EVALUATING THE IMPACT OF THE ATAL BHUJAL YOJANA ON GROUNDWATER QUALITY IN HARYANA: A DIFFERENCE-IN-DIFFERENCES APPROACH

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OVERVIEW

INTRODUCTION

- Groundwater quality problem in Haryana, India.
- The Atal Bhujal Yojana (ABY) policy was launched in 2019 to promote sustainable groundwater use.
- This study evaluates its impact on electrical conductivity (EC).
- Methods: Difference-in-Differences (DiD); plus Synthetic Difference-in-Differences (SDiD) & Bayesian Structural Time Series model (BSTS).

INTRODUCTION

RESEARCH QUESTIONS

(1) Has Haryana's groundwater conductivity improved as a result of the ABY policy?

(2) Do the outcomes hold true for the various modeling techniques (DiD, SDiD, and BSTS)?

LITERATURE REVIEW

01

Groundwater Stress in Haryana, India

-Quality & quantity declining due to:

- Over-extraction
- Intensive agriculture
- Population growth

02

Research on the ABY Policy

-Covers 7 high-stress states, including Haryana
-Focus: behavioral change, irrigation efficiency, community monitoring

03

Why Use Electrical Conductivity (EC)?

-EC = key indicator of groundwater salinity and mineral content
-Hypothesis: If ABY works → EC should decline after implementation

DATA DESCRIPTION

1

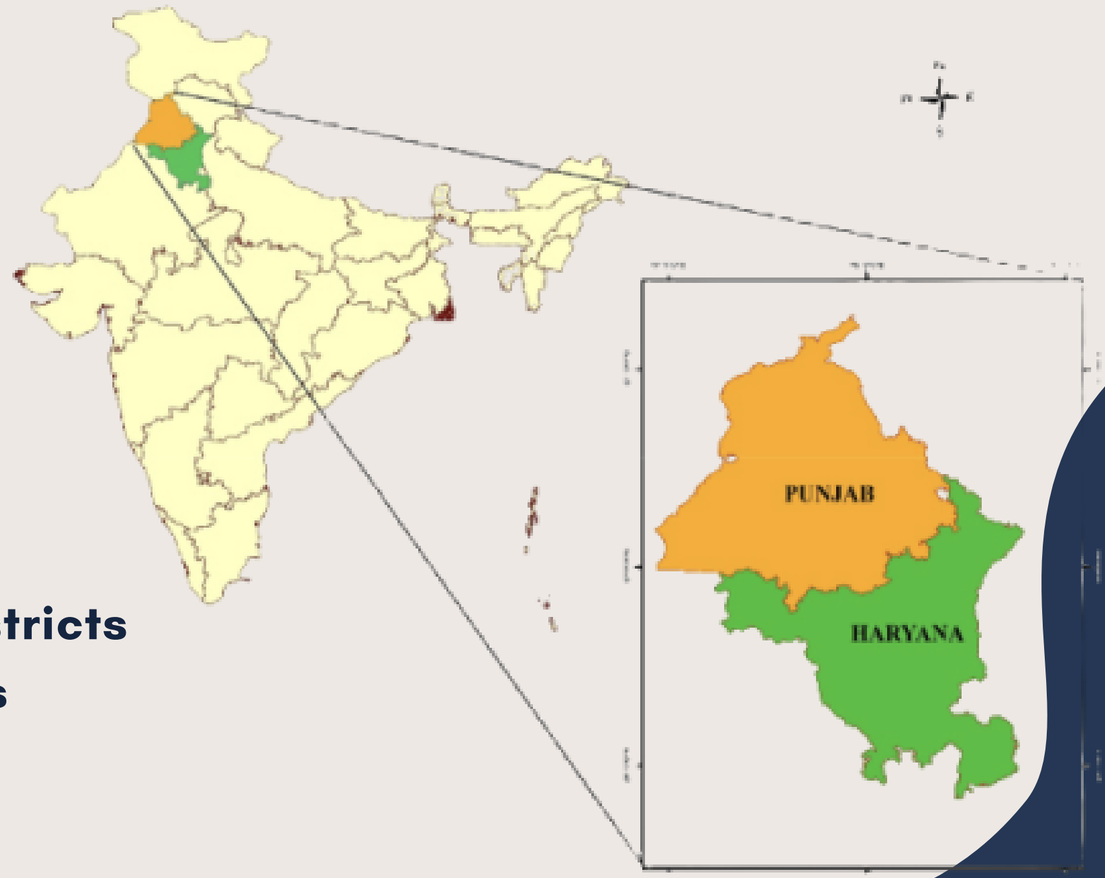
Source: National Ground Water Monitoring Network (NGWMN), by CGWB

2

Time Period: 2017–2022 (pre- & post-policy)

3

- **Haryana (ABY pilot) – 436 sites across 20 districts**
- **Punjab (control) – 317 sites across 17 districts**



4

Variables:

- **Geographic information**
- **Physical parameters**
- **Chemical indicators**

METHODOLOGY

DATA PROCESSING AND PANEL CONSTRUCTION

Variable filtering:

- Removed variables with >60% missing data
- Selected 18 variables available in both states

Panel construction:

- Unit of analysis: District-level panel (2017-2022)
- Aggregated site-level data into annual district averages
- Final sample: 213 observations
  - Haryana: 119
  - Punjab: 94

Outcome variable and covariates:

- Key outcome variable: Electrical Conductivity
- Covariates included: Chloride, Sodium, pH

METHODOLOGY

DATA PROCESSING AND PANEL CONSTRUCTION

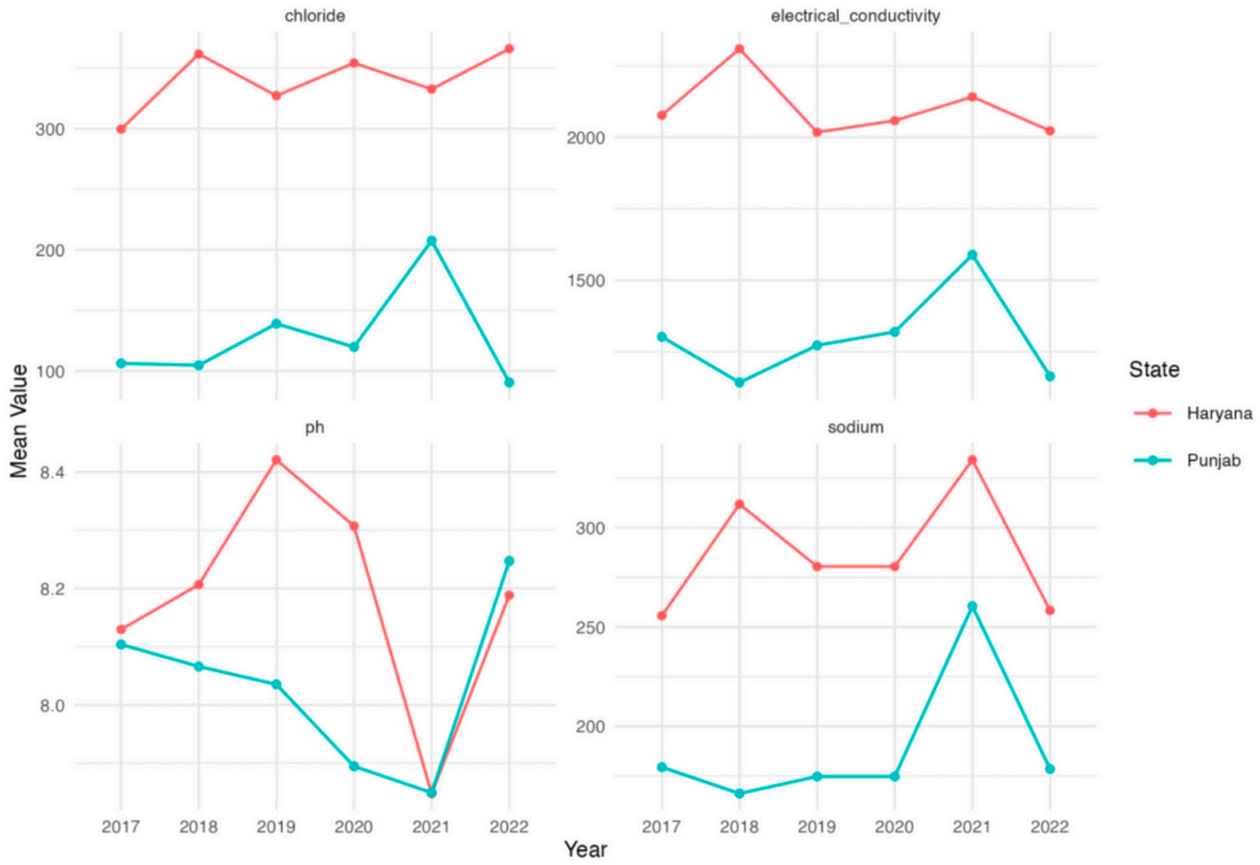


Figure 1. Trends of groundwater indicators by state (2017–2022)

METHODOLOGY

DIFFERENCE-IN-DIFFERENCES MODEL

Baseline DiD Model:

$$EC_{it} = \beta_0 + \beta_1 \cdot treated_i + \beta_2 \cdot post_t + \beta_3 \cdot (treated_i \times post_t) + \varepsilon_{it}$$

Extended Model with Fixed Effects:

$$EC_{it} = \alpha_i + \delta_t + \beta_3 \cdot (treated_i \times post_t) + \varepsilon_{it}$$

With Covariates (chloride, sodium, pH):

$$EC_{it} = \alpha_i + \delta_t + \beta_3 \cdot (treated_i \times post_t) + \gamma_1 \cdot chloride_{it} + \gamma_2 \cdot sodium_{it} + \gamma_3 \cdot ph_{it} + \varepsilon_{it}$$

Parallel Trend Assumption & Placebo Test (2017–2019):

Introduced fake policy period (fake_post)

$$EC_{it} = \beta_0 + \beta_1 \cdot treated_i + \beta_2 \cdot fake\_post_t + \beta_3 \cdot (treated_i \times fake\_post_t) + \varepsilon_{it}$$

If β_3 not significant → supports parallel trend assumption

METHODOLOGY

COMPLEMENTARY MODELS: SDID & BSTS

Synthetic Difference-in-Differences (SDiD):

-Combines features of Synthetic Control and DiD

-Introduces unit weights (ω_i) and time weights

$$\hat{\tau}^{\text{sdid}} = \sum_{i \in \text{treated}} \omega_i \left(\frac{1}{T_1} \sum_{t \in \text{post}} Y_{it} - \frac{1}{T_0} \sum_{t \in \text{pre}} Y_{it} \right) - \sum_{i \in \text{control}} \omega_i \left(\frac{1}{T_1} \sum_{t \in \text{post}} Y_{it} - \frac{1}{T_0} \sum_{t \in \text{pre}} Y_{it} \right)$$

Bayesian Structural Time Series (BSTS):

-Models counterfactual trend using pre-policy time series + Bayesian inference

-Effective for single-unit evaluation (Haryana) or

With external control (Punjab) or

With external control (Punjab) plus covariates: chloride and sodium

RESULTS

DIFFERENCE-IN-DIFFERENCES MODEL

Baseline Model

INTERACTION TERM (TREATED × POST): -173.0 (SE = 129.78, P = 0.192); ADJ. R^2 = 0.155
NOT STATISTICALLY SIGNIFICANT → WEAK EXPLANATORY POWER

Placebo Test (2017–2019)

INTERACTION (TREATED × FAKE_POST): 187.3 (P = 0.331)
NO SIGNIFICANT DIFFERENCE → SUPPORTS PARALLEL TRENDS ASSUMPTION

Two-Way Fixed Effects

INTERACTION (TREATED × POST): -170.33 (P = 0.19); ADJ. R^2 = -0.213
STILL NOT STATISTICALLY SIGNIFICANT

Two-Way Fixed Effects with Covariates

INTERACTION (TREATED × POST): -142.81 (P = 0.006); ADJ. R^2 = 0.823

- CHLORIDE: 2.640 (P < 0.001)
- SODIUM: 2.051 (P < 0.001)
- PH: -222.506 (P < 0.001)

RESULTS

SYNTHETIC DIFFERENCE-IN-DIFFERENCES

ATT ESTIMATE: -180.16 MS/CM

(SE = 137.36)

95% CI: [-445.72, 85.40] → NOT STATISTICALLY SIGNIFICANT

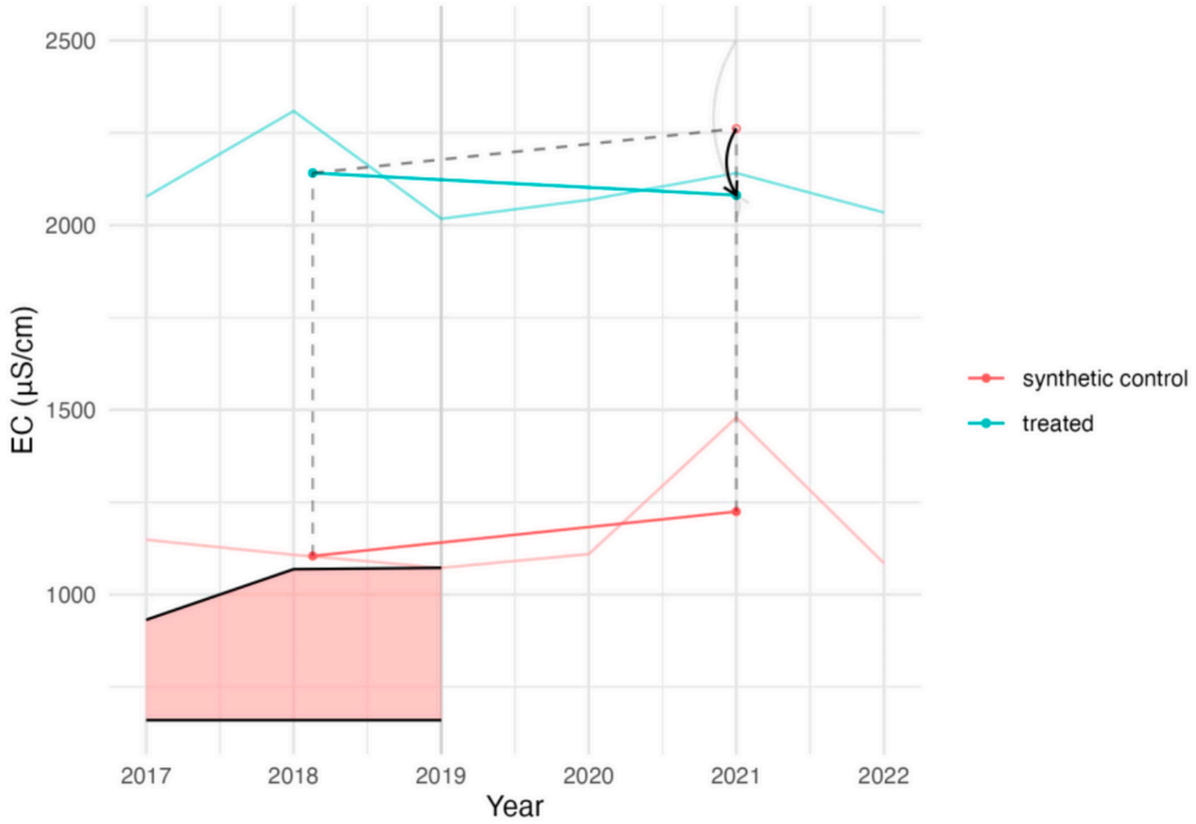
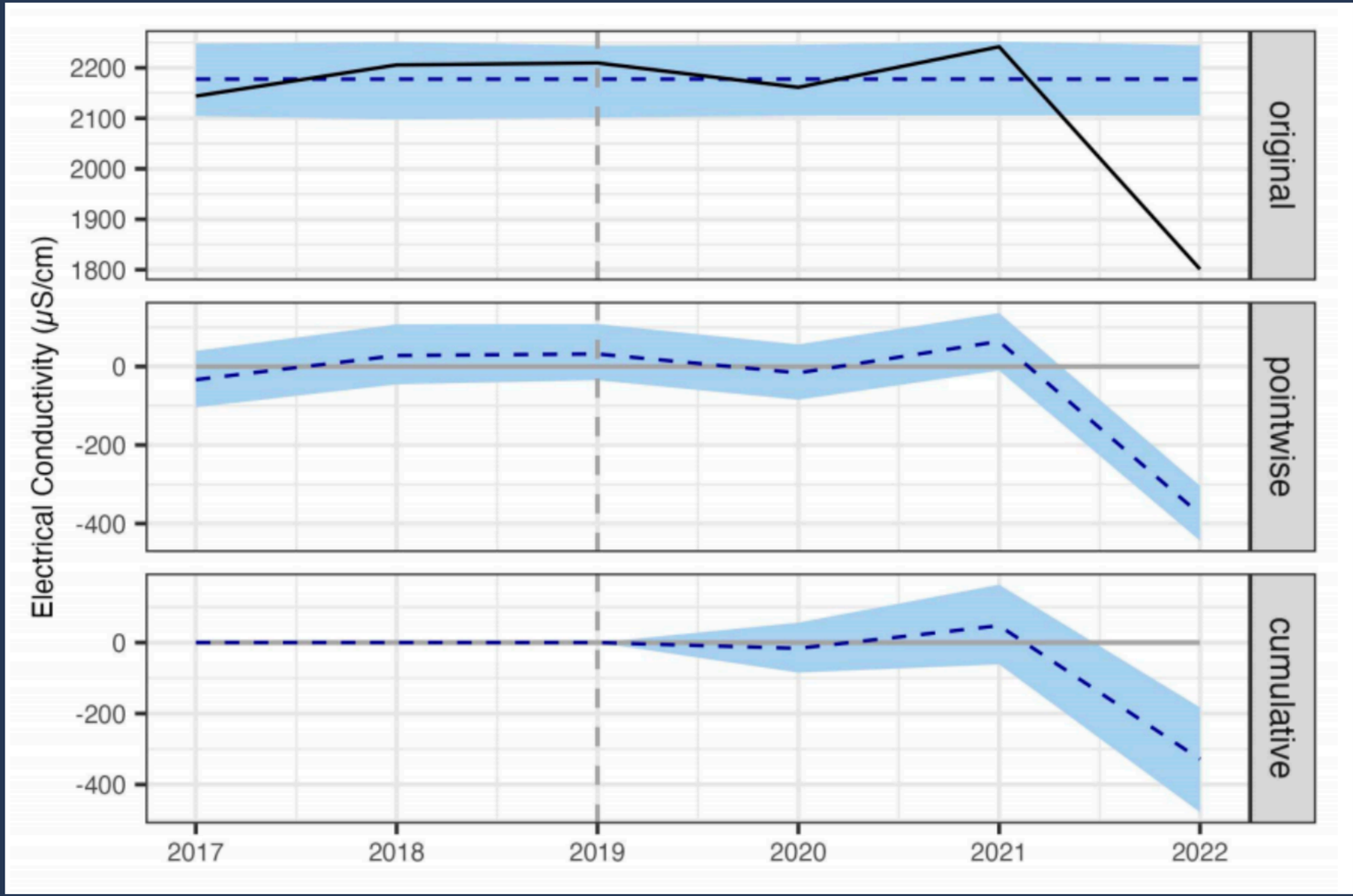


Figure 3. Synthetic control vs. actual treatment group: comparison of conductivity changes before and after intervention (2017-2022)

RESULTS

BAYESIAN STRUCTURAL TIME SERIES



ESTIMATED EFFECT:
-110 MS/CM
(-5%, P = 0.002)
POSTERIOR P: 99.8%

RESULTS

BAYESIAN STRUCTURAL TIME SERIES

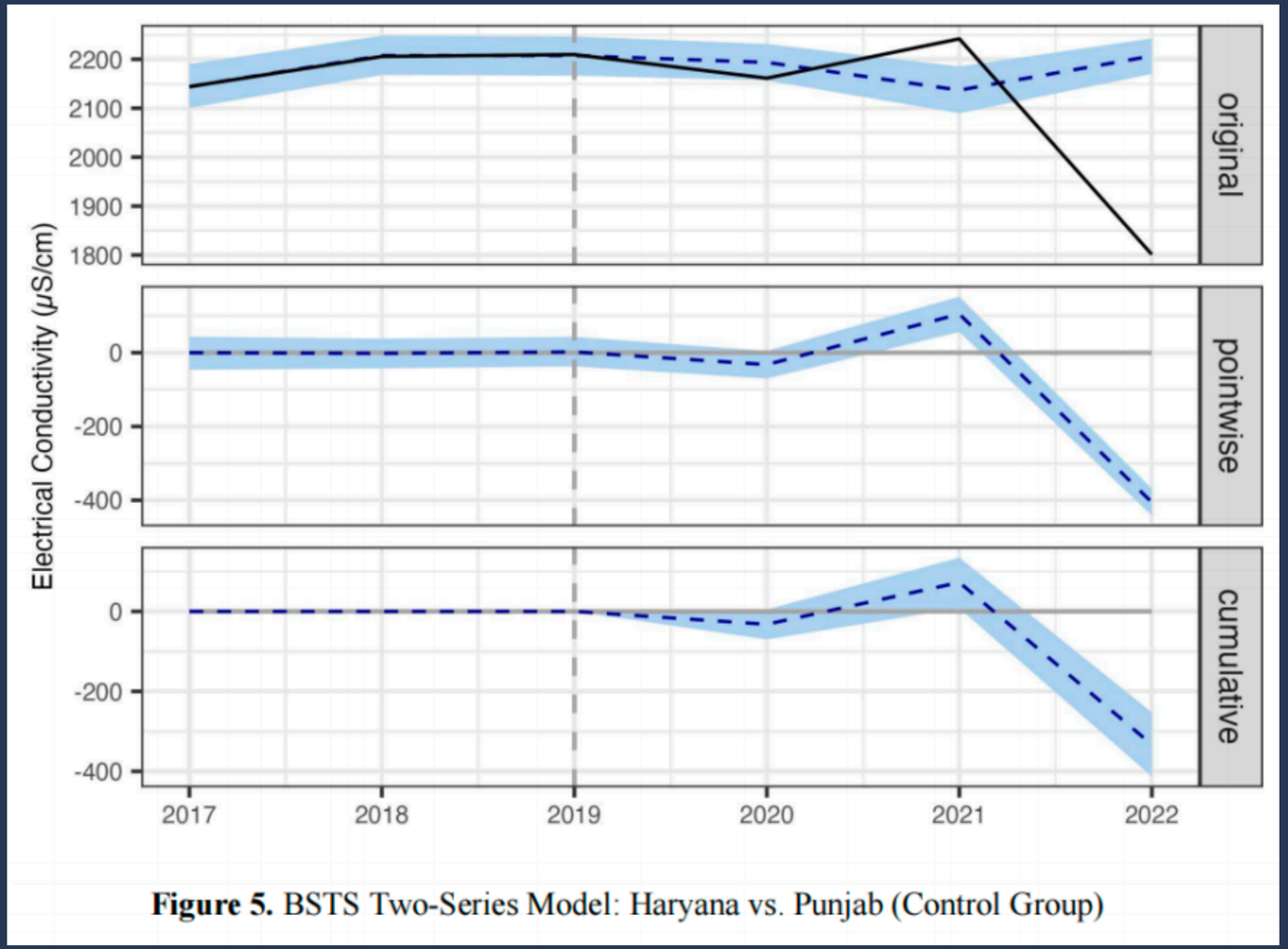


Figure 5. BSTS Two-Series Model: Haryana vs. Punjab (Control Group)

ESTIMATED EFFECT:
-111 MS/CM
(-5.1%, P = 0.001)
POSTERIOR P: 99.9%

RESULTS

BAYESIAN STRUCTURAL TIME SERIES

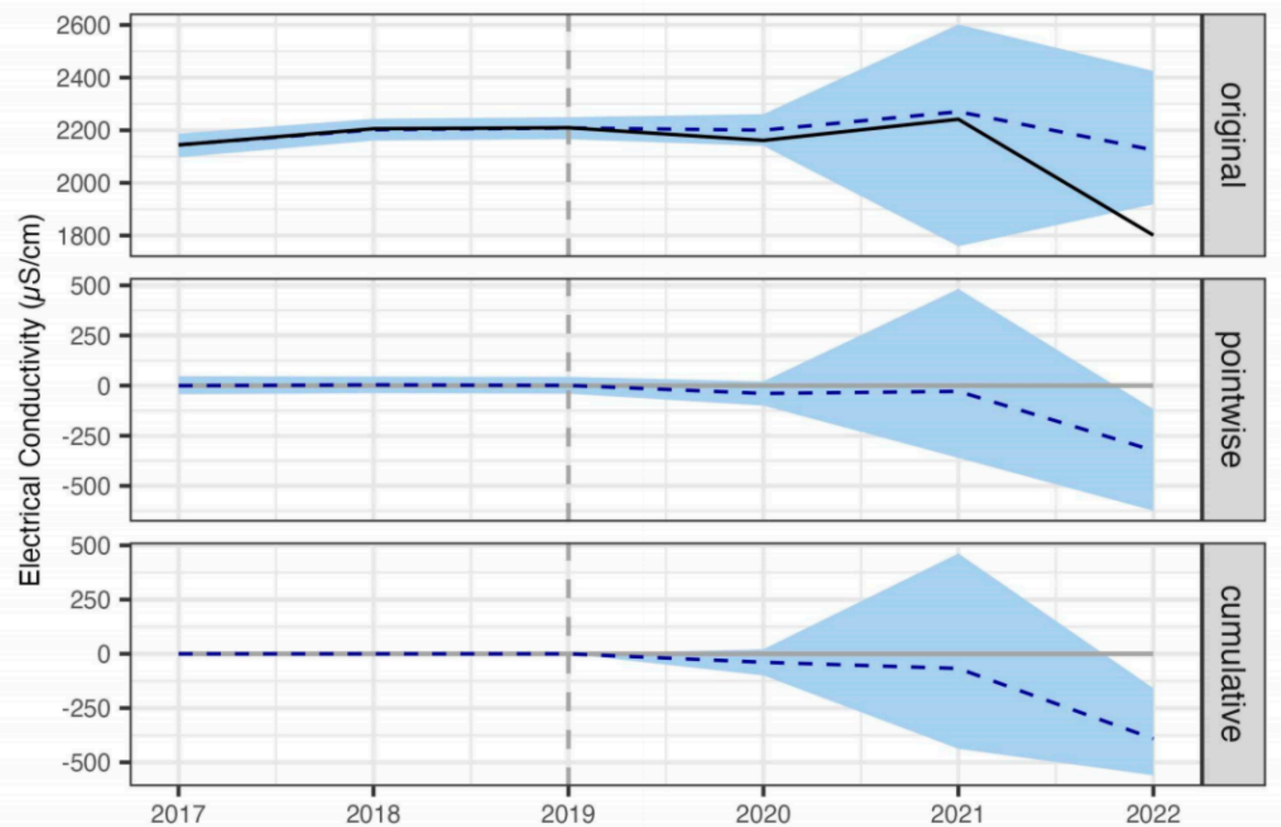


Figure 6. BSTS Two-Series Model: Haryana vs. Punjab (Control Group) with Chloride & Sodium Covariates

ESTIMATED EFFECT:
-130 MS/CM
(-5.9%, P = 0.003)
POSTERIOR P:
99.7%

DISCUSSION

Main Findings

- DiD (with FE & covariates): Significant reduction in conductivity post-ABY
- SDiD: Similar negative effect, not statistically significant
- BSTS: Strongest decline in 2022, indicating lagged effect

Mechanisms

Likely behavioral: irrigation & water-use changes

Not explained by natural ion variation

DISCUSSION

Limitations

Conductivity ≠ full water quality (e.g., heavy metals not included)

Short post-treatment period (only 3 years)

Only Haryana and Punjab → limited geographic & statistical scope

Future Directions

Include more contaminants & years

Expand to all Indian states

Link with behavioral & remote sensing data

CONCLUSIONS

1. ABY likely improved groundwater quality in Haryana
2. DiD shows significant reduction in conductivity
3. SDiD support similar direction
4. All three BSTS models identify a consistent decrease in conductivity
5. Triangulated approach adds robustness under data limits

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