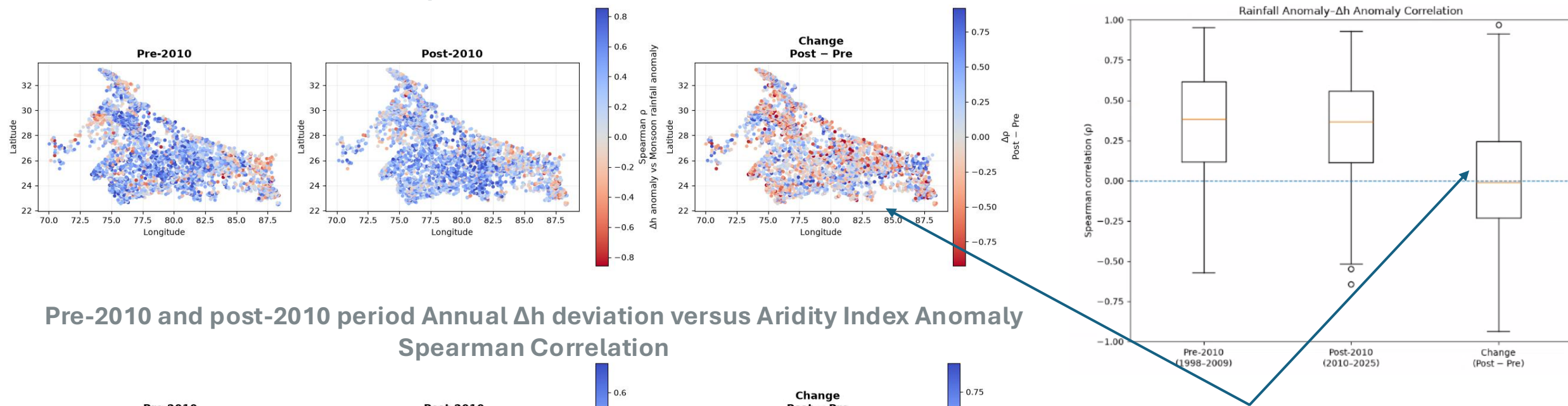


Mean Aridity Index Trend (1998-2025)

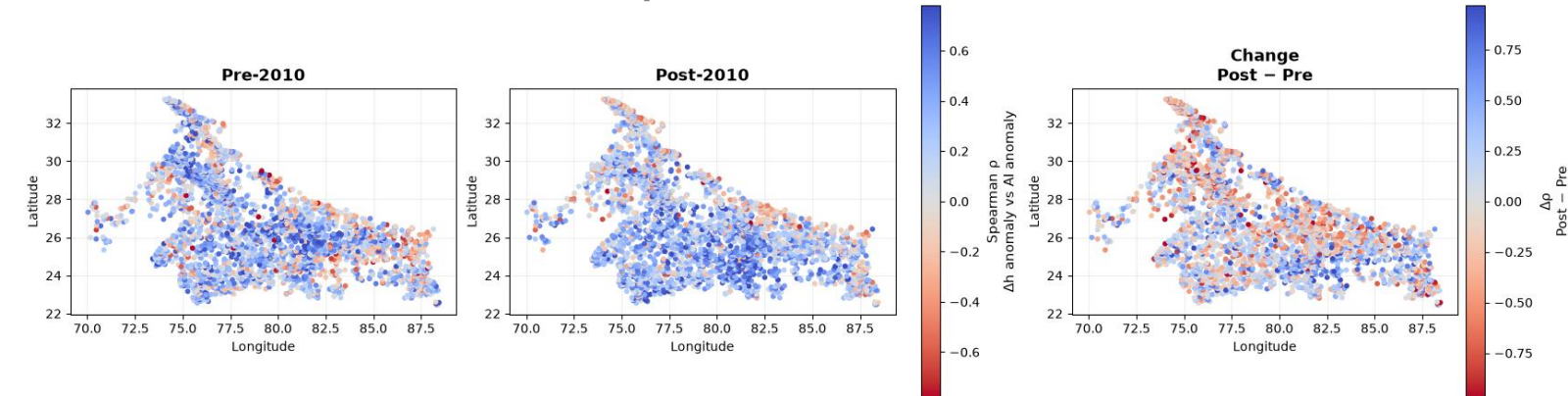


But the relationship itself may be changing

Pre-2010 and post-2010 period Annual Δh deviation versus Rainfall Anomaly
Spearman Correlation



Pre-2010 and post-2010 period Annual Δh deviation versus Aridity Index Anomaly
Spearman Correlation

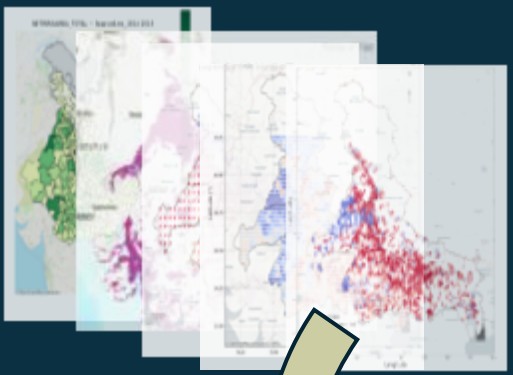


$\rho_{(2010-2025)} - \rho_{(1998-2010)}$ depicts increased spatial heterogeneity

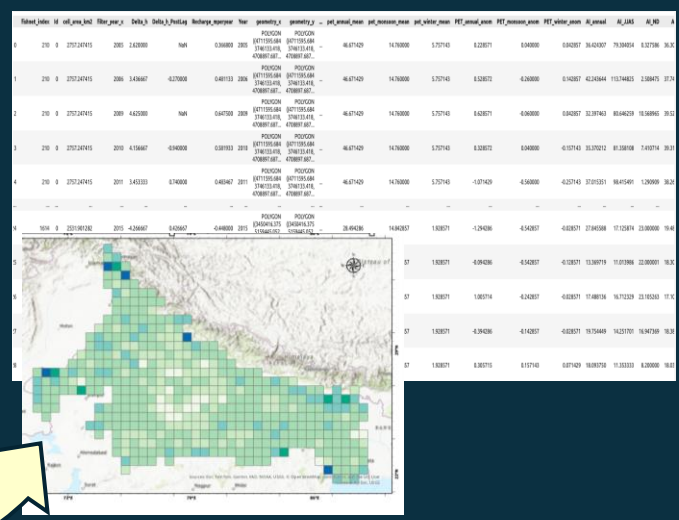
So what are the main drivers of these Groundwater patterns?

Understanding main controls on annual groundwater change (Δh).

RANDOM FOREST + SHAP eXplanability: Δh vs Climate+Natural+Anthropogenic Predictors

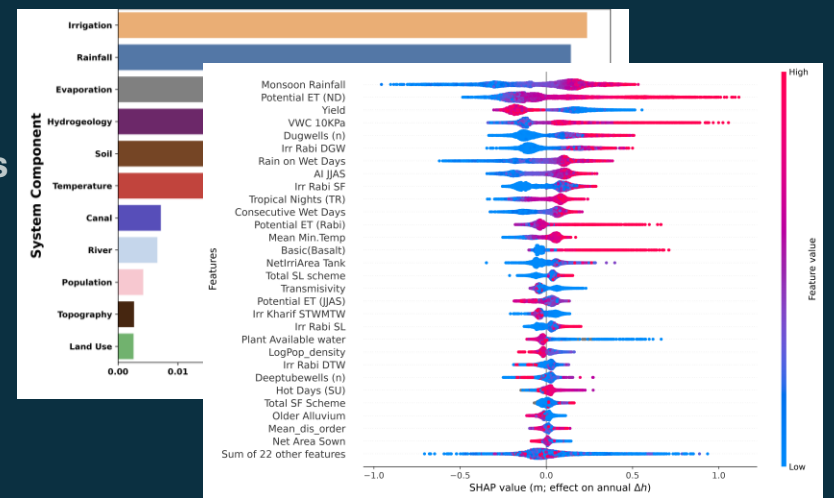
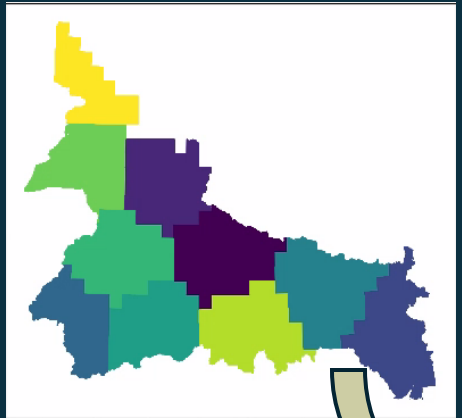


56+ predictor variables at different spatio-temporal resolutions

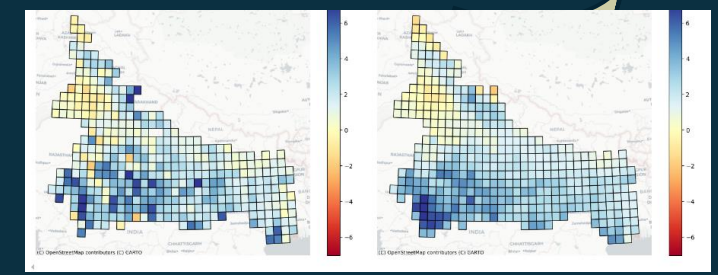


Gridding and harmonization of dataset into annual dataset table at 0.5°x 0.5° (2001-2024)

Spatio-temporal blocking and k-fold split Cross Validation for RF Model



Model Explainability and Interpretation



Model Predictability (Annual Δh), Hyper-parametrization and variable selection

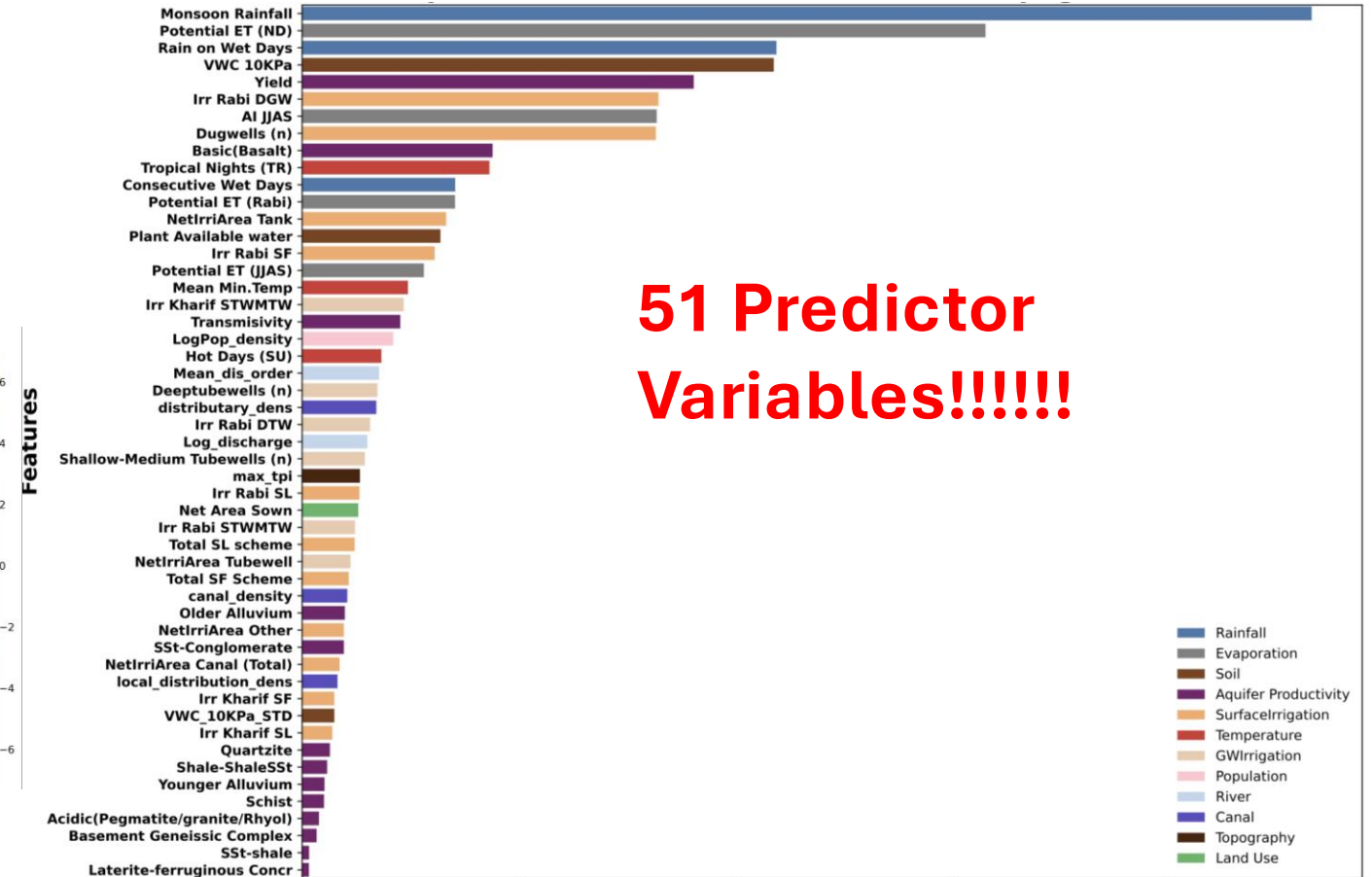
*Annual Δh = (Pre-Monsoon – Post Monsoon levels) : Dependent variable

Can multiple drivers explain Δh ?

Indus-Ganges Basin Joint Model

Can differences in climate, land use, irrigation, soil, hydrogeology and river characteristics explain groundwater response?

Permutation Feature Importance : RF Climate+Natural+Anthropogenic Model

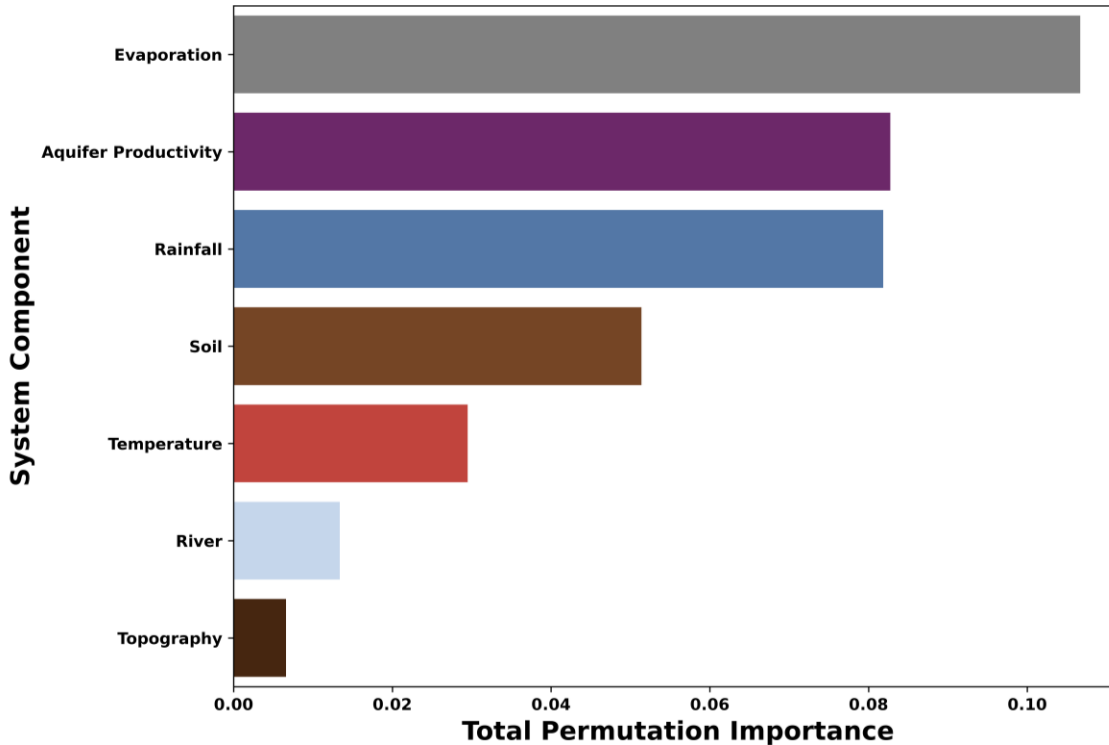


Permutation Importance helps identify main drivers

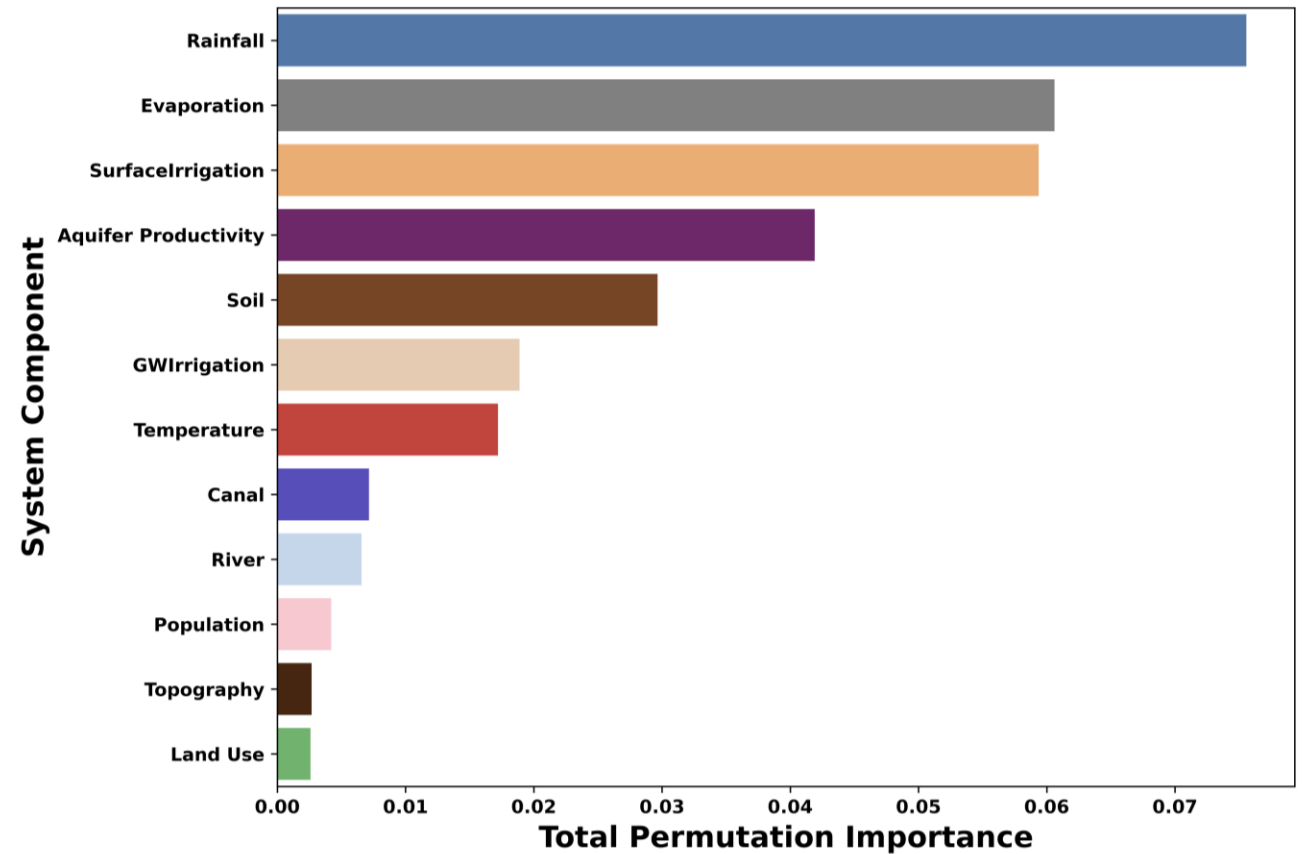
Can multiple drivers explain Δh response?

Indus-Ganges Basin Joint Model

Climate+Natural Predictors Importance



Climate+Natural+Anthropogenic Predictors Importance



Permutation Importance helps identify main drivers

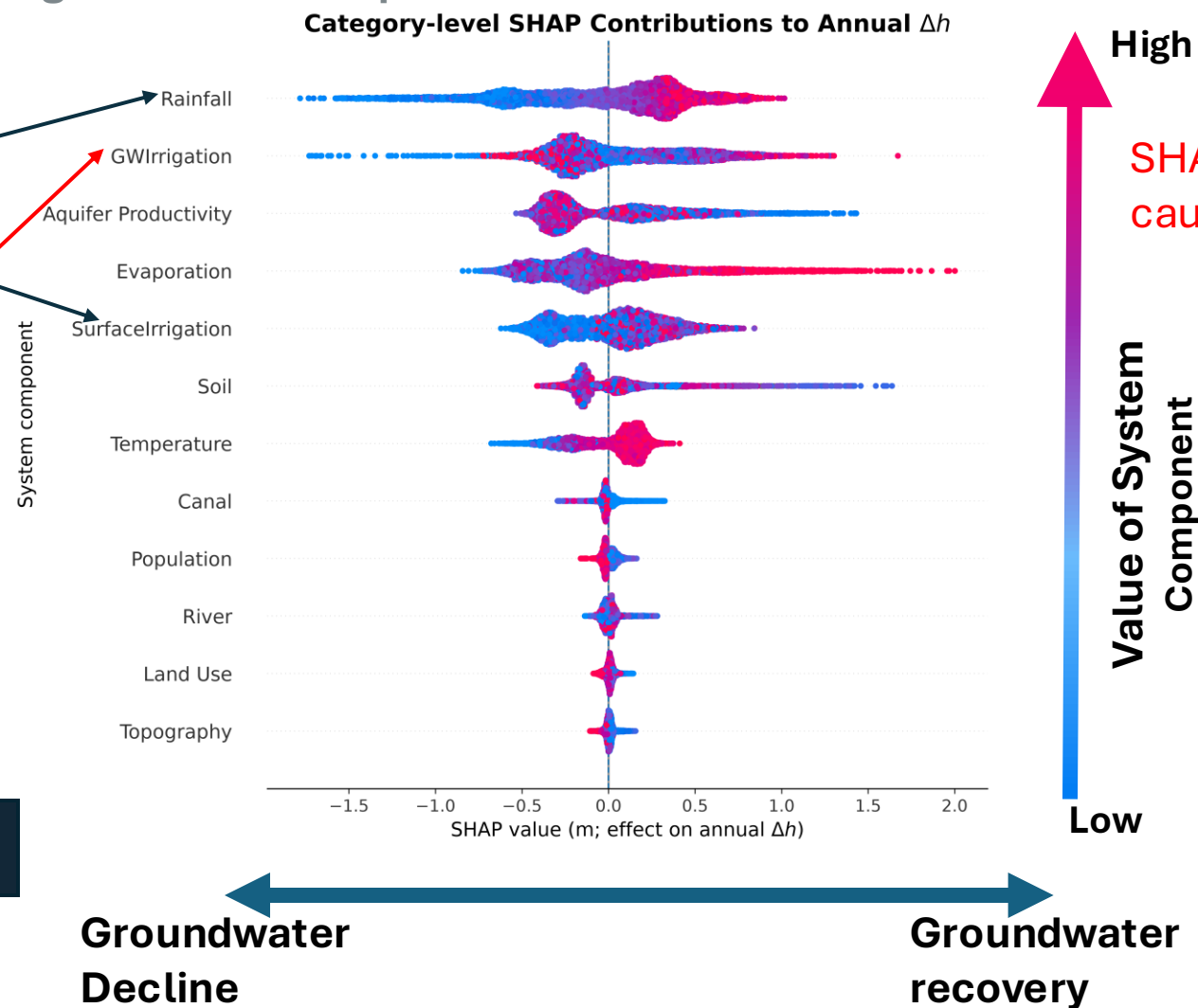
From importance to influence

SHAP explains how predictors push groundwater response

High Surface Irrigation
and High Rainfall
pushed GW response
towards recovery

Increased Irrigation
through GW pushes GW
response (Δh) towards
decline, its impact
exhibit high spatial
variance

SHAP shows magnitude and direction
of drivers and their interaction



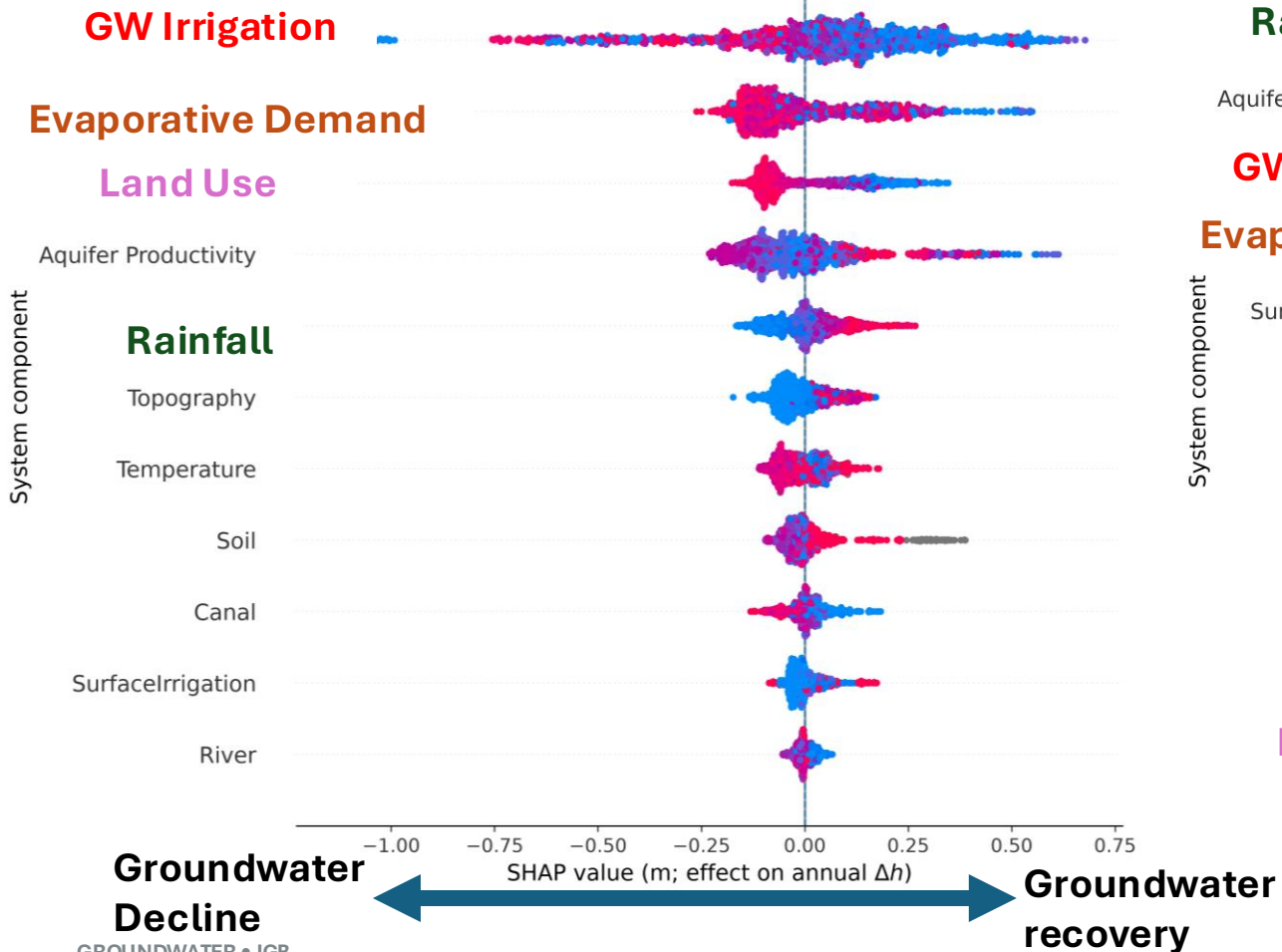
SHAP doesn't explain
causation.

Variability in drivers at basin scale?

Permutation Importance by System Component: RF Climate-Natural-Anthropogenic Pressures Model

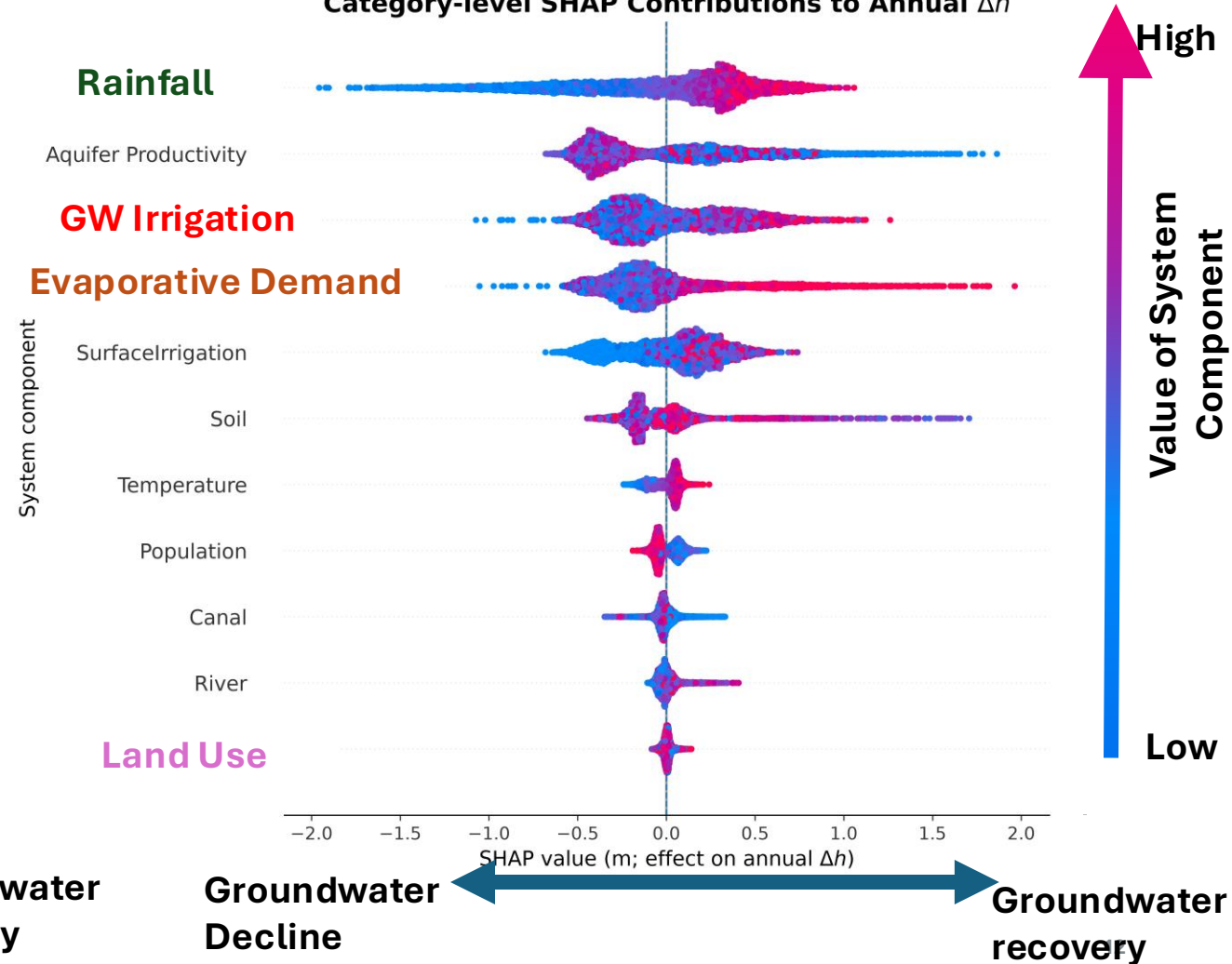
Indus Basin: An Extraction Driven System

Category-level SHAP Contributions to Annual Δh



Ganga Basin: Climate-Human Interaction Loop

Category-level SHAP Contributions to Annual Δh



The IGB doesn't have one groundwater story

Climate, human pressures, and aquifer setting jointly shape groundwater response



Same basin ≠ same response

Spatial heterogeneity is a result to explain, not noise to average away — avoid one-size-fits-all groundwater policy.

I INDUS

- **Extraction-driven System** → demands immediate management action
- Target interventions to local aquifer controls

G GANGA

- **Surface-subsurface-Human feedback Interaction System.**
- Aquifer-productivity paradox: **stabilization ≠ necessarily recovery**
- Wetter conditions+ Surface irrigation driven return flows → ↑ recovery opportunity
- Deeper aquifers respond slowly → emerging sustainability risk

Takeaway: Groundwater policy must match each basin's own climate – pressure – aquifer combination, not a single national template.

THANK YOU

Questions & discussion

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