Governing the Groundwater Use in India: Assessing the Effectiveness of the Punjab Preservation of Subsoil Water Act, 2009

Prabhat Kishore[a], Pratap S. Birthal[a], Shivendra K. Srivastava[a]
and Devesh Roy[b]

[a] ICAR-National Institute of Agricultural Economics and Policy Research, DPS Road, Pusa, New Delhi 110012, India.

[b] International Food Policy Research (IFPRI), South Asia Office, DPS Road, Pusa, New Delhi 110012, India.

Corresponding author e-mail: kishore.prabhat89@gmail.com

Acknowledgment: The paper emanates from Ph.D. research work of first author titled "Groundwater-Energy nexus in Agriculture and its Implications on Farm Economy in Western Uttar Pradesh".

Governing the Groundwater Use in India: Assessing the Effectiveness of the Punjab Preservation of Subsoil Water Act, 2009

Abstract

Employing synthetic control method, this paper has looked into the effectiveness of a legislation 'The Punjab Preservation of Subsoil Water Act, 2009' enacted by the Indian state of Punjab to regulate the groundwater use in agriculture. The findings show that despite the Act being in force the over-extraction of groundwater has aggravated. The failure of the Act in arresting over-extraction of groundwater suggests the need for designing a comprehensive irrigation water management strategy encompassing policy and institutional reforms, technological and agronomic solutions and incentive structures compatible with the principles of the conservation of natural resources.

Keywords: Groundwater depletion, Legislation, Impact, India.

1. Introduction

Globally, 308 million hectares of agricultural land is equipped with irrigation, of which 38% relies on groundwater (Siebert et al., 2013). India has the largest groundwater-equipped area, i.e., over 39 million hectares, equivalent to one-third of the world's groundwater-equipped area (Siebert et al., 2013). Driven by intensification of cropping systems and changes in farmers' crop choices in favour of high-yielding high-water footprint crops like paddy and wheat India's reliance on groundwater for irrigation has been increasing incessantly. Between 1970-71 and 2017-18, the share of groundwater-irrigated area in the total irrigated area increased from 38% to 64% (GoI, 2019a).

No denying, the use of groundwater for irrigation along with adoption of biochemical technologies has made significant contribution in enhancing agricultural productivity and food supplies (Birthal et al., 2015; Zaveri and Lobell, 2019), yet, at the same time, the groundwater resources have come under an excessive pressure (Singh et al., 2019; Panda et al., 2012). Groundwater resources in about 17% of the administrative blocks have been overexploited beyond their sustainable limits. And, it is apprehended that, if over-exploitation of groundwater is not arrested, aquifers may go dry, threatening sustainability of agriculture and agriculture-based livelihoods and food security of the nation (Jain et al., 2021; Zaveri et al., 2016).

The problem of groundwater over-exploitation is severe in north-western states of India, including Haryana and Punjab that heralded the Green Revolution (Kaur and Vatta, 2015; Jain et al. 2021). The north-western region has semi-arid type of climate, characterized by extreme temperatures (being as low as 0.5 ^{O}C during the winters and as high as 49.6 ^{O}C during the summers) and low rainfall (356 mm/annum), mostly received during July to September through the south-west monsoon. Canal irrigation is limited. Hence, farmers over time have shifted to using groundwater for irrigation. For instance, in Punjab, the share of groundwater-irrigated area in the total irrigated area has increased from 55% in 1970-71 to 72% in 2017-18 (GoP, 2020). Until the late 1990s, the groundwater level in the state did not change much, but afterwards, it has fallen at an annual rate of 40.9cm, from 8m in 1997-98 to 17m in 2017-18 (GoI, 2019b). The extraction rate of groundwater is estimated 66% more than its sustainable limit, and 79% of the administrative blocks are experience severe water stress (GoI, 2019c).

Several factors have contributed to the depletion of groundwater resources in the northwestern states. In the quest of achieving self-sufficiency in staple food grains, farmers were incentivized to adopt high-yielding biochemical technologies and invest in farm infrastructure, including the purchase of tractors and equipment and installation of tube-wells. The procurement of food grains, mainly paddy and wheat, at their pre-announced government-administered minimum support prices and the provision of subsidized inputs, especially agrochemicals and electricity for irrigation, have been the key fiscal incentives ever since the late 1960s. These incentives, no doubt, could help achieve self-sufficiency in food grains, but these have also adversely affected the health of natural resources, including the land, water and air. The government of Punjab has been providing free electricity for irrigation since 1997. This has led to a drastic shift in the cropping pattern in favour of more remunerative, risk-free water-guzzling crops like paddy. Before the advent of the Green Revolution, paddy had never been an important crop in Punjab, but its share the total cropped area gradually increased to 40% in 2018-19, from a mere 7% in 1970-71.

The political economy of agricultural incentives (i.e., output price support and input subsidies) is complex. Once introduced, these incentives are difficult to withdraw despite the recognition of their detrimental effect on the health of natural resources. The policymakers are in a dilemma: 'how to conserve natural resources'. The Government of Punjab enacted a legislation called "The Punjab Preservation of Subsoil Water Act, 2009" (hereafter termed as PPSWA, 2009) to discourage the excessive and indiscriminate use of groundwater for irrigation. The Act prohibits the raising of paddy nurseries before May 10 and their transplantation before June 10, or any other date notified by the government. The non-compliance to this condition attracts a penalty of Rs 10000 per hectare of paddy-cropped area or disconnecting supply of electricity supply or destroying paddy nurseries or all of these. The Act was expected to arrest the falling water table by 30cm and save electricity to the tune of 276 million kWh (Singh, 2009).

This paper investigates an important question: Has the PPSWA, 2009 been effective in arresting decline in groundwater level? 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). Nonetheless, these studies suffer from a major methodological limitation. While the Act applies to the entire state of Punjab, these studies have employed either a panel fixed effects model or a difference-in-difference approach assuming paddy-intensive districts as the units of treatment. When an intervention does not discriminate spatial units, the assumption that the Act is more effective in some and not in other districts may lead to biased estimates. Furthermore, these studies have used short-term data at the most for three years' post-implementation of the Act.

This paper addresses two important questions. One, has the Act been effective in regulating the groundwater use? Two, if it has not succeeded, then why? It employs synthetic control method (SCM) to the data for 2000-01 to 2016-17. SCM is unique in the sense that it is used to assess the impact of a policy intervention made at a higher administrative level, i.e., state or national level. Here, Punjab is our unit of treatment, and other Indian states serve as controls. Ideally, the implementation of the Act should have arrested the decline in the groundwater level. Nevertheless, our findings suggest that over-extraction of groundwater remains unabated despite the Act being in force. The groundwater level in the post-implementation of the Act has fallen by 31cm/annum as compared to 28cm/annum before the Act.

2. 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. 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. 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 2016-17.

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

To know 'how effective the PPSWA, 2009 has been in arresting the groundwater decline' we implement a synthetic control method (SCM), an often-used technique to assess the effectiveness of an intervention made at a higher geographical or administrative level — national or sub-national level (Abadie et al., 2010, 2015; Kreif, 2016). This approach, pioneered by Abadie and

Gardeazabal (2003), is data-driven in choosing the units for comparison. It provides insight 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.

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:

$$\delta_{it} = Y_{it}^{I} - Y_{it}^{N}$$

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:

$$Y_{it} = Y_{it}^N - \alpha_{it}\beta_{it}$$

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:

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

Where, α_t is unknown with constant factor loadings across the units, z_i is a *(r* ×1*)* vector of observed covariates (not affected by the intervention), θ_t is a *(*1 × *r)* vector of unknown parameters, τ_t is a *(*1×*F)* vector of unobserved common factors, and μ_i is an *(F*×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; $X_0 m$ 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.

3. Descriptive Statistics

Our treatment unit is the state of Punjab, which enacted the PPSWA, 2009 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 in the absence of the Act. These states are Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Himachal Pradesh, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttarakhand and West Bengal, and comprise the donor pool[1]. None of these states have made any such intervention. Key characteristics of each state in donor pool are given in Table A1 in the appendix.

Approximately 96% of the groundwater in Punjab is utilized for irrigation (GoI, 2019c). The groundwater extraction in the state is estimated 8391 cubic meters per hectare of net sown area, almost 16 times the national average. 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 the state are categorized as overexploited (GoI, 2019c).

Table 2 compares the key characteristics of Punjab vis-à-vis the averages for the donor pool. Our outcome variable is the groundwater level, and the predictor variables include the rainfall, electricity consumption, cropping intensity, dependence on groundwater, paddy-cropped area, hours of irrigation in paddy and tube-well density. The mean groundwater level (2000-01 to 2016-19) in Punjab was 12.19m, which is 2.74 m deeper than the average for the donor pool. Over time,

[1] 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.

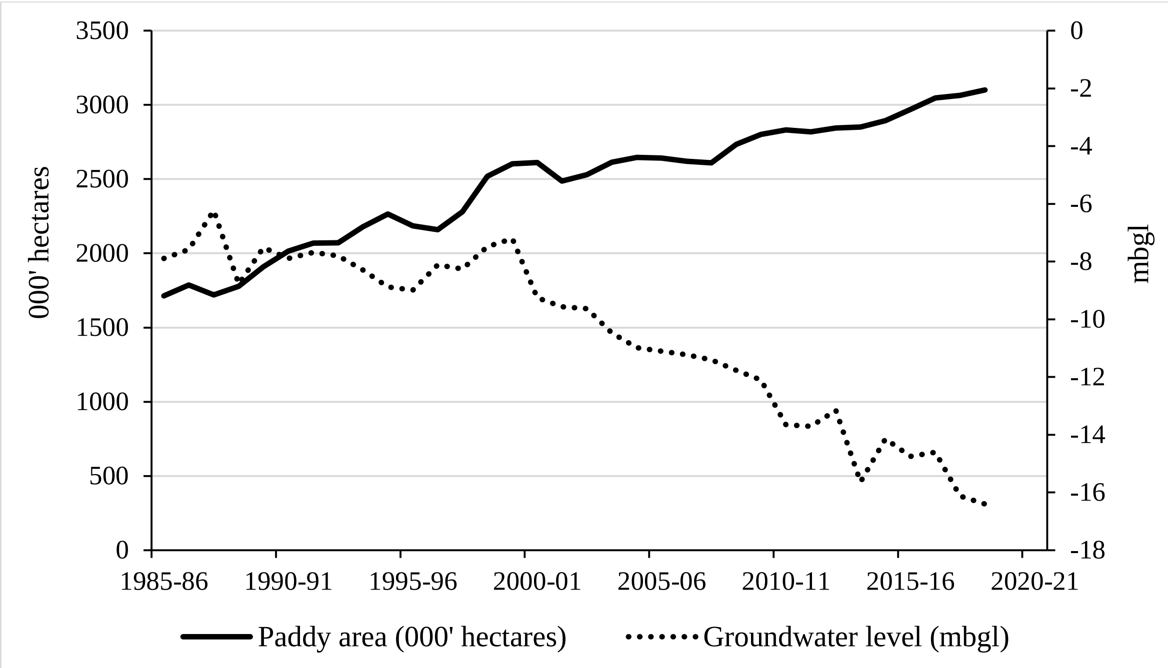
the groundwater level in the state has fallen to 14.61m in 2016-17 from 12.10m in 2009-10 and 9.25m in 2000-01. The mean annual rainfall in the state is 496mm, which is 60% less than for the donor pool states. The electricity consumption in Punjab agriculture is 1068.56 kWh/ha, almost twice the average of the donor pool. Higher electricity use in Punjab is 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.

Table 2. Summary statistics: Punjab vis-à-vis donor pool

Variables	Donor pool (15 states)				Punjab
	Mean	SD	Min	Max	Mean
Outcome					
Pre-monsoon groundwater level(m)	9.45	4.77	2.33	25.58	12.19
Predictors					
Annual rainfall (mm)	1237.87	563.69	184.75	3012.70	495.51
Electricity consumption (kWh/ha of gross cropped area	529.88	579.44	2.38	2842.38	1068.56
Cropping intensity (%)	137.90	20.77	107.69	185.14	188.60
Groundwater irrigation (%)	53.82	20.91	1.52	86.74	72.71
Tube-well density(No./ 000 ha)	131.79	98.18	8.82	464.66	279.48
Paddy-cropped area (000 ha)	2255.83	1802.25	72.50	6071.00	2738.53
Paddy irrigation-hours(No./ ha)	133.74	103.54	14.00	441.59	305.89

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 in Punjab (Figure 1)

Figure 1. Trends in the paddy-cropped area and groundwater level in Punjab



4. Results and Discussion

4.1. Estimates of the SCM

Has the groundwater level in Punjab changed after implementation of the PPSWA, 2009? The SCM constructs a synthetic Punjab as a convex combination of the states that closely resemble Punjab in key parameters that influence groundwater use. Similar to the matching estimators, the SCM demonstrates the affinity between an administrative unit exposed to the intervention and its counterfactual or synthetic situation.

The results of the SCM, in terms of the pre-treatment characteristics of the actual and synthetic Punjab and also of the donor pool are presented in Table 3. The estimates of the predictor variables for synthetic Punjab have been arrived at by assigning differential weights to the states in the donor pool based on the similarity in their characteristics with the actual Punjab. The estimated values of the predictor variables for synthetic Punjab for the pre-treatment period are closer to their corresponding actual values when compared without assigning weights to the states in the donor pool.

Table 3. Predictor balance of the synthetic control method

Predictor variables	Punjab		Average for
	Actual	Synthetic	donor pool states
Ln Rainfall (mm)	6.15	6.65	7.03
Ln Electricity consumption (kWh/ha)	6.79	5.53	5.34
Cropping intensity (%)	187.46	148.54	135.65
% groundwater in the irrigated area	72.94	73.82	52.45
Ln Paddy cropped area (000 ha)	7.87	7.42	7.19
Ln Paddy irrigation hours (No./ ha)	5.86	4.39	4.69
Ln Tube-well density (No./1000ha)	5.60	5.09	4.60

Note: All predictor variables represent their respective means during the pre-intervention period (2000-01 to 2008-09)

Table 4 shows the weights assigned to each state in the donor pool. The pre-intervention groundwater level in Punjab (before implementation of the PPSWA, 2009) can be best described by a combination of the covariates for Rajasthan, Tamil Nadu, Uttar Pradesh and Uttarakhand. No weights are assigned to other states in the donor pool.

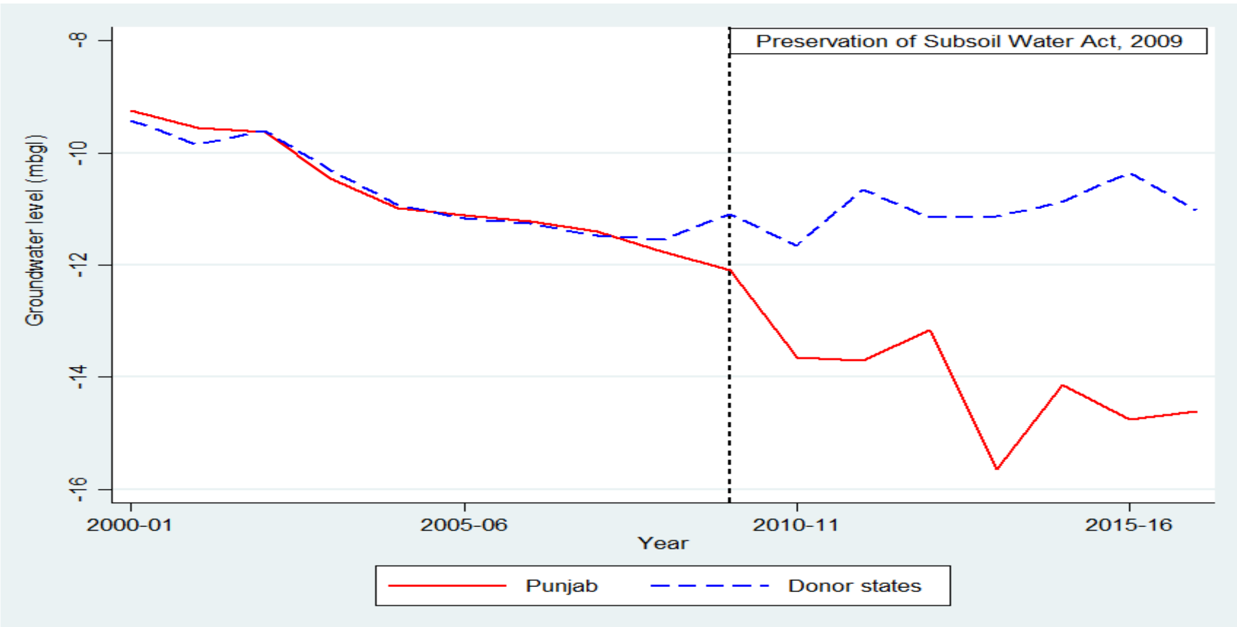
Table 4. Weights to the donor pool states

State	Weight	State	Weight
Andhra Pradesh	0.000	Madhya Pradesh	0.000
Assam	0.000	Maharashtra	0.000
Bihar	0.000	Rajasthan	0.171
Chhattisgarh	0.000	Tamil Nadu	0.011
Gujarat	0.000	Uttar Pradesh	0.630
Himachal Pradesh	0.000	Uttarakhand	0.188
Jharkhand	0.000	West Bengal	0.000
Karnataka	0.000		

Figure 2 shows the actual and synthetic groundwater level for Punjab. The trajectory of the synthetic groundwater level closely matches its trajectory of the actual level before the implementation of the PPSWA, 2009. The closeness between the trajectories of the actual and synthetic groundwater level and a high degree of predictor balance for groundwater depletion (Table 3) indicate that synthetic groundwater level in the post-treatment period (2009-2016) is a sensible approximation of the groundwater level in the absence of implementation of the Act.

Post-implementation of the Act, the trajectories of the actual and synthetic groundwater level diverge considerably. While the actual level of groundwater keeps on declining in the post-treatment period, its synthetic counterpart shows a marginally positive trend. The difference between the actual and synthetic groundwater level has widened after the implementation of the Act. Before implementation of the Act, the difference between the actual and synthetic groundwater level was in the range of -0.03 to +0.29m, as compared to -1.01 to -4.50 in the post-implementation period (Table A2 in the appendix). This means that the PPSWA, 2009 has not succeeded in its intended objective of arresting the groundwater depletion.

Figure 2. Actual and synthetic groundwater levels in Punjab

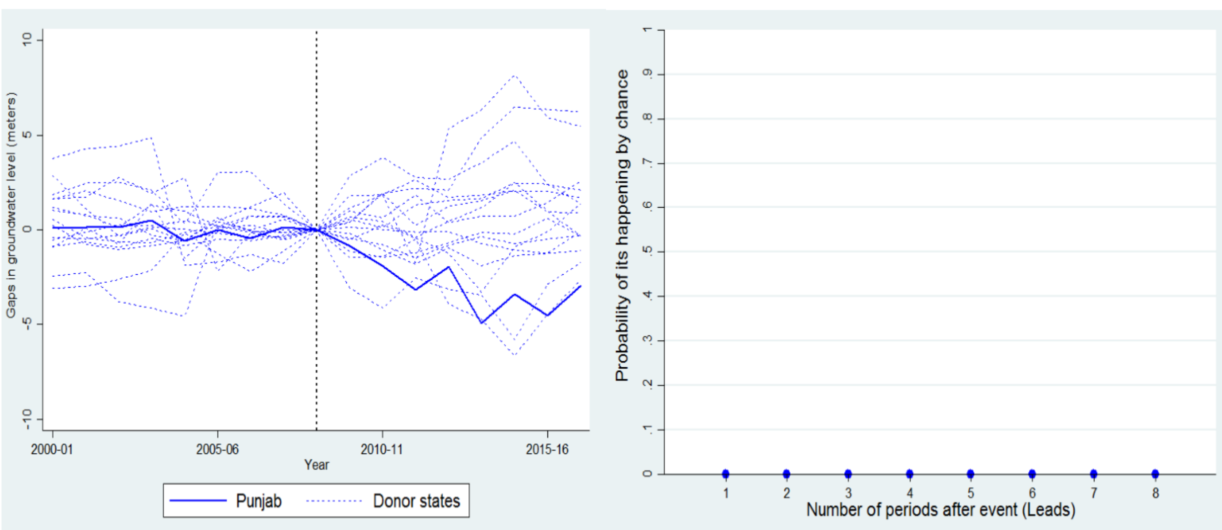


4.2. Robustness checks

To check the robustness of our results, we have conducted a placebo test on the hypothesis that similar estimates of groundwater level could have been obtained for any other state in the donor pool had it implemented such an Act instead of Punjab. We assign the PPSWA, 2009 to a randomly chosen state from the donor pool. If the estimated effect for the randomly chosen state is of similar magnitude as that for Punjab, then the results do not advocate for a significant effect (positive or negative) of the PPSWA, 2009 on the groundwater level in Punjab. In case, the estimated effect for the donor pool state, which has not been affected by the PPSWA, 2009, is substantially less than that for Punjab, then we conclude that the Act has made a significant effect on the groundwater level. In each iteration of the SCM, we assign PPSWA, 2009 to one of the states in the donor pool, assuming that the state had implemented it rather than Punjab, and then we compute the estimated effect for each state.

Figure 3 presents the results of the placebo test. Each line in figure 3 indicates the gap between the actual and synthetic levels of groundwater for each state. The solid line indicates the estimated gap between the actual and synthetic groundwater level in Punjab. The gap between the actual and synthetic groundwater level after implementation of the Act has become larger than for most donor pool states. This means that the probability of the estimated gap arising by chance is zero in the post-treatment period.

Figure 3. The gap between actual and synthetic groundwater levels



An alternative way of assessing Punjab's gap between the actual and synthetic level relative to the gaps assessed through the placebo test is to look into the distribution of the ratio of the post-Act root mean squared prediction error (RMSPE) to the pre-Act RMSPE. Table 5 shows the ranking anchored on the post-pre ratio of RMSPE for Punjab and donor pool states. With a ratio of 11.22

Punjab ranks at the top. The probability of obtaining a post-pre ratio as large as for Punjab on assigning the Act to any other state in the donor pool is extremely small (0.063).

Table 5. Rank test for states in donor pool and Punjab

Rank	State	Post-pre ratio	Rank	State	Post-pre ratio
1	Punjab	11.221	9	Jharkhand	2.080
2	Himachal Pradesh	3.624	10	Gujarat	1.971
3	Assam	2.910	11	Andhra Pradesh	1.884
4	Bihar	2.762	12	Karnataka	1.877
5	Madhya Pradesh	2.663	13	Uttar Pradesh	1.579
6	Rajasthan	2.570	14	Chhattisgarh	1.545
7	Maharashtra	2.224	15	Tamil Nadu	1.414
8	West Bengal	2.097	16	Uttarakhand	0.466

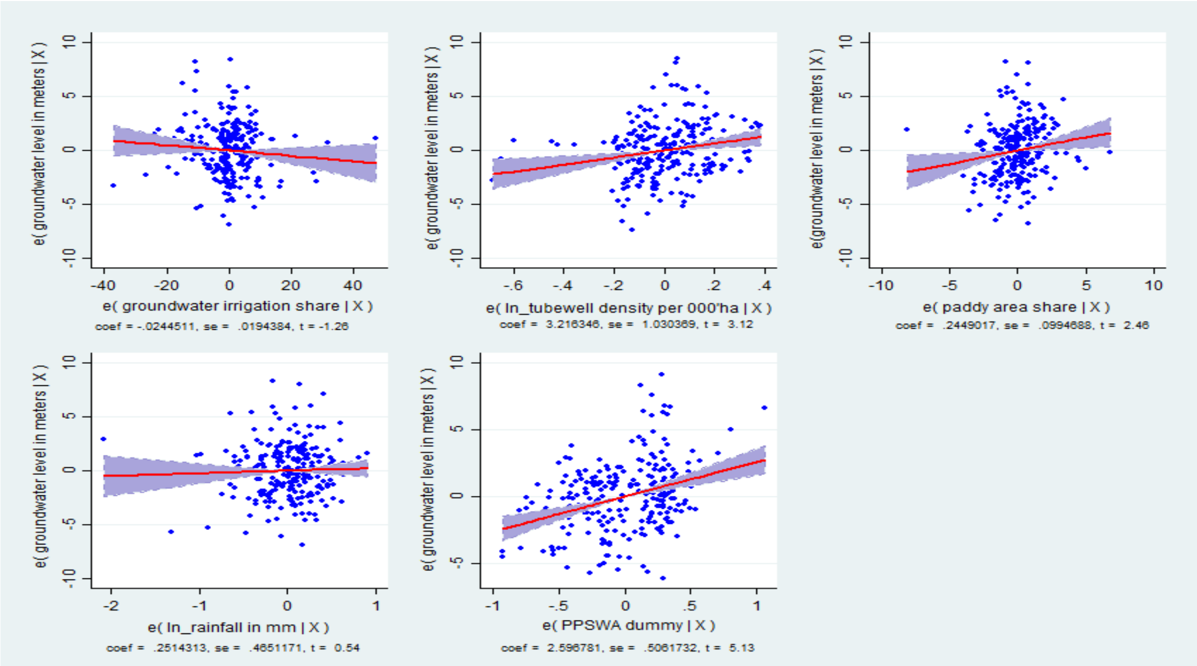
We go a step further and estimate a panel fixed effects model considering the districts of Punjab as units of observation. We regress district level groundwater level on a set of explanatory variables which includes the share of groundwater in the total irrigated area, area share of paddy, rainfall, tube-well density and a dummy for PPSWA, 2009. The results show tube-well density and paddy cultivation contributing to groundwater depletion (Table 6). Rainfall is insignificantly associated with groundwater depth, as expected. It recharges only 27% of the replenishable groundwater in the state (GoI, 2019c). Importantly, the dummy for PPSWA, 2009 is positive and highly significant confirming the decline in groundwater level in the post-treatment period.

Table 6. Estimates of the fixed effects regression

Dependent variable: Pre-monsoon groundwater level (m)	
Predictor variables	Coefficients
Groundwater irrigation (%)	-0.024
	(0.019)
Ln tube-well density (No./000 ha)	3.216***
	(1.030)
Paddy area share (%)	0.245**
	(0.099)
Ln Rainfall (mm)	0.251
	(0.465)
PPSWA (post-PPSWA =1, Otherwise =0)	2.597***
	(0.506)
Intercept	-13.779**
	(5.970)
Prob > F	0.000
Number of observations	238

For more clarity on the effects of different variables on the groundwater depth, in Figure 4 we show their partial correlations through the scatter plots.

Figure 4. Partial correlation between dependent and predictor variables



4.3 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. It is essential to know the underlying reasons so as to take corrective measures. 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 imply that it could not reduce the relative demand of the groundwater over its replenishment. The evidences from Cost of Cultivation Surveys reveal that per hectare groundwater irrigation hours from groundwater reduced from 309 in 2009-10 to 258 in 2016-17. 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 did not decline 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 3047 thousand hectares in 2026-17. Area expansion under paddy raised the total requirement of groundwater for irrigation. Second, installation of new wells remained unabated and well density increased from 331 to 343 wells/1000 ha NSA between 2009-10 to 2016-17. Further, 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 produced larger negative effects on groundwater as compared to the positive marginal effects of delayed sowing. Fourth, enforcement of the Act on field level was at slow pace leading to a weaker impact on groundwater level. 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.

5. 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 control method to the data from 2000-01 to 2016-17 this paper has constructed a counterfactual trajectory of the groundwater level for Punjab and compared it with its actual trajectory before and after the implementation of the Act. The findings show a 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.

The depleting groundwater is a matter of serious concern for the sustainability of agriculture and agriculture-based livelihoods in Punjab and the national food security. Irrigation is crucial for improving productivity and also reducing the sensitivity of crops to extreme climate changes (Birthal et al., 2015; Birthal et al., 2021; Zaveri and Lobell, 2019). Punjab agriculture is 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 0.28 % during 2009-2017 from 1.96% in 2001-08. 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.

References

Abadie, A., Diamond, A., Hainmueller, J., 2010. Synthetic control methods for comparative case studies: estimating the effect of California's Tobacco Control Program. *Journal of the American Statistical Association*, 105(490), 493-505.

Abadie, A, Diamond, A., Hainmueller, J., 2015. Comparative politics and the synthetic control method. *American Journal of Political Science*, 59(2), 495-510.

Abadie, A., Gardeazabal, J., 2003. The economic costs of conflict: A case study of the Basque country. *American Economic Review*, 93(1), 113-132.

Birthal, P.S., Hazrana, J., Negi, D.S., Pandey, G., 2021. Benefits of irrigation against heat stress in agriculture: Evidence from wheat. *Agricultural Water Management*, 255(C), 106950.

Birthal, P.S., Negi, D.S., Khan, Md. T., Agarwal, S., 2015. Is Indian agriculture becoming resilient to droughts? *Food Policy* 56, 1-12.

Galiani, S., Quistorff, B., 2017. The synth_runner package: Utilities to automate synthetic control estimation using synth. *The Stata Journal*, 17(4), 834-849.

GoI-Government of India. 2019a. Land Use Statistics. Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India.

GoI-Government of India. 2019b. India Water Resource Information System. Ministry of Jal Shakti, Government of India.

GoI-Government of India. 2019c. National Compilation on Dynamic Groundwater Resources of India. Ministry of Jal Shakti, Government of India.

GoP-Government of Punjab. 2020. Statistical Abstract of Punjab, Economic and Statistical Organisation, Department of Planning, Government of Punjab.

Gupta, D., 2021. Free power, irrigation and groundwater depletion: impact of the farm electricity policy of Punjab, India**.** Working papers 316, Centre for Development Economics, Delhi School of Economics, University of Delhi.

Jain, M., Fishman, R., Mondal, P., Galford, G.L., Bhattarai, N., Naeem, S., Lall, U., Singh, B., Defries, R.S., 2021. Groundwater depletion will reduce cropping intensity in India. *Science Advances*, 7(9).

Jat, M.L., Chandna, P., Gupta, R., Sharma, S.K., Gill, M.A., 2006. Laser land leveling: a precursor technology for resource conservation. *Rice-Wheat Consortium Technical Bulletin Series 7*. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains. pp 48.

Kaur, S., Vatta, K., 2015. Groundwater depletion in Central Punjab: pattern, access and adaptations. Current Science, 108, 485-490.

Kreif, N., Grieve, R., Hangartner, D., Turner, A.J., Nikolova, S., Sutton, M., 2016. Examination of the synthetic control method for evaluating health policies with multiple treated units. *Health Economics Health Economics,* 25, 1514–1528.

Kumar, A., Katagami, M., 2016. Developing and disseminating water-saving rice technologies in Asia. *ADB Brief No-60.*

Panda, D.K., Mishra, A., Kumar, A., 2012. Quantification of trends in groundwater levels of Gujarat in western India. *Hydrological Sciences Journal*, 57, 1325–1336.

Ranjan, A., Samarpreet, K., Amarjeet, S., 2010. Assessment of saving in water resources through precision land levelling in Punjab. *Journal of Soil and Water Conservation* 9:182-185.

Sekhri, S., 2012. Sustaining groundwater: role of policy reforms in promoting conservation in India, Indian Policy Forum, National Council of Applied Economic Research, Delhi.

Sidhu, B.S., Kandlikar, M., Ramankutty, N., 2020. Power tariffs for groundwater irrigation in India: a comparative analysis of the environmental, equity, and economic tradeoffs, *World Development*, *128, 104836.*

Siebert, S., Henrich, V., Frenken, K., Burke, J., 2013. Update of the global map of irrigation areas to version 5. University of Bonn/FAO, Bonn, Germany/Rome, Italy. doi:10.13140/2.1.2660.6728.

Singh, K., 2009. Act to save groundwater in Punjab: its impact on water table, electricity subsidy and environment. *Agricultural Economics Research Review*, 22, 365–586.

Singh, K., 2012. Electricity subsidy in Punjab agriculture: extent and impact. *Indian Journal of Agricultural Economics*, 67(4), 617-632.

Singh, O., Kasana, A. Singh, K.P., Sarangi, A., 2019. Analysis of drivers of trends in groundwater levels under rice-wheat ecosystem in Haryana, India. *Natural Resources Research*, 29, 1101-1126.

Tripathi, A., Mishra, A., Verma, G., 2016. Impact of Preservation of Subsoil Water Act on groundwater depletion: the case of Punjab, India. *Environmental Management*, 58, 48–59.

Vatta, K., Sidhu, R.S., Lall, U., Birthal, P.S., Taneja, G. Kaur, B. Devineniand, N., MacAlister, C., 2018. Assessing the economic impact of a low-cost water-saving irrigation technology in Indian Punjab: the tensiometer. *Water International*, 43(2), 305-321.

Yadav, S., Humphreys, E., Kukal, S.S., Gill, G., Rangarajan, R., 2011. Effect of water management on dry seeded and puddled transplanted rice. *Field Crops Research*, 120, 123–132.

Zaveri, E., Lobell, D.B., 2019. The role of irrigation in changing wheat yields and heat sensitivity in India, *Nature Communications*, 10, 4144.

Zaveri, E., Grogan, D.S., Fisher-Vanden, K., Frolking, S., Lammers, R.B. Wrenn, D.H., Prusevich, A., Nicholas, R.E., 2016. Invisible water, visible impact: groundwater use and Indian agriculture under climate change. *Environmental Research Letter*, 11, 084005.

Table A1. Status of groundwater in selected states

State	Stage of groundwater development (%)	Share of irrigation in groundwater draft (%)	Share of rainfall in groundwater recharge	Groundwater extracted (m^3/ha of NSA)	Electricity used (kWh/ha)	Well density (no/000 ha of NSA)	Electric wells (%)	Blocks over-exploited (%)
Treated unit (with the enactment of Punjab Subsoil Water Preservation Act)								
Punjab	165.77	96.59	28.63	8390.7	2482	280.71	95.67	79
Donor pool states (without the enactment of Punjab Subsoil Water Preservation Act)								
Rajasthan	139.88	88.55	75.55	847.5	985	85.85	70.68	63
Himachal Pradesh	86.37	51.28	0.88	363.7	87	14.38	93.15	50
Tamil Nadu	80.94	88.66	42.33	2710.1	2551	414.71	93.83	40
Uttar Pradesh	70.18	89.20	56.24	2463.5	615	241.63	14.80	11
Karnataka	69.87	90.81	54.99	934.9	1800	121.80	99.47	26
Gujarat	63.89	94.55	71.30	1246.4	1430	123.58	98.87	10
Uttarakhand	56.83	79.27	40.79	1856.7	491	77.05	16.10	0
Madhya Pradesh	54.76	92.32	76.66	1135.4	772	127.03	94.05	7
Maharashtra	54.62	92.47	66.75	870.6	1283	152.62	97.69	3
Andhra Pradesh	52.24	87.93	60.97	1407.8	2060	235.39	95.92	9
Bihar	45.76	81.30	73.13	2042.3	61	113.84	6.73	2
West Bengal	44.6	91.55	81.73	2069.3	226	76.34	27.25	0
Chhattisgarh	44.43	84.68	74.16	850.3	532	64.71	97.20	0
Jharkhand	27.73	50.63	91.14	577.8	67	89.80	4.89	1
Assam	11.25	72.16	95.92	696.8	13	46.98	0.66	0
India	63.38	89.08	66.72	1569.7	1198	145.55	72.77	17

Table A2. Actual and synthetic groundwater level in Punjab

Year	Actual	Synthetic	Difference
	Pre-intervention period		
2000-01	-9.25	-9.42	0.17
2001-02	-9.56	-9.85	0.29
2002-03	-9.63	-9.60	-0.03
2003-04	-10.47	-10.31	-0.16
2004-05	-10.98	-10.93	-0.05
2005-06	-11.11	-11.17	0.06
2006-07	-11.23	-11.26	0.03
2007-08	-11.40	-11.47	0.07
2008-09	-11.77	-11.54	-0.23
	Post-intervention period		
2009-10	-12.10	-11.09	-1.01
2010-11	-13.65	-11.65	-2.00
2011-12	-13.71	-10.65	-3.05
2012-13	-13.16	-11.15	-2.01
2013-14	-15.64	-11.14	-4.50
2014-15	-14.14	-10.87	-3.27
2015-16	-14.75	-10.35	-4.41
2016-17	-14.61	-11.03	-3.58

Note: Negative sign shows the depth of water below the ground level.