Impact of Subsoil Water Preservation Act, 2009 on burgeoning trend of groundwater depletion in Punjab, India

by P. Kishore, D.R. Singh, S.K. Srivastava, P. Kumar, and G.K. Jha

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Kishore[1&2], P., Singh[1], D.R., Srivastava[2], S.K., Kumar[1], P. and Jha[1], G.K.

[1]ICAR- Indian Agricultural Research Institute, New Delhi-12
[2]ICAR- National Institute of Agricultural Economics and Policy Research, New Delhi-12
Corresponding author email- *kishore.prabhat89@gmail.com*

Abstract

In India, groundwater development has been more intense in north-western region of the country which considered being origin and colossal beneficiary of Green Revolution. Government incentives to install water extraction mechanisms at farmers' field and policy of free/subsidies electricity for agriculture have rapidly increased number of wells leading to over-exploitation of groundwater. With rapid decline in groundwater level, Punjab and Haryana state came up with an act namely "Preservation of Subsoil Water Act, 2009" to restrict groundwater depletion. The Act prohibit farmers from sowing paddy nursery before 10th of May and transplantation before 10th of June or any dates as notified by the state government.

This study is an attempt to assess the impact of "Preservation of Subsoil Water Act, 2009" on declining groundwater level in Punjab. We employed synthetic control method to construct counterfactual of Punjab and same tested for its robustness. Result indicates that enactment of Punjab Subsoil Water Preservation Act, 2009, has not been effective in controlling groundwater depletion. Robustness test in term of space placebos has further bolster the result by assigning highest rank to Punjab among 16 Indian states considered for the study and also indicates lower probability to chance happing for estimated value of counterfactual groundwater level. The continuous decline in groundwater level could be due to increase in area under paddy cultivation, more dependency on groundwater with increase in number of deep tubewell and its electrification. Further policy of free electricity for agriculture might have acted as deterrent in restricting groundwater depletion. So, to abate fast decline of groundwater level, prime focus should be on availability of resources primarily water for crop selection and tweaking water use efficiency for crops grown. Also, revisiting of canal irrigation system and groundwater recharge can be pivotal to confine groundwater depletion in the state.

Keywords: Irrigation, Groundwater level, Over-exploitation, Punjab, Synthetic control method

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" conducted at ICAR-IARI, New Delhi.

Introduction

Groundwater has emerged as a predominant source of fresh water to fulfill increasing water demand of various sector of economy (Jia et al., 2020; Singh et al., 2019; Matthew et al., 2009). It is assessed that more than one third of the world's fresh water requirement is realized through groundwater (Siebert et al., 2010; Moreaux and Reynaud 2006). The unrestricted extraction of groundwater without accounting its availability in aquifer, has led to stern depletion of groundwater level in several parts of the world (Singh and Kasana 2017; Steward and Allen 2016; Patle et al. 2016; Machiwal and Jha 2014; Chaudhuri and Ale 2014; Panda et al. 2012; Chawla et al. 2010). Groundwater depletion is much more serious in north-western Indian states-Rajasthan, Punjab, Haryana and Delhi (40 mm/year), the high plains of the USA (27.6 mm/year) and the north China plain (22.0 mm/year) (Famiglietti, 2014; Feng et al., 2013; Scanlon et al., 2012; Matthew et al., 2009).

In India, irrigation infrastructure has improved significantly and the country has emerged as a world leader in terms of irrigated area (GoI, 2019; Shah 2012; Aeschbach-Hertig and Gleeson 2012). Over time, dependency on groundwater as a source of irrigation is rising steadily and the share of groundwater in net irrigated area has increased from 29 per cent in the year 1950-51 to 64 per cent in 2016-17 (GoI, 2019). For extraction of groundwater, the escalated installation of tubewells/borewell at farmers' field led to several environmental problems including groundwater depletion (Singh et al., 2019; Kaur and Vatta, 2015; Singh and Singh 2002). In last 20 years, groundwater extraction stage and share of over-exploited assessed unit (blocks/mandals/talukas) has increased by more than 100 and 200 per cent respectively (CGWB, 2019; Tripathi, 2016; Singh and Singh 2002; Planning Commission, 2007). This alarming rate of groundwater depletion will be detrimental for sustainable aquifer development and escalate its extraction cost, setting pressure on agricultural production system (Chaudhuri and Ale 2014; Gandhi and Bhamoriya 2011; Akther et al. 2009; Zektser et al. 2005).

Punjab-granary of India, is primarily based on paddy-wheat cropping pattern with almost all area endowed with irrigation facilities. Over the years, groundwater level has depleted at alarming rate (40.9 centimeter/year) from 8 meter in 1996 to 17 meter in year 2017 (CGWB, 2019). In Punjab, groundwater extraction is 66 per cent higher than its replenishable availability and 79 per cent of administrative blocks have been categorized as over-exploited which is highest among other Indian states (CGWB, 2019). Endorsing the faster depletion of groundwater level as serious issue, state government came up with a legislation titled "Punjab Preservation of Subsoil Water Act, 2009". The act prohibits sowing of paddy nursery before 10th of May and its transplantation in main field before 10th of June or any date as notified by the government. It was estimated that delaying of paddy crop by 10th of June can check fall in water level by 30 centimeter besides saving 276 million kWh electricity subsidy worth Rs.1220 million (Singh, 2009).

So, it is pertinent to assess impact of this legislation on groundwater level after a decade of its implementation. The study employs synthetic control method and assesses the impact of "Punjab Subsoil Water Preservation Act (PSWPA), 2009" on groundwater depletion at aggregate level.

Methodology

The study is based on secondary data for different aspects of groundwater and its use in agriculture, collected from various published sources such as Central Groundwater Board, minor Irrigation Census, Directorate of Economics and Statistics, Indian Metrological Department, and Economics and Statistical Organization of Punjab Government. The selected variables analyzed in the study include groundwater level, Rainfall, Electricity consumption per hectare, cropping intensity, Share of groundwater area, Paddy cropped area, Paddy irrigation hours, and Tubewell density per thousand hectare.

The study has employed synthetic control method (SCM) to assess the impact of legislative changes (Punjab Subsoil Water Preservation Act, 2009) on groundwater level. Any policy intervention usually takes place at aggregate level such as state or country. Traditional 'with-without' and 'before-after' approaches of impact assessment suffer primarily from two limitations, a) how fairly comparison unit selected (degree of selection ambiguity) and, b) it typically employ sample data at disaggregate level and uses inferential techniques that measure uncertainty at aggregate level for entire population. In reality, it is often difficult to find a single untreated unit that approximates the most relevant characteristics of the treated unit.

In recent years, SCM is a widely used impact assessment technique at aggregate level in several sectors (Abadie et al 2010, 2015; Kreif, 2016). Its application in agricultural sector is also gaining importance over time. The SCM, pioneered by Abadie and Gardeazabal (2003), is a data-driven approach in choosing comparative units. It gives insight for systematic selection of comparison unit based on similarity of parameter considered in the model. SCM construct counterfactual of treated unit by considering weighted average assigned to non-treated units. In contrast to a difference-in-differences (DID) design, SCM does not give same weight to untreated units (Galiani and Quistorff, 2016). Further, it also allows the effects of observed and unobserved predictors of the outcome to change over time, while assuming that pre-intervention covariates have a linear relationship with outcomes in post-treatment (Kreif et al., 2016). The advantage of constructing counterfactual unit with this method is that the pre-intervention characteristics of the treated unit can often be much more accurately approximated by a combination of untreated units than by any single untreated unit (Abadie et al. 2015). The basic idea behind the SCM is that the outcomes from the control units are weighted so as to construct the counterfactual outcome for the treated unit, in the absence of the treatment (Kreif et al., 2016). If the intervention has significant impact then there will be divergence in outcome values between the synthetic and treated unit in the post-treatment period.

Econometric model

Suppose there is S+1 state in India where one state received intervention at state level and remaining states never received such intervention. States without intervention could be considered as "potential control" or "donor pool". Let Y_{it}^{N} be the outcome that would be observed for state i^{th} at time t in absence of intervention where i= 1, 2...,S+1 and time t=1, 2,…,T. let T_0 be intervention year where $1 \leq T_0 < T$. Further, Y_{it}^{I} be the outcome that would be observed for unit i^{th} at time t if i^{th} unit for intervention in period T_0+1 to T. Here assumption is outcome of untreated unit does not affected by intervention in treated unit. Impact of intervention is quantified by δ_{it} where

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

β_{it} be an indicator that take value 1 if unit i^{th} is exposed to treatment at time *t* and value 0 otherwise. So the observed outcome for unit i^{th} at time *t* is

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

In our study we assumed that only one state is exposed with treatment and that only after period T_0 (with $1 < T_0 < T$), so

$$\beta_{it} = \begin{cases} 1 & if\ i = treated\ unit\ and\ t > T_0 \\ 0 & Otherwise \end{cases}$$

As Y_{it}^{I} is observed, to estimate α_{it}, we just need to estimateY_{it}^{N}. Suppose that Y_{it}^{N} is given by factor model

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

where δ_t is an unknown common factor with constant factor loadings across 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, μ_i is an *(F*×1*)* vector of unknown factor loadings, and the error terms ε_{it} are unobserved transitory shocks at the state level with zero mean

The synthetic control technique, subjects the attribute of 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 the optimal values of W and V_m where X_{1m} is the value of the m^{th} attribute of the treated unit; X_0m is a 1 x *j* vector containing the values of the m^{th} predictor attribute of each of the S potential comparison or control units; *W* is a vector of weights on control units; and V_m is a vector of weights on attributes of the control units such that they maximize the ability to predict the outcome variable of interest (Abadie et al., 2010). This optimization process minimizes prediction error between the actual and the synthetic in the pre-treatment period.

Y_1 is the observed outcome data for the treated, unit. Y_0W is the weighted average of outcome variables for the included control units. If there are no important omitted predictor variables then a reliable synthetic match will be created such that Y_1 -Y_0W, the distance is small in pre-intervention period (Abadie et al., 2010). If the outcome variable of the synthetic control diverges significantly from the actual outcome in the post-treatment period, the gap between actual and synthetic attributed to the effect of the treatment.

For robustness of result, placebo test applied to donor units that were not subjected to the intervention to analyse the divergence between synthetic and treated unit. The idea is that replicating the same analysis should not generate a significant divergence between synthetic and actual outcomes in the absence of treatment. These tests bolster confidence in the result obtained. Creating a synthetic for each donor unit enables researchers to ascertain whether the estimated treatment effect for the treated unit is of unique magnitude and direction.

Empirical strategy

Evaluating impact of the “PSWPA, 2009”, few article appeared in the research journal using difference-in-difference (Sekhri 2012) and panel regression (Tripathi et al 2016) on disaggregate data (district level) till year 2011, however, the intended act came up just before (in year 2009). Sekhri (2012) paper considers district with lower paddy intensification as control although this act was for whole state and Tripathi et al (2016) analysis is based on only before-after approach. In this paper, we employed SCM to assess impact at aggregate level by generating counterfactual of treated state based on weighted average of other states included in the model. Ambiguity in selection of comparison unit circumvented, and we extended data till year 2014-15 which allowed stronger depiction of anticipated impact.

Groundwater level has been considered as outcome variables and predictor variables are rainfall, electricity consumption per hectare, cropping intensity, share of groundwater irrigation, paddy cropped area, paddy irrigation hours per hectare and tubewell density per hectare.

Result and discussion

Table 1 shows the groundwater status for Punjab and other states considered for the study. At national level, 89 per cent of extracted groundwater (249 billion cubic meters) utilized as irrigation, however extraction is 38 per cent lower than extractable groundwater. In Punjab, groundwater extraction is about 66 per cent higher than extractable limit and primarily used for irrigation. Groundwater extraction per hectare is highest in Punjab states compared to other Indian states. With over extraction of groundwater in Punjab, about 80 per cent of assessed units (blocks) are over exploited projecting the state at first place among other states. Altogether, footing of groundwater resource in Punjab seems to be gloomy on groundwater resource front.

Table 2 represents summary statistics of the variables considered in the model. Average groundwater level of Punjab is nearly 2.29 meter deeper compared to donor pool states with mean water level of 11.91 meter. For Punjab, groundwater level depleted from 9.25 meter in 2000-01 to 15.64 meter in year 2014-15. Average rainfall is much lesser in Punjab compared to rainfall for the donor pool states. Electricity use per hectare is 1068.56 kWh which is much higher due to free electricity policy in Punjab since year 1997. Intensive agriculture followed in Punjab which uses almost all the crop area in both the season primary dependent on groundwater with higher density of tubewells. Punjab agriculture predominates with paddy cultivation in kharif season and applies significantly higher irrigation hours per hectare compared to average of donor pool state.

Table 1. Status of groundwater resources for states considered in the study

State	Stage of GW extraction (%)	Share of irrigation in GW draft (%)	Share of rainfall in GW recharge	GW extraction (m^3/ha of NSA)	Electri-city use (kWh/ha)	Well density (no/000 ha of NSA)	Electric wells (%)	Share of over-exploited blocks (%)
Treated unit (with 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 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

Note- data based on dynamics of groundwater resources-2017 and 5th minor irrigation census-2013-14; GW-groundwater; NSA- net sown area. Haryana state excluded from analysis as state enacted similar policy in same year.

Table 2. Summary statistics of Punjab and donor pool

	Donor pool (15 states)				Punjab
	Mean	Std. Dev.	Min	Max	Mean
Outcome variable: 2000-01 to 2014-15					
Pre-monsoon groundwater level (meters)	9.62	4.77	2.34	25.58	11.91
Predictor variables: 2000-01 to 2014-15					
Rainfall (millimeters)	1250.59	568.02	184.75	3012.70	491.70
Electricity consumption (kWh per hectare)	529.88	579.44	2.38	2842.38	1068.56
Cropping intensity (per cent)	137.28	20.74	107.69	185.14	188.47
Share of groundwater irrigation (per cent)	53.49	21.23	1.52	86.74	72.74
Tubewell density (per 000' hectares)	128.58	90.60	8.82	440.74	272.12
Paddy cropped area (000' hectares)	2255.34	1797.25	72.50	6071.00	2702.53
Paddy irrigation hours (per hectares)	137.46	106.26	14.00	441.59	313.30

Impact of Punjab Subsoil Water Preservation Act, 2009 on groundwater level

Table 3 presents weight assigned by SCM to each state in order to construct counterfactual of Punjab's groundwater level. The estimated weight is based on similarity in characteristics of predictors variable considered in the model i.e. higher weight given to that states which are similar in characteristics to treated states (Punjab) while constructing counterfactual. In our analysis, SCM have given weight to 4 states out of 15 states in donor pool namely Uttar Pradesh, Uttarakhand, Rajasthan and Tamil Nadu.

Table 3. Weight assigned to the donor pool state to construct counterfactual

State	Weight	State	Weight
Andhra Pradesh	0.000	Madhya Pradesh	0.000
Assam	0.000	Maharashtra	0.000
Bihar	0.000	Rajasthan	0.170
Chhattisgarh	0.000	Tamil Nadu	0.011
Gujarat	0.000	Uttar Pradesh	0.628
Himachal Pradesh	0.000	Uttarakhand	0.191
Jharkhand	0.000	West Bengal	0.000
Karnataka	0.000		

Figure 1 shows groundwater level of Punjab and its synthetic (counterfactual) during 2000-2014. Groundwater level of synthetic Punjab closely tracks the trajectory of actual groundwater level of Punjab during pre-treatment period. Close trajectory of real and synthetic Punjab in pre-treatment period indicate close approximation of the groundwater level during post treatment period. Synthetic Punjab during post treatment period represent trajectory of groundwater level of Punjab in the absence of policy intervention. In post-intervention period, there is much divergence in trajectory of actual and synthetic groundwater level of Punjab. The actual groundwater level of state further depleted even after passage of legislation which indicates that legislation could not able to restrict groundwater depletion for which this act came into force. This finding is similar to Sekhri (2012) who observed deterioration in annual groundwater level situation in paddy growing area of Punjab and Haryana even after the enactment of the PSWPA, 2009. Reason for worsening water level is that the farmers might have responded to the policy by increasing the number of irrigations applied or using more water per irrigation after the mid June transplanting (Sekhri, 2012). In our model, we included irrigation hours per hectare for paddy crop as proxy for these constraints to estimated model, however result indicate similar pattern. On the other hand, our study contradict the findings of Tripathi (2016) who came up with research that enactment of the PSWPA 2009 has significantly improved groundwater level in Punjab based on panel data analysis for period of 1985 to 2011.

Figure 1. Groundwater level of Punjab and it's synthetic

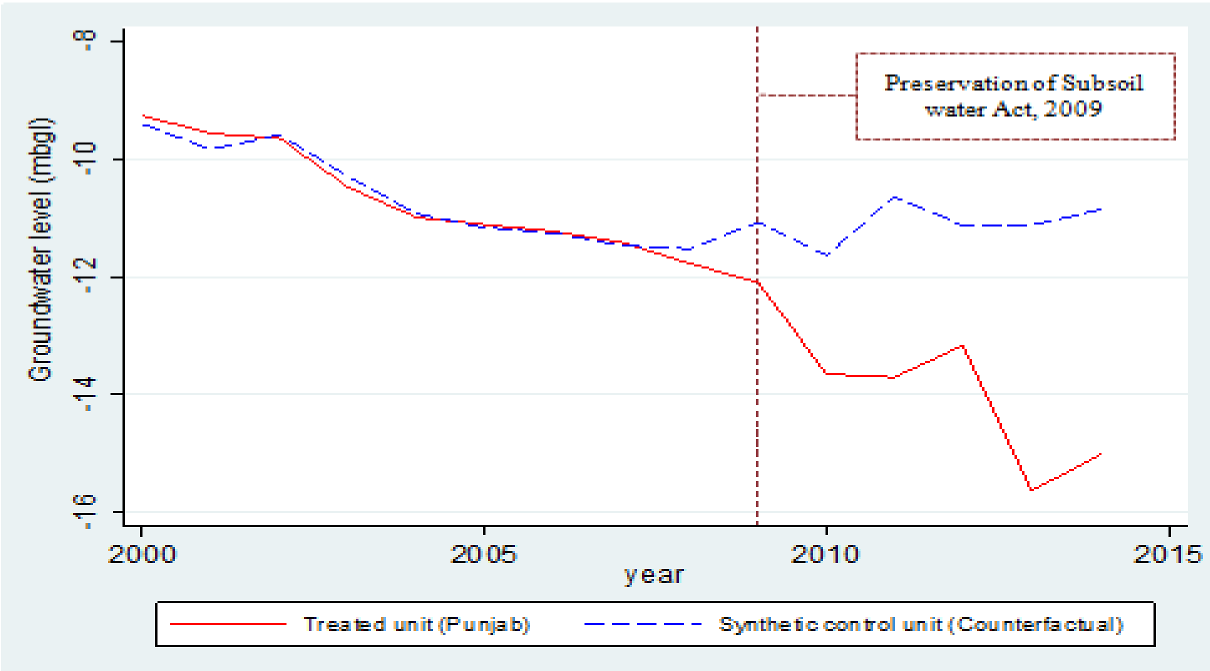


Table 4 presents the estimated value of predictor variable for real and synthetic Punjab. Estimates for predictor variables to create counterfactual of Punjab arrived by assigning relevant weight to particular state under donor pool based on characteristics similarity of actual Punjab. So, the estimated value of predictor variable for synthetic is much closer to actual value Punjab, compared to average of predictor variable without weight.

Table 4. Predictor balance of synthetic control

Predictor variables	Punjab		Average of 15 states as donor pool
	Real	Synthetic	
Ln(Rainfall in millimeters)	6.15	6.65	7.03
Ln(Electricity consumption in kwh/ha)	6.79	5.53	5.34
Cropping intensity in per cent	187.46	148.43	135.65
Share of groundwater irrigation in per cent	72.94	72.04	52.45
Ln(Paddy cropped area in thousand hectare)	7.87	7.41	7.19
Ln(Paddy irrigation hours per hectare)	5.86	4.38	4.69
Ln (Tubewell density per thousand hectare)	5.64	5.58	4.60

Note: all the variable averaged for pre-intervention period (2000-01 to 2008-09).

Groundwater level estimated for synthetic Punjab is presented in table 5. In period of pre-intervention period difference between actual and synthetic groundwater level of Punjab varied from 0.02 to 0.27 meter which is much lesser compared to post-intervention period. In post-intervention period, difference in actual and synthetic value of groundwater level varied between 1.03 meters to 4.52 meters indicating towards higher depletion of groundwater level.

Table 5. Groundwater level of actual and synthetic Punjab during pre- and post-intervention

Outcome variables	Punjab		Difference
	Actual	Synthetic	
	Pre intervention period		
groundwater level(2000)	-9.25	-9.40	0.14
groundwater level(2001)	-9.56	-9.83	0.27
groundwater level(2002)	-9.63	-9.58	-0.06
groundwater level(2003)	-10.47	-10.28	-0.19
groundwater level(2004)	-10.98	-10.92	-0.06
groundwater level(2005)	-11.11	-11.16	0.05
groundwater level(2006)	-11.23	-11.25	0.02
groundwater level(2007)	-11.40	-11.46	0.06
groundwater level(2008)	-11.77	-11.53	-0.25
	Post intervention		
groundwater level(2009)	-12.10	-11.07	-1.03
groundwater level(2010)	-13.65	-11.63	-2.02
groundwater level(2011)	-13.71	-10.63	-3.07
groundwater level(2012)	-13.16	-11.13	-2.03
groundwater level(2013)	-15.64	-11.12	-4.52
groundwater level(2014)	-15.03	-10.85	-4.17

Note: negative sign shows depth of water level below ground level.

In post estimation, placebo test and rank test done to verify robustness of the result obtain in previous section. In placebo test, state in donor pool assigned similar treatment for groundwater level and its effect estimated to see how these state behave. In case of significant impact of policy change (positive or negative) for treated state (Punjab), difference of actual and synthetic groundwater level of the donor pool states should not be higher than treated state. In figure 2, line which represent treated (Punjab) significantly deviated from other state in donor pool which indicates that groundwater level have significantly gone deeper even after enactment of PSWPA. Significance level of difference between actual and synthetic in post treatment is also depicted in figure 2. Post estimation shows that there is significant difference of groundwater level in entire post-intervention period.

Rank test conducted based on root mean squared prediction error (RMSPE) of post- and pre-intervention of all states in donor pool including Punjab (Table 6). Estimate of post-pre ratio indicates towards the effect of treatment for the states in consideration. Based on post-pre ratio of RMSPE, ranking done for each state in which Punjab received first rank. This shows that there is higher difference in actual and synthetic groundwater level of Punjab compared to donor pool states in post treatment year. Rank test bolster earlier result that groundwater level in Punjab has significantly depleted even after enactment of the PSWPA.

Figure 2. Groundwater level differences between actual and synthetic Punjab (placebo gap) with their significance level

Table 6. Rank test for states in donor pool and Punjab

Rank	State	Post-pre ratio	Rank	State	Post-pre ratio
1	Punjab	8.500	9	West Bengal	2.104
2	Bihar	3.670	10	Andhra Pradesh	2.062
3	Himachal Pradesh	3.485	11	Rajasthan	1.874
4	Assam	2.569	12	Karnataka	1.717
5	Madhya Pradesh	2.508	13	Tamil Nadu	1.575
6	Gujarat	2.342	14	Chhattisgarh	1.350
7	Jharkhand	2.212	15	Uttar Pradesh	0.815
8	Maharashtra	2.149	16	Uttarakhand	0.557

Reasons for behind groundwater depletion at aggregate level

To know why groundwater level has depleted in Punjab even after enactment of law to restrict groundwater depletion, we analysed groundwater level at districts level and found that for most of the districts, there is continuous decline in water level even after enactment of PSWPA (figure 3). Pictorial depiction of groundwater depletion, groundwater extraction and scatter diagram of groundwater level of observation wells is given in appendix 1a, 1b and 1c respectively. Average rate of groundwater depletion is higher in post intervention period compared to pre-intervention for most of Punjab's districts (table 7). Also, in groundwater depleted districts, share of paddy and groundwater irrigation intensified over the years. Overall, groundwater level of state depleted with 8 centimeter higher in post intervention compared to pre-intervention period. Decadal mean groundwater (mbgl) is depicted in figure 4. Paddy, considered being water guzzling crops, is major kharif crops grown in state, managed to increase even after passes of the PSWPA. Share of gross irrigated area by groundwater has also increased by 7 per cent in post treatment period indicating towards more intensification of tubewell and higher withdrawal of groundwater for irrigation. This could be one of the reasons for faster depletion of groundwater level in Punjab.

Figure 3. Trends of groundwater level in districts of Punjab

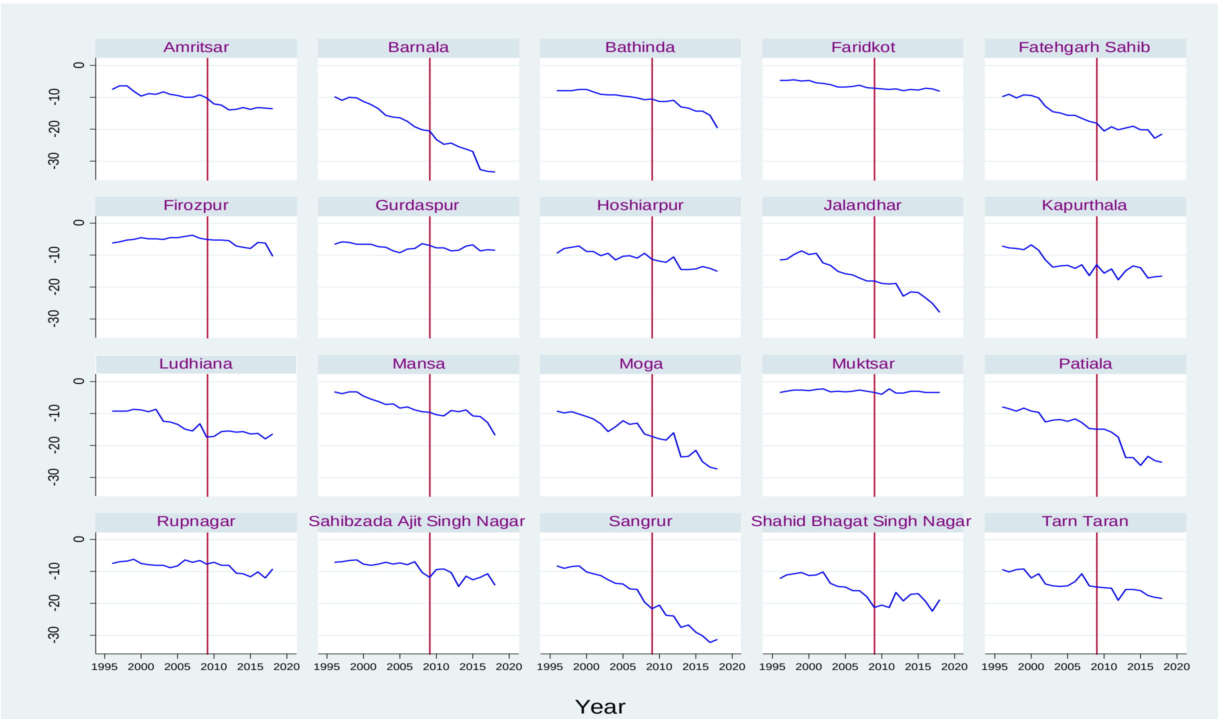


Table 7. Depletion of groundwater level, share of paddy and groundwater area in Punjab

Districts	Average rate of groundwater depletion (meter/year)			Share[@] paddy area (%)			Share[@] of groundwater irrigation (%)		
	Pre[$]-	Post[$]-	diff	2000	2009	2018	2000	2009	2018
Moga	0.52	1.09	0.57	38.23	44.98	46.75	76.61	80.83	100
Patiala	0.53	1.03	0.50	28.84	30.41	33.77	95.77	99.22	99.98
Barnala	0.95	1.31	0.36		41.05	45.43		79.59	76.16
Firozpur	-0.04	0.3	0.35	29.29	29.21	45.67	73.56	65.24	85.49
Bathinda	0.29	0.6	0.31	16.93	17.33	26.99	19.8	29.83	57.78
Rupnagar	0.04	0.33	0.29	43.68	44.71	45.32	95.73	97.82	99.7
Sangrur	1.01	1.23	0.22		28.06	31.21		98.81	100
Amritsar	0.18	0.36	0.18	38.7	43.24	42.62	57.17	71.75	94.69
Tarn Taran	0.31	0.46	0.15		42.94	45.97		52.15	89.75
Hoshiarpur	0.28	0.37	0.09	21.11	19.23	22.49	95.81	86.92	97.75
Gurdaspur	0.06	0.15	0.08	43.15	42.58	42.80	88.07	75.81	93.12
Muktsar	0.03	0.04	0.01	19.85	19.83	37.19	88.09	6.83	0
SAS Nagar	0.28	0.26	-0.02	28.68	30.03	31.91	92.05	89.31	95.71

Jalandhar	0.83	0.76	-0.07	32.58	36.63	40.95	96.67	98.54	100
Faridkot	0.21	0.08	-0.13	35.84	37.22	46.25	22.35	14.96	76.79
Mansa	0.57	0.43	-0.14	23.92	19.2	27.68	26.09	40.7	44.61
Fatehgarh Sahib	0.78	0.41	-0.37	42.91	43.94	45.46	98.37	92.81	99.97
Kapurthala	0.65	0.26	-0.39	38.68	41.07	43.86	99.11	99.91	99.98
Ludhiana	0.64	0.15	-0.49	39.58	42.48	44.07	97.15	95.44	99.02
SBS Nagar	0.76	0.18	-0.58	38.47	43.04	44.77	80.48	91.63	87.79
Punjab	0.37	0.45	0.08	33.47	35.01	39.1	74.49	70.98	77.67

Note: $-policy intervention; @-based on gross irrigated area; estimated value is based on triennium ending.
Source: CGWB, 2018

Figure 4. Decadal mean groundwater level in pre-post policy intervention in Punjab

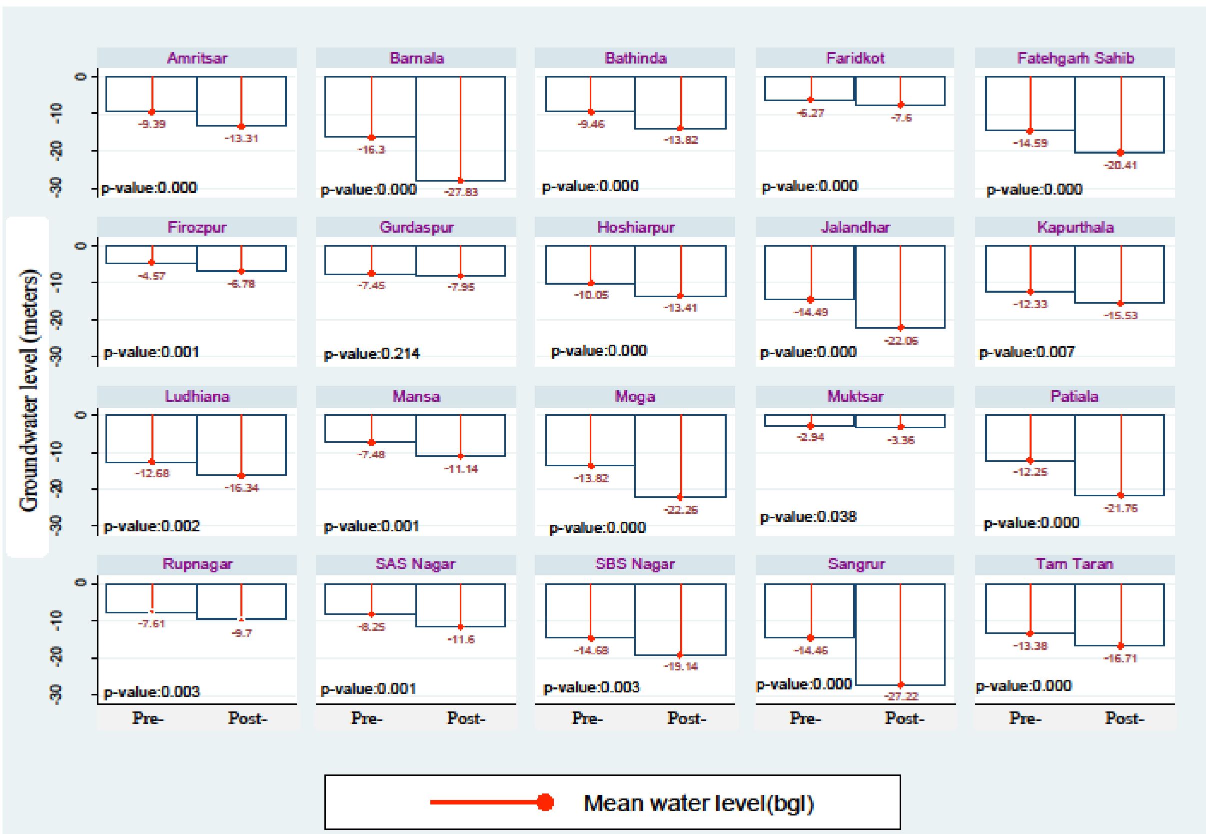
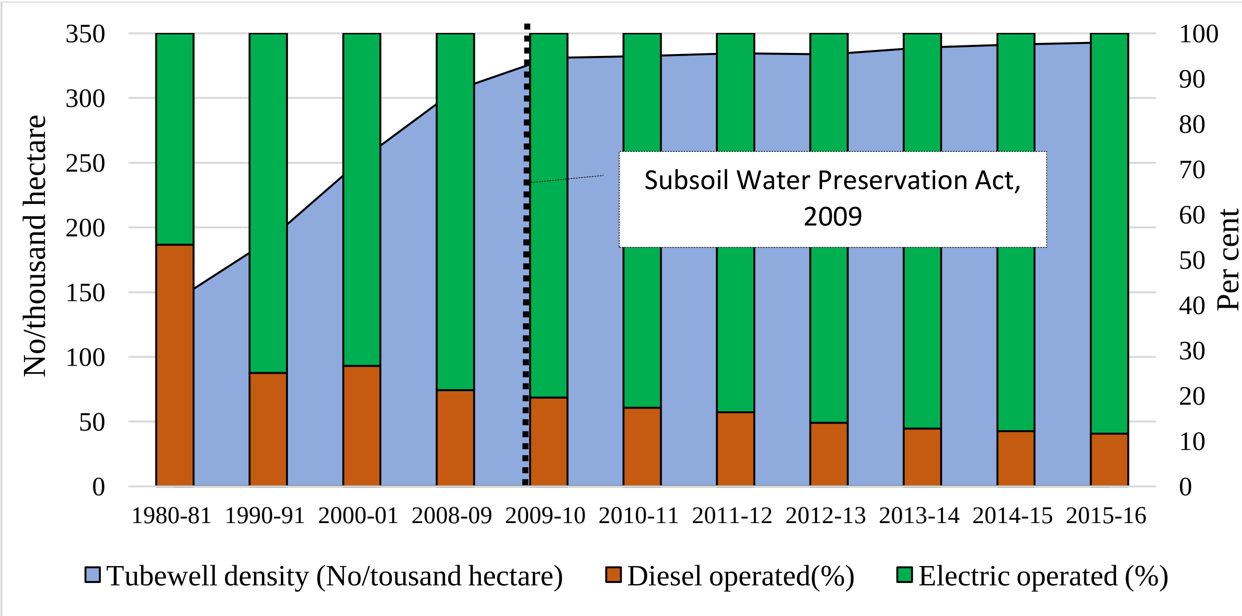


Figure 5 shows tubewell density and share of electric & diesel operated tubewells. Share of electric tubewell has increased from 47 per cent in year 1980 to 88 per cent in year 2015 by replacing diesel operated tubewells. Incentivizing farmers who owns electric tubewell with passes of free electricity policy in 1997 could be prime factor for high electric connection of tubewells. Also, zero private costing for groundwater extraction through electric tubewell could be one of the key factors for its higher draft leading to deepening of water level and causing failure of diesel operated tubewells. Number of tubewell per thousand hectares has increased from 143 in year 1980 to 343 in year 2015 which might have led to deepening of water level.

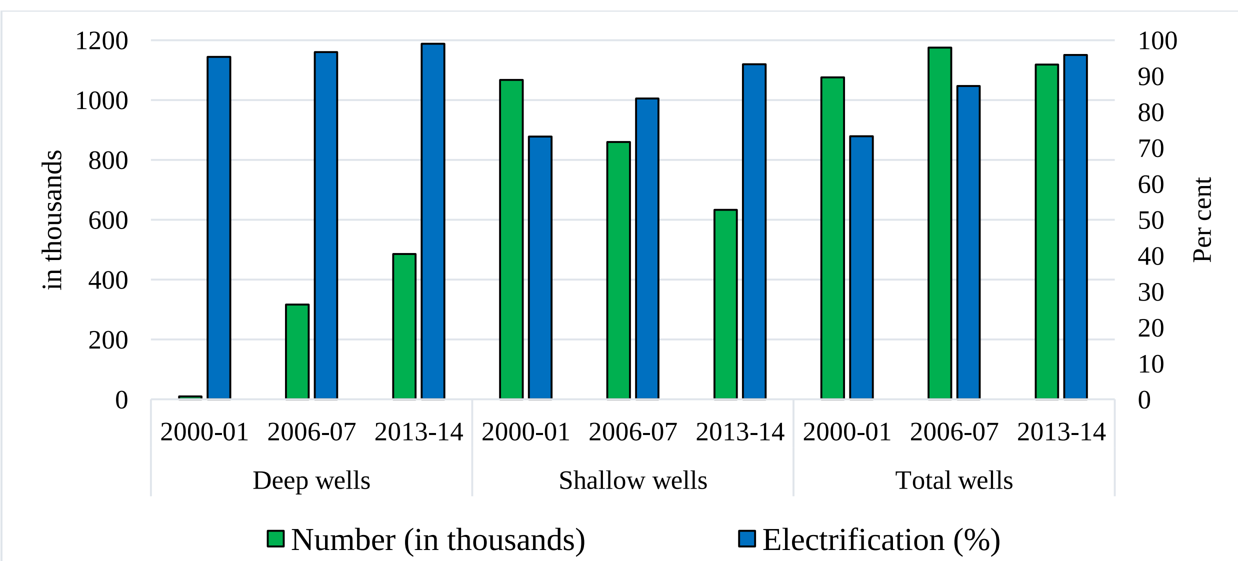
Figure 5. Tubewell density and share of electric & diesel tubewell



Source: Government of Punjab, 2017.

Number of deep wells has increased significantly, from 10 thousand in 2000-01 to 485 thousand in 2013-14 with almost all well electrified (figure 6). Number of shallow wells has decreased from 1067 thousand in year 2000-01 to 633 thousand in year 2013-14. Deepening of water level leads to failure of shallow wells and farmers switched for installation of deep well primarily submersible which have higher capacity in drafting groundwater. Further, with free electricity policy, farmers incentivized to electrify their wells and extracted groundwater more intensively.

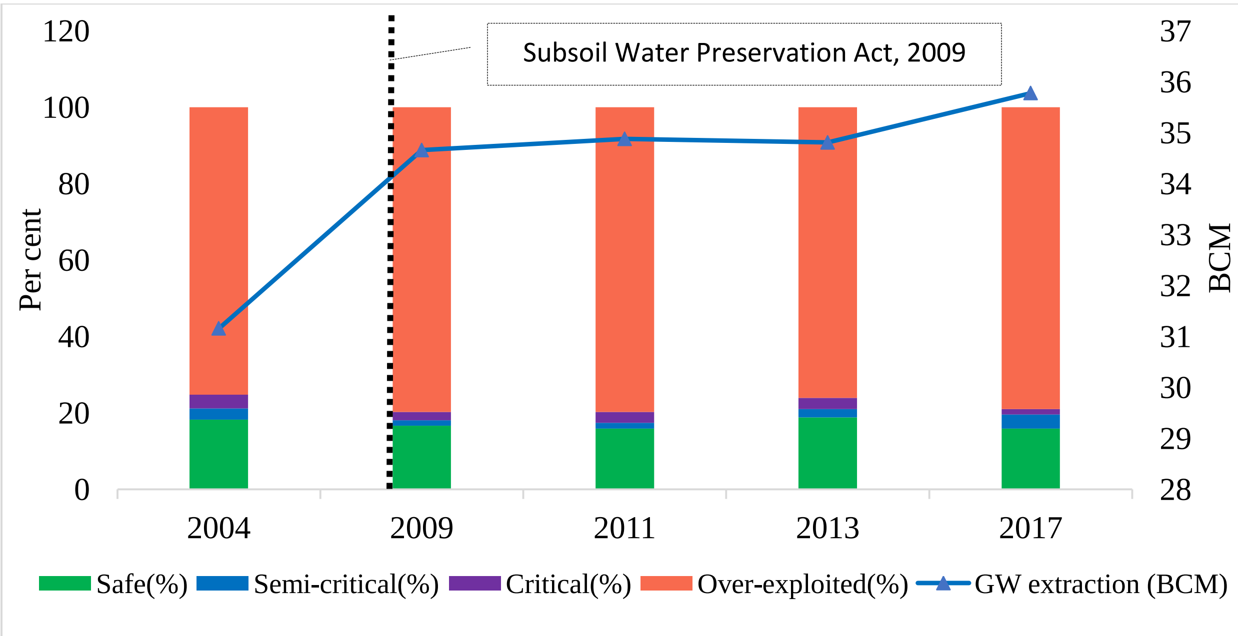
Figure 6. Number of wells and its electrification



Source: Minor Irrigation Schemes, 2017

Figure 7 shows temporal changes in groundwater status of Punjab. Nearly 80 per cent of 138 assessment blocks in Punjab categorized as over-exploited where annual groundwater extraction remain higher than its availability. Even after policy intervention in the year 2009, situation remained unchanged. Groundwater draft increased from 31.16 BCM in 2004 to 35.78 BCM in 2017 whereas, annual groundwater availability remains to be near 21 BCM.

Figure 7. Groundwater extraction and categorization of blocks in Punjab



Source: CGWB, 2019

Conclusion and policy implications

In Punjab, Subsoil Water Preservation Act, 2009 was enacted to restrict groundwater depletion by prohibiting sowing of paddy nursery and its transplantation before certain date as notified by government. Groundwater level data signify continuous decline in water level even after enactment of PSWPA. Analysis employing synthetic control method shows that the enactment of PSWPA, 2009 could not able to restrict the deepening of water level in post treatment period. In the state, continuous increase in paddy area and significant rise in deep wells observed over the years. Also, electrification to the wells increased over the years possibly due to policy of free electricity in the state. So, to abate fast depletion of groundwater, prime focus should on availability of resource primarily water for crop selection and tweaking water use efficiency of crops grown. In recent years, government innovation in groundwater extraction policy like “Pani Bachao Paisa Kamao” may have higher potential to restrict groundwater depletion.

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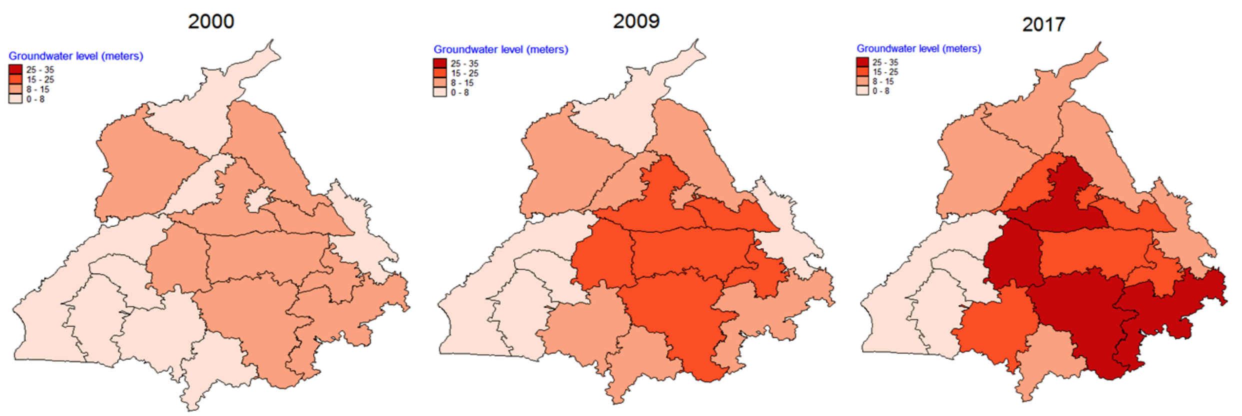
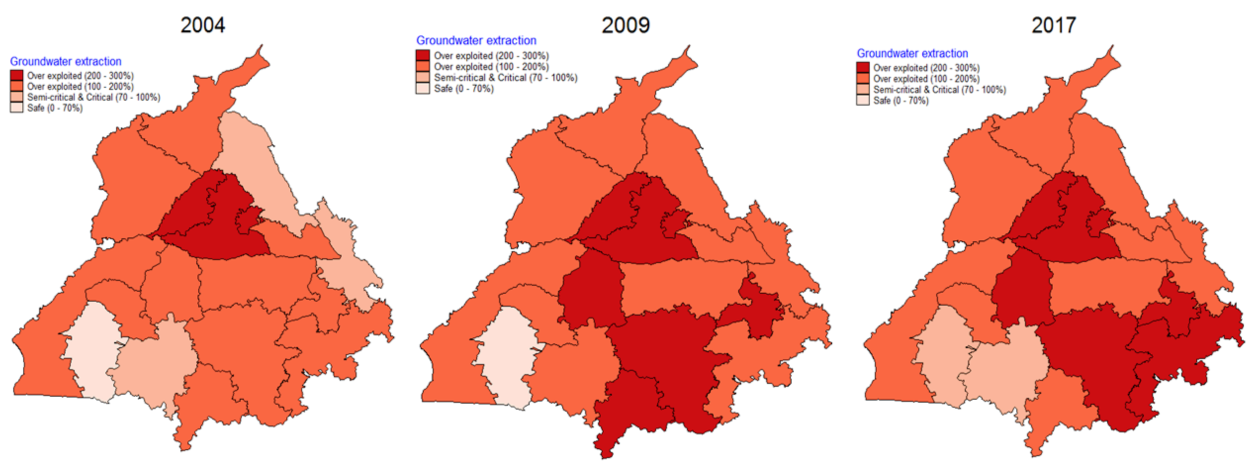
Appendix

Appendix 1a. Groundwater level across Punjab districts



Appendix 1b. Groundwater extraction across Punjab districts



Appendix 1c: Spatial and temporal depiction of groundwater level in observation wells