Sustaining Groundwater: Role of Policy Reforms in Promoting Conservation in India*

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Abstract

Groundwater depletion has become an increasingly important policy concern in many countries around the world especially so in India, which is the largest user of groundwater for irrigation. Groundwater is contended to have ushered green revolution in the country. However, a downside to this pattern of development is that it is not sustainable. As in other countries, the stocks of groundwater are rapidly depleting in India. Against this backdrop, it is important to understand what policies can help conserve this vital resource. This study uses data from observation and monitoring wells of the country to identify depletion hot-spots and evaluate the impact of two policies- rainwater harvesting mandates and delaying of paddy transplanting time-on water tables. Rain water harvesting mandates did not have beneficial effects on water tables in the short run and delayed transplanting of paddy resulted in increased use of groundwater.

Keywords: Groundwater, India

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1 Introduction

India is the largest user of groundwater for irrigation in the world. The amount of groundwater drawn is estimated to be 230 billion cubic meters per year (in 2004) compared to 101 billion cubic meters in China and 108 billion cubic meters in US in 2005 (FAO, Aquastat dataset). Indian agriculture is sustained by groundwater. According to the 2005-06 Agricultural Census of the country, 60.4 percent of the net irrigated area is irrigated using groundwater. Agriculture is the source of livelihood for majority of Indian population. In 2009-10, agriculture employed 52.9 percent of the working population (National Sample Survey Organization, 2011). In addition, around 80 percent of the rural population relies on groundwater for meeting their drinking water needs.

Groundwater is contended to have ushered green revolution in the country (Repetto, 1994; Shah et al 2007). Groundwater irrigation has ensured food security in times of deficit rainfall and facilitated a manifold increase in agricultural productivity. The country has become a net exporter of food grains. However, this pattern of development is not sustainable. As in other countries, the stocks of groundwater are rapidly depleting in India. According to the central groundwater board, 15 percent of the administrative blocks are over-exploited (more water is extracted than is replenished each year) and are growing at a rate of 5.5 percent per annum.

India’s legal framework allows for unchecked open access to groundwater. Riparian rights govern extraction of groundwater. Any person who owns land can extract groundwater free of cost. In addition to this, most states provide huge electricity subsidies to the farm sector. In large agricultural states such as Punjab and Tamil Nadu, farmers get free electricity. In other states, electricity is not metered but provided at a flat rate based on horse power of the pumps used for groundwater extraction. The central governments assured minimum support pricing policy distorts the prices of food-grains such as wheat, and more importantly, paddy incentivizing growing paddy in areas not conducive for it. These factors compound the depletion problem.

Against this backdrop, it is important to understand what policies can help conserve this vital resource. There are more than 27 million private tube-wells in the country (Shankar et al, 2011). Pervasive usage of individual wells makes monitoring and enforcement extremely difficult, and hence impedes conventional policy design to check over-extraction. Therefore,
public policy focus has mostly been on supply side interventions. This study uses data from observation and monitoring wells to evaluate the impact of two policies—rainwater harvesting mandates and delaying of paddy transplanting time—on water tables.

This paper has three objectives. First, the paper highlights the depletion hot-spots and trends in water table decline in these hot-spots. Second, the paper summarizes the literature to establish the expected welfare costs of groundwater depletion. Third, the paper presents detailed evaluation of three policies targeted towards reversing water table decline in various parts of the country. The paper is organized as follows: Section 2 discusses current groundwater situation and trends in groundwater decline in the entire country. Section 3 discusses potential welfare implications of declining groundwater levels. In section 4, I provide detailed discussion of the three policies being evaluated in this paper. Section 5 provides concluding remarks including comments on the characteristics of policies that can effectively address the issue of declining groundwater levels.

2 Current Groundwater Scenario and Depletion Trends

In this section, I highlight the spatial distribution of the current groundwater situation in the country and the trends in the depletion rates. For the purposes of this assessment, I use the monitoring wells (observation wells) level data for each well from 1980 onwards and the spatial boundaries of Indian districts from Census of India 2001. Monitoring wells data contains 4 quarterly observations on level of groundwater in meters below ground level (mbgl). Annual averages are constructed for each district for each year using this data.

Figure 1 shows the changes in the stock of groundwater over a period of 30 years between 1980 to 2010. The most substantial decline in groundwater level is observed in north western India. In parts of Gujarat and Rajasthan, groundwater level fell more than 16 meters over this period. In central Punjab and Haryana, the groundwater level declined between 12-16 meters. Other pockets of Punjab, Haryana, Rajasthan, Gujarat, Western Uttar Pradesh, and New Delhi also experienced noticeable declines between 8 to 12 meters. A few districts in coastal Gujarat, central Rajasthan, Madhya Pradesh, Uttar Pradesh, West Bengal, Karnataka and Tamil Nadu saw a decline of 4 to 8 meters. In addition, a 1 to 4 meters decline over this period was widespread extending to many other states. Figure 2 Panels A, B, and C show the patterns of
decline by decade. Groundwater depletion had already commenced between 1980-1990. But in
the following decades, there was a sharp downward trend in the North Western region of the
country. Trends in groundwater level for states in the top quartile of absolute water table decline
and top quartile of percentage change are shown in Figure 3, panels A and B. Punjab, Gujarat
and Delhi experienced the largest quantum of change. Figure 4 shows the area within states that
experienced different degree of decline. Delhi has the largest area experiencing the worst
decline, followed by Punjab.

The cost of extracting groundwater depends on the depth of water table. There is a sharp
rise in the fixed cost of extracting groundwater at around 8 meters. At 8 meters, surface pumps
become infeasible to extract water and farmers have to invest in more expensive technologies
such as submersible pumps to extract groundwater. From social and economic perspective, it
becomes important to determine the extent of depletion where water tables fall from over 8
meters to below 8 meters. Figure 5 shows the districts where water table has fallen below 8
meters between 1980 and 2010. Most districts in Punjab have experienced such patterns of
decline. Other states including Haryana, New Delhi, Gujarat, Rajasthan, Madhaya Pradesh,
Maharashtra, Uttar Pradesh, Bihar, Jharkhand, West Bengal, Andra Pradesh, Pondicherry,
Kerala, and Tamil Nadu also have pockets where declines of water table are costly to the
farmers. Figure 6 shows the trends over time in the top 5 states -Punjab, Gujarart, Delhi,
Pondechery and Madhya Pradhesh - where average groundwater depth went from above 8 meters
to below 8 meters. Figure 7 shows the area of the states that experienced decline from above 8 to
below 8 meters. Punjab had the largest area experiencing such decline, followed by Pondicherry,
Madhya Pradesh, Haryana, New Delhi and Gujarat.

Three important facts emerge from these figures. One, the decline in water tables in India
is spatially heterogeneous with North Western region affected the most. Two, the bread basket
states, including Punjab and Haryana with endowments of thick aquifers are experiencing
significant declines in water tables. These states are the role models of green revolution. Three,
the decline has accelerated over time.

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1 Surface pumps use atmospheric pressure to draw water. Atmospheric pressure can practically support the weight of
a column of water of height 8 meters.
2 This is consistent with other findings using recent satellite based data. Data from NASA’s GRACE satellites shows
significant depletion of groundwater levels in Northern India. Non-renewable aquifers are being mined over large
areas (NASA, 2009).
3 Why is Conservation Vital? Poverty and other Implications

From welfare perspective, rapid decline in water tables can result in significant social cost. Case studies have documented that access to groundwater can reduce poverty and ensure food security (Moench, 2001; Moench, 2003; Mookherji, 2008). Sekhri (2011a) uses groundwater data in conjunction with annual agricultural output data at the district level to show that a 1 meter decline in groundwater from its long term mean can reduce food grain production by around 8 percent. Controlling for district fixed effects, year fixed effects, and district specific trends, this paper uses the plausibly exogenous fluctuations in groundwater depth from long term means to estimate the effect of groundwater scarcity on food grain production. A 1 meter decline of groundwater depth results in very large reduction in food grain production. Given that groundwater irrigation is the main stay of irrigation in India, this is not unexpected. Consistent with previous field studies, this paper shows that groundwater depletion can have significant effect on food security in the country.

Sekhri (2012) identifies the causal impact of groundwater scarcity on poverty. Using village level data from Uttar Pradesh, and exploiting the fact that there is a non-linearity in cost required to access groundwater at 8 meters, this study shows that poverty rate increases by around 11 percent as groundwater depth falls below 8 meters. The full sample estimation controls for other village characteristics that may be correlated with poverty rate and hence, generate omitted variable bias. These include geographical controls like rainfall and temperature; geological controls like elevation and slope; demographic characteristics like population, literacy rate, total female population; infrastructure including availability of schools, medical facilities, access to electricity, distance to nearest town, village council expenditure on public goods, banking facility and bus service. This study uses a regression discontinuity design for identification. Both parametric and non-parametric techniques have been used to show that the results do not depend on the estimation method. The study provides a variety of tests to substantiate the findings. This study also shows that self-reported conflict over irrigation water increases substantially near the cutoff. The findings echo the results of field studies. Groundwater scarcity increases poverty. On the flip side, uncontrolled access can lead to very rapid depletion. Therefore, sustainable access
to groundwater is required to curb poverty in rural areas of the country. One limitation of this study is that it provides a static estimate. How poverty dynamically evolves with groundwater depletion is not well understood. More work is required to understand and estimate the optimal level of depletion in the long term.

In Gujarat, where the water tables are falling almost at a rate of 3 meters a year, Narula et al (2011) estimate that water savings of 30 percent can free up 2.7 billion units of electricity for non-agricultural use. Department of Drinking Water Supply, Government of India estimates that in 2010, approximately 15 percent of the total habitations in the country went from full coverage of drinking water to partial coverage due to drying up of sources. These findings indicate that the welfare costs of groundwater depletion are very large in magnitude, and thus groundwater depletion warrants an appropriate policy response.

4 Policy Response

State governments have introduced policies with the objective to reverse these trends of rapidly falling groundwater. One of the first policies that has been introduced across many states is mandated rainwater harvesting. States opted into selecting various measures for mandating rainwater harvesting. These measures included construction of rainwater harvesting structures on the roofs of buildings which met specific size criterion. Delhi was the first to pass this mandate in 2001. The other states that mandated rainwater harvesting include Andhra Pradesh, Tamil Nadu, Kerala, Madhya Pradesh, Rajasthan, Bihar and West Bengal. Table 1 provides details of the mandates along with the dates on which the mandates were passed. In this paper, I conduct a district level analysis to examine whether such mandates have had any short run impact on water table decline.

I also examine the impact of a policy pursued by the Gujarat government that promoted decentralized rainwater harvesting. Concentrated efforts to recharge groundwater began in the Saurashtra region of Gujarat after the drought of 1987 (Mehta, 2006). Initial efforts to divert run-off to groundwater wells led to widespread adoption of the practice by farmers throughout Saurashtra without government intervention. Over time, farmers experimented with new technologies and farmers began constructing check dams in streams and rivers to reduce water
speed and to allow the river water to seep into the ground and replenish the groundwater supply (Mehta, 2006). Farmers continued constructing check dams through the 1990s with assistance from NGOs who bore some of the costs.

In January, 2000, the Gujarat government introduced the Sardar Patel Participatory Water Conservation Project in response to the work of farmers and NGOs in the Saurashtra, Kachchh, Ahdamabad, and Sabar Kantha regions (Government of Gujarat, 2012b). The first phase of the program ran from January 17, 2000 to February 20, 2001, and 10,257 check dams were constructed by September 1, 2000. The program initially funded 60 percent of the estimated cost of new check dams, and beneficiaries/NGOs financed the remaining 40 percent. By early 2004, almost 24,500 check dams had been constructed, of which roughly 18,700 were in the Saurashtra region (Pandya, 2004). In 2005, the government increased its financing to 80 percent of the estimated cost, and the pace of construction increased outside of the Saurashtra region. According to statistics from the Gujarat government, by the end of March, 2012 70,719 check dams had been constructed in total under the project. Of these, 26,799 (38 percent) are in the Saurashtra region, and 22,257 (31 percent) are in Kachchh or North Gujarat (Government of Gujarat, 2012a). Figure 8 shows the geographic distribution of check dams constructed under the Sardar Patel Participatory Water Conservation Project.

As discussed above, Punjab and Haryana are experiencing very rapid decline in water tables. This can threaten future food security in the country. Punjab did not mandate rain water harvesting. One of the key initiatives undertaken in Punjab to decelerate water table decline is mandated delay of paddy transplanting. In 2006, the state government influenced the date of paddy transplanting by changing the date on which free electricity is diverted to the farm sector for operating mechanized tube wells for groundwater extraction. The date was pushed to June 10, thereby reducing the amount of intensive watering that the crop can receive during its production cycle (Tribune News service, 2006). The delayed date was mandated in 2008 via an ordinance. This was later turned into a law - The Punjab Preservation of Sub Soil Water Act, 2009. The main purpose of the law is to preserve groundwater by prohibiting sowing paddy before May 10 and transplanting paddy before June 10. In addition, the law creates the authority to destroy, at the farmer's expense, paddy sowed or transplanted early, and the law assesses a penalty of 10,000 rupees per month, per hectare of land in violation of the law (Government of Punjab, 2009).
Haryana followed suit and mandated delay in paddy transplanting in 2009. Haryana passed its Preservation of Sub-Soil Water Act in March 2009, and it is very similar to the Punjab act. Its main provisions prohibit sowing paddy before May 15 and transplanting paddy before June 15. The law also contains punitive provisions similar to Punjab. These include destruction of paddy sowed or transplanted early and a penalty of 10,000 rupees per month, per hectare of land in violation of the law (Government of Haryana, 2009). The law took immediate effect for the 2009 paddy season. In this paper, I make use of the timing of the introduction of this policy in Punjab and Haryana to isolate the causal effect of the policy on water tables. Because of the de facto prohibition of transplanting paddy before June 10 in Punjab, I treat 2006 as the effective year for Punjab's policy rather than 2008.

4.1 Data

Data from several sources has been combined to analyze the trends in Indian groundwater levels since 1980, and to evaluate the impact of various policies on water table decline. The groundwater level data are from the Indian Central Ground Water Board. Individual monitoring well data has been used to construct measures of district groundwater depth from 1980 through 2010. The precipitation data from the University of Delaware Center for Climactic Research have been used to calculate district annual average monthly precipitation through 2008. The district precipitation data from the India Meteorological Department has been used for the years 2009 to 2010. In addition, district demographic and socioeconomic characteristics are from the 2001 Census of India. Area under various crops by districts is from the Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture. This has been used to classify districts as high rice growing districts as explained later.

4.1.1 Groundwater Data

The Indian Central Ground Water Board measures groundwater depth throughout each year at approximately 16000 monitoring wells across India. In this paper, I use observations from 1980 to 2010 to construct district-level measures of groundwater depth. Groundwater depth is

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3 Singh (2009) provides more details.
typically measured in January, May, August, and November although some wells have more or fewer observations within a given year. The number of wells in the sample increased greatly over the years. There were 3,305 wells in 1980, 11,063 in 1990, 15,782 in 2000, and 13,683 in 2010. The density of wells in states increased to cover more geographical area and more states started coverage. In the policy analysis conducted later, I use observations from year 2000 to 2010. During this time, the number of wells was, by and large, stable. The monitoring wells are spread over the entire country and not concentrated in any particular area. Wells have not been located in places where the groundwater has been depleting the most. For these reasons, endogenous well placement will not be a concern in the policy analysis.

In addition to groundwater depth, the data include latitude and longitude for each well, and I use this information to match each well to the spatial boundaries of the Indian districts in 2001 and construct a district-level panel of monthly and annual groundwater depth. These district-level measures of groundwater levels are the primary outcomes studied in this paper.

4.1.2 Precipitation Data

I use precipitation data from the University of Delaware and the India Meteorological Department to control for annual variation in precipitation which greatly affects groundwater depth. The Center for Climactic Research at the University of Delaware compiled monthly weather station data from 1900 to 2008 from several sources. From this data, all grid points within India's administrative boundaries were extracted to construct district-level annual average and monthly precipitation in each year. Since the Center for Climactic Research's data only cover years through 2008, I use data from the India Meteorological Department for 2009 to 2010. The India Meteorological Department collects monthly rainfall data for all Indian districts and publishes tables for each district containing monthly rainfall for the past 5 years.

4 These sources include the Global Historical Climatology Network, the Atmospheric Environment Service/Environment Canada, the Hydrometeorological Institute in St. Petersburg, Russia, GC-Net, the Automatic Weather Station Project, the National Center for Atmospheric Research, Sharon Nicholson's archive of African precipitation data, Webber and Willmott's (1998) South American monthly precipitation station records, and the Global Surface Summary of Day. After combining data from various sources, the Center for Climactic Research used various spatial interpolation and cross-validation methods to construct a global 0.5 degree by 0.5 degree latitude/longitude grid of monthly precipitation data from 1900 to 2008 (Matsuura and Wilmott, 2009).
Meteorological Department, 2012). For 2009 to 2010, district-level annual average and monthly precipitation was calculated from these tables.

### 4.1.3 Demographic Data

The 2001 Indian census data has been used to control for district demographic and socioeconomic characteristics. Specifically, district population, percent of the district population with at least some college education, district literacy rate, district employment rate, and the percent of the district population that is female have been controlled. Because these variables have not been observed in intercensal years, these have been interacted with indicators for each year in the sample to control for these characteristics non-parametrically in regression analysis.

### 4.1.4 Crop Production Data

Data on area under various crops by district has been used to construct high rice production and low rice production district groups in the analysis of Punjab's and Haryana's policies to delay paddy transplanting before the middle of June. Specifically, the fraction of cultivated area under rice for each district in Punjab and Haryana has been calculated. I then classify districts in Punjab and Haryana above the median as “high rice growing districts.”

### 4.2 Conceptual Framework

The change in the depth of groundwater is a function of demand side variables, supply side variables, and natural recharge rate. The change in depth can be modeled as: \[ W_t - W_{t-1} = R_t - D_t + S_t + E_t \]

Where \( R_t \) is the rate of recharge. This would be influenced by the geology of the place including soil characteristics, slope, elevation and such features. These features are time invariant. The recharge will also be affected by precipitation. \( D_t \) represents the demand side variables which may include population, type of industry or sector that is dominant in the district, crops grown, area under various crops, number of pumps being used, availability of alternate form of irrigation, prices of crops, and inputs such as electricity and diesel. The supply side variables \( S_t \)
include management policies and prevalent institutions. \( E_t \) represents an error term. Most of the policies that have been designed change the factors in the set \( S_t \). In what follows, I examine a subset.

A few comments on relating this model to the policy analysis conducted are in order. I use panel data and the methodologies used control for time invariant characteristics of districts. I also control for rainfall and temperature in every regression to account for the recharge. I do not have data on very comprehensive set of variables that can affect the demand for groundwater. I do control for a set of demographic and economic variables. But to the extent that these variables have not influenced policy choices or implementation logistics differentially in treated and control areas, the estimation yields unbiased results.

The following analysis is carried out at the level of districts. Districts are administrative units under states. Most program allocations and monitoring of government programs are delegated to districts. Hence, they are a natural choice for unit of analysis. One concern may be that the underlying aquifers are interconnected. The lateral velocity of groundwater is very low (Todd, 1980). Hence, over this time frame spatial externalities may not have arisen. I address this more specifically in the analysis, where I allow spatial correlation between standard errors.

### 4.3 Identification Strategy

Rain Water Harvesting Mandates

The states selected into mandating rainwater harvesting. Hence, comparing the outcomes in the states that mandated rain water harvesting with the ones that did not, will result in biased estimates. Therefore, I compare groundwater levels in districts in the states that passed the mandates earlier to the states that passed them later in order to circumvent selection concerns. The identifying assumption is that the timing of such mandates is plausibly exogenous.

The empirical model is as follows:

\[
Y_{ist} = \alpha_0 + \alpha_1 T_t + \alpha_2 d_{is} + \alpha_3 Post \ast d_{is} + \alpha_4 X_{ist} + \varepsilon_{ist}
\]

where \( Y_{ist} \) is the groundwater level in district \( i \) in state \( s \) at time \( t \), \( T_t \) are the year fixed effects, \( d_{is} \) is the treatment indicator which takes the value 1 if the district is in a treated state, and \( X_{ist} \) is a vector of time varying district specific controls. \( Post \) is an indicator variable that switches to 1
after the rain water harvesting mandates were passed in the states. The coefficient \( \alpha_3 \) is the parameter of interest. \( \varepsilon_{ist} \) is the error term. Robust standard errors are clustered at the level of states. Year specific common shocks to all districts are absorbed by the time fixed effects. Time invariant district specific omitted variables that affect the likelihood of treatment are controlled for by including the treatment indicator. The interaction \( Post \times d_{is} \) yields the effect of the treatment on the treated post treatment where the treatment is passing of rain water harvesting mandates.

4.3.1 Decentralized Rain Water Harvesting – Sardar Patel Participatory Water Conservation Project

I compare the groundwater levels of districts in the regions that received the subsidy program earlier in January 2000 (treatment regions – Saurashtra, Kachchh, Ahdamabad, and Sabar Kantha regions) to the districts that received the program later in 2005 when it expanded (control regions). Figure 9 plots the average groundwater level in the treated and the control districts from 1990 to 2011. The pretreatment groundwater levels prior to 2000 are similar across these districts and the two groups do not exhibit differential trends. The following empirical model is estimated using the data from 1990 to 2011:

\[
Y_{drt} = \theta_0 + \theta_1 T_t + \theta_2 \tau_{dr} + \theta_3 Post \times \tau_{dr} + \theta_4 X_{drt} + \theta_5 R_r + \varepsilon_{ist}
\]  

where \( Y_{drt} \) is the groundwater level in district \( d \) in region \( r \) at time \( t \), \( T_t \) are the year fixed effects, \( \tau_{dr} \) is the treatment indicator which takes the value 1 if the district is in a treated region, and \( X_{drt} \) is a vector of time varying district specific controls. Post is an indicator variable that switches to 1 after 1999. The coefficient \( \theta_3 \) is the parameter of interest. \( \varepsilon_{ist} \) is the error term. Robust standard errors are clustered at the level of districts. Year specific common shocks to all districts are absorbed by the time fixed effects. Time invariant district specific omitted variables that affect the likelihood of treatment are controlled for by including the treatment indicator. Region specific time invariant unobservables are absorbed by the region fixed effects \( R_r \) in certain specifications. It is important to note that the areas where the subsidy was initiated first were the

\[5\] Districts in treated group include Rajkot, Junagadh, Bhavnagar, Porbandar, Jamnagar, Amreli, Surendranagar, Ahmadabad, Kachchh, and Sabar Kantha. Control group includes Banas Kantha, Patan, Mahesana, Gandhinagar, Kheda, Anand, Panch Mahals, Dohad, Valdora, Narmada, Bharuch, Surat, Navsari, the Dangs, and Valsad.
ones where such decentralized initiatives were successful with the help of NGOs and donor funding. Hence, the estimated coefficient cannot be interpreted as causal. Although pretrends in groundwater level are controlled for, there can be other potential time varying factors that influenced early initiation of the program and are unobserved. An example could be a gradual change in people's attitude towards groundwater conservation or awareness about implications of water depletion.

4.3.2 Delayed Paddy Transplanting

In the estimation procedure, I employ a difference-in-difference methodology comparing the paddy growing areas in Punjab to the bordering Haryana. Since both states adopted measures to ensure delayed transplanting of paddy at different time, I use the variation in the timing of introduction of the policy to evaluate its impact on groundwater levels. As mentioned before, in Punjab, the de-facto change in date of transplanting happened in 2006 and in Haryana, the mandate was passed in 2009. The rice growing districts were identified using the area under various crops. The districts where the ratio of area under rice to the total cultivated area exceeded the sample median in 2003 for all districts in Haryana and Punjab are considered the high rice growing districts. Since the policy delayed transplanting rice, the policy should have affected the water use in rice growing districts, and hence impact water tables in these districts. Figure 10 maps the high rice production districts (treatment) and low rice production districts (control) in Punjab and Haryana. I compare the high rice growing districts with low rice growing districts before and after the policy change.

The empirical specification is given by:

\[
Y_{its} = \beta_0 + \beta_1 T_t + \beta_2 R_{is} + \beta_3 Post \times R_{is} + \beta_4 X_{its} + \beta_5 S_t \times R_{is} + \beta_6 R_{is} \times T_t + \epsilon_{its}
\]

where \(Y_{its}\) is the groundwater level in district \(i\) at time \(t\). \(T_t\) are the year fixed effects, \(R_{is}\) is an indicator variable which takes value 1 if the district is rice growing district and 0 otherwise, and \(X_{its}\) is a vector of time varying district specific controls. Post is an indicator variable that

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6 High rice production districts are Gurdaspur, Amritsar, Firzopur, Faridkot, Moga, Kapurthala, Jalandhar, Nawanshahr, Ludhiana, Sangrur, Fatehgarh Sahib, Patala, Kaithal, Kurukshetra, Ambala, Yamunanagar, Karnal, and Panipat. The low rice production districts are Hoshiapur, Rupnagar, Muktsar, Bathinda, Mansa, Panchkula, Sirsa, Fatehabad, Hisar, Jind, Sonipat, Rohtak, Bhiwani, Jhajjar, Manendragarh, Rewari, Gurgagon, and Faridabad.
switches to 1 after the paddy transplanting was delayed and is equal to 0 before that. The coefficient $\beta_3$ is the parameter of interest. The regressions include full sets of interaction between state and rice growing districts, and rice growing districts and year indicators. $\epsilon_{its}$ is the error term. Robust standard errors are clustered at the level of districts. I also report Conley (1999) errors to account for spatial correlation in groundwater levels of neighboring districts.\footnote{The aquifers could be interconnected. The lateral velocity of groundwater is very low. In the short run, cross district externalities are not likely to arise. Conley's standard errors correct for such externalities.} Year specific common shocks to all districts are absorbed by the time fixed effects. Time invariant rice growing district specific omitted variables are controlled for by including the rice growing indicator. The specifications allow for high rice growing districts in the two states to be different by including state times rice growing fixed effects. Differences in high rice growing and low rice growing districts over years are also accounted for by including high rice growing districts times year fixed effects. The vector $X_{its}$ includes average annual rainfall in the district and demographic controls including percentage of females, percentage of working population, percentage of literate population, percentage of population with some college, and total population.\footnote{These variables are available for the year 2001 from the Census of India. These are interacted with year indicators to control for trends in these variables starting at the 2001 initial values.} The interaction term $Post \times R_{is}$ yields the difference-in-difference estimator. In robustness checks, I also allow for state specific trends that non-parametrically account for time varying state specific factors that may have influenced timing of treatment.

4.3.3 Results

Tables 2 and 3 report the results for the impact of rain water harvesting mandates on groundwater levels. Table 2 reports the effect on groundwater levels for 4 different months-January, May, August, and November. Each specification includes treatment and year fixed effects. I do not find evidence of beneficial effects of rainwater harvesting mandates on groundwater levels at least in the short run. The coefficients on the interaction term are statistically insignificant.\footnote{The number of observations change across specifications because of missing data in some of the district year cells.} In Table 3, this analysis is repeated for annual groundwater levels. Each specification controls for state and year fixed effects. In column (ii), annual average district precipitation is added to the empirical specification and in column (iii), demographic controls interacted with year indicators are added in addition to the precipitation. Although, the
interaction term is marginally significant at 10 percent in the columns (i) and (ii), this is not robust to including demographic controls in column (iii). These results do not bear out any evidence of a beneficial effect of rain water harvesting mandates on water tables in the short run.

Table 4 reports the results for the impact of the Sardar Patel Participatory Water Conservation Project on annual groundwater levels. The subsidy program had an ameliorative effect on groundwater levels. Column (i) reports the baseline specification. The coefficient is negative but statistically insignificant. In column (ii), I add region fixed effects. Columns (iii) and (iv) control for annual precipitation levels with and without region fixed effects. The effect continues to be statistically insignificant. In columns (v) and (vi), demographic controls are added interacted with year indicators are added in addition to the precipitation. Both specifications -with and without region fixed effects- yield a negative and highly statistically significant effect of the program. The point estimate of 9.3 is 0.82 of a standard deviation and very large in magnitude. The subsidy program had a huge effect on the annual groundwater level in treated areas. However, these results should be interpreted with caution as the areas that received the early treatment were the areas where decentralized rain water harvesting was very effective prior to the subsidy program. The government focused the subsidy in regions where NGOs and other donor funded projects were successful. Hence, I cannot rule out selection bias. As mentioned before, previous experience with such projects may have gradually changed the attitudes towards conservation which is unobserved. Controlling demographic characteristics in column (v) of Table 4 relative to column (iv) changes the results substantially. This strongly suggests that program was targeted selectively in certain types of areas. Figure 9 shows that there are no differential trends in groundwater level prior to the program. Hence, it is likely that the results emerge as a result of this program alone. On the other hand, it is possible that such programs may not be successful in randomly chosen areas, where people do not have prior experience with such projects. More research is required to address selection and establish the causal impact of such subsidy programs.

Tables 5 and 6 report the results of the impact of delayed paddy transplantation on groundwater levels. The outcome variable is depth to groundwater in meters below ground level (mbgl). Paddy transplantation occurs in June. Table 5 reports the effect of the policy on post transplanting groundwater level in August and Table 6 reports the results for annual depth to groundwater. Column (i) in Table 5 shows the coefficient of the interaction term from a
specification which includes year fixed effects, state X rice fixed effects, and rice X year fixed effects. In column (ii), precipitation is added to the regression specification. Column (iii) controls for trends in demographic variables, and column (iv) includes state specific time trends in addition to the above mentioned controls. In all specifications, the policy increases depth to groundwater. The coefficient is marginally significant at 10 percent significance level is the most conservative specification in column (iv). The August groundwater levels declined in response to the policy. The depth to groundwater level in high rice growing districts post the policy change was 1.17 meters deeper than the low rice growing districts. Similar specifications are repeated for the annual depth to groundwater in Table 6. In each specification, the coefficient on the interaction term is positive and highly statistically significant. In the last column, we observe a decline in depth of 1.60 mbgl and it is significant at 1 percent level. This effect is 0.28 of a standard deviation and is economically moderate. The findings indicate that the annual groundwater level situation worsened in rice growing areas after the policy change.\textsuperscript{10} It is possible that the farmers responded to the policy by increasing the number of irrigations applied or using more water per irrigation after the mid June transplanting.\textsuperscript{11}

5. **What do we learn from the experience with these policies?**

The rain water harvesting mandates were unsuccessful in reversing the depletion rates whereas the decentralized experience in Gujarat has been more positive. From this comparison it appears that technical or engineering limitations or short duration that has elapsed since the program commencement are not the principal explanations for success or failure of these policies. The effective policies will need to be decentralized in nature. Engagement of the stake holders is an important ingredient for these policies to work. Bottom-up rather than top-down policy tools are more successful. None of these policies are pricing mechanisms. In Sekhri (2011b), I show that public wells provision can reduce the rate of depletion. If an optimal price is charged it can also reverse depletion. But this can work only where cost of groundwater extraction is high, or in other words in areas where water tables are deep. In Sekhri and Foster (2008), we find evidence

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\textsuperscript{10} In contrast to these findings, Singh(2009) estimates a 30 cm water saving effect of the policy but the estimate is based on simulations using historic data from central Punjab and does not account for selection issues.

\textsuperscript{11} In the absence of farm level data on applied number of irrigations and water use, it is not possible to establish the mechanism.
that bilateral trade arrangements between farmers who sell and buy groundwater also decelerate depletion rates. The benefit of promoting these is that these arrangements do not require top down monitoring. Introduction of pricing mechanisms may be another important lever to reduce over-extraction.

6. Future Directions with Policy Choices

What kind of policies- direct or indirect- can or cannot work? Reducing electricity subsidies can potentially affect groundwater extraction rates (Badiani and Jessoe, 2011). West Bengal and Uttarakhand have recently adopted metering of electricity for tube wells. Gujarat, under the flagship Jyotirgram Yojana, has separated agricultural feeders from non-agricultural feeders, improved the quality of the power supply and rationed the number of hours of electricity to agriculture to 8 hours a day. Important policy lessons can be learnt from the experience of these states. Other possibilities include promoting water saving infrastructure and agricultural practices. More research is required to understand the effect of policies that promote such practices, and is a very promising area of future research.

12 Mukherji et al (2010) provide details of the reforms.
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Mukherji, A. (2008), "Poverty, groundwater, electricity and agrarian politics: Understanding the linkages in West Bengal"

Todd, D. 1980 Groundwater hydrology, John Wiley & Sons
Figure 1. Changes in Indian District Groundwater Depth, 1980-2010
Figure 2. Decadal Changes in Indian District Groundwater Depth

Panel A: Changes in Indian District Groundwater Depth, 1980-1990

Panel B: Changes in Indian District Groundwater Depth, 1990-2000

Panel C: Changes in Indian District Groundwater Depth, 2000-2010
Figure 3. District Groundwater Depth in Selected States, 1980-2010

Panel A: Groundwater Depth, 1980-2010
Indian States in Top Quartile of Absolute Change

Panel B: Groundwater Depth, 1980-2010
Indian States in Top Quartile of Percent Change
Figure 4. District Groundwater Depth Changes
Selected States, 1980-2010

-4m - <1m
1m - 4m
4m - 8m
8m - 12m
12m - 16m
>16m

DELHI

GUJARAT

HARYANA

PUNJAB
Figure 5. Costly Changes in Indian District Groundwater Depth, 1980-2010
Figure 6. Groundwater Depth, 1980-2010
Indian States Transitioning from <8m to >8m

- PUNJAB
- DELHI
- MADHYA PRADESH
- GUJARAT
- PONDICHERRY

Groundwater Depth (m)

Year

1980
1990
2000
2010
Figure 7. Costly Changes in Indian State Groundwater Depth, 1980-2010

Fraction of Land Area Transitioning from <8m to >8m

- PUNJAB
- PONDICHERY
- MADHYA PRADESH
- HARYANA
- DELHI
- GUJARAT
- TAMIL NADU
- UTTAR PRADESH
- WEST BENGAL
- MAHARASHTRA
- RAJASTHAN
- JHARKHAND
- KARNATAKA
- ANDHRA PRADESH
- KERALA
- BIHAR
Figure 8. SPPWC Check Dams in Gujarat, March 2012

Legend

- State Boundaries
- SPPWC Check Dams

- 0 - 500
- 500 - 1000
- 1000 - 2000
- 2000 - 5000
- 5000 - 9000

0 20 40 80 Miles
Figure 9. Groundwater Depth in Gujarat Treatment and Control Districts, 1990-2011
Figure 10. Rice Paddy Treatment and Control Districts
<table>
<thead>
<tr>
<th>State</th>
<th>Year Passed</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delhi</td>
<td>2001</td>
<td>RWH mandatory for all new buildings with more than 100 sq m roof area and all newly developed plots of land larger than 1000 sq m. Also, mandated RWH by March 31, 2002 for all institutions and residential colonies in notified areas (South and southwest Delhi, and adjoining areas) and all buildings in notified areas that have tubewells.</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>2002</td>
<td>Andhra Pradesh Water, Land and Tree Act, 2002 stipulates mandatory provision to construct RWH structures at new and existing constructions for all residential, commercial and other premises and open space having area of not less than 200 sq m in the stipulated period, failing which the authority construct such RWH structures and recover the cost incurred along a prescribed penalty.</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>2003</td>
<td>Vide Ordinance No. 4 of 2003 dated July, 2003 mandates RWH facilities for all existing and new buildings. Like Andhra Pradesh, the state may construct RWH facilities and recover the cost incurred by means of property taxes.</td>
</tr>
<tr>
<td>Kerala</td>
<td>2004</td>
<td>Roof top RWH is mandatory for all new buildings as per Kerala Municipality Building (Amendment) Rules, 2004.</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>2006</td>
<td>The State Govt. vide Gazette notification dated 26.8.2006, has made roof top RWH mandatory for all buildings with plot size larger than 140 sq.m. Also there is a 6% rebate in property tax to individuals for the year in which the individual installs roof top RWH structures.</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>2006</td>
<td>Roof Top RWH is mandatory in state-owned buildings and all buildings with plots larger than 500 sq m in urban areas.</td>
</tr>
<tr>
<td>Bihar</td>
<td>2007</td>
<td>The Bihar Ground Water Act, enacted in 2007, mandates privions of RWH structures for buildings with plots larger than 1000 sq m.</td>
</tr>
<tr>
<td>West Bengal</td>
<td>2007</td>
<td>Vide Rule 171 of the West Bengal Municipal (Building) Rules, 2007, mandates installation of RWH system on new and existing buildings.</td>
</tr>
</tbody>
</table>

Sources:  
[http://www.rainwaterharvesting.org/Policy/Legislation.htm#](http://www.rainwaterharvesting.org/Policy/Legislation.htm#)  
State profiles at: [http://cgwb.gov.in/gw_profiles/st_ap.htm](http://cgwb.gov.in/gw_profiles/st_ap.htm)  
[http://www.cseindia.org/content/legislation-rainwater-harvesting](http://www.cseindia.org/content/legislation-rainwater-harvesting)
Table 2: The Impact of Rain Water Harvesting Mandates on Seasonal Groundwater Levels

<table>
<thead>
<tr>
<th></th>
<th>(i) January</th>
<th>(ii) May</th>
<th>(iii) August</th>
<th>(iv) November</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post * Treatment</td>
<td>0.84*</td>
<td>0.86*</td>
<td>0.51</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>(0.44)</td>
<td>(0.37)</td>
<td>(0.42)</td>
<td>(0.24)</td>
</tr>
<tr>
<td>Observations</td>
<td>2,206</td>
<td>2,153</td>
<td>2,060</td>
<td>2,118</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.435</td>
<td>0.433</td>
<td>0.405</td>
<td>0.433</td>
</tr>
</tbody>
</table>

Robust standard errors are clustered at the state level.

*** p<0.01, ** p<0.05, * p<0.1

Notes: Sample is restricted to states which implemented Rain Water Harvesting legislation by 2010. Sample includes observations from 2000-2010. Each specification includes year and treatment fixed effects.
Table 3: The Impact of Rain Water Harvesting Mandates on Annual Groundwater Levels

<table>
<thead>
<tr>
<th></th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post * Treatment</td>
<td>0.62*</td>
<td>0.83*</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>(0.29)</td>
<td>(0.41)</td>
<td>(0.36)</td>
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<tr>
<td>Observations</td>
<td>2,230</td>
<td>2,204</td>
<td>2,196</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.431</td>
<td>0.456</td>
<td>0.497</td>
</tr>
<tr>
<td>District Precipitation</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Demographic Controls</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Robust standard errors are clustered at state level.
*** p<0.01, ** p<0.05, * p<0.1

Notes: Sample is restricted to states which implemented Rain Water Harvesting legislation by 2010.
Sample includes observations from 2000-2010. Each specification includes year and treatment fixed effects.
Precipitation is district average monthly precipitation in mm.
Demographic controls include 2001 district demographics interacted with year dummies and include percent female, percent literate, percent working, percent with some college, and total population.
Table 4: The Impact of Sardar Patel Water Conservation Subsidy Program on Annual Groundwater Level

<table>
<thead>
<tr>
<th></th>
<th>(i)</th>
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<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
<th>(vi)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>(2.918)</td>
<td>(2.932)</td>
<td>(2.661)</td>
<td>(2.974)</td>
<td>(1.540)</td>
<td>(1.593)</td>
</tr>
<tr>
<td></td>
<td>[2.847]</td>
<td>[2.847]</td>
<td>[2.586]</td>
<td>[2.882]</td>
<td>[1.309]</td>
<td>[1.347]</td>
</tr>
<tr>
<td>Observations</td>
<td>550</td>
<td>550</td>
<td>550</td>
<td>550</td>
<td>550</td>
<td>550</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.056</td>
<td>0.597</td>
<td>0.249</td>
<td>0.598</td>
<td>0.762</td>
<td>0.810</td>
</tr>
<tr>
<td>Year FE</td>
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<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Treatment FE</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
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<td>Region FE</td>
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<td>NO</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Precipitation (mm)</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
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<tr>
<td>Census Controls</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>

Robust standard errors clustered at district level are in parenthesis and Conley (1999) standard errors correcting for spatial correlation are in brackets. *** p<0.01, ** p<0.05, * p<0.1

Note: Sample restricted to districts in Gujarat and includes observations from 1990-2011. All regressions include a Treatment dummy for districts which received early check dam construction from the Sardar Patel Participatory Water Conservation Program. These include the Saurashtra region, Kachchh, Ahdamabad, and Sabar Kantha. Regions in Gujarat include Kachchh, North Gujarat, Central Gujarat, Saurashtra, East Gujarat, and South Gujarat. Precipitation is district average monthly precipitation in mm. Census controls include 2001 district demographics interacted with year dummies and include percent female, percent literate, percent working, percent with some college, and total population.
Table 5: The Impact of Delay in Paddy Transplantation on Groundwater Levels Post Transplanting
(Groundwater Level Measured in August)

<table>
<thead>
<tr>
<th></th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post * High Rice Producing Districts</td>
<td>1.30**</td>
<td>1.28**</td>
<td>1.13</td>
<td>1.17*</td>
</tr>
<tr>
<td></td>
<td>(0.53)</td>
<td>(0.53)</td>
<td>(0.70)</td>
<td>(0.64)</td>
</tr>
<tr>
<td></td>
<td>[0.51]</td>
<td>[0.51]</td>
<td>[0.62]</td>
<td>[0.57]</td>
</tr>
</tbody>
</table>

Observations 324 321 321 321
R-squared 0.100 0.101 0.252 0.254
State x Rice FE Yes Yes Yes Yes
Year x Rice FE Yes Yes Yes Yes
District Precipitation No Yes Yes Yes
Census Controls No No Yes Yes
State Specific Time Trend No No No Yes

Robust standard errors clustered at district level are in parentheses. Conley (1999) standard errors correcting for spatial correlation are in brackets. *** p<0.01, ** p<0.05, * p<0.1

Note: Sample is restricted to districts in Punjab and Haryana. Each regression controls for year fixed effects Sample includes observations from 2003-2011. Districts with rice area as a fraction of total cultivated area above the median in Punjab and Haryana (.30) are classified as rice-producing.
Punjab began limiting paddy water supply in 2006 (2 years before its legislation) by way of rationing electricity, and Haryana passed legislation in 2009. Precipitation is district average monthly precipitation in mm. Census controls include 2001 district demographics interacted with year dummies and include percent female, percent literate, percent working, percent with some college, and total population.
Table 6: The Impact of Delay in Paddy Transplantation on Annual Groundwater Levels

<table>
<thead>
<tr>
<th></th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post * High Rice Producing Districts</td>
<td>1.25***</td>
<td>1.13**</td>
<td>1.58***</td>
<td>1.60***</td>
</tr>
<tr>
<td></td>
<td>(0.45)</td>
<td>(0.46)</td>
<td>(0.54)</td>
<td>(0.53)</td>
</tr>
<tr>
<td></td>
<td>[0.44]</td>
<td>[0.45]</td>
<td>[0.48]</td>
<td>[0.47]</td>
</tr>
<tr>
<td>Observations</td>
<td>324</td>
<td>321</td>
<td>321</td>
<td>321</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.090</td>
<td>0.097</td>
<td>0.248</td>
<td>0.249</td>
</tr>
<tr>
<td>State x Rice FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year x Rice FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>District Precipitation</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Census Controls</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>State Specific Time Trend</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Robust standard errors clustered at district level are in parentheses. Conley (1999) standard errors correcting for spatial correlation are in brackets. *** p<0.01, ** p<0.05, * p<0.1

Note: Sample is restricted to districts in Punjab and Haryana. Each regression controls for year fixed effects. Sample includes observations from 2003-2011. Districts with rice area as a fraction of total cultivated area above the median in Punjab and Haryana (.30) are classified as rice-producing.

Punjab began limiting paddy water supply in 2006 (2 years before its legislation) by way of rationing electricity, and Haryana passed legislation in 2009. Precipitation is district average monthly precipitation in mm. Census controls include 2001 district demographics interacted with year dummies and include percent female, percent literate, percent working, percent with some college, and total population.