Regulation and responses to policies for checking groundwater depletion in India: Evaluation using Synthetic difference in difference approach.

Abstract

Employing synthetic difference-in-difference methods, we investigate the impact of the legislation 'The Punjab Preservation of Subsoil Water Act, 2009' and similar act "The Haryana Preservation of Subsoil Water Act, 2009" to regulate groundwater use in agriculture. Potentially the two acts aimed to arrest the precipitous decline in groundwater in the most challenging water environments in north-west India. The acts mandated timings of water intensive paddy transplantation towards arrival of monsoon thus minimizing groundwater draft. Transplanting earlier than cutoff date was adjudged a penal offence. The findings show that despite the act being in force, the over-extraction of groundwater continued and the act can be attributed to reduce groundwater depth on average by 4 meters below ground level (mbgl) much less than the targets. The causal impacts of this stringent regulation show that the policy engendered behavioral responses that not only offset the policy effects but rather overshot the groundwater extraction responses with expanded paddy acreage, intensification of water extraction comprising more powerful pumps and employment of more efficient submersible pumps as groundwater levels plummeted, changes in irrigation hours and probably diminishing compliance. The legislation for checking groundwater abstraction ended up not checking it significantly with greater draft in both the states. The failure of the Act in arresting over- extraction of groundwater suggests the need for designing an irrigation water management strategy encompassing policy and institutional reforms, technological and agronomic solutions, and accounting for incentives. Working with process standards instead of product standards can be limiting in policy effectiveness.

Keywords: Groundwater depletion, Groundwater draft, Synthetic Difference in Difference, Behavioral Response.

Highlights

- Regulating groundwater use- If not implemented properly and incentives of the agents are not accounted for, the regulations can fail to manage groundwater resources.
- Perverse incentives and lack of compliance can overshoot in the opposite direction.
- Managing groundwater resources requires a comprehensive irrigation strategy encompassing technologies, institutions, and policies.

1. Introduction

It is estimated that over 2 billion people (35% of the world population) suffer from severe water stress [Alcamo et al., 2000]. Water stored beneath earth's surface in soil and porous rock aquifers account for as much as 33% of total water withdrawals worldwide. Groundwater plays a major, if often unrecognized, role in both hydrologic and human systems. Most of drinking water probably comes from groundwater, and in the last half century, there has been an unparalleled increase in groundwater use in agriculture that though has provided improved livelihoods and food security to billions of farmers and consumers, it has created significant concerns for sustainability particularly in water stressed regions with large aquifer systems (Falamiglietti 2014).

If groundwater abstraction exceeds natural groundwater recharge, overexploitation or persistent groundwater depletion occurs (Wada et al 2014). Many of the well-known hot spots of groundwater depletion exist in North-East Pakistan and North-West India (the focus of this paper) [Rodell et al. 2009]. India, the most populous country on the planet, and the largest user of groundwater (quarter of world total) for irrigation, is one of the most water stressed nation (World Bank 2014). In agriculture, equivalent to one-third of the world's groundwater-equipped area (Siebert et al., 2013) is in India. A 2011 study conducted by the National Aeronautics and Space Administration (NASA), United States of America concluded that during the past few decades, the groundwater beneath Punjab, Haryana, and Rajasthan has decreased by more than 88 million acre-feet. This is nearly eight times the amount that Lake Mead, the largest reservoir in the United States, holds.

The government in states of India with acute groundwater situation have thus tried several policies to arrest groundwater depletion. Both states at nearly the same time in 2009 implemented far reaching regulations for groundwater management like rainwater harvesting (for urban areas), in rural areas/agriculture, the Punjab Preservation of Subsoil Water Act, 2009" (hereafter termed as PPSWA, 2009) and the Haryana Preservation of Subsoil Water Act, 2009 (HPSWA 2009). The acts prohibits the raising of paddy nurseries before May 10 and their transplantation before June 10, or any other date notified by the government. The acts aimed to discourage excessive and indiscriminate use of groundwater for irrigation.

The non-compliance with this regulation attracts a penalty of Rs. 10,000 ($122) per hectare of paddy-cropped area or disconnecting supply of electricity or destroying paddy nurseries at farmer's expense or all of these. The legislation also empowers an authorized officer to enter a farmer's field to assess any violations. The core provision in both is setting a date in May as the earliest date before which a farmer cannot sow the paddy's nursery. The Act was expected to arrest the falling water table by 30cm and save electricity to the tune of 276 million kWh (Singh, 2009). In Punjab, the late transplanting was brought in through an ordinance first but was later turned into a law.

This paper assesses the impact of these wide-reaching regulations relating to mandatory timing of transplanting paddy (one of the most water intensive staple) to check over exploitation of groundwater in water stressed environments in the rice bowl and wheat basket regions of India. We investigate the question: Have these acts in the two states been effective in arresting decline in groundwater level through reduced groundwater draft?

The situation of groundwater depletion has been particularly dire in Punjab and Haryana, the seats of the green revolution (Hanasaki et al., 2008]. Punjab and Haryana are a part of the water-rich Indo-Gangetic River basin, one of the world's richest fluvial aquifers and one of the world's largest transboundary freshwater systems. Yet they account for a quarter of total global groundwater withdrawals. Several factors have contributed to the depletion of groundwater resources. In the quest of achieving self-sufficiency in food grains, farmers were incentivized to produce cereals including water guzzling paddy with installation of tube-wells.

The proliferation of tube wells to support irrigation is assessed to be responsible for more than 90 percent of the groundwater extraction in both states. Overexploitation or persistent groundwater depletion leading to lowering of groundwater levels can have devastating effects on natural streamflow, groundwater fed wetlands and related ecosystems (Gleeson et al 2010).[1] As groundwater levels drop, deeper wells need to be dug, increasing the cost of pumping water affecting livelihoods and disadvantaging the smaller farmers and leading to increased inequality.

The two states constitute only 1.5 and 1.4 percent of the country's total land area respectively but are among the biggest producers of wheat and rice in the country. Agriculture contributes more than 28 percent of Punjab's gross domestic state product (GSDP). In Haryana, despite the continuously decreasing share of agriculture in state's GDP owing to comparatively high industrialization, most of its population continues to depend on agriculture. The two states contribute nearly 12 percent of the country's total rice production and seven percent of India's national food grain production, respectively (where food grain includes both cereals and pulses).

[1] Between 1970-71 and 2018-19, the share of groundwater-irrigated area in the total irrigated area increased from 38% to 64% (GoI, 2019a). Until the late 1990s, the groundwater level in the state did not change much, but afterwards, it has fallen at an annual rate of 45.46cm, from 8m in 1997-98 to 18m in 2018-19 (GoI, 2019b).

The procurement of food grains, mainly paddy and wheat, at their pre-announced government-administered minimum support prices (MSP) and the provision of subsidized inputs, especially agrochemicals and electricity for irrigation, have been the key incentives to the farmers. The government in Punjab has been providing free electricity for irrigation since 1997 leading to a drastic shift in the cropping pattern in favor of more remunerative, comparatively risk-free water-guzzling crops like paddy which also has the support of MSP and public procurement. Before the advent of the Green Revolution, paddy was not an important crop in Punjab, but its acreage share increased to 40% in 2018-19, from a mere 7% in 1970-71.

Earlier, farmers in Punjab and Haryana used to practice the early transplantation of rice. They transplanted the rice crop during the summer season's peak, i.e., in May. As a result, rice cultivation depended entirely on groundwater. In the absence of rainfall or surface water irrigation, groundwater was extensively withdrawn for preparing the rice field through regular irrigation until the onset of the monsoon (mid-June) (Puthuchary and Tripathi 2021). Further, due to the hot and dry season and no rainfall, rice fields would experience considerable evapo-transpiration losses.

If complied with, both legislations prohibit farmers from sowing paddy nursery before the 15th and 10th May in a year, respectively. It is however difficult to uproot the entire paddy crop as it is sown over a large area. Therefore, in place of destruction, officials started levying penalties. Nevertheless, both legislations, which represent the first attempt by both states to regulate groundwater exploitation and arrest the falling water tables, did have some compliance being able to prevent the sowing and transplantation of paddy before the notified dates.

Using synthetic difference in difference evaluation we look not only at the outcome from these stringent regulations in terms of groundwater levels, but the groundwater draft itself. Our submission is that the similar acts in the two states engendered behavioral responses in terms of crop choices, acreage of crops, intensification of irrigation systems (power and type of pumps used, irrigation hours employed) and both legit and illegit lack of compliance (like planting water intensive summer maize). These responses not only offset the effects of the law but worsened the outcomes.

Using indirect instruments like regulating date of transplanting paddy rather than groundwater extraction itself (logistical difficulty with vast number of small farmers and non-separable groundwater and land rights by law) led to perverse responses especially when supplementary policies like near zero cost of electricity, support prices and procurement, subsidies on inputs like fertilizer and seeds persisted as before. The legal framework in India that does not explicitly define groundwater ownership and rights, still determined by the Indian Easement Act, 1882 that gives landowners withdraw limitless groundwater. Specifically, concerning groundwater's legal status in India, it is based on the common-law approach to the land ownership doctrine. Under this, groundwater belongs to the landowner, since legally, the term 'land' includes water (Rosencranz et al 2021).

Given the stringent laws on subsoil preservation for arresting groundwater depletion, it has indeed attracted research on the effects of this act but only in Punjab. Haryana implementing an identical regulation around the same time provides a good basis to understand the effects of the design itself in terms of indirect instruments and possible responses offsetting the effects.

Singh (2009) using time series data on experimental plots on paddy transplanting, comprising crop water requirements, rainfall, monsoon recharge, groundwater behavior and paddy area, estimated that the fall in water table can be checked by about 30 cm, and the savings in electricity was estimated at 276 million units in Punjab. The limitation is that the ex-ante estimates under experimental conditions assume full compliance and more importantly no offsets from behavioral responses like changes in power and nature of the pumps used for extraction, acreage in water intensive crops, factors that would affect groundwater draft .

Sekhri (2013) using Difference in Difference (DiD) estimates indicates that the annual groundwater level situation worsened in rice growing areas after the policy change. The paper conjectures (and not estimate) on possible responses like possibility of farmers' increasing the number of irrigations applied or using more water per irrigation after mid-June transplanting. The resultant effect on groundwater draft is not assessed in the paper. Sharma et al. (2021) like Sekhri (2013) employ DID technique, focus only on Punjab while using Haryana as comparator with a different timing of intervention. The evidence suggests that it had made a small impact initially (Sekhri, 2012; Tripathi et al., 2016) — groundwater level did not show any significant change post two years of the Act, but afterwards, it started falling (Gupta, 2021).

In the canonical DID set up employed in DiD estimations, high paddy acreage districts comprise the treatment unit and below the median acreage districts comprise the control group. The DiD set up moreover treats all pre-intervention periods neutrally i.e., there is no weighting on time in preparing the counterfactual. Times near to intervention period i.e., 2009 were characterized by differences inter alia in power of pumps, level of groundwater, support prices and procurement of cereals, implying that not only units but also time periods deserve differential weights in preparing a counterfactual for Punjab and Haryana.

The studies based on district level data while the act applies to the entire state of Punjab and Haryana respectively employ either a panel fixed effects model or a difference-in-difference approach as discussed above assuming paddy-intensive districts as the units of treatment. In this case, the extent of paddy acreage itself could be endogenous which we observe after the act. Constrained by shorter cultivation cycle, growers could respond by expanding the acreage under paddy assuming shorter duration crops to be associated with lower yields (at least in perception). The acreage could change if perceptions exist among farmers about not being able to optimize the paddy variety grown due to delayed transplanting leading to delayed sowing ultimately to lower yields and production. Similar perceptions could bring in more irrigation and greater draft of groundwater.[2]

In the classic DiD estimation, it is not possible to account for time varying demographic and economic variables. Such variables can influence both policy choices as well as implementation differentially in treated and control units. There are several time varying factors/behavioral responses that would affect groundwater draft and ultimately the level of groundwater.

Other factors comprise inter alia increased wattage of pumps over time, prior groundwater level, crop specific support prices and procurement, changes in types of pumps used (including submersibles in lieu of centrifugal pumps) and adjustments in irrigation hours; all time varying factors affecting groundwater depth. Further, identification dependent on paddy acreage with high acreage districts being the treatment unit may be problematic if acreage of paddy changes across districts with respect to the baseline. Moreover, none of the studies estimate the causal effect on the draft itself, which we argue is suitable outcome to look at as it incorporates responses of the agents to policy change.

Finally most of these studies use short-term data only up-to year 2011-12 of post enactment period (only two-three years). We consider data up-to year 2018-19 (nine years) enabling comparison of both short and long run effects that can be expected to be quite

[2] At least seven districts, four in Punjab (Rupnagar, Bhatinda, Mansa and 3 in Haryana (Fatehabad, Jind., Panchkula) switched from control to treatment based on the median cutoff.

different. If the acts were to be ineffective in arresting groundwater extraction or aggravating it, what factors could explain this paradox which is reflected in the draft itself.

This paper thus has three objectives. First, it assesses the causal effects of the legislation in two states to arrest the depletion of a valuable resource i.e., groundwater. The analysis does so by using methods that capture the role of time varying unobserved factors using the most recent technique of synthetic difference in difference that brings in differential weighting also for time periods in the preintervention spell.

The perverse outcomes because of the incentives engendered from the policy offset the purported objective of checking the groundwater depletion and worked instead in aggravating it. Each period prior to intervention contributed differentially to making the no-treatment counterfactual which use of synthetic DiD is able to capture. Synthetic DID improve the estimation by using the good features of both synthetic control as well as difference in difference.

Estimated as causal impacts, our findings suggest that over-extraction of groundwater remains unabated in the two states despite the stringent act being in force. The groundwater level post-implementation of the Act in fact worsened by 60cm/annum as compared to 28cm/annum before the Act.

The paper is organized as follows. Section 2 presents the groundwater scenario in India and summarizes policies in the states of Haryana and Punjab to address the issue of groundwater depletion.

1. Data and Method

The study utilizes secondary data compiled from different sources (Table 1). The data on groundwater depth has been compiled from the Ministry of Jal Shakti, Government of India. Groundwater depth is typically measured in January, May, August, and November allowing assessment of situation pre as well as post monsoon. The data on rainfall have been obtained from the Indian Metrological Department, Ministry of Earth Science, Government of India. The information on cropping patterns was compiled from the Directorate of Economics and Statistics, Ministry of Agriculture and Farmers' Welfare, Government of India.

Table 1. Data sources used

Type of data	Source

Groundwater level	India Water Resource Information System, Ministry of Jal Shakti, Government of India- https://indiawris.gov.in/wris/#/groundWater
Rainfall	India Meteorological Department, Ministry of Earth Science, Government of India- https://mausam.imd.gov.in/
Electricity consumption in Agriculture	Central Electricity Authority, Ministry of Power, Government of India- https://cea.nic.in/annual-generation-report/?lang=en
Cropped area and irrigation sources	Land Use Statistics, Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India- https://eands.dacnet.nic.in/
Tube-wells number and electrification	Minor Irrigation Census, Ministry of Jal Shakti, Government of India- http://micensus.gov.in/ Economic and Statistical Organisation, Department of Planning, Government of Punjab- https://www.esopb.gov.in/static/Publications.html
Paddy Irrigation hours	Cost of Cultivation, Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India- https://eands.dacnet.nic.in/Cost_of_Cultivation.htm

The number of tube-wells run on electricity or otherwise was taken from the Minor Irrigation Census, Ministry of Jal Shakti, Government of India. The electricity used for irrigation has been obtained from the Central Electricity Authority, Ministry of Power, Government of India. The hours of irrigation in paddy cultivation have been estimated using the farm-level data from the Cost of Cultivation Scheme of the Commission on Agricultural Costs and Prices (CACP), Government of India. Our dataset pertains to 2000-01 to 2018-19.

Central Ground Water Board (CGWB) monitors ground water levels four times a year during pre-monsoon (April/ May), monsoon (August), post-monsoon kharif (November) and post-monsoon rabi (January) through a network of 22730 observation wells spreading throughout the country. At the aggregate (Punjab and Haryana level), the determinants of groundwater draft comprise the predictor variables in the analysis including the rainfall, electricity consumption, cropping intensity, dependence on groundwater, paddy-cropped area, hours of irrigation in paddy, tube-well density, and power of groundwater extraction units.

Between the treatment and donor pool states, the mean groundwater level (2000-01 to 2018-19) in Punjab was 12.71m, which is 3.22 m deeper than the average for the donor pool. Over time, the groundwater level in the state has fallen to 18.06m in 2018-19 from 12.10m in 2009-10 and 9.25m in 2000-01. In Haryana the annual extractable groundwater resources have been assessed at 8.1bcm. With the extraction, it is 134% of the extractable resource.

The mean annual rainfall in the state is 503mm, which is 60% less than for the donor pool states. The electricity consumption in Punjab agriculture is 2195 kWh/ha, almost thrice the average of the donor pool. Higher electricity use in Punjab is also due to the provision of free electricity for irrigation. Tube-well density and cropping intensity are much higher in Punjab than in any other Indian state. Notably, about 96% of the tube-wells in Punjab are run on electricity.

Notably, the average area under paddy cultivation is larger in Punjab compared to the average of the donor pool states. Also, the number of irrigation hours per hectare of paddy area is 2.3 times more in the state. The increasing area under paddy cultivation, especially after 1999, has accelerated the rate of decline in the groundwater level

Table 2: Electricity tariff (Rs./BHP/month)

year	AP	AS	BR	CG	GJ	HR	HP*	JH	KT	KL*	MP*	MH	OD*	PB	RJ	TN	UP	UK	WB*
2000	21				140		67.1				268.6		147.7	60	15	0	40		73.9
2001					140		67.1				268.6		147.7	60	15	0	40		87.3
2002					140		67.1				268.6		147.7	60	15	0	55		100.7
2003	35				140		67.1		20		268.6		147.7	60	15	0		55	114.1
2004	0				140		67.1		20		268.6		147.7	60	20	0		70	127.6
2005	0			65	140		208.1		20		268.6		147.7	60		0		105	141.0
2006	0		100	65	140		208.1		20		268.6		147.7	0		0		105	154.4

2007	0			65	140		208.1	65	20		272.6		161.1	0		0		105	201.4
2008	0		100	65	140		248.4		20	87.3	325.0		147.7	0		0		105	214.8
2009	0			65	160		248.4		0		335.7		147.7	0		0		130	235.0
2010	0		100	20	160		248.4		0	87.3	376.0	206	147.7	0	85	0		150	339.7
2011	0			20	175	35	248.4	50	0		402.8		147.7	0	85	0			393.4
2012	0			25	175	35	335.7	50	0		429.7	295	147.7	0	85	0	75	165	542.5
2013	0		120	25	200	35	335.7	60	0		429.7	374	147.7	0	85	0	100		542.5
2014	0			50	200	15	335.7	60	0		429.7	374	147.7	0	85	0	100	180	643.2
2015	0		120	70	200	15	496.8	75	0		470.0	374	201.4	0	85	0	100	180	678.1
2016	0		120	80	200	15	496.8	100	0		523.7	309	201.4	0	85	0	100		678.1
2017	0			80	200	15	496.8	375	0		577.4	309	201.4	0	85	0	150		678.1
2018	0		168	80	200	15	496.8	400	0	268.6	577.4	309	201.4	0	85	0	150		678.1

*- estimated from metered tariff assuming 6 hours of electricity supply daily (= 0.746 X 6 X 30 X tariff charge in Rs/kwh)

Our treatment units are the states of Punjab and Haryana, which enacted the subsoil preservation acts to check excessive and indiscriminate withdrawal of groundwater for irrigation. Other states are not affected by this Act; hence these serve as controls for creating a counterfactual groundwater level for Punjab and Haryana in the absence of the Act. These states are Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttarakhand, and West Bengal, and comprise the donor pool.[3] None of these states have made any such intervention.

To assess the impact of PPSWA, 2009 in the two states. in arresting the groundwater decline' we implement a synthetic difference in difference method where the SCM part constructs a synthetic Punjab and Haryana as a convex combination of the states that closely resemble treatment states in key parameters that influence groundwater use. Like the matching estimators, the Synthetic difference in difference demonstrates the affinity between an administrative unit exposed to the intervention and its counterfactual or synthetic situation. The SCM approach, pioneered by Abadie and Gardeazabal (2003), is data-driven in choosing the units for comparison. It provides insight

[3] Haryana is not included in the donor pool because it implemented a similar Act called 'The Haryana Preservation of Subsoil Water Act, 2009' in the same year.

into the systematic selection of comparison units based on similarity in the relevant parameters. It constructs a counterfactual of the treated unit by assigning appropriate weights to the non-treated units.

Like other impact evaluation techniques (e.g., difference-in-difference), the SCM does not assume equal weights for the untreated units (Galiani and Quistorff, 2017). Further, the SCM allows us to capture the temporal effects of the observed and unobserved predictors on the outcome variable on the assumption that the pre-intervention covariates have a linear relationship with the post-treatment outcome (Kreif et al., 2016). The advantage of constructing a counterfactual is that the pre-intervention characteristics of the treated unit are more accurately approximated by a combination of the untreated units than by a single untreated unit (Abadie et al., 2015). The outcomes of the untreated units are weighted to construct a counterfactual outcome for the treated unit in the absence of an intervention or treatment (Kreif et al., 2016). If the intervention is effective, then there should be a divergence, positive or negative, between the synthetic and actual outcomes in the post-treatment period.

In SCM, suppose there are S+1 administrative units of which one unit receives treatment and the rest do not. The untreated units serve as "potential controls" or "a donor pool". Let, Y_{it}^{N} be the outcome for unit *i* at time *t* in absence of an intervention, where *i*= 1, 2..., S+1 and time t=1, 2,…,T. T_0 be the timing of intervention such that $1 \leq T_0 < T$. Further, Y_{it}^{I} is the outcome that could have been realized by unit *i* at time t in periods T_0+1 to T. Here, the assumption is that the outcome of the untreated units is not affected by the intervention in the treated unit. The effect of the intervention, thus, can be assessed as:

$$\delta_{it} = Y_{it}^{I} - Y_{it}^{N} \qquad (1)$$

Let, β_{it} be an indicator taking the value of 1 if the unit *i* is exposed to the intervention at time *t*, and zero otherwise, i.e., $\beta_{it} = \begin{cases} 1 & if\ i = treated\ unit\ and\ t > T_0 \\ 0 & Otherwise \end{cases}$. Then, the observed outcome for unit *i* at time *t* is:

$$Y_{it} = Y_{it}^{N} - \alpha_{it}\beta_{it} \qquad (2)$$

Since, Y_{it}^{I} is observed, we need to estimate Y_{it}^{N} to calculate α_{it}. Let, Y_{it}^{N} is given by a factor model such that:

$$Y_{it}^{N} = \alpha_t + \theta_t z_i + \tau_t \mu_i + \varepsilon_{it} \qquad (3)$$

Where, α_t is unknown with constant factor loadings across the units, z_i is a *(r* $\times$1*)* vector of observed covariates (not affected by the intervention), θ_t is a *(*1 $\times$ *r)* vector of unknown parameters, τ_t is a *(*1$\times$*F)* vector of unobserved common factors, and μ_i is an *(F*$\times$1*)* vector of unknown factor loadings. The error term, ε_{it}, is an unobserved transitory shock at the administrative level with zero mean.

The SCM subjects the attributes of a predictor variable in the pre-treatment period to a dual optimization process that minimizes $\sum V_m(X_{1m} - X_{0m}W)^2$ by selecting optimal values of *W* and V_m. X_{1m} is the value of *m*th attribute of the treated unit; X_0m is a 1 x *j* vector of the values of the *m*th predictor attribute of each control unit in S; *W* is a vector of weights for the control units; and V_m is a vector of weights for the attributes of the control units such that these maximize the probability to predict the outcome (Abadie et al., 2010). Such an optimization process minimizes the prediction error between the actual and its counterfactual in the pre-treatment period.

Y_1 is the observed outcome for the treated unit. Y_0W is the weighted average of the outcomes of the untreated units. If no important predictor variable is omitted, then a reliable synthetic match is created such that Y_1 -Y_0W is small in the pre-intervention period (Abadie et al., 2010). If the counterfactual outcome diverges significantly from the actual outcome in the post-treatment period, then the gap between the two is attributed to the intervention.

In recent years, flurry of papers on SCM has emerged that introduces a setting with only single or few numbers of treated unit compensating for parallel trends by reweighting control units to match their pre-exposure trends. For holding up estimated result obtained with SCM, Arkhangelsky et al., (2022) presented a new method in the field of impact evaluation- synthetic difference-in-difference (SDID) method, that combine attractive features of SCM and DID. Similar to SCM, SDID method reweights and matches pre-exposure trends to weaken the reliance on parallel trend assumptions. Similarly, SDID is invariant to additive unit level shift like DID. In SDID, estimator i) assign more weight to the control units that are more similar to the treated units and ii) emphasizes higher on period that are more similar to the treated periods. For the DID method, raw data rarely exhibit parallel time trends for treated and control units, and necessitating adjusting for covariates or selecting appropriate time periods. However, SDID method makes this process automatic while retaining statistical guarantees.

Synthetic DID (Arkhangelsky et al 2021)

Moving from Synthetic Control Method, Synthetic-DID involves the following maximization.

$$\left(\hat{\tau}^{sdid},\ \hat{\mu},\ \hat{\alpha},\hat{\beta}\right) = arg.min\left\{\sum_{i=1}^{N}\sum_{t=1}^{T}(Y_{it}-\mu-\alpha_i-\beta_t-W_{it}\tau)^2\hat{w}_i^{sdid}\hat{\lambda}_t^{sdid}\right.$$

In synthetic DID, it puts more weight on units and period that on average similar in term of their past to the treated. The unit weights are designed so that the average outcome for the treated unit is approximately parallel to weighted average of control units and time weights are designed so that the average post-treatment outcomes for each of the control units differ by a constant from weighted average of the pre-treatment outcomes for the same control units. Like SCM, reweight and matches pre-exposure trend to weaken the reliance on parallel trend and like canonical DID, it is invariant to additive unit-level shift. Both the DID method and SCM are special cases of nested models. The optimization for a DID method would have no time &and unit weights)

$$\left(\hat{\tau}^{did},\ \hat{\mu},\ \hat{\alpha},\hat{\beta}\right) = arg.min\left\{\sum_{i=1}^{N}\sum_{t=1}^{T}(Y_{it}-\mu-\alpha_i-\beta_t-W_{it}\tau)^2\right.$$

Synthetic control method

$$\left(\hat{\tau}^{sc},\ \hat{\mu},\ \hat{\alpha},\hat{\beta}\right) = arg.min\left\{\sum_{i=1}^{N}\sum_{t=1}^{T}(Y_{it}-\mu-\beta_t-W_{it}\tau)^2\hat{w}_i^{sc}\right.$$

Synthetic Difference-in-Differences (SynthDiD) method is a generalized version of SCM and DiD that combines the strengths of both methods. It enables causal inference with large panels, even with a short pretreatment period. A synthetic control group is constructed using the same approach as in the synthetic control method outlined above. The average treatment effect (ATT) is however estimated using the elements of DiD where it is estimated by comparing the change in outcomes between the treated unit and the synthetic control group before and after the treatment.

The synthetic DiD approach thus improves on DiD by accounting for pre-existing differences between the treatment and control groups. With this comparison the method deviates from standard synthetic control method which for treatment effect compares post-treatment outcomes of the treated unit to those of the synthetic group. Synthetic DiD estimates treatment effects by comparing the change in outcomes between the treated unit and the synthetic control group before and after the treatment is introduced thus combining the two meathods (Alagoz 2022).

By construction, in contrast with synthetic control method, SDiD can be used for impact evaluation even when pre-treatment period is short. The estimations however are comparatively robust if there is greater number of pretreatment periods which is an advantage in our case where we have large number of pretreatment periods. The estimator is considered consistent and asymptotically normal, given that the combination of the number of control units and pretreatment periods is sufficiently large relative to the combination of the number of treated units and posttreatment periods which happens to be true in ourcase when the impacts are evaluated individually for the two states or ahen they are combined (**Arkhangelsky et al 2021)**.

The benefit in relation to DiD method comes from not requiring a strict parallel trends assumption (PTA) requirement. The flip side of synthetic DiD method are the requirements of a balanced panel and treatment timing to be identical for all treatment units.[4] In the process of pretreatment matching, SynthDiD tries to determine the average treatment effect across the entire sample. This approach might cause individual time period estimates to be less precise. Nonetheless, the overall average yields an unbiased evaluation.

The standard errors for the treatment effects are estimated with jacknife, bootstrap or if a cohort has only one treated unit with placebo method. Hence when we estimate models separately for Punjab and Haryana, we rely on placebo methods for inference. Since the regulation is identical and the timing of treatment (in terms of year is the same in the two states i.e., 2009, we also estimate the model with combined datasets resulting in more than one treatment units and allowing us to obtain standard errors using jacknife or bootstrap methods.

In practice, pre-treatment variables play a minor role in Synthetic DiD, as lagged outcomes hold more predictive power, making the treatment of these variables less critical. A particularly active area is that applied to estimating the impact of policy when observations are available in a panel or repeated cross section of groups and time (see for example recent surveys by Roth et al. (2022). A large number of empirical studies in this setting employ difference-in-difference (DID) methods to estimate causal impacts. These impacts are evaluated by

[4] Recent innovations in synthetic DiD admit staggered timing of treatment.

comparing treated to control units, where causal inference is contingent on the presence of parallel trends/paths.[5] Whether this assumption is reasonable in a particular context is an empirical issue.

In many cases, parallel trends may be a questionable modelling assumption. One particular solution to the challenge has been the application of synthetic control methods. Early work in synthetic control explores the setting of comparative case studies, where a single treated unit is observed, and one wishes to construct a matched synthetic control from a larger number of potential donor units (Abadie and Gardeazabal 2003; Abadie et al. 2010, 2015).

These methods seek to generate a single synthetic control from a unique weighting of underlying control units, such that this synthetic control is as closely matched as possible to the treated unit in pre-treatment outcomes, and potentially other covariates. This weights are optimally generated and fixed over time, potentially assigning zero weight to certain control units, and larger weights to others (Ben-Michael et al. 2021).

Synthetic difference in difference allows for treated and control units to be trending on entirely different levels prior to treatment. The synthetiuc control part of the method using optimal weights it can generate a matched control unit which wekens the need for parallel trend assumptions. The demerit that synthetic DID addresses in relation to the sythetic cntrol method is to unbind in terms of the requirement that treated unit be located in the convex hull of control units.

We estimate the synthetic DiD model using the sDiD command in Stata 17. While principally written to conduct SDID estimation, the sdid command nests as possible estimation procedures SC and DID, which we employ to comparison based on estimation procedures of SCM and DiD. SDID method assigns the weight to the control states make time trend parallel (not necessarily identical) to the Punjab in pre-intervention period, then apply a DID method to the re-weighted panel.

Arkhangelsky et al. (2021) in which a single state adopts a treatment at a given time, as well as an example where exposure to a policy occurs at mutiple periods: that is not the case for the regulation in two states. As input, SDID requires a balanced panel of N units or groups, observed over T time periods which we adopt.

[5]Recently, methodologies have worked with less stringent assumptions including methods that allow bounded deviation from strict parallel treands settling on partial identification (Roth and Rambachan 2022, Goodman-Bacon 2021).

A key element of both of these designs is that once treated, units are assumed to remain exposed to treatment forever thereafter. In the particular setting of SDID, we require at least two pre-treatment periods of which to determine control units. The goal of SDID is to consistently estimate the causal effect of a policy intervention (an average treatment effect on the treated, or ATT) even if we believe that parallel trends assumption may not hold completely between all treatment and control units on average.

As the estimation procedure includes the unit-fixed effects, it implies that SDID seeks to match treated and control units on pretreatment trends, and not necessarily on both pre-treatment trends and levels, allowing for a constant difference between treatment and control units (Clarke et al 2023). The synthetic control, obtains optimally chosen unit-specific weights but does not seek to optimally consider time periods via time weights, and omits unit fixed effects implying that the synthetic control and treated units should maintain approximately equivalent pre-treatment levels, as well as trends (Clarke et al 2023).

2. **Groundwater scenario in India and policies in Haryana and Punjab**

As the biggest user of groundwater, annual groundwater draft in India is 245 billion cubic meters (bcm), out of which an overwhelming 89% is for irrigation use. The number of deep tube wells in India surged from 1.46 million to 2.6 million between 2006-07 and 2013-14 (fifth minor irrigation Census -Union Water Resources Ministry, GOI). Majority of the deep tube wells, which irrigate nearly 13 million hectares of land, are in states of Punjab, Rajasthan, Andhra Pradesh, Telangana, Tamil Nadu, Haryana, Madhya Pradesh, Maharashtra, and Karnataka and are dominantly owned by farmers. 40% tube wells have a depth range of 70-90 meters, while 26% are in the range of 90-110 meters.

Three crops-paddy, wheat and sugarcane which share 62% of cropped area, consume nearly 80% of irrigation water. Groundwater rights and land rights are congruent (riparian rights) and treated as private property of landowner. Preponderance of individual wells makes monitoring and enforcement of groundwater extraction extremely difficult, and hence policy focus has mostly been on supply side interventions.

Figure1-Irrigation development in India

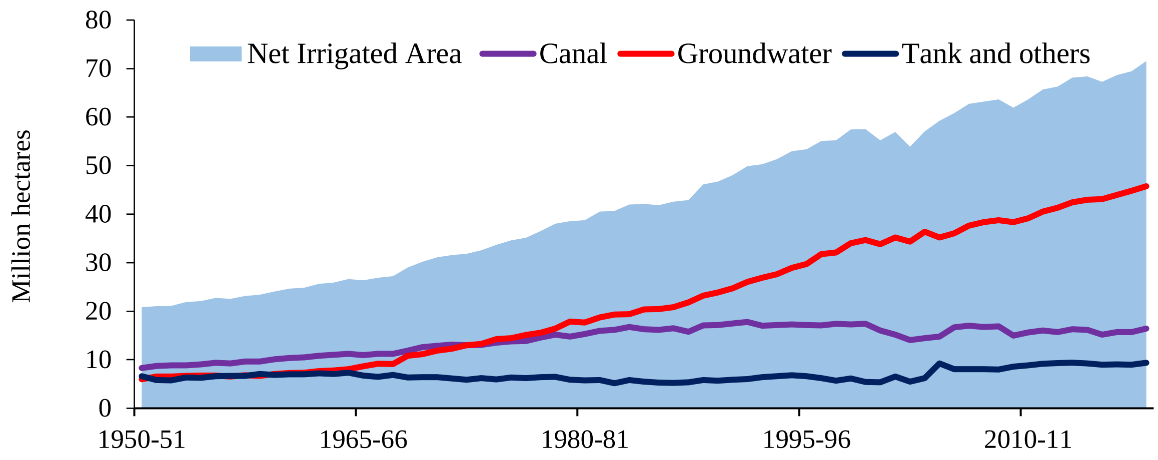


Figure 1 plots the path of irrigation development in India. After the initial lead of surface irrigation, for the last four decades, groundwater has singularly dominated the landscape of irrigation. While the share of irrigated area with groundwater was 31% between 1950-51 to 1968-69, the corresponding figure for 1991-92-to 2018-19 is 60%. Parallelly, the share of canal irrigation has come down from 42% to 27%. Figures 2a and 2b, 2c and 2d show the high irrigation intensity and sub-state overexploitation in north-west India where Punjab and Haryana lie. Compared across states, the first and third positions (out of 28 states) in overexploited groundwater blocks are in Punjab and Haryana. Figures show deteriorating groundwater situation being comparatively severe in paddy growing regions that tally with regions in red (figure 2d).

Groundwater has been made available primarily through either free or highly subsidized electricity for extracting it, with no charge or fee levied on the water itself, implying that farmers face (close to) zero marginal costs of irrigation (Pahuja et al., 2010; Shah et al., 2012) (Mitra et al 2020).

Figure 2a: Spatial variation in irrigation credentials in India

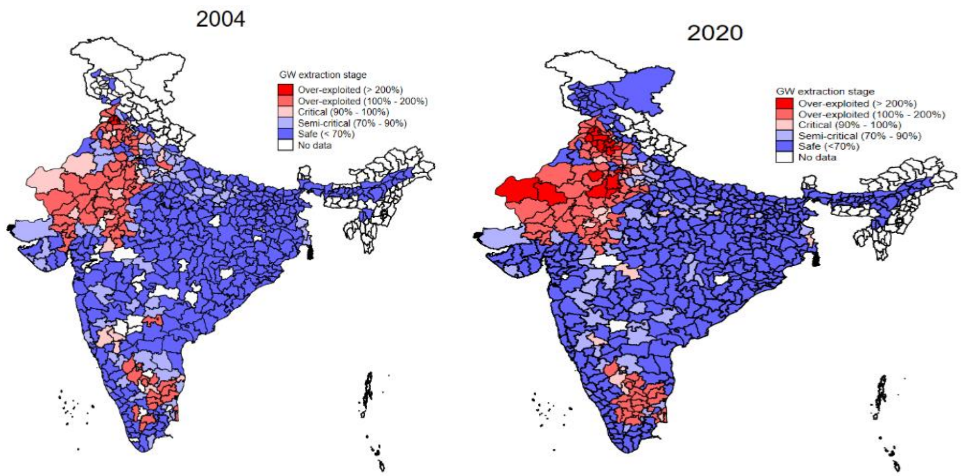


Figure 2b: Groundwater usage and condition of availability across Indian states

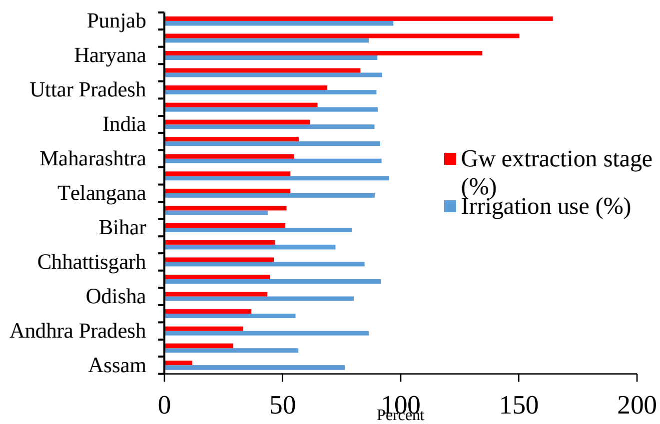


Figure 2c: Overexploited groundwater blocks in Indian states

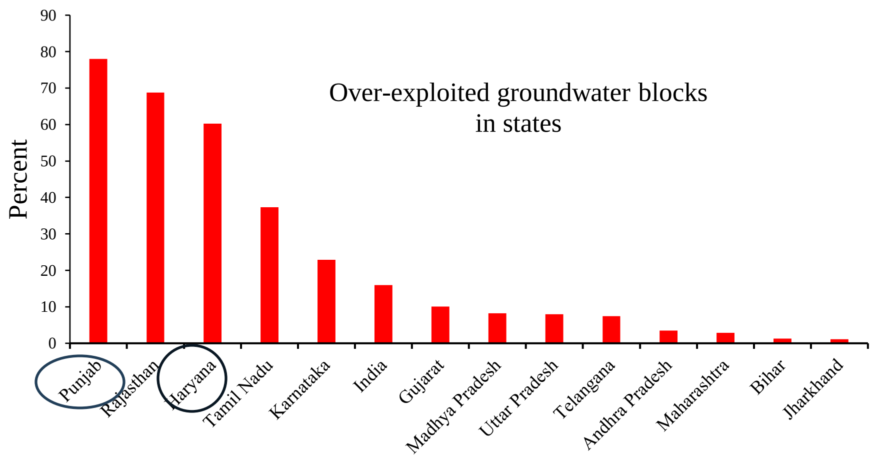
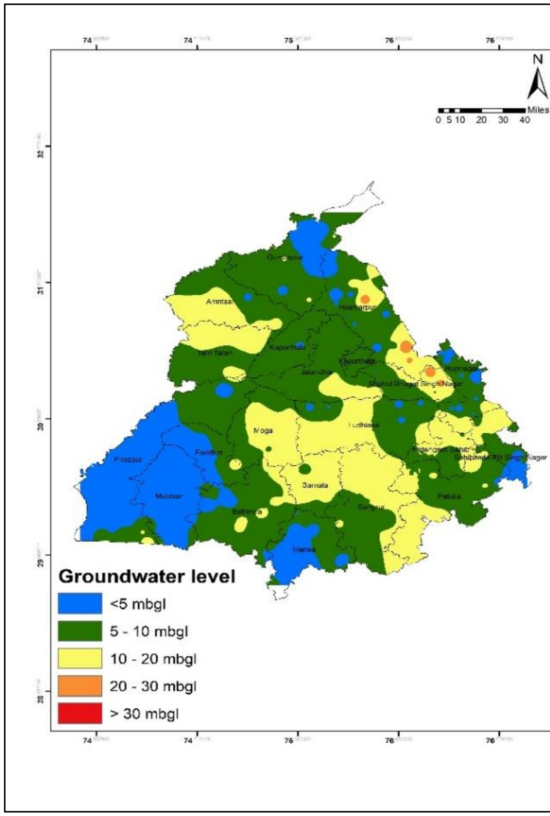
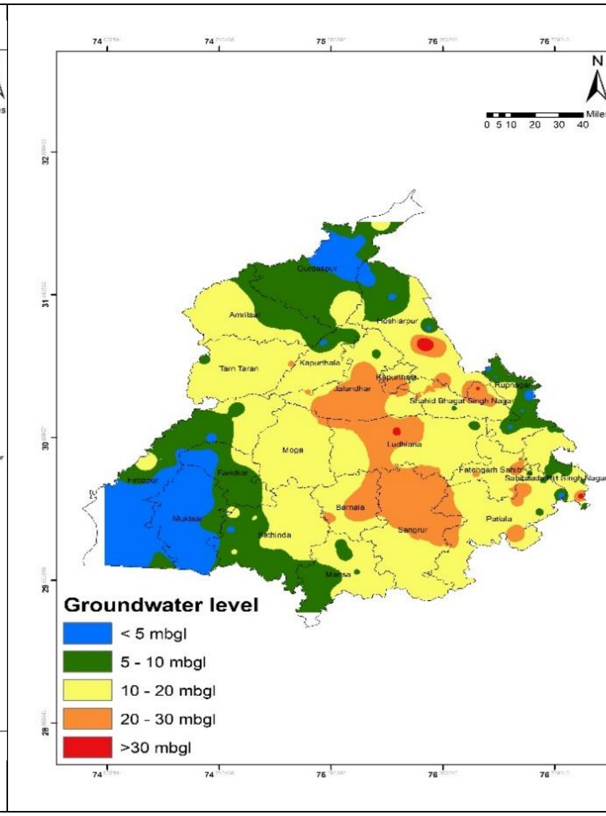


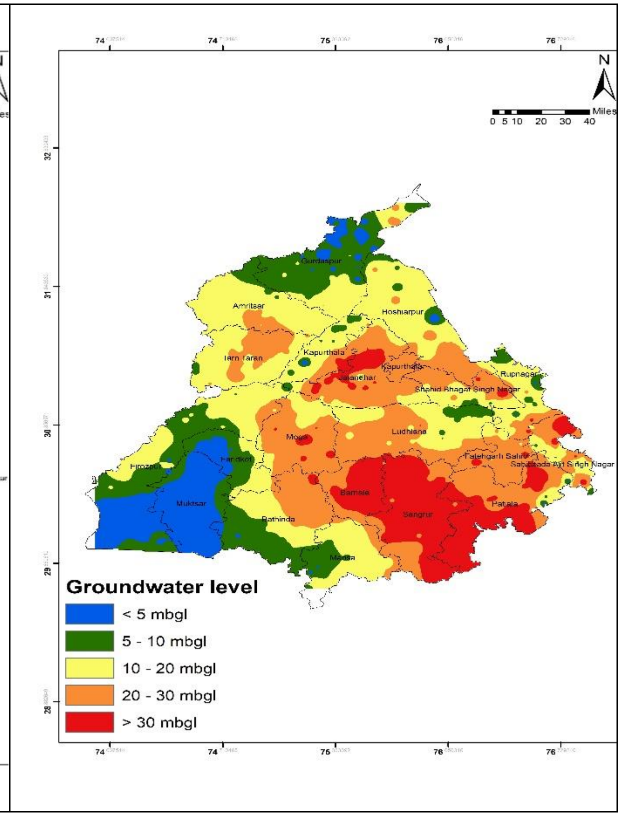
Figure 2d: Groundwater situation in Punjab and Haryana (substate level)

Punjab

2000	2009	2018

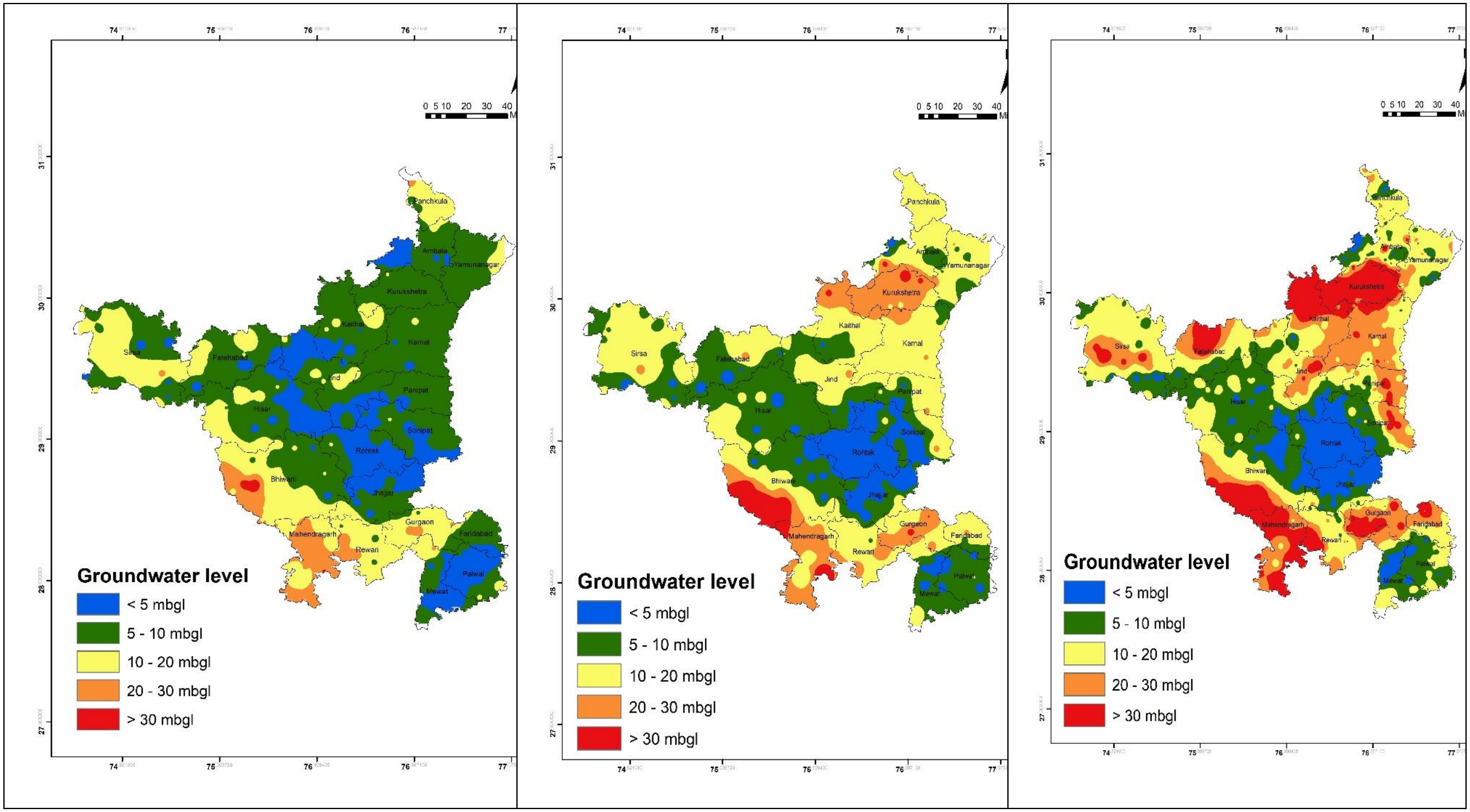






Haryana

2000	2009	2018



Groundwater extraction has gone up uniformly in all states in India but exceptionally in Punjab and Haryana. Between 2004 and 2017, groundwater extraction for irrigation went up from 30.34 billion cubic meters (bcm) to 34.56 bcm in Punjab i.e., an increase of 14 percent. Haryana is a smaller state, the extraction increased from 9.1 bcm to 11.53 bcm (increase of 27 percent). As a fraction of net sown area, the exceptionality of the two states is far more evident. In 2017, cubic meter groundwater extraction per hectare was 8381 in Punjab and 3278 in Haryana respectively. The third highest figure is from Tamil Nadu state at only 2816 and the lowest is for the state of Himachal Pradesh at 368 (CGWB reports, 2004, 2009, 2017).

Table 3 provides the important details on determinants of groundwater use across treated (Punjab and Haryana) and untreated states. In share of groundwater in irrigation, electricity used per unit of net sown area or well density, the two states stand out as among the highest in India and comparatively low in groundwater recharge from rainwater.

Table 3: Status of groundwater in selected states

State	Share of irrigation in groundwater draft (%)	Share of rainfall in groundwater recharge	Electricity used (kWh/ha of NSA)	Well density (no/000 ha of NSA)	Electric wells (%)	Blocks over-exploited (%)
Treated unit (with the enactment of Punjab Subsoil Water Preservation Act and similar act in Haryana)						
Punjab	96.59	28.63	2735.8	261	96.78	79
Haryana	92.24	45.22	2698.04	73.98	94.05	61
Donor pool states (without the enactment of Subsoil Water Preservation Acts-)						
Rajasthan	88.55	75.55	1310.6	76	70.68	63
Himachal Pradesh	51.28	0.88	116.1	19	93.15	50
Tamil Nadu	88.66	42.33	2853.8	439	93.83	40
Uttar Pradesh	89.20	56.24	1049.8	208	14.80	11
Karnataka	90.81	54.99	2136.8	129	99.47	26
Gujarat	94.55	71.30	1417.1	137	98.87	10
Uttarakhand	79.27	40.79	695.0	84	16.10	0
Madhya Pradesh	92.32	76.66	1334.0	142	94.05	7

Maharashtra	92.47	66.75	2058.6	081	97.69	3
Andhra Pradesh	87.93	60.97	3447.3	220	90.66	9
Kerala	45.69	79.55	171.5	46	98.34	1
Bihar	81.30	73.13	140.6	124	6.73	2
West Bengal	91.55	81.73	288.8	67	27.25	0
Chhattisgarh	84.68	74.16	1076.8	87	97.20	0
Odisha	80.37	71.86	139.5	51	23.34	0
Jharkhand	50.63	91.14	164.3	133	4.89	1
Assam	72.16	95.92	17.2	52	0.66	0

Source: CGWB, 2017; Minor irrigation census, 2017; CEA, 2018.

Paddy consumes nearly twice the amount of water as wheat. Consequently, both rely heavily on irrigation requirement that is met primarily with groundwater, facilitated by the proliferation of tube well irrigation in the rice–wheat system. Following the land consolidation program in the 1950s, farmers gradually began to rely on tube wells to augment groundwater supply that provided farmers with greater control over the quantity and duration of the water supply. Tube well irrigation became so widespread in these states that economist Repetto argued that 'the Green Revolution is more [a] tube well revolution than [a] wheat revolution'. There has been rise of the so called tube well capitalists of mono-cropping.

Many Indian states, including Punjab and Haryana implemented agricultural power subsidy policies to encourage groundwater irrigation. Until the 1970s, the state electricity utilities levied electricity charges on tube well owners based on metered consumption. However, as the number of tube wells increased rapidly in the next decade, the state electricity utilities removed electricity meters, stopped recording and introduced flat tariffs for agricultural electric supply. The idea was that the state electricity utilities would gradually increase the flat tariff according to the electricity generated and the transaction costs, but it turned out hard to implement.

The competitive populist policies to provide subsidies to gain popular support, and governments in different states even provided free and unmetered supply.[6] An unmetered power tariff (flat tariff) enabled farmers to use electricity intensively because the marginal cost of electricity use was almost zero (except for labor cost). As an important factor in groundwater extraction, we control (use as predictor) for electricity tariffs throughout in our analysis.

In 1997, in the pre-treatment period, the Punjab government started providing free electricity to its agriculture sector. This led to further expansion in tube wells in the state. Free electricity also created a market for tube well irrigation (tube well capitalists). The number of tube wells rose significantly, leading to an overall increase in the state's rice-wheat crop rotation. Meanwhile, despite huge investments, canal irrigation or surface water irrigation share progressively declined.

Haryana also provided subsidized electricity on tube wells, albeit at flat rates, i.e., based upon the power rating of the farmer's ground pump. Presently, farmers in Haryana are required to pay a paltry sum of INR 15 (18 cents for tube wells with motor capacity up to 15 brake horsepower (BHP)) and INR 12 (16 cents for tube wells with motor capacity above 15 BHP) per month on unmetered connections.

Overall, the electricity subsidies provided by Punjab and Haryana to agriculture, resulted in an increase in water-intensive cropping and better pumping technology that have contributed to the drastic fall in the water table in both states. Concerning Haryana, the Central Ground Water Board (2016–2017) reports that around percent of the observational wells in the state have indicated a significant water level decline during the past decade, and almost 8–13 percent of the wells indicate a decline of more than 4 meters. Groundwater extraction in Punjab is 66% higher over its sustainable limit, while its recharge rate is extremely low, i.e., 28%. Close to 80% of the administrative blocks in Punjab and over 60% in Haryana are categorized as overexploited (GoI, 2019c).

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[6] According to the Minor Irrigation Census 2013–14, the number of deep tube wells belonging to the SCs, STs and OBCs stood at astonishingly low figures of 563, 60 and 1012, respectively. The number was 13,356 for the rest of the farmers in Haryana. The figures relating to medium tube wells owned by SCs, STs and OBCs are equally stupefying. During 2013–14, the number of medium tube wells owned by STs was 14, while it was 32 for SCs and 188 for OBCs.60 The situation is similar in Punjab, where SCs, STs and OBCs owned 8308, 861 and 12,435 deep tube wells, respectively, while the rest of the farmers owned over 400,000 deep tube wells (Rosencraz et al 2021).

3. Factors for Groundwater Sustainability- groundwater draft

Principally, there are 4 ways in which erosion of groundwater resources in agriculture could be checked.

(i) *Crop choices*- The most direct way for groundwater sustainability in agriculture is through crop choices in favor of less water intensive crops. In the two states, the dominance of paddy has had the most significant effects on groundwater extraction. Additionally specific water intensive crops like sugar cane or summer maize can also lead to comparatively high groundwater depletion. Table 4 and figures 3a and 3b present the features of crop agriculture that influences water use for irrigation. In both states, the gross sown area in cereals has grown consistently while the cropping intensity has grown slowly (figure 3a).

The minimum support price (MSP) policy with procurement for select cereal crops, which began in 1966, induces farmers to move to water-intensive crops (table 4). This increased wheat production in Punjab by 9 percent between 1966 and 1974, while rice, which was not commonly grown before this, developed at a remarkable rate of 18 percent. Similarly, Haryana also witnessed an increase in rice and wheat production.

Overall, agri-food policy has emphasized the cultivation of staple food crops such as paddy and wheat by providing farmers with incentives like subsidies on fertilizers, electricity, and diesel for irrigation.

The dominance of paddy has resulted in a significant rise in water use in agriculture that is reflected in continuously depleting groundwater levels without adequate recharge (figure 3b). The policy has also assured public procurement of these commodities at government-administered minimum support prices (table 4). These agri-food policies and subsidies have encouraged farmers, especially those in irrigated regions, to shift their production portfolio from traditional water-efficient but less remunerative crops such as coarse cereals, pulses, and oilseeds towards water-intensive but more remunerative and less risky crops like paddy (Shah, 2012; Vatta, Sidhu, & Kaur, 2013).

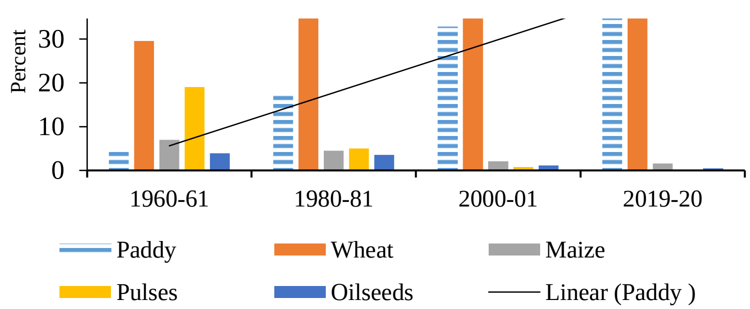
Given its water-intensive nature, rice crop cultivation was naturally considered the primary factor behind the increasing groundwater use in both Punjab and Haryana. However, this view obscures the reality that it is not rice crop per se but its transplanting date that decides the rise or decline in the water table. This factor motivated the two subsoil preservation acts in the two states, the impacts of which we study in this paper. The proportion of transplanted rice areas up to mid- June becomes too high in Punjab. During 1996-2005, it had reached, on average, about 25 percent up to May-end and about 60 percent by mid-June. The maximum area transplanted up to May- end touched 36 percent in 1997-98. The maximum area up to mid- June also touched a peak of 66 percent in 1998-99 and almost remained at this level up to 2004-05. About, 48 percent of rice area was transplanted before 15 June even in 2007-08 (Singh 2009). Early transplantation of rice has a higher evapotranspiration rate (ETR) and consequently, there would be more fall in water table.

Table 4: Cropping characteristics in the two states (Punjab/Haryana)

	1960-61/1966-67	1980-81	2000-01	2019-20
Gross sown area ('000ha)	4732/4599	6763/5462	7941/6115	7838/6617
Gross irrigated area ('000ha)	2646/1736	5781/3309	7664/5223	7724/6279
Cropping intensity (%)	126/134	161/152	187/173	190/185
Irrigation intensity (%)	131/134	171/155	191/177	187/185
Groundwater irrigation (%)	41/22	57/45	73/50	71/64
Canal irrigation (%)	58/77	42/54	26/50	29/36

Source: xxx

Figure 3a: crop acreage in Punjab and Haryana over time



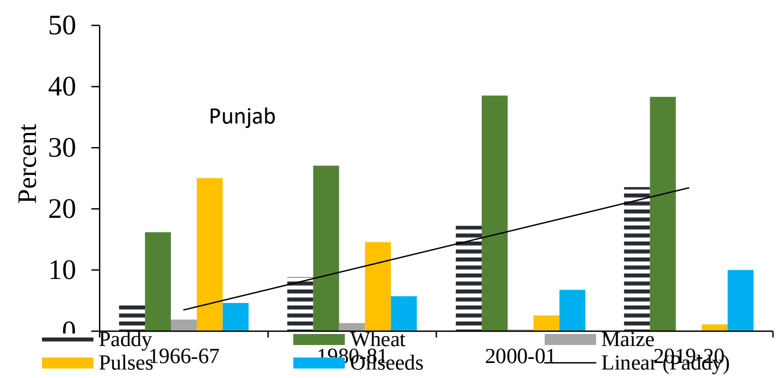
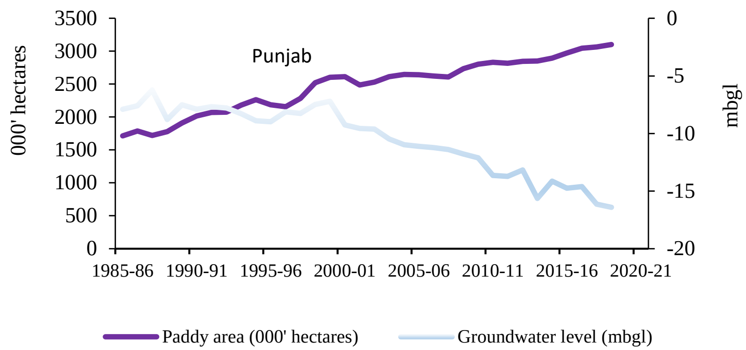
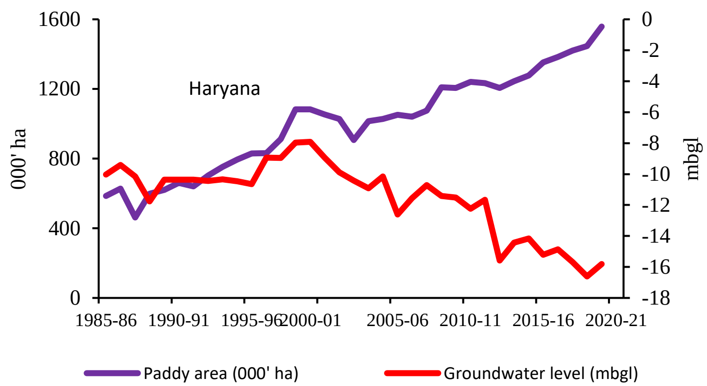


Figure 3b: Paddy area and groundwater level in Punjab and Haryana





Sources of irrigation- The irrigation intensity has grown in both states led by groundwater and decline of surface irrigation. While groundwater share was 41 and 22 percent respectively for Punjab and Haryana in the 1960s, it increased to 71 and 64 percent respectively by 2019-20.

Table 5- Crop procurement for the central pool (Punjab and Haryana)

Year	*Paddy (Lakh metric tons)*	*Wheat (Lakh metric tons)*

	Production	Procurement for central pool	Procurement (%)	Production	Procurement for central pool	Procurement (%)
1980-81	*32.33*	*25.20(45)*	*77.95*	*76.77*	*42.80(73)*	*55.75*
1990-91	*65.06*	*48.20(41)/*	*74.09*	*121.59*	*67.50(61)/*	*55.51*
		69.40(33) 13.64			*94.20(58) 45.07*	
2000-01	*91.57/40.42*	*(6.41)/*	*75.79/33.75*	*155.51/96.5*	*(27.56)/*	*60.57/46.70*
		86.30(25) 24.82			*102.10(45) 63.47*	
2010-11	*108.33/51.98*	*(7.26)/*	*79.66/47.75*	*164.72/104.88*	*(28.19)/*	*61.98/60.52*
		93.50(27) 42.7			*103.44(37) 67.7*	
2015-16	*118.06/61.79*	*(12.48)/*	*79.20/69.11*	*160.77/103.54*	*(24.10)/*	*64.34/65.39*
		108.76(21) 64.71			*129.12(38) 93.6*	
2019-20	*126.75/68.66*	*(12.49)*	*85.81/94.25*	*176.16/128*	*(27.42)*	*73.30/73.13*

(iii) *Systems for groundwater extraction -*

Our basic outcome variable is the groundwater level but most importantly the groundwater draft i.e., the level of extraction. Groundwater draft is a function of demand (crop choices and ground water needs) and supply side factors like existing levels of groundwater, pump capacity and efficiency (power and type of pumps), irrigation hours and preexisting levels of groundwater.

$$Groundwater\ draft = f(crop\ needs\ (electricity\ tariffs, subsidies\ , output\ support\ prices), pump\ credentials\ (power\ and\ nature\ of\ pumps), supporting\ factors\ (groundwater\ recharge, alternative\ irrigation)\ \ (1)$$

Energy use for irrigation

Table 6 presents the energy use in agriculture in the two states with the proliferation of the pumps accompanied with increased capacity for extraction (power and nature of pumps). More comprehensive-and effective policies could be inclusion of other crops that reduce relative risk of non-cereal crops or adding value of ecosystem services rendered by the crops in MSP could be important factors. Rationalizing electricity use for agriculture (moving away from free or heavily subsidized electricity policy to one of volumetric pricing be important for checking excessive groundwater extraction. However, such policies have been either politically or fiscally infeasible. Orienting the sowing date of paddy crops (water guzzler) with monsoon arrival to reduce groundwater extraction is in principle not the best policy option as we will see the pitfalls of this indirect instrument in trying to achieve preservation of groundwater.

Table 6: Electricity use in the treatment states

Year	Electricity (Million KWh)		Agricultural share (%)	Electricity use (Kwh/ha)
	Total sale	Agricultural use		
1970-71	1219.50	463.40	38.00	114.34
1980-81	4236.34	1849.75	43.66	441.36
1990-91	11906.90	5104.00	42.87	1210.34
2000-01	19184.50	5534.30	28.85	1302.19
2010-11	32231.72	10116.89	31.38	2433.11
2015-16	40767.91	11513.88	28.24	2783.15
2019-20	53097.50	11537.64	21.73	2795.65

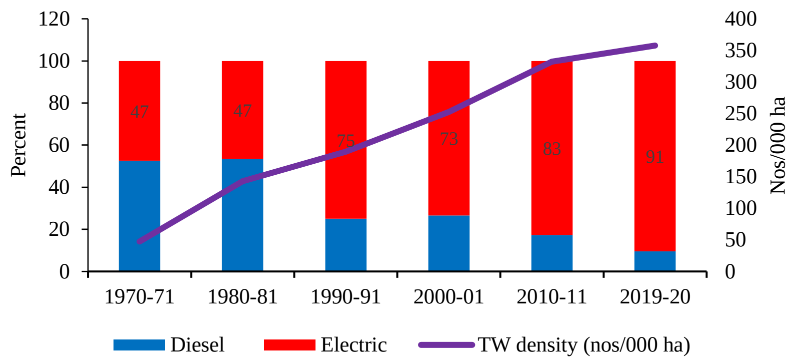
Energy use (Haryana)

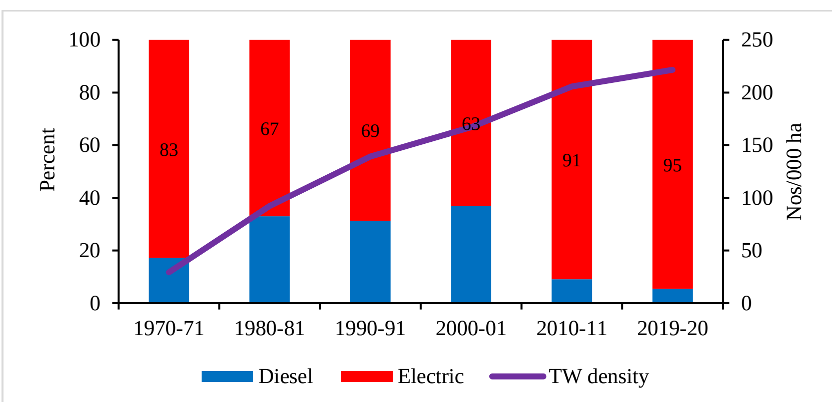
Year	Electricity (Million KWh)		Agricultural share (%)	Electricity use (Kwh/ha))
	Total sale	Agricultural use		
1970-71	903.87	298.57	33.03	83.75
1980-81	2555.72	953.77	37.32	264.79
1990-91	6051.38	2711.78	44.81	758.54
2000-01	10143.62	4755.94	46.89	1348.82
2010-11	24012.47	8097.34	33.72	2301.69
2015-16	32172.20	9294.57	28.89	2641.25

2019-20	43094.56	10307.29	23.92	2887.20

In terms of responses, figures 4 show the progression of the energy sources for pumping in Punjab and Haryana. There has been a secular increase in electrification of pumps. Post the enactment of the subsoil preservation acts in the two states, the share of electric pumps increased by 8 and 4 percentage points in Punjab and Haryana respectively. The power and nature of the pumps also changed (centrifugal pumps to submersible).

Figure 4a/4b: Energy sources and density of tube wells-Punjab/Haryana





As groundwater level depletes, more powerful and efficient pumps (submersibles) are being deployed particularly by comparatively resource rich farmers. Table 5 presents the share of submersible tube wells in Punjab and Haryana (treatment states) and control states. Submersibles are employed after groundwater falls below a certain level and are comparatively efficient in drawing groundwater i.e., with the same amount of power and irrigation hours, these pumps have greater draft of groundwater. Note that the regulation has no provision for the power and nature of the pumps used for extraction nor it has provision for monitoring of the draft of groundwater itself (nor it is legally or logistically possible). If the policy of delayed transplanting engenders responses like using more powerful pumps, using submersibles or expanding irrigation hours, that are aligned with incentives to expend more of the private good groundwater, these all can be legitimately done.

Table 5: Submersible and tube wells with groundwater level >10 meters below ground level

	2006-07 (4th Minor irrigation census)		**2013-14 (5th Minor irrigation census)**		**2017-19 (6th Minor irrigation census)**	
	share of submersible Pump (%)	share of wells >10 meters (%)	share of submersible Pump (%)	share of wells >10 meters (%)	share of submersible Pump (%)	share of wells >10 meters (%)
Andhra Pradesh	62.56	25.99	74.59	26.69	80.06	40.95
Assam	0.62	1.90	0.89	1.98	16.46	2.68
Bihar	5.82	1.83	7.16	4.97	17.67	8.72
Chhattisgarh	24.93	20.46	87.10	22.51	93.13	19.58
Gujarat	59.20	45.04	94.77	53.30	95.76	53.23
Haryana	67.47	44.83	87.47	54.05	83.62	57.36
Himachal Pradesh	51.09	32.93	67.18	29.67	70.16	23.53
Jammu	52.55	17.86	11.44	16.67	67.22	15.66
Jharkhand	1.50	21.92	4.51	19.66	3.01	14.9
Karnataka	74.60	31.79	89.58	43.12	94.29	29.71
Kerala	6.55	18.38	17.37	35.43	24.93	22.58
Madhya Pradesh	62.75	48.28	63.52	45.47	73.42	48.54
Maharashtra	23.34	26.57	57.39	31.26	53.1	33.71
Odisha	2.74	5.86	10.33	12.34	29.42	3.31

Punjab	52.73	44.33	83.83	66.21	90.85	71.76
Rajasthan	33.51	72.81	57.09	65.38	63.83	68.49
Tamil Nadu	21.97	14.62	48.91	31.04	54.55	19.11
Uttarakhand	14.35	38.3	14.05	20.80	42.41	43.9
Uttar Pradesh	4.06	23.91	9.63	43.64	15.26	28.92
West Bengal	15.63	17.29	25.65	29.35	36.53	21.16

(iv) *Technology driven solutions.*

This regulation may also induce the adoption of water-saving technologies and practices, such as laser land levelling and sensor-based application of irrigation (Aryal, Bhatia-Mehrotra, Jat, & Sidhu, 2015; Chahal, Kataria, Abbott, & Gill, 2014; Sidhu & Vatta, 2012). However, state-sponsored tariff-free electric power for agriculture for the past two decades, and the lack of political will to introduce volumetric pricing of irrigation water, are some of the major obstacles to the efforts to reverse groundwater depletion in the state (Shah, 2009, 2012). Given the political economy of irrigation management in the states, policy makers have been looking at technological and institutional solutions for minimizing groundwater resources without compromising farm profitability.

One such option is the application of soil-moisture-sensor-based scheduling of irrigation using devices like tensiometers. A tensiometer measures the amount of energy required by the plant to pull soil water (water potential) at the current moisture level and guides farmers on when to irrigate. Several studies based on experimental data report tensiometers as a technically feasible option for groundwater management without yield penalty (Bhatt, Arora, & Chew, 2016; Bhatt & Sharma, 2010; World Bank, 2010). According to Bhatt et al. (2016), tensiometer-based irrigation application in paddy cultivation in Punjab could save 14–15% of water consumption and save 170–250 kWh of electric power per hectare per season.

Results and Discussion

Tables 6a-8b present and figures 5a-7b illustrate the estimates of groundwater levels in Punjab, Haryana, and combined sample (for obtaining standard errors with bootstrapping or jackknifing which requires more than one treatment unit. The estimates are done both without and with time varying exogenous covariates. The results present the Average Treatment Effect on the treated (ATT) using difference in difference, synthetic control and synthetic difference in difference methods where the first two are special cases of synthetic DID. The estimates for the causal impacts of subsoil preservation acts are obtained for pre monsoon levels, post monsoon levels and average groundwater levels. Qualitatively the results are similar across the three cases. The results presented correspond to pre-monsoon groundwater level in Punjab, Haryana and combined respectively. The results on post monsoon levels and average groundwater levels all measured in units of meters below ground level (mbgl) are available upon request. Without covariates, the post treatment outcome from PPSWA 2009 shows a decline in groundwater level of 4mbgl. Conditioning on covariates the estimates rise to 4.63 mbgl. The standard errors for the estimates are obtained using placebo method.

The estimates for Haryana are without covariates larger (in absolute terms) at -4.35mbgl and conditional on covariates of -4.8mbgl. In both individual estimates placebo methods are used to get the standard errors for the estimates. With the synthetic DID routine, standard errors can be obtained through bootstrap method provided there is more than a single treatment unit. Given the similarity of the treatment as well as timing in the two states we are able to combine where we have averaged the variables and run synthetic DID estimation over the combined sample. This analysis also lets us assess the average effect of a generic subsoil preservation act. The average treatment effect across two states show reduction in groundwater by 4.1 and 4.6 mbgl respectively with the act in place relative to control states over time. This comparison does not lend itself to judge that subsoil preservation acts raised the groundwater level but the meters below ground level reduced in groundwater that will be considered a positive. The states with zero weight are denoted by an ‘x’ symbol (Gujarat and Tamil Nadu). Here, we can find that the weights assigned through SDID to the states under donor pool are less sparse i.e. it does not give much weigh to any particular state, due to more balanced weighting compared to the weight assigned by the SCM giving higher weight to particular state (Uttar Pradesh).

Table 6a: Estimates Groundwater level (without covariates & replication-500)

Difference in Difference	Synthetic control	Synthetic Difference in Difference

Difference-in-Differences Estimator

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf. Interval]	
treat_unit	-3.90203	0.95981	-4.07	0.000	-5.78322	-2.02084

95% CIs and p-values are based on Large-Sample approximations.

Synthetic Control

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf. Interval]	
treat_unit	-3.54776	1.97765	-1.79	0.073	-7.42389	0.32838

95% CIs and p-values are based on Large-Sample approximations.

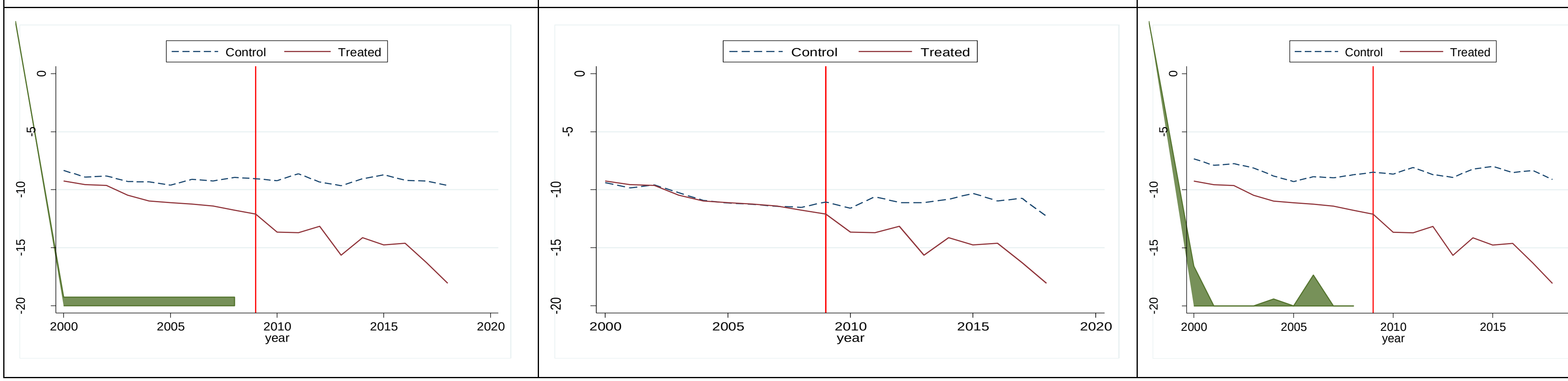
Synthetic Difference-in-Differences Estimator

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf. Interva	
treat_unit	-4.00040	1.16546	-3.43	0.001	-6.28465	-1.71

95% CIs and p-values are based on Large-Sample approximations.
Refer to Arkhangelsky et al., (2020) for theoretical derivations.

Figure 5a: DID, SCM and SDID treatment effects groundwater levels (Punjab)

Difference in Difference	Synthetic control	Synthetic Difference in Difference



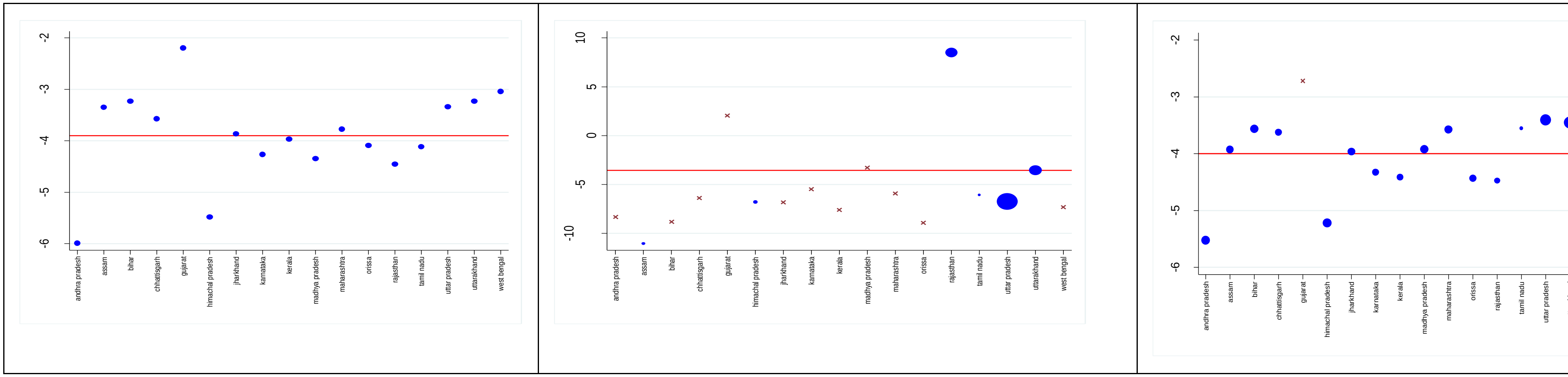
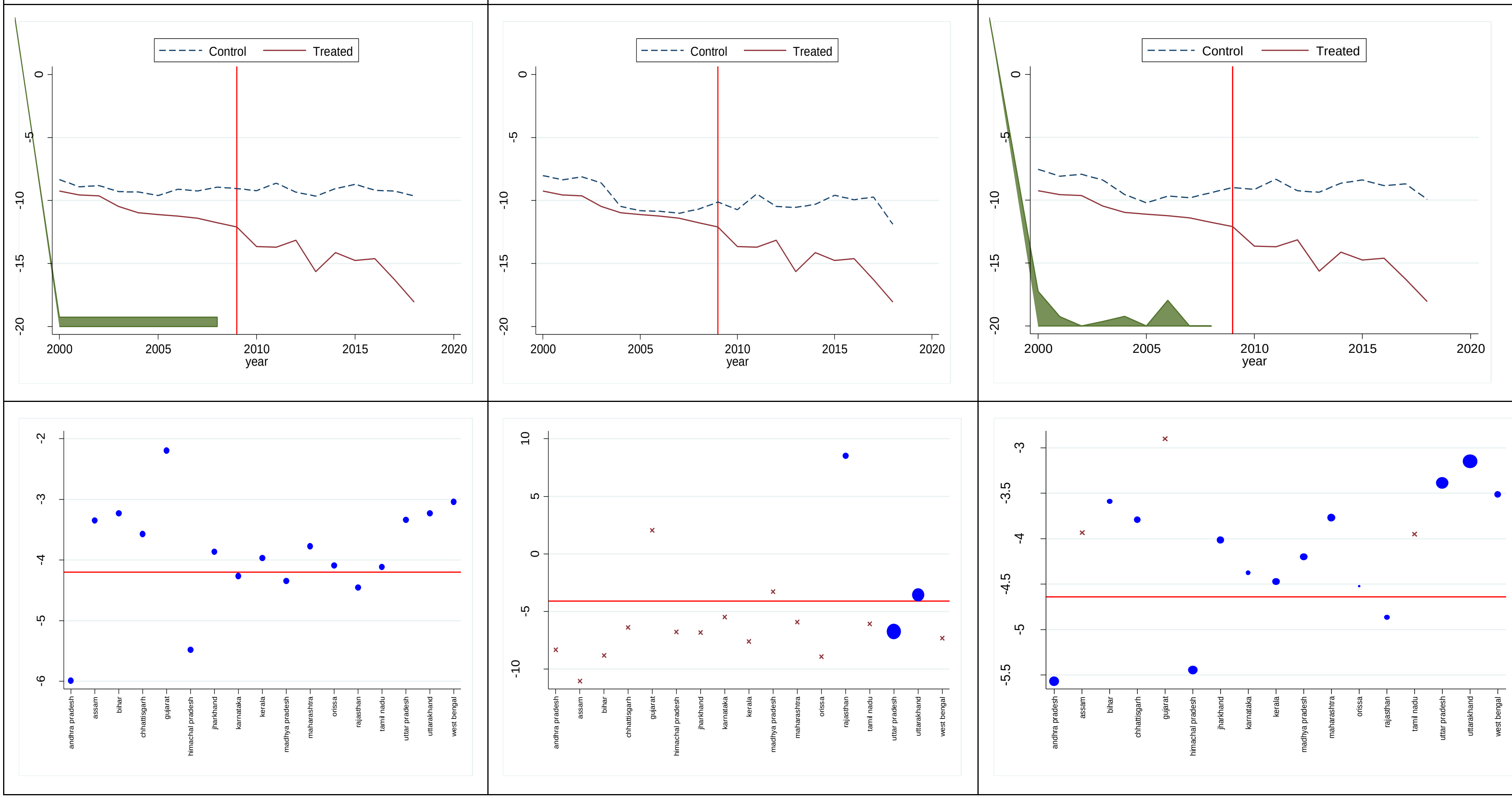


Table 6b: Groundwater level (with covariates & replication-500)- Punjab

Difference in Difference	Synthetic control	Synthetic Difference in Difference
Difference-in-Differences Estimator pre_monsoonl | ATT | Std. Err. | t | P>|t| | [95% Conf. Interval] treat_unit | -4.20301 | 0.95110 | -4.42 | 0.000 | -6.06713 | -2.33888 95% CIs and p-values are based on Large-Sample approximations.	Synthetic Control pre_monsoonl | ATT | Std. Err. | t | P>|t| | [95% Conf. Interval] treat_unit | -4.07962 | 2.31934 | -1.76 | 0.079 | -8.62544 | 0.46621 95% CIs and p-values are based on Large-Sample approximations.	Synthetic Difference-in-Differences Estimator pre_monsoonl | ATT | Std. Err. | t | P>|t| | [95% Conf. I treat_unit | -4.63884 | 1.07818 | -4.30 | 0.000 | -6.75202 95% CIs and p-values are based on Large-Sample approximations. Refer to Arkhangelsky et al., (2020) for theoretical derivations.

Figure 5b: DID, SCM and SDID treatment effects with covariates - groundwater levels (Punjab)

Difference in Difference	Synthetic control	Synthetic Difference in Difference



Haryana

Table 7a: Groundwater level (without covariates & replication-500)- Haryana

Difference in Difference	Synthetic control	Synthetic Difference in Difference

Difference in Difference

Difference-in-Differences Estimator

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf.	Interval]
treat_unit	-3.27927	0.95981	-3.42	0.001	-5.16046	-1.39809

95% CIs and p-values are based on Large-Sample approximations.

Synthetic control

Synthetic Control

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf.	Interval]
treat_unit	-4.27097	1.97483	-2.16	0.031	-8.14157	-0.40037

95% CIs and p-values are based on Large-Sample approximations.

Synthetic Difference in Difference

Synthetic Difference-in-Differences Estimator

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf.	Interv
treat_unit	-4.35133	1.16542	-3.73	0.000	-6.63551	-2.06

95% CIs and p-values are based on Large-Sample approximations.
Refer to Arkhangelsky et al., (2020) for theoretical derivations.

Figure 6a: DID, SCM and SDID treatment effects groundwater levels (Haryana)

Difference in Difference	Synthetic control	Synthetic Difference in Difference

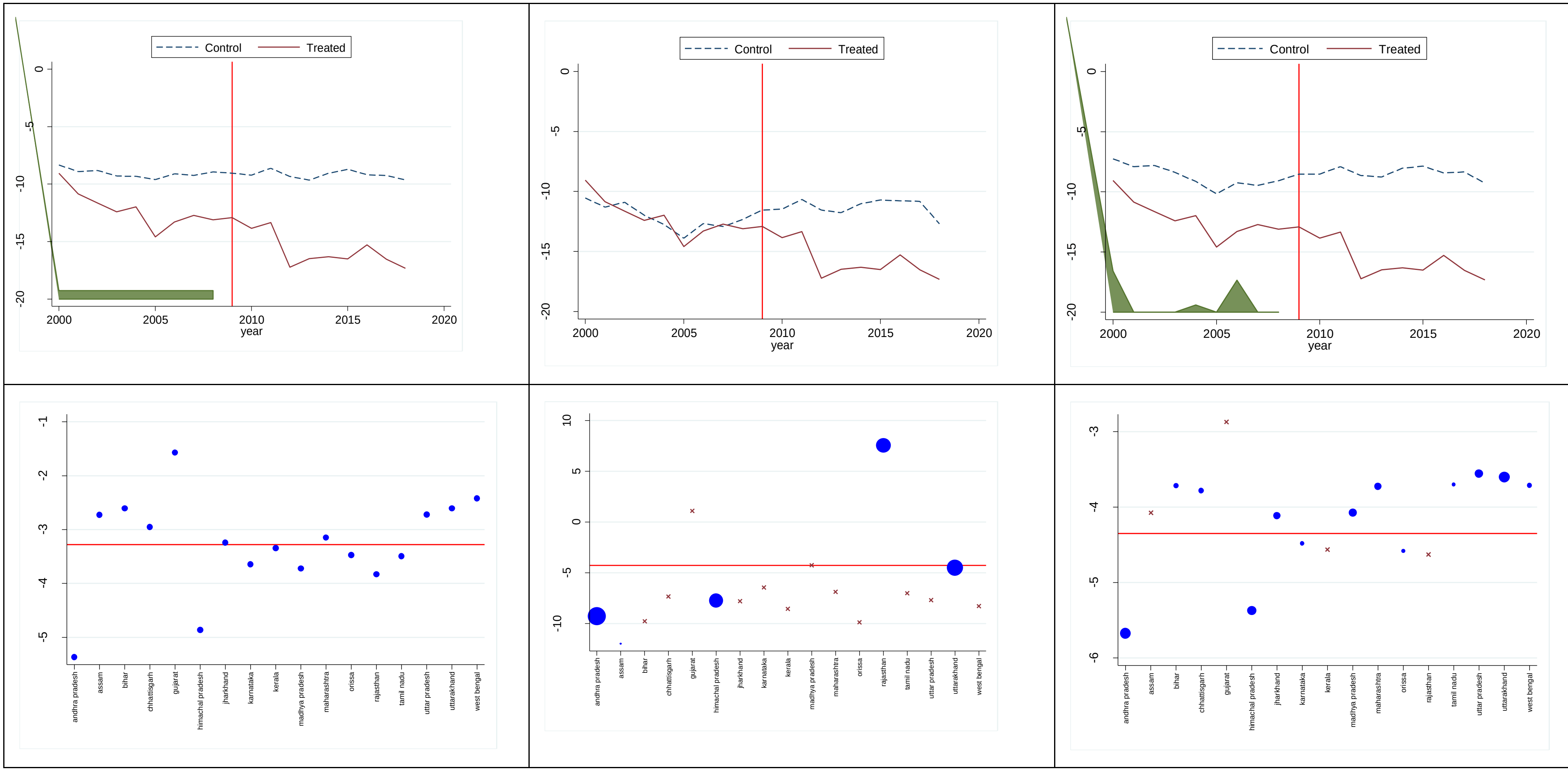


Table 7b: Groundwater level (with covariates & replication-500)

Difference in Difference	Synthetic control	Synthetic Difference in Difference

Difference-in-Differences Estimator

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf.	Interval]
treat_unit	-3.32911	0.95110	-3.50	0.000	-5.19323	-1.46498

95% CIs and p-values are based on Large-Sample approximations.

Synthetic Control

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf.	Interval]
treat_unit	-4.33173	2.31868	-1.87	0.062	-8.87626	0.21280

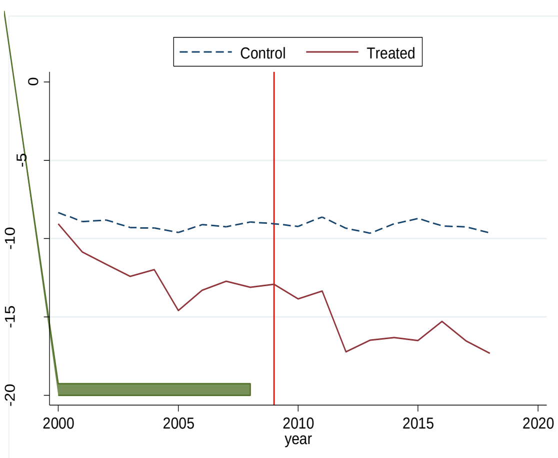
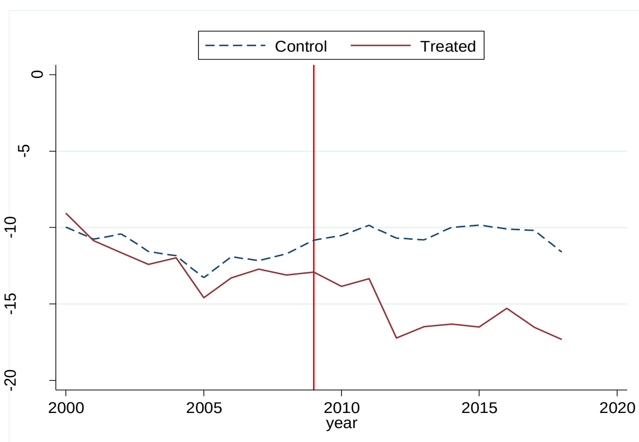
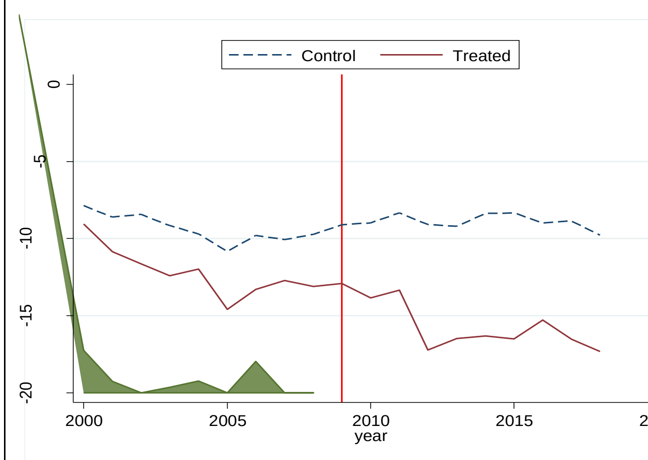
95% CIs and p-values are based on Large-Sample approximations.

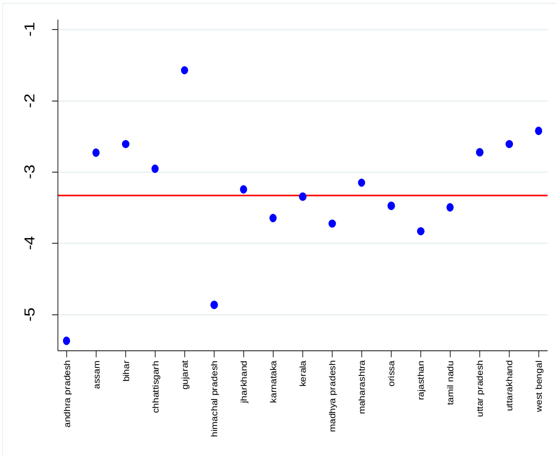
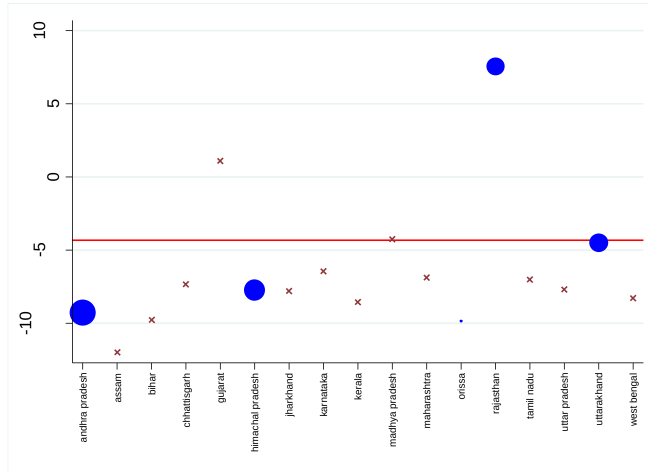
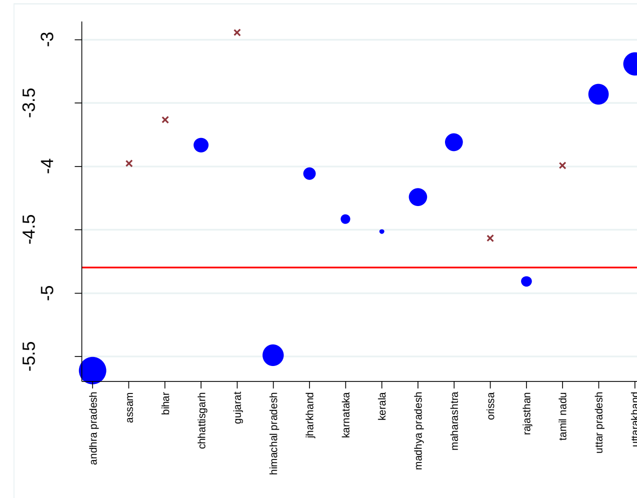
Synthetic Difference-in-Differences Estimator

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf.	Inter
treat_unit	-4.79756	1.07819	-4.45	0.000	-6.91076	-2.6

95% CIs and p-values are based on Large-Sample approximations.
Refer to Arkhangelsky et al., (2020) for theoretical derivations.

Figure 6b: DID, SCM and SDID treatment effects with covariates - groundwater levels (Haryana)

Difference in Difference	Synthetic control	Synthetic Difference in Difference
		

Punjab & Haryana combined (Bootstrap)

Table 8a: Groundwater level (without covariates & replication-500)- Bootstrap standard errors

Difference in Difference	Synthetic control	Synthetic Difference in Difference

Difference-in-Differences Estimator

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf. Interval]	
treat_unit	-3.59065	0.30806	-11.66	0.000	-4.19445	-2.98686

95% CIs and p-values are based on Large-Sample approximations.

Synthetic Control

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf. Interval]	
treat_unit	-4.45437	0.65537	-6.80	0.000	-5.73887	-3.16987

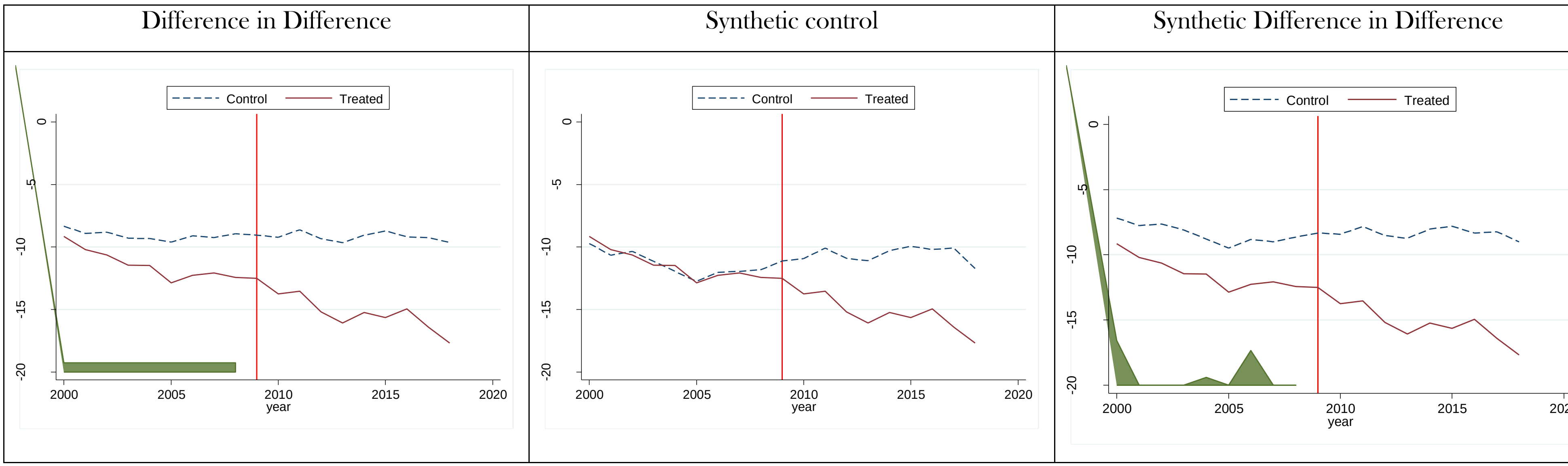
95% CIs and p-values are based on Large-Sample approximations.

Synthetic Difference-in-Differences Estimator

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf
treat_unit	-4.14828	0.66877	-6.20	0.000	-5.45904

95% CIs and p-values are based on Large-Sample approximations.
Refer to Arkhangelsky et al., (2020) for theoretical derivations.

Figure 7a: DID, SDID and SCM estimates on combined Punjab and Haryana (without covariates)- Bootstrap standard errors



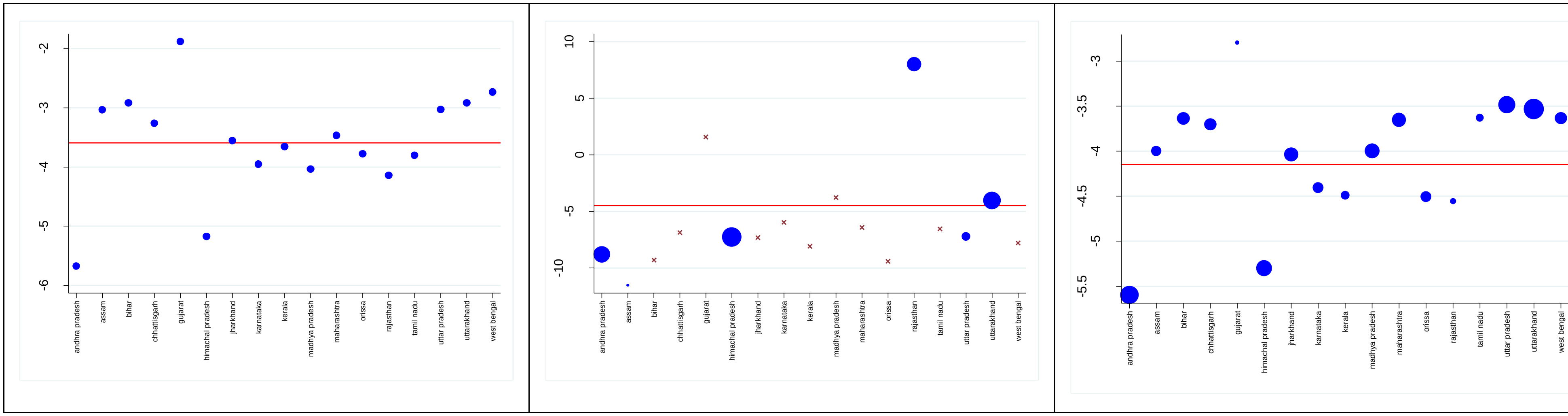


Table 8b: Groundwater level (with covariates & replication-500)- bootstrap standard errors

Difference in Difference

Difference-in-Differences Estimator

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf. Interval]	
treat_unit	-3.76606	0.67911	-5.55	0.000	-5.09709	-2.43503

95% CIs and p-values are based on Large-Sample approximations.

Synthetic control

Synthetic Control

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf. Interval]	
treat_unit	-4.48345	0.79054	-5.67	0.000	-6.03287	-2.93403

95% CIs and p-values are based on Large-Sample approximations.

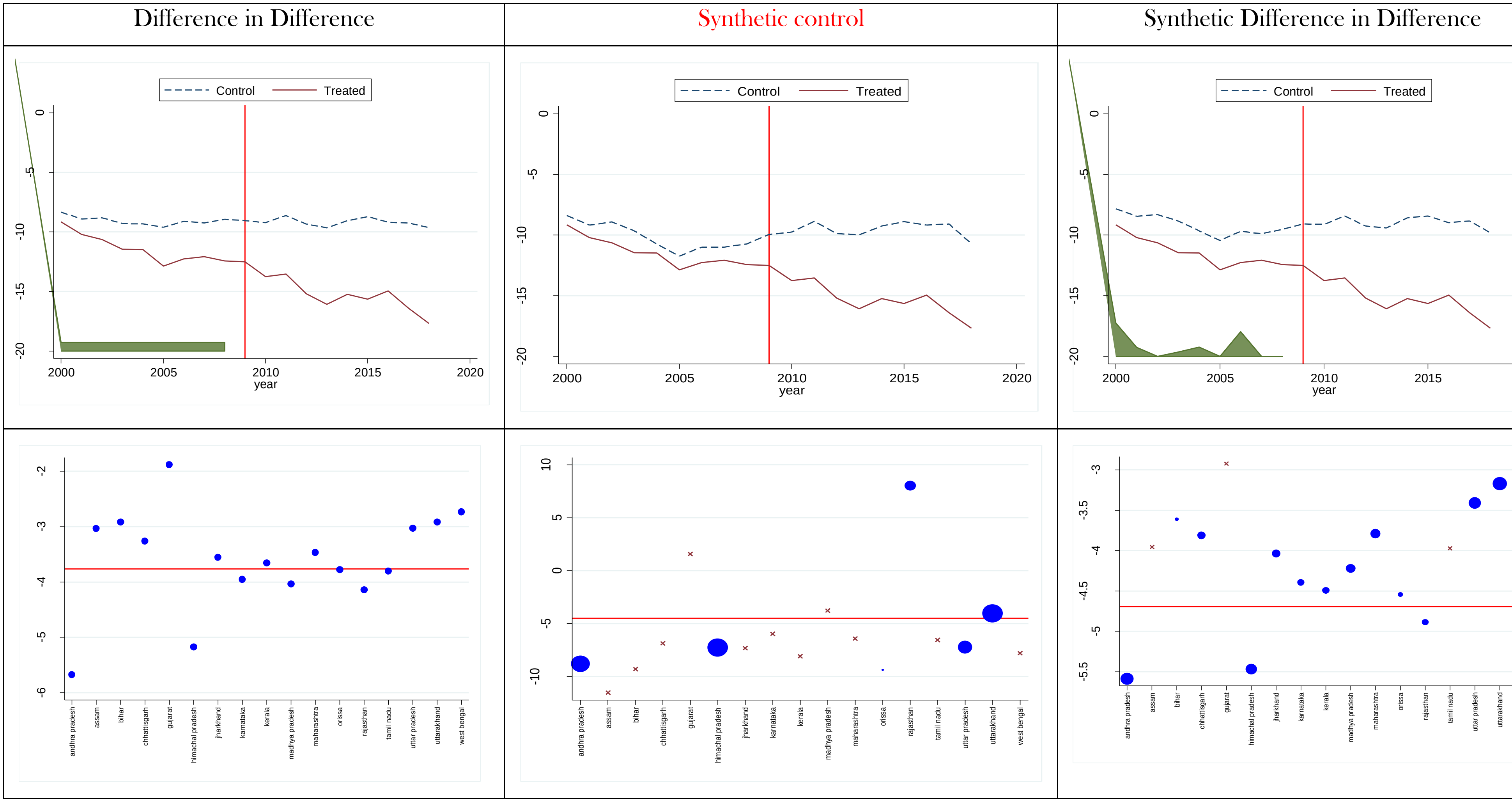
Synthetic Difference in Difference

Synthetic Difference-in-Differences Estimator

pre_monsoonl	ATT	Std. Err.	t	P>|t|	[95% Conf. Interval	
treat_unit	-4.69431	1.04439	-4.49	0.000	-6.74128	-2.6473

95% CIs and p-values are based on Large-Sample approximations.
Refer to Arkhangelsky et al., (2020) for theoretical derivations.

Figure 7b: DID, SDID and SCM estimates on combined Punjab and Haryana (with covariates)- Bootstrap standard errors



Responses to the subsoil preservation acts in the two states

What could be behind the impacts of the act to preserve groundwater in two states. The estimates show that there was an improvement in groundwater level in the two states. As discussed above, the pathway for the impact of this policy would be in terms of what the policy affects in terms of crop choices (crop and acreage (legit compliance and non-compliance)), extraction methods and intensity (power, type of pumps and irrigation hours), factors that determine groundwater draft. The depletion of groundwater has followed a secular trend in the post intervention period. The true measure of the impact of the acts on groundwater preservation would be in terms of impact on determinants of draft and subsequently draft itself. Below we use the combined data for Haryana and Punjab and estimate the groundwater draft per unit of gross sown area and net sown area. In both cases, the results show that groundwater draft has gone up significantly relative to the counterfactual of no act in the two states.

Figure 8a: Groundwater draft per hectare of gross sown area

```
. sdid gw_draft_gsa state year treat_unit, vce(placebo) graph g1_opt(xtitle("")) g2_opt(ylabel(0(1000)5000)) seed (1234) covariat
> es(pre_monsoon1 ln_rain ln_elec_kwhhanca cropingintensity ln_rice share_gwater ln_twdensity_ncano000ha ln_paddy_irrg_hrs1 ln_bh
> p ln_paddy_yield tariffratersbhpmonth ln_paddy_prcmnt, projected)
Placebo replications (50). This may take some time.
----+--- 1 ---+--- 2 ---+--- 3 ---+--- 4 ---+--- 5
..................................................     50


Synthetic Difference-in-Differences Estimator
```

gw_draft_gsa	ATT	Std. Err.	t	P>|t|	[95% Conf. Interval]	
treatment	782.63070	192.34410	4.07	0.000	405.64319	1.16e+03

```
95% CIs and p-values are based on Large-Sample approximations.
Refer to Arkhangelsky et al., (2020) for theoretical derivations.
```

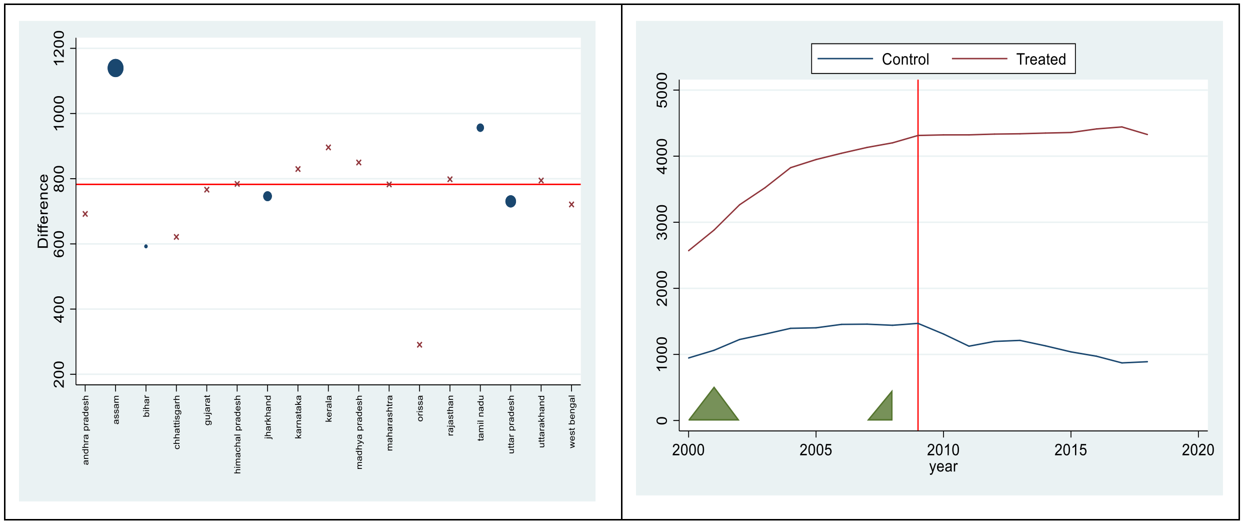


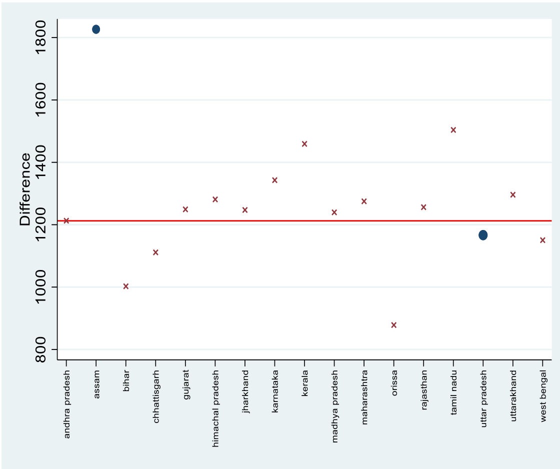
Figure 8b- Groundwater draft per hectare of net sown area

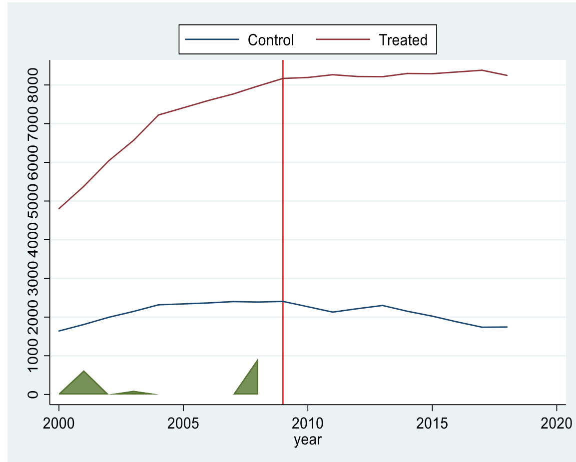
```
. sdid gw_draft_nsa state year treat_unit, vce(placebo) graph g1_opt(xtitle("")) g2_opt(ylabel(0(1000)8000)) seed (1234) covariat
> es(pre_monsoon1 ln_rain ln_elec_kwhhanca cropingintensity ln_rice share_gwater ln_twdensity_ncano000ha ln_paddy_irrg_hrs1 ln_bh
> p ln_paddy_yield tariffratersbhpmonth ln_paddy_prcmnt, projected)
Placebo replications (50). This may take some time.
----+--- 1 ---+--- 2 ---+--- 3 ---+--- 4 ---+--- 5
..................................................     50
```

Synthetic Difference-in-Differences Estimator

gw_draft_nsa	ATT	Std. Err.	t	P>|t|	[95% Conf. Interval]	
treatment	1.21e+03	266.26470	4.55	0.000	690.62578	1.73e+03

95% CIs and p-values are based on Large-Sample approximations.
Refer to Arkhangelsky et al., (2020) for theoretical derivations.





Effect of the PPSWA, 2009

	Year of study	method	Estimated effect
Sheetal Sekhri	2003-2011	DID	Groundwater declined by 1.17 meter (August water level) and by 1.60 meter (annual water level).
Sharma et al.	1999-2018	DID	Groundwater declined by 1.53 meter (pre-monsoon water level) and by 1.39 meter (post-monsoon water levl).
Tripathi et al.	1985-2011	Panel regression	Coefficient of policy dummy is significant in groundwater level of pre-monsoon (-2.795***), post-monsoon (-2.310***) and annual (-2.115***) suggesting policy led to improvement in groundwater level.

Punjab

Synthetic Difference-in-Differences Estimator

ln_rice	ATT	Std. Err.	t	P>|t|	[95% Conf.	Interval]
treatment	0.14581	0.08384	1.74	0.082	-0.01851	0.31013

```
Synthetic Difference-in-Differences Estimator
```

ln_rice	ATT	Std. Err.	t	P>|t|	[95% Conf.	Interval]
treatment	0.12987	0.07773	1.67	0.095	-0.02248	0.28222

```
95% CIs and p-values are based on Large-Sample approximations.
Refer to Arkhangelsky et al., (2020) for theoretical derivations.
```

Why groundwater depletion continued in post PPSWA, 2009

The above results indicated that PPSWA failed to check the declining trend in groundwater level in Punjab though it checked the depth of groundwater bya bit. It is essential to know the underlying reasons. The increase or decrease in groundwater level is a net outcome of total demand and supply of groundwater. Thus, the failure of PPSWA to check groundwater depletion to its potential imply that it could not reduce the relative demand of the groundwater over its replenishment. The evidence from Cost of Cultivation Surveys reveal that per hectare groundwater irrigation hours from groundwater reduced from 309 in 2009-10 to 217 in 2018-19. However, as response power and nature of pumps employed also changed.

This could be due to reduction in groundwater dependence on account of postponement of date of transplanting till arrival of monsoon. Despite reduction in per hectare pumping hours, total groundwater demand for irrigation increased from 30.34 BCM in year 2004 to 34.56 BCM in year 2017 and groundwater depletion remained unchecked.

There could be several factors behind such outcome. First, assured prices and procurement by the government provide a strong incentive to the farmers to grow paddy. Total acreage under paddy increased after the enactment of PPSWA- from 2795 thousand hectares in 2009-10 to 3102 thousand hectares in 2018-19. Area expansion under paddy raised the total requirement of groundwater for irrigation. Second, newly installed wells in the state are primarily high horse-power submersible pumps with high discharge capacity. Total extraction of groundwater, therefore, increased in post PPSWA period. Third, free electricity for irrigation does not instill scarcity value among farmers, resulting to inefficient use of groundwater extraction.

The groundwater-energy-food nexus was still operational in post PPSWA period which offset effects on groundwater as compared to the positive marginal effects of delayed sowing. Fourth, the increasing total demand (despite reduction in per hectare groundwater irrigation hours) did not accompanied by the increase in the supply/recharge of the groundwater resources which hovered around 23-24 BCM in both pre and post PPSWA period. Thus, it can be concluded that although PPSWA was reduced the groundwater irrigation intensity, it could not check the overall groundwater depletion due to other demand side factors operating against it.

Factors behind continued or increased groundwater depletion

1. Expectations of the farmers – pump more in shorter time and expand acreage of paddy
2. Policy offsets – free electricity and minimum support prices
3. Riparian rights govern extraction of groundwater. Any person who owns land can extract groundwater free of cost.

2. Conclusion and implications

To reduce excessive pressure on the groundwater resources, the Indian state of Punjab enacted a legislation "The Punjab Preservation of Subsoil Water Preservation Act, 2009" which prohibits the raising of paddy nurseries their transplantation before the notified dates and provides for penalties for non-compliance with it. Employing the synthetic difference-in-difference method to the data from 2000-01 to 2018-19, this paper has constructed a counterfactual trajectory of the groundwater level for Punjab and Haryana and the groundwater draft and compared it with its actual trajectory before and after the implementation of the Act. The findings show a small check on depletion where farmer responses and policy offsets determined the outcomes. significant divergence between the actual and synthetic trajectories post-implementation of the Act indicating an unabated withdrawal of groundwater despite the Act being in place. The means the legislation has not been implemented in a true spirit. We argue that there is an urgent need to (1) delink groundwater rights from land rights and (2) adopt an integrated resource management strategy if to utilise their groundwater sustainably.

The depleting groundwater is a matter of serious concern for the sustainability of agriculture and agriculture-based livelihoods in Punjab and Haryana and the national food security. Irrigation is crucial for improving productivity and reducing the sensitivity of crops to extreme climate changes (Birthal et al., 2015; Birthal et al., 2021; Zaveri and Lobell, 2019). Punjab and Haryana agriculture are at a crossroads now, and the technological gains realized during the Green Revolution period have started tapering off. The annual rate of growth in the yield of paddy decelerated to 0.90 % during 2009-2018 from 1.96% in 2000-08. If the Act could not restrict over-extraction of the groundwater, then the question is: What kind of interventions can help sustainable management of the groundwater resources?

Paddy and wheat are the two most important crops grown in Punjab. These crops are procured by the Government of India at pre-announced minimum support prices, which renders them free from any price and market risks. In 2018-19, about 88% of the paddy and 69% of the wheat produced in the state was procured by the government. The yield of paddy and wheat is much higher than their competing crops. Moreover, the farmers are risk-averse as the delay in sowing of paddy, as mandated in the Act, condenses the window for sowing of wheat, the most important crop in the subsequent season.

These facts call for reforming the price policy and designing an incentive structure that motivates farmers to grow alternative but less water-intensive crops. Another factor for excessive and indiscriminate withdrawal of groundwater has been the provision of free electricity for irrigation since 1997, which coupled with the output price policy, has prompted farmers to allocate more area to paddy cultivation. To discourage groundwater extraction the need for volumetric pricing of electricity cannot be undermined (Singh, 2012; Sidhu et al., 2020).

The political economy of agricultural reforms is complex, and the incentives once provided are difficult to withdraw. The option is to provide the same level of incentives for the adoption of a package of practices compatible with the principles of natural resource conservation. These include the adoption of short-duration crop varieties, alternate wet and drying system, direct seeding, zero tillage, irrigation scheduling and pressurized irrigation systems that lead to significant savings of water (Vatta et al., 2018; Yadav et al., 2011; Kumar and Katagami, 2016; Ranjan et al., 2010; Jat et al., 2006). Finally, the government should encourage the grass-root institutions to coordinate programs and policies, to create awareness among farmers on the judicious use of water and to monitor the implementation of resource conservation technologies and practices. The importance of the regulation not being a direct or price instrument is clear.

Why groundwater depletion continued in post PPSWA, 2009

The above results indicated that PPSWA failed to check the declining trend in groundwater level in Punjab though it checked the depth of groundwater bya bit. It is essential to know the underlying reasons. The increase or decrease in groundwater level is a net outcome of total demand and supply of groundwater. Thus, the failure of PPSWA to check groundwater depletion to its potential imply that it could not reduce the relative demand of the groundwater over its replenishment. The evidence from Cost of Cultivation Surveys reveal that per hectare groundwater irrigation hours from groundwater reduced from 309 in 2009-10 to 217 in 2018-19. However, as response power and nature of pumps employed also changed.

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The groundwater-energy-food nexus was still operational in post PPSWA period which offset effects on groundwater as compared to the positive marginal effects of delayed sowing. Fourth, the increasing total demand (despite reduction in per hectare groundwater irrigation hours) did not accompanied by the increase in the supply/recharge of the groundwater resources which hovered around 23-24

BCM in both pre and post PPSWA period. Thus, it can be concluded that although PPSWA was reduced the groundwater irrigation intensity, it could not check the overall groundwater depletion due to other demand side factors operating against it.

Factors behind continued or increased groundwater depletion

4. Expectations of the farmers – pump more in shorter time and expand acreage of paddy
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6. Riparian rights govern extraction of groundwater. Any person who owns land can extract groundwater free of cost.

3. Conclusion and implications

To reduce excessive pressure on the groundwater resources, the Indian state of Punjab enacted a legislation "The Punjab Preservation of Subsoil Water Preservation Act, 2009" which prohibits the raising of paddy nurseries their transplantation before the notified dates and provides for penalties for non-compliance with it. Employing the synthetic difference-in-difference method to the data from 2000-01 to 2018-19, this paper has constructed a counterfactual trajectory of the groundwater level for Punjab and Haryana and the groundwater draft and compared it with its actual trajectory before and after the implementation of the Act. The findings show a small check on depletion where farmer responses and policy offsets determined the outcomes. significant divergence between the actual and synthetic trajectories post-implementation of the Act indicating an unabated withdrawal of groundwater despite the Act being in place. The means the legislation has not been implemented in a true spirit. We argue that there is an urgent need to (1) delink groundwater rights from land rights and (2) adopt an integrated resource management strategy if to utilise their groundwater sustainably.

The depleting groundwater is a matter of serious concern for the sustainability of agriculture and agriculture-based livelihoods in Punjab and Haryana and the national food security. Irrigation is crucial for improving productivity and reducing the sensitivity of crops to extreme climate changes (Birthal et al., 2015; Birthal et al., 2021; Zaveri and Lobell, 2019). Punjab and Haryana agriculture are at a crossroads now, and the technological gains realized during the Green Revolution period have started tapering off. The annual rate of growth in the yield of paddy decelerated to 0.90 % during 2009-2018 from 1.96% in 2000-08. If the Act could not restrict over-extraction of the groundwater, then the question is: What kind of interventions can help sustainable management of the groundwater resources?

Paddy and wheat are the two most important crops grown in Punjab. These crops are procured by the Government of India at pre-announced minimum support prices, which renders them free from any price and market risks. In 2018-19, about 88% of the paddy and

69% of the wheat produced in the state was procured by the government. The yield of paddy and wheat is much higher than their competing crops. Moreover, the farmers are risk-averse as the delay in sowing of paddy, as mandated in the Act, condenses the window for sowing of wheat, the most important crop in the subsequent season.

These facts call for reforming the price policy and designing an incentive structure that motivates farmers to grow alternative but less water-intensive crops. Another factor for excessive and indiscriminate withdrawal of groundwater has been the provision of free electricity for irrigation since 1997, which coupled with the output price policy, has prompted farmers to allocate more area to paddy cultivation. To discourage groundwater extraction the need for volumetric pricing of electricity cannot be undermined (Singh, 2012; Sidhu et al., 2020).

The political economy of agricultural reforms is complex, and the incentives once provided are difficult to withdraw. The option is to provide the same level of incentives for the adoption of a package of practices compatible with the principles of natural resource conservation. These include the adoption of short-duration crop varieties, alternate wet and drying system, direct seeding, zero tillage, irrigation scheduling and pressurized irrigation systems that lead to significant savings of water (Vatta et al., 2018; Yadav et al., 2011; Kumar and Katagami, 2016; Ranjan et al., 2010; Jat et al., 2006). Finally, the government should encourage the grass-root institutions to coordinate programs and policies, to create awareness among farmers on the judicious use of water and to monitor the implementation of resource conservation technologies and practices. The importance of the regulation not being a direct or price instrument is clear.