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Role of public policy in sustaining groundwater: impact of 'The Punjab Preservation of Sub Soil Water Act, 2009'

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Abstract Employing the Difference-in-Difference technique to the time series of groundwater level, this study assesses the impact of 'The Punjab Preservation of Sub Soil Water Act, 2009' on the groundwater extraction in Punjab. Over the past two decades, the groundwater level in the state has fallen by 0.43 metres per annum. Our results indicate that even after the implementation of the Act, the groundwater depth in the state has kept on falling, more so in the high rice-growing districts. After the policy change, the groundwater depth in the high rice-growing districts was 1.48 meters lower than in low rice-growing districts.

Keywords Groundwater, Critical stage, Difference-in-difference

JEL Codes C54, O38, Q25

Agriculture relies on both surface and groundwater for irrigation. However, due to the ever-increasing demand for water in agriculture, groundwater has emerged as the dominant source of irrigation. With an annual 251 billion cubic metres (bcm) of groundwater, India is the largest user of groundwater for irrigation in the world (CGWB 2017; Vijayshankar, Kulkarni, and Krishnan 2011). However, the technology-led intensification of agriculture has put excessive pressure on groundwater resources, raising concerns about its effects on the long-term sustainability of agriculture. At least 60% of India's districts are facing the challenge of over-exploitation of the groundwater.

The legal structure in India permits unrestricted free access to groundwater. Riparian rights govern groundwater exploitation, and a landowner has the right to extract groundwater. Groundwater regulation in India operates through state policies, different strategies and instructions (Shah et al. 2001; Shah 2008; Siebert et al. 2010). For example, the state of Punjab provides free electricity to the farm sector. Although, in other states, electricity is not metered; it is provided at a flat rate depending on the pumps' horsepower for lifting the water from under the ground. At the same time, the federal government provides guaranteed minimum support for paddy and wheat, the water-intensive crops.

The federal and state governments have undertaken several initiatives to conserve groundwater resources (Mahajan, Bharaj, and Timsina 2009). However, recognizing groundwater depletion as a serious concern for agricultural growth, the Government of Punjab passed the 'The Punjab Preservation of Sub Soil Water Act, 2009' (hereafter called as Act, 2009). The Punjab government implemented the Act, 2009 to control groundwater depletion through mandatory restrictions on the raising of the paddy nurseries before May 10, and their transplantation before 10th June. The primary purpose of the Act, 2009, was to save groundwater by prohibiting sowing and transplanting of paddy before the specified dates. This paper examines if the Act 2009 could help check the groundwater depletion in Punjab.

Materials and methods

Data and variables

We studied the impact of the Act, 2009, utilizing panel data on 20 districts for 20 years from 1999 to 2018. The study period was divided into two-time slices, i.e., 1999-2008 (pre-Act) and 2009-2018 (post-Act). At present, the state has 22 districts, but due to the non-availability of time series data on the two newly carved districts, viz., Pathankot and Fazilka, these were merged with their parent districts Gurdaspur and Ferozepur, respectively.

The groundwater levels and rainfall data were obtained from the Central Ground Water Board and Indian Meteorological Department. The data on population density were obtained from the Population Statistics of Punjab published by the Economic and Statistical Organisation, Punjab. In addition, we relied on various issues of the Statistical Abstract of Punjab for the data on canal and tube-well irrigated areas and cropping patterns.

Groundwater levels are being monitored by the Central Ground Water Board four times a year. The regime monitoring was started in 1969 by the Central Ground Water Board. There are 23196 observation wells in India, including 984 in Punjab. About 80% of the groundwater observation wells are located in the canal command areas of different canal systems. The minor command areas are part of Pathankot, Hoshiarpur, SBS Nagar, Rupnagar, SAS Nagar, Gurdaspur, Jalandhar and Ludhiana districts. We used groundwater level data compiled from the CGWB to calculate various parameters viz. change in water level from June-over-June and October-over-October, change through June-to-October and October-to-June. The change in water level from June-over-June and October-over-October captures the effect of annual rainfall and other variables. The change through June-to-October depicts the net monsoon recharge in the kharif season. It captures the impact of monsoon rainfall, the paddy area (the main crop that needs water) and other factors such as water management and water-use-efficiency. The change through October-to-June depicts the effect of withdrawals in the rabi season. The withdrawals during the rabi season indirectly affect the monsoon recharge.

Model specification

We used Difference-in-Difference (DiD) approach to study the impact of the Act, 2009. DiD is used to estimate the effect of an intervention by comparing changes in the outcomes over time between a population exposed to the intervention (the treated group) and a population that is not (the control group). Here, the high rice-growing districts were compared with low rice-growing districts before and after the Act, 2009. The districts, whose ratio of area under the rice to the total cultivated area exceeded the sample median (0.6) in 1999, were considered as the high rice-growing (treated) districts and the remaining districts as control. We hypothesized that the Act 2009 affected the groundwater level in the treated districts. Table 1 shows treated and control districts.

The DiD equation cab be written as:

$$Y_{it} = \beta_0 + \beta_1 \text{ Act} + \beta_2 \text{ Tr} + \beta_3 \text{ Act} * \text{Tr} + \beta_4 \text{ Rain} + \beta_5 \text{ CaIrri} + \beta_6 \text{ TbIrri} + \beta_7 \text{ Pd} + \beta_8 \text{ Cdi} + D_i + T_t + \varepsilon_{it} \quad \ldots(1)$$

Where Y_{it} is the annual groundwater level (m) in *i* district at time *t*, Rain is the annual average rainfall (mm), Act is an indicator variable that switches to 1 for the post-Act period i.e. 2009 to 2018 after the Act, 2009 was passed in the Punjab state and equals 0 for pre-act period i.e. 1999-2008. Tr is the treatment indicator that takes the value 1 if the district is treated and is 0 if the district is control. Act*Tr is an interaction

Table 1 High and low rice-growing districts

High rice-growing districts (Treated)		Low rice-growing districts (Control)	
Gurdaspur	Patiala	Jalandhar	Ferozepur
Amritsar	Sangrur	SBS Nagar	Muktsar
Tarn Taran	Barnala	Hoshiarpur	Moga
Kapurthala	Faridkot	Rupnagar	Bathinda
Ludhiana	F. Sahib	SAS Nagar	Mansa

of Act and treatment indicator. CaIrri is the ratio of canal irrigated area to total irrigated area, TbIrri is the ratio of tube well irrigated to total irrigated area, Pd is the population density, and Cdi represents Herfindahl crop diversification index. D_i is the district fixed effects, T_t is year fixed effects and ε_{it} is the error term. Coefficient β_3 (interaction term) is the parameter of interest. It gives the impact of the Act on the groundwater level. Year specific common shocks to all districts of the state are soaked up by the year or time fixed effects. Time invariant district-specific omitted variables that affect the likelihood of treatment are controlled for by including the treatment indicator.

Two specifications of Eq.(1) were estimated. One, only with district and year fixed effects:

$$Y_{it} = \beta_0 + \beta_1 \text{ Act} + \beta_2 \text{ Tr} + \beta_3 \text{ Act} * \text{Tr} + D_i + T_t + \varepsilon_{it} \quad \ldots(2)$$

And, another including all time-varying covariates with district and year fixed effects:

$$Y_{it} = \beta_0 + \beta_1 \text{ Act} + \beta_2 \text{ Tr} + \beta_3 \text{ Act} * \text{Tr} + \beta_4 \text{ Rain} + \beta_5 \text{ CaIrri} + \beta_6 \text{ TbIrri} + \beta_7 \text{ Pd} + \beta_8 \text{ Cdi} + D_i + T_t + \varepsilon_{it} \quad \ldots(3)$$

Unit root test

We tested for the stationarity in the time series by applying the unit root test. The unit root test exhibits whether the data are stationary or non-stationary and avoids spurious regression. As time progresses, the shocks decrease gradually for stationary time series, and there is a possibility that the process reverts to the mean. However, for non-stationary time series, the shocks persist over time, and there is no possibility to completely revert to the mean (Intriligator, Bodkin, and Hsiao 1996). The mean, variance and covariance of stationary data are independent of time. The Levin-Lin-Chu and Harris-Tzavalis unit-root tests were employed (Table 2).

Hausman test

The Hausman test favours fixed effect regression over random effect regression. The fixed effect model is defined as:

$$Y_{it} = \beta X_{it} + \gamma U_i + \varepsilon_{it}$$

Where Y_{it} is the outcome of individual *i* at time *t*, X_{it} is the vector of variables for individual *i* at time *t*, U_i is a set of unobservable factors for individual *i* that are not changing through time, hence the lack of the time subscript and ε_{it} is the error term. The fixed effect model removes the effect of time-invariant characteristics so we can assess the net effect of the predictors on the outcome variable.

Parallel trend

We tested the key assumption of DiD, i.e. the outcome in the treatment and control group would follow the same time trend in the absence of the treatment, i.e., a parallel trend would have existed between the two groups (Angrist and Pischke 2009). One way is the visual inspection of the trend (Fig 1.) for the treated and control groups for the pre-treatment period. A second way is to perform a 'falsification test or placebo test'. We performed a falsification test to estimate the DiD using the same treated and control districts used

Table 2 Unit root test for stationarity in data

Variables	Levin-Lin-Chu test			Harris-Tzavalis test	
	Unadjusted t	Adjusted t	p-value	Rho	p-value
	H_0: Panels contain Unit Root H_1: Panels are Stationary			H_0: Panels contain Unit Root H_1: Panels are Stationary	
Annual rainfall	-14.06	-4.47	0.00	0.14	0.00
CaIrri	-10.56	-2.04	0.02	0.51	0.00
TbIrri	-10.92	-2.42	0.00	-0.07	0.00
Population density	-12.21	-4.27	0.00	0.52	0.00
Crop diversification index	-11.89	-3.01	0.00	0.28	0.00
Annual water levels	-9.61	-1.91	0.02	0.69	0.75

Notes CaIrri = Ratio of Canal irrigated area to total irrigated area, TbIrri = Ratio of Tube well irrigated to total irrigated area

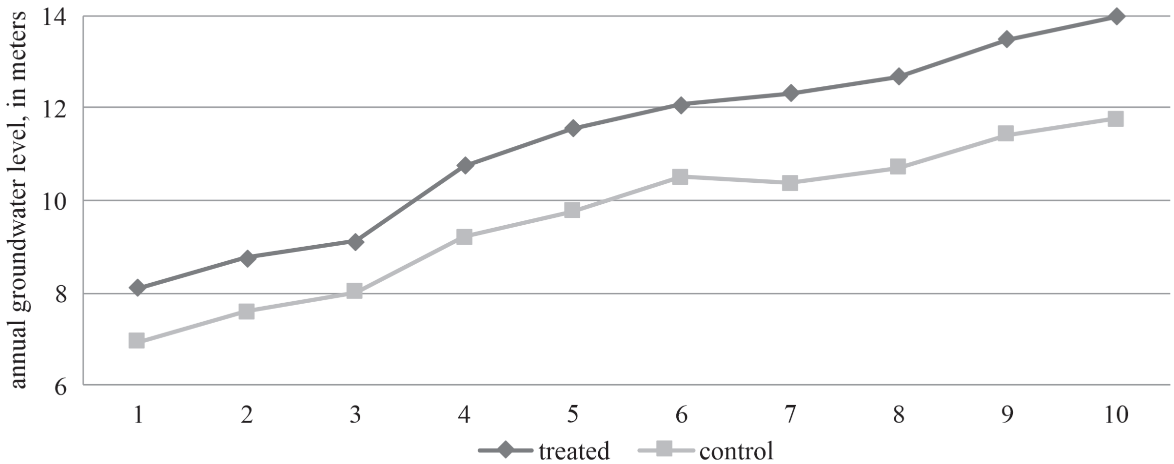

Figure 1 Parallel trend of annual groundwater levels for treated and control districts

in the previous regression for the pre-Act period. The modified version of the DiD model is:

$$Y_{it} = \beta_0 + \beta_1 \text{ Time} + \beta_2 \text{ Tr} + \beta_3 \text{ Time} * \text{Tr} + \varepsilon_{it} \quad \ldots(4)$$

Where β_3 is the placebo interaction term from 1999 to 2008. The interaction term coefficient was statistically not significant, satisfying the parallel trend assumption.

Crop diversification index (CDI)

We measured the extent of crop diversification using the Herfindahl-Hirschman Index (HHI).

$$HHI = \left(\frac{Area_i}{Total\ Cropped\ Area} \right)$$

Where $Area_i$ is the area under 'i[th]' crop. The value of HHI varies from zero (for perfect diversification) to one (for complete specialization). However, this concentration index cannot assume a theoretical minimum value for a finite number of crops. Also, it gives relatively more weight to larger crop activity (De and Pal 2017). The crop diversification index is defined as:

CDI = 1-HHI

Results and discussion

The shift of area under different water table depths

The area under critical water table depths has increased in Punjab. Figure 2 depicts the area under different water table depths within the state. The area under the water table depth of <10 m is considered non-critical as the water could be lifted through centrifugal pumps. A depth of more than 10 m is considered critical for groundwater resources sustainability. The area under the non-critical stage has decreased while it has increased in the critical stage. The critical area in the state was around 32% in 1996, which rose to 85% in 2018.

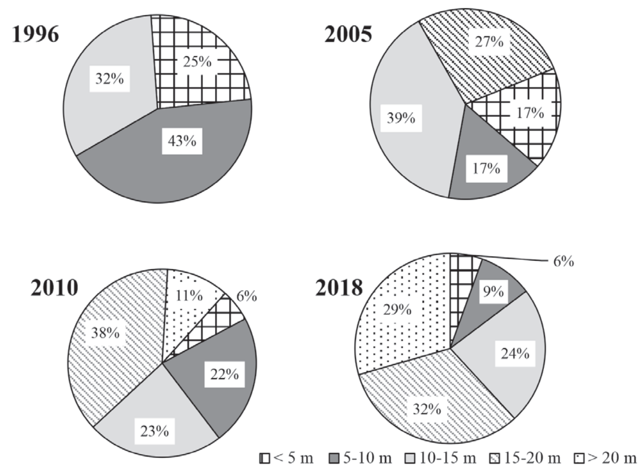

Figure 2 Change in water table depth, Punjab, 1996 to 2018

Source CGWB (2017) and Statistical Abstract of Punjab (various issues)

A significant part of the irrigated area has shifted to deeper water table depths (Fig. 2), signifying that the state faces a sharp decline in groundwater resources. One of the reasons is intensive rice-wheat crop rotation practised in the state and decreased rainfall (Aggarwal et al. 2009). Even the non-critical area lies in those parts of the state where either the extraction is limited due to its brackish water (Muktsar, Bathinda, Mansa, i.e. south-west zone[1]) or the extraction is economically unviable due to rocky terrain (Hoshiarpur, SAS Nagar, Rupnagar, i.e. Kandi zone).

Stage of groundwater development

The annual groundwater recharge for the state increased 1.5 times, from 17 billion cubic metres (bcm) in 1984 to 23.93 bcm in 2017, while the annual draft increased 2.5 times from 14 bcm to 34.05 bcm resulting in a negative groundwater balance of 10.63 bcm (GOP 2017). The current stage of groundwater development is 166%. The draft as a percentage of recharge increased from 72 in 1984 to 98 in 1997 and further to 166 in 2017. All the districts of the Central zone are over-exploited, the stage of groundwater development is above 100 %. The state of groundwater development exceeded 200 % in most of the districts of the Central zone. The only two districts, Muktsar and Bathinda have 74% and 98% groundwater development, respectively. Bestowed at the time of the Green Revolution the boon of nature reversed in the later years due to the extreme utilization of water, soil, pesticides, and fertilizers (NABARD 2019). The block-wise map of groundwater assessed units reveals that out of the total 138 blocks in Punjab, 109 blocks are over-exploited, two are in critical, and five are in the semi-critical stage (Fig. 3). The increase in the number of over-exploited blocks (Shah et al. 2008; Kaur, Sidhu, and Vatta 2010; Kaur, Vatta, and Sidhu 2015; Kumar and Kaur 2019; Bhardwaj and Kaur 2019) is the result of indiscriminate extraction of groundwater for agricultural, industrial and domestic uses. The state's limited surface water supply and its reduction over time coupled with increased irrigation demand have strained groundwater resources (Singh et al. 2019). There is an immediate need to recharge groundwater in the over-exploited blocks and improve the available shallow groundwater in the safe blocks to prevent waterlogging soon.

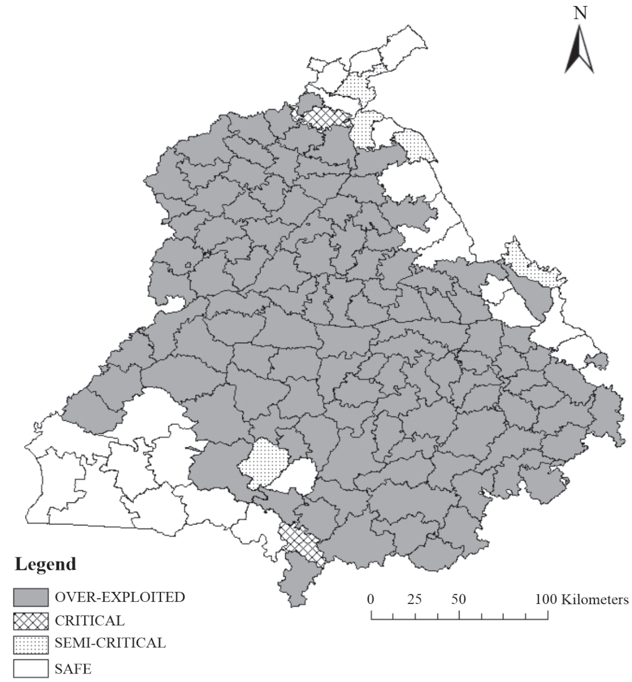

Figure 3 Categorization of developmental blocks, Punjab-2017
Source CGWB, 2017

Year to year fall of the water table

The June-over-June fluctuations in water level ranged between -0.11 to +0.93 metres with a cumulative fall of more than 8 metres (Table 3). The cumulative fall of 9.5 metres in the water table was observed for October-over-October. The impact of net monsoon recharge was captured through June-to-October water level fluctuations. The net monsoon recharge decreased 1 metre in 1996 to -1.11 metres in 2018. Since 2012, a greater fall in the water table in the monsoon months indicates less recharge as the water table goes deep and more stress on groundwater for withdrawal. The change through October-to-June depicts the effect of withdrawals in the rabi season. The withdrawals during the rabi season affect the monsoon recharge. The change in water level during October to June shows a fall from 0.31 metres to -0.26 metres during 1996-2018.

Surprisingly, central Punjab witnessed a greater water table fall than the southwestern and Kandi parts. The rate of fall in water-table (June-over-June) in central Punjab doubled after the first 12 years from 1974 and more than tripled during the next twelve years. The current fall has been arrested in the last eight years, although the figure reached 70.4 cms. The October-

[1]Kandi zone includes Gurdaspur, Hoshiarpur, SAS Nagar, Rupnagar, SBS Nagar and Pathankot; Central zone includes Ludhiana, Sagrur, Barnala, Moga, Jalandhar, Patiala, F. Sahib, Tarn Taran, Amritsar and Kapurthala while Southwest zone includes Bathinda, Mansa, Faridkot, Ferozepur, Fazilka and Muktsar.

Table 3 Year-to-year fall of the water table in Punjab

Year	June-over-June (m)	Cumulative fall June-over-June (m)	Oct-over-Oct (m)	Cumulative fall Oct-over-Oct (m)	June-to-Oct (m)	Oct-to-June (m)	Total water depletion (km^3)	Annual Average Rainfall (mm)
1996	—	-	—	-	0.61	-		607.4
1997	0.30	0.30	0.32	0.32	0.63	0.31	-3.02	708.7
1998	0.59	0.89	0.07	0.39	0.11	0.04	-5.94	477.4
1999	0.10	0.99	-0.62	-0.23	-0.61	0.01	-1.01	390.9
2000	-0.76	0.23	-0.38	-0.61	-0.23	0.15	7.65	391.9
2001	-0.28	-0.05	-0.53	-1.14	-0.48	0.05	2.82	462.8
2002	-1.00	-1.05	-1.19	-2.33	-0.67	0.52	10.07	314.5
2003	-0.47	-1.52	-0.13	-2.46	-0.33	-0.20	4.73	459.5
2004	-0.79	-2.31	-1.06	-3.52	-0.6	0.46	7.95	375.2
2005	-0.17	-2.48	0.50	-3.02	0.07	-0.43	1.71	565.9
2006	-0.15	-2.63	-0.09	-3.11	0.13	0.22	1.51	418.3
2007	-0.11	-2.74	-1.42	-4.53	-1.18	0.24	1.11	438
2008	-0.91	-3.65	0.37	-4.16	0.1	-0.27	9.16	529.2
2009	-0.22	-3.87	-0.69	-4.85	-0.37	0.32	2.21	384.9
2010	-0.40	-4.27	0.22	-4.63	0.25	0.03	4.02	472.1
2011	-0.11	-4.38	0.33	-4.3	0.69	0.36	1.10	218.9
2012	0.93	-3.45	-2.42	-6.72	-2.66	-0.24	-9.36	345.5
2013	-2.31	-5.76	0.36	-6.36	0.01	-0.35	13.19	619.7
2014	0.66	-5.1	-0.87	-7.23	-1.52	-0.65	-6.64	384.9
2015	-0.61	-5.71	-0.25	-7.48	-1.16	-0.91	6.14	546.9
2016	-0.16	-5.87	-1.39	-8.87	-2.39	-1.00	1.61	426.7
2017	-1.43	-7.30	-0.09	-8.96	-1.05	-0.96	14.40	493
2018	-0.79	-8.09	-0.85	-9.81	-1.11	-0.26	7.95	598.3

over-October analysis shows that groundwater table, which went down by less than 10 cms per year up to 1985 increased to about 20 cms during the period 1986-97 and became very serious thereafter, the average fall per year is nearly four times during 1998-2009 and almost 4.5 times during 2010-18 compared with the period of 1986-97 (Table 4).

However, the more fall in October-over-October signifies less rise in water level due to monsoon recharge and consequent fall in the groundwater table. This decline might be due to multiple factors such as an increase in area under paddy, an increase in the number of electricity-operated wells and a decrease in rainfall.

Table 4 Average per year fall in groundwater level in central Punjab

(cms)

Period	Average per year fall in groundwater level in cms	
	June-over-June	Oct-over-Oct
1974-85	9.4	8.4
1986-97	20.3	18.4
1998-09	62.5	75.5
2010-18	70.4	82.3

Source Singh, 2007 and Authors' calculation

Erratic monsoon and post-monsoon rainfall

We examined the % increase in rice area, the number of electricity operated tube-wells, electric tube well density and groundwater levels to strengthen our view that these multiple factors can be attributed to the area's groundwater regime.

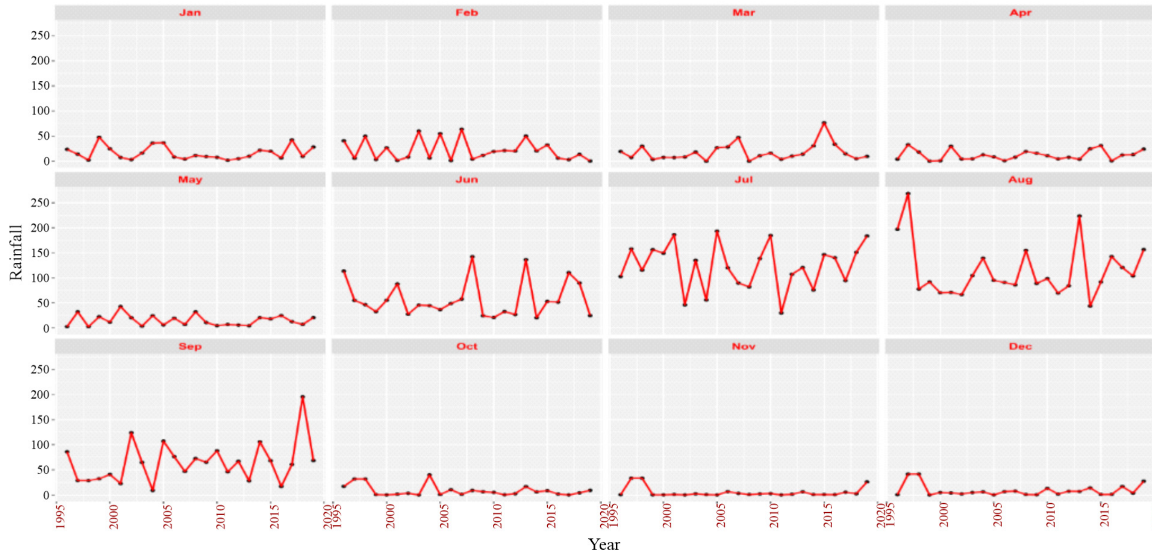

Figure 4 Monthly rainfall in Punjab
Source Statistical Abstract of Punjab (various issues)

Firstly, we studied the rainfall pattern over the period 1996 to 2019. It was observed that spatial variations in precipitation have occurred, with some years receiving more than average rainfall and some years receiving deficit rainfall (Fig. 4). October to May months depict low rainfall from 1995 to 2020. We have shown the annual rainfall pattern in Fig 5, which portrayed a more declining trend after implementing the Act, 2009.

The monthly and annual behaviour of rainfall shows that over-time decline in its quantity had an adverse effect on groundwater. Over the years, the decreasing rainfall has adversely affected the flow of water in major rivers and the natural recharge of groundwater resources. The inadequate amount of canal water for irrigation and groundwater use in excess of recharge has led to over-exploitation of groundwater resources

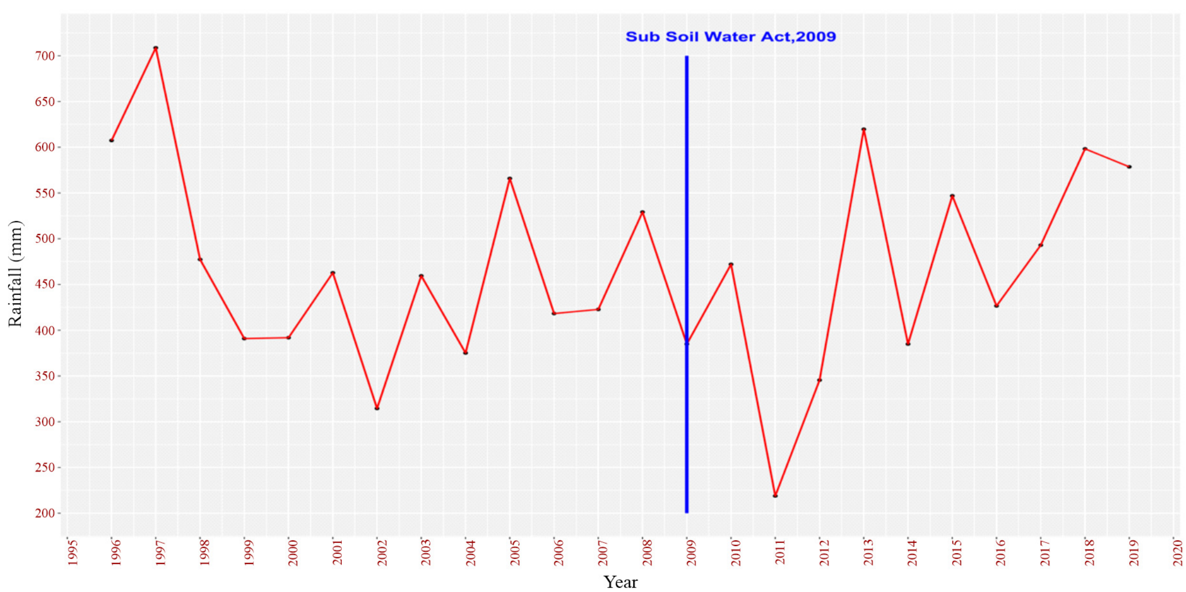

Figure 5: Annual rainfall pattern for the year 1999 to 2018
Source Indian Meteorological Department

Table 5 % increase in rice area and electric tube well density in Punjab

Particulars	1999	2008	% increase	2009	2018	% increase
Rice area ('000 hectares)	2543	2639	3.77	2762	3095	12.05
Number of electricity-operated tube-wells (Lakhs)	7.59	9.81	29.16	10.33	13.66	32.30
Electric tube-well density ('000 ha of NSA)	3555	4676	31.54	4916	6769	37.68

Source Statistical Abstract of Punjab (various issues)

in the state. Additionally, the rice area post the Act showed an increase of 12% (Table 5).

The number of electricity-operated tube-wells in 1999 was 7.59 lakhs which rose to 9.81 lakhs in 2008, increasing 29%. The increase in the post-Act period was 32%. The density of the tube-wells also showed a similar trend.

We studied the water table behaviour (shown in figure 6) pre and post the Act; it depicts a fall of more than 2 m pre-Act and more than 4 m post-Act. The groundwater level during June, which was 8.1 m in 1999, went down to 13.6 m in 2009 and further to 18.4 m in 2018.

We also studied the average decline in the water table during pre- and post-Act, which revealed that the groundwater level declined at an annual rate of 0.36 m from 1999-2009 (pre-Act) to 0.46 m per year during 2009-2018 (post-Act). A pictorial representation of the same is shown in Figure 7. This critical scenario of overexploitation brings forth the fact overtime decline in rainfall have put massive pressure on groundwater resources due to increased demand for water on account of water-intensive rice-wheat crop rotation.

Impact of 'The Punjab Preservation of Sub Soil Water Act, 2009'

The results of DiD are presented in Table 6. The outcome variable is groundwater depth in mbgl (metres below groundwater level). The sign of the coefficient of the interaction term (Act*Tr) is interpreted opposite as water level is measured below the ground. Therefore, a positive coefficient of Act*Tr would be interpreted as falling groundwater depth. The effect of the Act, 2009 on annual groundwater levels has been shown in figure 7.

We used DiD approach to find the coefficient value of the parameter in two ways. The first specification of the DID model estimates the coefficient of an interaction term with district and year fixed effects. The second specification estimates the coefficient of

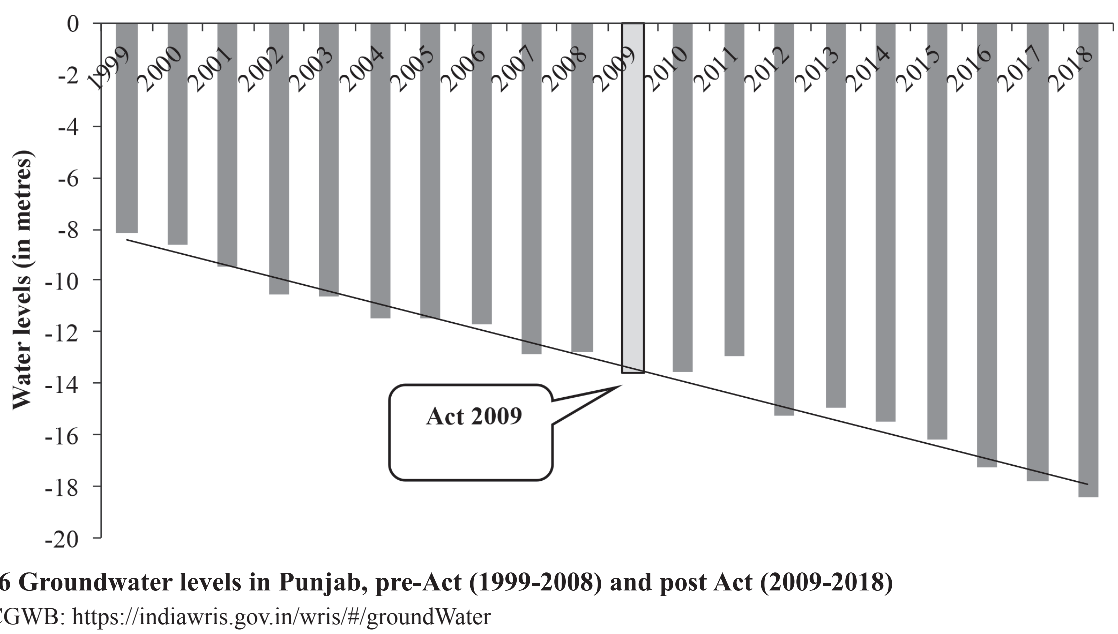

Figure 6 Groundwater levels in Punjab, pre-Act (1999-2008) and post Act (2009-2018)

Source CGWB: https://indiawris.gov.in/wris/#/groundWater

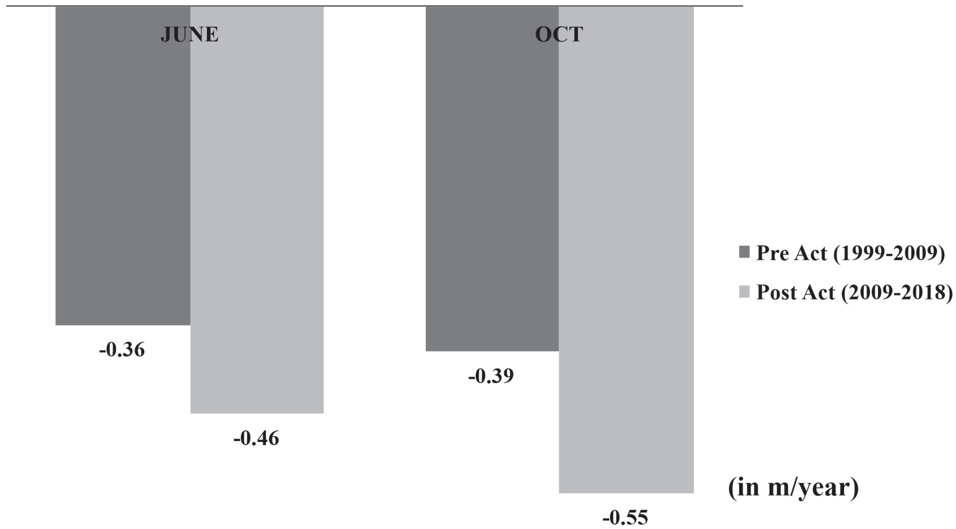

Figure 7 Average decline in the water table in Punjab, Pre and Post Act

an interaction term with all time-varying covariates like the ratio of canal irrigated area to total irrigated area, ratio of tube-well irrigated area to total irrigated area, population density and crop diversification index along with district and year fixed effects. In column (1) only the district and year fixed effects are added to the empirical model. All other covariates are added to the model in column (2).

Even after implementing the Act, 2009, the groundwater depth has fallen in the treated districts (high rice-growing). In both the specifications, the coefficient of the interaction term(Act*Tr) is highly significant and positive, indicating a decline in water level depth of nearly one and a half metres in treated districts. The groundwater depth in the high rice-growing districts was 1.62 mbgl deeper than in the low rice-growing districts after enacting the Act, 2009. Controlling demographic characteristics and other related variables such as irrigated area, canal availability, cropping pattern and rainfall reduces the fall in groundwater to 0.14 mbgl, clearly depicting the effect of these on the groundwater regime of the region. Overall, the groundwater levels fell more after the policy change in the high rice-growing, i.e. treated districts.

The increased paddy area, increased number of tube-wells, and replacement of centrifugal pumps into high HP submersible pumps would have resulted in a greater fall in groundwater in the absence of the Act, 2009. Undoubtedly, this Act, 2009 has created a gradual

Table 6 Impact of 'The Punjab Preservation of Sub Soil Water Act, 2009' on annual groundwater levels

	Coefficient value (1)	Coefficient value(2)
Act*Tr	1.62*** (0.43)	1.48*** (0.44)
Annual rain(Rain)	No	Yes
The ratio of canal irrigated area to the total irrigated area(CaIrri)	No	Yes
The ratio of tube well irrigated area to the total irrigated area (TbIrri)	No	Yes
Crop diversification index(Cdi)	No	Yes
Population density(Pd)	No	Yes
District fixed effects(D_i)	Yes	Yes
Time fixed effects(T_t)	Yes	Yes
Observations	400	400
R^2	0.70	0.71

Note *** indicate significance at 1% probability level. Figures in parentheses are standard errors.

change in people's attitude toward groundwater conservation or awareness about the implications of water depletion. Otherwise, the rate of fall would have been even more, which got arrested due to this act. Some evidence shows that this regulation has arrested the rate of groundwater depletion. Tripathi, Mishra, and Verma (2016), using time series data from 1985 to 2011, found an annual rise of 0.2 cm in the groundwater table after implementation of the Act, despite an increase in the area under paddy cultivation (Vatta et al. 2018). Singh (2009) estimated a potential increase of 30 cm in water level on implementing the Act. But, both these studies do not account for selection issues. However, Sekhri (2012) reports that the policy reforms in Punjab and Haryana, where delayed transplanting of paddy Act passed, had not impacted it positively.

Conclusions and policy implications

The agricultural sector in Punjab is currently in a crisis, with natural resources depleting, yields stagnating, and farm incomes declining. The continuous reliance on wheat and rice cultivation and an over-reliance on groundwater resources have prompted concerns about Punjab's agricultural sustainability. The available surface water is incapable of satisfying agricultural demand; as such, the groundwater is under increasing pressure. Punjab's depleting water table is a cause of grave concern as it has caused water quality problems in Punjab. The present study results revealed that the annual groundwater levels for the treated districts, after the Act, lowered by 1.48 metres as compared to the control districts. The groundwater in Punjab is falling with an average annual fall of 0.47 m. On the other hand, the soils of Punjab are still healthy and can continue to produce a variety of crops if the mono-cropping cycle of rice-wheat can be interrupted. The judicious use and conservation of water resources should be given top priority. A "Water Resources Regulatory Authority" should be established to encourage and regulate the optimum use of ground and surface water. In the state's Central region, special attention needs to be paid to the diminishing water tables. So, effective implementation of this Act requires that it be decentralized in nature. Engagement of the stakeholders (especially end-users) is an essential element for these policies to work. Shifting the date of paddy transplantation to the last week of June or the first week of July may not be a promising solution to halt the declining groundwater levels. Instead, adding new crops in cropping patterns and water use restrictions and placing the maximum limit on the cultivation of water-intensive crops can be adopted. Suitable risk management tools, such as insurance coverage or price support for potentially feasible alternative agricultural systems, must be implemented to encourage farmers to make the changeover.

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