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Missing Water

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Missing Water: Agricultural Stress and Adaptation Strategies in Response to Groundwater Depletion among Farmers in India *

Sheetal Sekhri†

Abstract

Groundwater depletion is becoming a serious policy concern in many developing countries but little is known about the costs of groundwater depletion. This paper examines the impact of ground water stress on agricultural outcomes in India. I use annual deviations of district groundwater levels from 1999 to 2003 from the 1985-1995 decadal means, to investigate how production and area under cultivation respond to groundwater fluctuations. I find that a 1 meter decline in groundwater level in a year reduces food-grain production by 8 percent, water intensive crop production by 9 percent and cash crops by 5 percent. I also use year-to-year transitions of groundwater around a cutoff value, at which cost of technology required to access groundwater exogenously increases due to physical constraints, to examine coping mechanisms. I find that for short run shocks to groundwater, agricultural production for food-grains and water intensive crops are unchanged, but area under cultivation falls by 7 to 8 percent, whereas there is no change for cash crops. This suggests that farmers cultivate less area but use complementary inputs more intensively. I evaluate the effect of the transition of 10 year means of groundwater around this cutoff on exit from farming. I do not find evidence of exit of marginal or small farmers from agriculture.

JEL Classifications: O12, O13, Q01, Q25,

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1 Introduction

Groundwater depletion in many countries is becoming an increasingly important public policy concern. Groundwater provides timely irrigation, which can increase agricultural productivity (Food and Agricultural Organization, 2003). Around 38 percent of the world's irrigated area is irrigated with groundwater, and groundwater reliance is much higher in South Asia with 57 percent of the area irrigated with groundwater(World Bank, 2010). On the other hand, groundwater irrigation in many countries including Mexico, United States, Yemen, Pakistan, India, and China is leading to a substantial decline in groundwater levels. [1] This can impose huge costs in terms unmet drinking water needs and long term declines in productivity. This can also have gender implications as women walk significant distances to collect groundwater for drinking water needs. Inspite of these costs and benefits of increasing groundwater irrigation, there is no systematic empirical evidence on the impact of groundwater stress on agricultural outcomes. The objective of this paper is to fill this gap by providing this evidence. I focus on India as India is the largest user of groundwater in the world (World Bank, 2010) and the groundwater depletion rates are strikingly high. I evaluate the impact of groundwater stress using a panel of Indian districts and a nationally representative panel data on groundwater. [2]

A comparison of regions with deeper groundwater levels with shallow ones is unlikely to provide causal estimate of the impact of groundwater stress since these regions may differ from each other along other dimensions.In order to circumvent this, I use within district variation of groundwater over time. I use annual deviations of district groundwater levels for the period 1999 to 2003 from the 1985-1995 decadal means, to investigate how production and area under cultivation respond to groundwater fluctuations. Conditional on district fixed effects, year fixed effects, and district specific time trends, the variation of groundwater

[1] Groundwater level is the mean depth from surface to where groundwater is first observed.

[2] In the short run, spatial externalities arising from groundwater extraction are likely to be limited. Depending upon the medium, the lateral velocity of the groundwater can be as much as 1 cm a year (Todd, 1980). Therefore, I focus on inter-temporal externalities.

from its decadal mean is plausibly exogenous. I find that a 1 meter decline in groundwater level in a year reduces food-grain production by 8 percent, water intensive crop production by 9 percent, and cash crops by 5 percent.

Fixed cost of groundwater extraction increases exogenously at around 8 meters of depth due to physical constraints imposed by well technology used to extract groundwater. [3] I use year-to-year transitions of groundwater around this cutoff value, at which cost of technology required to access groundwater exogenously increases due to physical constraints, to examine coping mechanisms. I find that for short run shocks to groundwater, agricultural production for food-grains and water intensive crops are unchanged, but area under cultivation falls by 7 to 8 percent, whereas there is no change for cash crops. This suggests that farmers cultivate less area but use complementary inputs more intensively.

Groundwater plays a crucial role in providing rural livelihood, but as noted before, there is a dearth of research that shows causal links between the access to groundwater and agricultural production. While previous research has studied the effect of irrigation dams on agricultural outcomes (Duflo and Pande, 2007), empirical investigations of the effects of groundwater are limited. In addition, little is known about the response of farmers to groundwater stress. This paper makes two contributions. First, it determines the causal impact of groundwater stress on agricultural outcomes using a detailed panel data set which provides actual measures of groundwater level. Second, it sheds light on the short term adaptation strategies that the farmers use to cope with water stress. From policy perspective, these results are important to understand the cost- benefit of increasing groundwater access for irrigation, and designing conservation strategies in the future.

Rest of the paper is organized as follows. Section 2 provides a background on groundwater irrigation in India and pump technology used in irrigation. Section 3 describes the data used in the analysis. Section 4 discusses the estimation strategy. I discuss the results in Section 5, and conclude in Section 6.

[3] This feature has been used in Sekhri(2010).

2 Background

2.1 Groundwater Irrigation in India

Irrigation is one of the most prominent uses of groundwater in the world. In India, the world's largest user of groundwater, about sixty percent of agriculture relies on groundwater for irrigation, and 80 percent of the rural population meets its drinking water needs by using groundwater. There has been a tremendous increase in reliance on groundwater over the last 4 decades. Canal irrigation use to be prominent until the 1970s, by the late 1990s, groundwater irrigation become the major source of irrigation in India (Sekhri, 2010). According to the World Bank, as of 2010 there has been a 500 percent increase in area irrigated by groundwater since 1960 (World Bank, 2010, and there are more than 20 million wells in India (IWMI, 2002). However, since fixed cost to construct a well is very high, there are disparities in access. Marginal and small farmers are not as likely to invest in wells as larger farmers (Foster and Sekhri, 2008). Groundwater is called 'water by demand' due to its immediate availability in times of moisture stress and crucial stages of plant growth. Researchers at the Indian Council of Agricultural Research contend that groundwater helps prevent famines. There was a severe drought in India in 1965-66, when food production fell by 19 percent due to acute rainfall deficit. However, a comparable rainfall deficit in 1987-88 had a marginal effect on food production, which declined by around 2 percent. Groundwater is being over exploited in India. Central groundwater board estimates that fifteen percent of the administrative blocks in India extract more water than is replenished. A world Bank study cited in a recent article in *The Economist* estimated that 15 percent of India's food is produced by mining or over-extraction of groundwater.

2.2 Irrigation Technology

Centrifugal pumps are the most common type of pumps used to extract groundwater in a mechanized well. These operate on the surface and create a low pressure in the tube well so the atmospheric pressure pushing down on water outside the well causes the water level in the well to rise. If a perfect vacuum could be created, the water would rise to a height of 34 feet. This happens because the weight of the column of of height 34 feet exerts pressure equal to *atmospheric pressure*. However, since a perfect vacuum cannot be created, the accepted practical standard for vertical lift using these pumps is around 8 meters. If groundwater is at a depth of more than 8 meters from the surface, then the surface pumps cannot be used. In that case, submersible pumps that are placed inside the well tube are used in in order to extract water. These are much more expensive than the surface pumps. Sekhri(2010) uses this cost differential as an exogenous source of variation in fixed cost of private extraction, to examine the effects of public provision of groundwater on water tables. In this paper, year-to-year fluctuations of groundwater level around 8 meters are interpreted as short term water stress, and the paper examines how farmers cope with such stress.

3 Data

There are two main sources of data. The groundwater level data is from the 16000 monitoring wells monitored by the Central Groundwater Board of India. These wells are fairly evenly spread across India (This excludes the hilly regions in the North and North East). The data provides groundwater levels in 4 different months (pre and post harvest) along with the spatial co-ordinates of the monitoring wells for the years 1996-2006. Groundwater data is maintained in a restricted access database and has been provided by the Central Groundwater Board of India. In addition, the Central Ground Water Board of India also provided decadal means for each well for the period 1985 to 1995. A krigging algorithm was used to construct the district annual average levels for each year in the sample.

The agricultural data on production and area under cultivation for various crops for years 1999-2003 are available from the Directorate of Economics and Statistics, Ministry of Agriculture, Government of India. This data was matched to the district level water level data. Districts and states that did not report the agricultural output to Directorate of economic statistic are not in the sample.[4] The details of various crops and their classification into food-grains, cash crops, and water intensive crops is provided in Appendix Table A1. These categories are not mutually exclusive.

District average annual rainfall and temperature values for the years 1999-2003 are interpolated from the University of Delaware 0.5 degree resolution data,[5]. District-level demographic data (population density, literacy rate, unemployment rate, percentage of population employed in agriculture, percentage of population residing in rural areas, and adult sex ratio) are taken from the 2001 Census of India. Data on operational holdings by size group for years 1995, 2000 and 2005 is from the Agricultural Census of India.[6] Table 1 provides summary statistics.

4 Empirical Strategy

A regression of agricultural outcomes on groundwater level will not yield causal estimates of the the effect of groundwater levels and depletion on agricultural outcomes. There might be omitted variables that are correlated with both groundwater levels and agricultural outcomes. In order to address such endogeneity concerns, I follow two approaches. In the first approach, I use within district variation in a fixed effects model in which I control for district fixed effects, year fixed effects, and district specific time trends. This saturated model controls for unobserved time invariant district specific omitted variables, year specific common shocks to districts, and unobserved district specific time varying omitted variables. I also control for geographical variables that change over time including rainfall and temperature. The empirical model can be specified as:

[4]New states were carved in this time period. These did not start reporting the data until 2004. So the districts that comprised these states were dropped from the parent states in addition to these new states.

[5]Available at http://climate.geog.udel.edu/~climate/html_pages/archive.html

[6]Agriculture Census was not conducted in states of Bihar, and Maharashtra. hence , these states are not in our sample.

$$Y_{it} = \pi_1 \, W_{it} + \pi_2 \, X'_{it} + \theta_i + \kappa_t + \delta_{it} + \varepsilon_{it} \quad (1)$$

Where Y_{it} is the outcome variable in district i in year t, W_{it} is the groundwater level in district i and year t, X_{it} is a set of district level time varying controls controls, and θ_i and κ_t are district and year fixed effects, and δ_{it} is district specific time trend. ε_{it} is the random disturbance term. Robust standard errors are clustered at district level.

In the second approach, I augment the fixed effects model by taking the annual deviations of groundwater levels from the decadal mean for the period 1985-1995. After controlling for district fixed effects, time fixed effects and district specific time trends, deviations in groundwater level will be plausible exogenous shocks and orthogonal to any omitted variables. The model is specified as:

$$Y_{it} = \pi_1 \, G(W_{it} - \overline{W_i}) + \pi_2 \, X'_{it} + \theta_i + \kappa_t + \delta_{it} + \varepsilon_{it} \quad (2)$$

Where Y_{it} is the outcome variable in district i in year t, W_{it} is the groundwater level in district i and year t, G is a function of the deviation of the groundwater from its decadal mean for 1985-1995 $\overline{W_i}$, and I use a linear spline with a fixed knot at zero. This allows me to distinguish between shocks to groundwater that increase or decrease the levels, separately. X_{it} is a set of district level time varying controls controls, and θ_i and κ_t are district and year fixed effects, and δ_{it} is district specific time trend. ε_{it} is the random disturbance term. Robust standard errors are clustered at district level.

As described in section 2.2, cost of accessing groundwater shifts exogenously at 8 meters. I examine how agricultural outcomes respond to shocks that switch water level from below to above 8 meters. I use the following empirical model:

$$Y_{it} = \beta_0 + \beta_1 \, I^W_{it} + \beta_2 \, X'_{it} + \theta_i + \kappa_t + \delta it + \epsilon_{it} \quad (3)$$

Where Y_{it} is the outcome variable in district i in year t, X_{it} is a set of district level time varying controls controls, and θ_i and κ_t are district and year fixed effects, and δ_{it} is district specific time trend. ε_{it} is the random disturbance term. Robust standard errors are clustered at district level. I_{it}^{W} is an indicator which takes the value 1 if groundwater level in district i and year t changes from being between 0-8 meters to being above 8 meters in year t relative to t-1. This is indicative of short run water stress. [7]

5 Results

The results from estimation of (1) are reported in Tables II.A and II.B. Table (ii) reports the effect of groundwater depth from the surface (level) on log production. Column (i) shows the estimates controlling for district and and year fixed effects. In column (ii), I add geographical controls including mean annual rainfall and temperature. Column (iii) shows the results where I control for district specific time trends and saturate the model. A 1 meter increase in depth (or decrease in level) reduces total agricultural production by 7.18 percent. Food grains production decreases by 7 percent, cash crops decrease by 6.13 percent, and water intensive crops decrease by 8.54 percent. All these coefficients are highly statistically significant at less than 1 percent significance level. Demographic variables are not available for this time period. As a robustness check, I interact the demographic variables available in year 2001 with year indicators to control for trends in these variables. Column (iv) controls for district and year fixed effects, and geographical and demographic controls, but not district specific time trends. Column (v) controls for district and time fixed effects, district specific time trends, and geographical and demographic controls. The demographic controls include percentage of literate population, percentage of employed population, percentage of schedule caste population, percentage of female population, percentage of working population, and total population. Estimates in column (iii) and (v) are very similar. Column (iii) is the most preferred specification. These results are economically significant. Dam placement increases production of 6 major crops in India by 0.34 percent (Duflo and Pande, 2007). In contrast,

[7] Water is accessible by the cheaper technology upto a depth of 8 meters.

a 1 meter decline in groundwater levels reduces agricultural production by 7.18 percent for the 43 crops pooled in our data, and 7 percent for food grains. These estimates reflect the very heavy reliance of Indian agriculture on groundwater.

Table II.B examines the effect on area under cultivation. Neither overall area nor area under food-grains or cash crops changes, whereas the area under water intensive crops falls by 2.2 percent in the most saturated specification in column (iii). The coefficients are highly statistically significant across all but one specifications, and at 5 percent in the most saturated model in column (v).

In the next approach, I report the estimates from the regressions where the independent variable is the deviation of groundwater levels from the decadal average. The results from estimation of (2)are reported in Tables III.A and III.B. I report the estimates from similar specifications as before. Overall production (reported in Table III.A) declines by 8.1 percent when groundwater levels fall and depth exceeds the mean depth. On the other hand, there is no change when the water level rises (column (iii), row 1). Food-grains production falls by 7.2 percent when water level falls below mean, and increases by 5 percent when water level rises. Although this coefficient is marginally significant at 10 percent. Cash crops production decreases between 8.3 percent across specifications when water level falls below the decadal mean. However, cash production falls by 7.6 percent when the water level rises above its mean. The coefficient from the saturated model is statistically significant at 10 percent. This could be due to the fact that cash crops are high risk high return crops, and any unaccounted fluctuations in water level, which cause too much watering with the aim to increase production can have effects to the contrary. Finally, for water intensive crops, a decline in water level below its mean reduces output by 9.8 percent, whereas no change is discerned for a positive water shock. Table III.B shows the results for area under cultivation. The area under water intensive crops falls by 2.8 percent when water levels decline (the production also falls, so the yield is potentially unaffected).

I examine bins of deviations of groundwater level from the decadal mean and calibrate these by the district specific standard deviation to investigate any non-linearity in the effects. A bin of 0.75 standard deviations centered on the mean is the reference category, and I report the results for increments of 0.75 standard deviations on either side. I report the results for overall log production in Table III.C using the similar specifications as before. The effect gets consistently larger for each bin relative to the reference, when water declines below its decadal mean, although the effect does seem to change non-linearly in that it does not double in moving from one bin to the next. Larger fluctuations of groundwater when it declines lead to more pronounced reduction in production. Most of the bins for rise in water levels have no effect in the most saturated specification (column (iii)), although the production does increase statistically significantly in the second bin. Table III.D reports the results for food-grains production. For declining water levels, the effect does get consistently larger in all specifications, but it does not nearly double. Similarly, the effect of rising water level is also larger progressively but eventually becomes constant. In the case of cash crops reported in Table III.E, the decline in water level leads to a reduction in production by 12.4 percent in the second bin relative to the reference category, and remains in the range of 13 to 16 percent as we move to farther bins. However, the standard errors are large in the farther bins, and the effects are statistically insignificant. For water intensive crops, the results are shown in Table III.F. The smaller declines as the first bin do not have an effect, whereas as we move farther, the effect consistently increases from 22.8 percent to 34.8 percent reduction (column (iii)). For rise in water, production seems to increase in second bin by 9.5 percent and not others.

Next, I investigate how year-to-year fluctuations of groundwater level around 8 meters, the depth at which cost to extract water rises exogenously, effect agricultural outcomes. I estimate (3) and report the results in Tables IV.A and IV.B. I use the similar specifications as before. I do not discern any changes in production for any of the crop categories. However, the area under food-grains falls between 6.5 percent and the coefficient is significant at 5 percent in the most saturated model (column (iii)). Similarly, area under water intensive crops falls by 7 percent (significant at 5 percent, column (iii)) when the district groundwater level switches from being below 8 meters to above 8. This indicates that when faced with a short run water stress, farmers respond by cultivating less area but cultivating it more intensely using other inputs. I evaluate whether a transition of the 10 year means of the groundwater levels for 1985-1995 and 1996 to 2005, from below 8 meters to above 8 meters affects ext of farmers from agriculture. Table V reports the results separately for marginal (0-1 ha), small (1-2), medium (2-10), and large(greater than 10 ha) groups. Neither the number of holdings, nor the area under various size groups of holdings, changes. With 2 years, district specific trends cannot be controlled. The fixed effect estimates are statistically insignificant.

6 Conclusion

Despite groundwater comprising around 97 percent of world's fresh water reserves, sustaining world's food production, and meeting drinking water needs for rural populations, very limited research has examined the implications of groundwater stress particularly in the developing countries, where groundwater access is more salient in the rural livelihood generation. This paper presents the first systematic empirical evidence on the impact of groundwater stress on agricultural outcomes. I make use of natural fluctuations in groundwater levels around their decadal means within Indian districts and transitions of ground water levels around an exogenously generated depth of 8 meters, at which physical constraints limit use of cheaper technology to access groundwater, to estimate the impact of groundwater stress and coping strategies used. I find that a 1 meter decline in groundwater level in a year reduces food-grain production by 8 percent, water intensive crop production by 9 percent, and cash crops by 5 percent. I also find that for short run shocks to groundwater, agricultural production for food-grains and water intensive crops are unchanged, but area under cultivation falls by 7 to 8 percent, whereas there is no change for cash crops suggesting that farmers resort to intensifying the use of inputs to maintain their yields. I do not find evidence of exit of marginal or small farmers from agriculture. From a policy perspective, these results indicate that groundwater depletion can lead to a significant reduction in agricultural production. Groundwater depletion can have implications for rural welfare as this can bid up food prices and increase the cost of production in the farm sector.

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Table 1: Summary Statistics

	year	1999-00	2000-01	2001-02	2002-03	2003-04	Overall
Total Production	**Mean**	1239.62	1207.39	1233.15	1135.98	1161.17	1195.46
	Min	11.90	9.78	9.21	10.32	11.77	9.21
	Max	14246.55	19028.58	14749.54	15092.61	16057.75	19028.58
	Std dev	1783.91	1836.67	1764.81	1757.31	1597.21	1748.79
Total Area Under Cultivation	**Mean**	338.22	334.07	339.61	315.96	337.60	333.09
	Min	8.41	4.77	2.21	4.07	7.79	2.21
	Max	1400.76	1361.14	1622.88	1349.31	1397.51	1622.88
	Std dev	244.71	228.47	240.13	215.79	233.09	232.62
Average Groundwater Level	**Mean**	6.54	6.95	6.99	7.78	7.55	7.16
	Min	1.20	0.84	0.86	1.07	1.33	0.84
	Max	57.61	60.38	53.82	60.33	66.47	66.47
	Std dev	5.72	6.18	5.78	6.42	6.47	6.13
Average Temperature	**Mean**	25.50	25.60	25.59	25.79	26.19	25.73
	Min	9.50	9.33	9.74	9.43	10.19	9.33
	Max	29.27	29.45	29.27	29.48	29.58	29.58
	Std dev	1.96	2.01	1.98	2.13	1.98	2.02
Average Rainfall	**Mean**	97.83	94.08	103.70	90.13	110.71	99.29
	Min	7.77	10.12	13.63	4.58	11.17	4.58
	Max	519.68	572.59	672.65	570.50	606.84	672.65
	Std dev	61.57	62.66	68.14	66.28	72.50	66.69
Observations		466	466	466	466	466	2330

Table II.B: Fixed Effect Estimates of District Groundwater Depth on Agricultural Production

	(i)	(ii)	(iii)	(iv)	(v)
Total Log Production	**-0.0784*** **	**-0.0673*** **	**-0.0718*** **	**-0.0681*** **	**-0.0671*** **
	[0.0130]	[0.0121]	[0.0162]	[0.0127]	[0.0161]
Observations	2323	2323	2323	2323	2323
Districts	466	466	466	466	466
R-Squared	0.17	0.20	0.437	0.24	0.46
Foodgrains	**-0.0814*** **	**-0.0673*** **	**-0.0693** **	**-0.0650*** **	**-0.0629** **
	[0.0215]	[0.0197]	[0.0289]	[0.0203]	[0.0283]
Observations	2323	2323	2323	2323	2323
Districts	466.00	466.00	466	466.00	466.00
R-Squared	0.19	0.24	0.515	0.30	0.55
Cash Crops	**-0.0490*** **	**-0.0411** **	**-0.0613** **	**-0.0571*** **	**-0.0556** **
	[0.0164]	[0.0174]	[0.0241]	[0.0170]	[0.0243]
Observations	2318	2318	2318	2318	2318
Districts	465	465	465	465	465
R-Squared	0.02	0.04	0.383	0.10	0.41
Water Intensive Crops	**-0.0845*** **	**-0.0724*** **	**-0.0854*** **	**-0.0757*** **	**-0.0816*** **
	[0.0163]	[0.0164]	[0.0241]	[0.0168]	[0.0237]
Observations	2323	2323	2323	2323	2323
Districts	466	466	466	466	466
R-Squared	0.11	0.13	0.439	0.18	0.46
Controls:					
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes	Yes
District Time Trends	No	No	Yes	No	Yes
Temperature and Rainfall	No	Yes	Yes	Yes	Yes
Clustered Standard Errors	Yes	Yes	Yes	Yes	Yes

Notes: Independent variable is the annual average distance from the surface of groundwater within the district. The demographic controls are percent literate, percent employed, percent of scheduled caste population, percent female population, percent population working, and total population interacted with year indicators. *** indicates significance at 1 % level, ** at 5 %, and * at 10 % level.

Table II.B : Fixed Effects Estimates of District Groundwater Depth on Area Under Cultivation

	(i)	(ii)	(iii)	(iv)	(v)
Total Log Area	**-0.0122***	-0.0093	-0.00836	-0.00359	-0.00647
	[0.00707]	[0.00721]	[0.00787]	[0.00712]	[0.00813]
Observations	2323	2323	2323	2323	2323
Districts	466	466	466	466	466
R-Squared	0.0350	0.0430	0.379	0.1400	0.4250
Foodgrains	**-0.0162***	-0.0134	-0.0192	-0.00902	-0.018
	[0.00843]	[0.00838]	[0.0129]	[0.00833]	[0.0132]
Observations	2323	2323	2323	2323	2323
Districts	466	466	466	466	466
R-Squared	0.0450	0.0510	0.403	0.1520	0.4400
Cash Crops	0.0087	0.0150	0.00411	0.0163	0.0097
	[0.0104]	[0.0110]	[0.00904]	[0.0118]	[0.00910]
Observations	2318	2318	2318	2318	2318
Districts	465	465	465	465	465
R-Squared	0.0240	0.0350	0.347	0.0950	0.4130
Water Intensive Crops	**-0.0215****	-0.0171	**-0.0221****	-0.0124	**-0.0206****
	[0.0105]	[0.0110]	[0.00961]	[0.0101]	[0.00970]
Observations	2318	2318	2323	2318	2318
Districts	465	465	466	465	465
R-Squared	0.0230	0.0290	0.462	0.0940	0.4920
Controls:					
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes	Yes
District Time Trends	No	No	Yes	No	Yes
Temperature and Rainfall	No	Yes	Yes	Yes	Yes
Demographics	No	No	No	Yes	Yes
Clustered Standard Errors	Yes	Yes	Yes	Yes	Yes

Notes: Independent variable is the annual average distance from the surface of groundwater within the district. The demographic controls are percent literate, percent employed, percent of scheduled caste population, percent female population, percent population working, and total population interacted with year indicators. *** indicates significance at 1 % level, ** at 5 %, and * at 10 % level.

Table III.A: Fixed effect Estimates of deviation of District Groundwater Depths on Production

	(i)	(ii)	(iii)	(iv)
Total Log Production				
Districts=459				
Meters Below Mean	**0.0719*** **	**0.0503*** **	0.0137	**0.0595*** **
	[0.0194]	[0.0186]	[0.0256]	[0.0197]
Meters Above Mean	**-0.0805*** **	**-0.0716*** **	**-0.0812*** **	**-0.0699*** **
	[0.0159]	[0.0146]	[0.0195]	[0.0144]
Foodgrains				
Districts=459				
Meters Below Mean	**0.109*** **	**0.0799*** **	**0.0503* **	**0.0874*** **
	[0.0214]	[0.0197]	[0.0265]	[0.0199]
Meters Above Mean	**-0.0753*** **	**-0.0646*** **	**-0.0721** **	**-0.0603*** **
	[0.0257]	[0.0234]	[0.0344]	[0.0229]
Cash Crops				
Districts=458				
Meters Below Mean	-0.0117	-0.0232	**-0.0764* **	0.0172
	[0.0329]	[0.0336]	[0.0437]	[0.0355]
Meters Above Mean	**-0.0630*** **	**-0.0552*** **	**-0.0836*** **	**-0.0650*** **
	[0.0198]	[0.0203]	[0.0252]	[0.0198]
Water Intensive Crops				
Districts=459	**0.0600** **	0.0346	0.00781	**0.0532** **
Meters Below Mean	[0.0258]	[0.0250]	[0.0318]	[0.0268]
Meters Above Mean	**-0.0908*** **	**-0.0812*** **	**-0.0980*** **	**-0.0801*** **
	[0.0203]	[0.0198]	[0.0275]	[0.0194]
Controls:				
Year Fixed Effects	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes
District Time Trends	No	No	Yes	No
Temperature and Rainfall	No	Yes	Yes	Yes
Demographics	No	No	No	Yes
Clustered Standard Errors	Yes	Yes	Yes	Yes

Notes: Independent variable is the number of meters above or below the decadal mean groundwater level from 1985-1996. Below the mean indicates groundwater level is closer to the surface. The demographic controls are percent literate, percent employed, percent of scheduled caste population, percent female population, percent population working, and total population interacted with year indicators. *** indicates significance at 1 % level, ** at 5 %, and * at 10 % level.

Table III.B: Fixed Effects Estimates of Deviations of District Groundwater Depth on Area

	(i)	(ii)	(iii)	(iv)
Overall Log Area				
Districts=459				
Meters Below Mean	0.00717	0.0027	-0.0112	-0.00655
	[0.0118]	[0.0119]	[0.0156]	[0.0126]
Meters Above Mean	-0.0134	-0.0109	-0.0112	-0.00518
	[0.00876]	[0.00871]	[0.00926]	[0.00830]
Foodgrains				
Districts=459				
Meters Below Mean	0.0139	0.00804	-0.00997	0.0026
	[0.0115]	[0.0116]	[0.0178]	[0.0123]
Meters Above Mean	-0.0168	-0.0147	-0.0237	-0.00997
	[0.0104]	[0.0102]	[0.0157]	[0.00972]
Cash Crops				
Districts=458				
Meters Below Mean	-0.05	**-0.0563***	-0.0512	-0.0544
	[0.0319]	[0.0328]	[0.0407]	[0.0343]
Meters Above Mean	-0.00019	0.0066	-0.00314	0.00983
	[0.0113]	[0.0115]	[0.00962]	[0.0121]
Water Intensive Crops				
Districts=459				
Meters Below Mean	-0.000873	-0.0109	-0.015	-0.0155
	[0.0231]	[0.0234]	[0.0286]	[0.0253]
Meters Above Mean	**-0.0270****	**-0.0236***	**-0.0280****	-0.0175
	[0.0134]	[0.0135]	[0.0110]	[0.0124]
Controls:				
Year Fixed Effects	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes
District Time Trends	No	No	Yes	No
Temperature and Rainfall	No	Yes	Yes	Yes
Demographics	No	No	No	Yes
Clustered Standard Errors	Yes	Yes	Yes	Yes

Notes: Independent variable is the number of meters above or below the decadal mean groundwater level from 1985-1996. Below the mean indicates groundwater level is closer to the surface. The demographic controls are percent literate, percent employed, percent of scheduled caste population, percent female population, percent population working, and total population interacted with year indicators. *** indicates significance at 1 % level, ** at 5 %, and * at 10 % level.

Table III.C : Non- Linearity in Estimates of Deviations of Groundwater Depth from Mean

	Total Production			
	(i)	(ii)	(iii)	(iv)
Total Log Production				
>2.625 Deviations Below Mean	**0.141*** **	**0.0948** **	0.0544	**0.0787***
	[0.0420]	[0.0404]	[0.0569]	[0.0433]
1.875-2.625 Deviations Below Mean	**0.123*** **	**0.0858*** **	0.066	**0.0861*** **
	[0.0340]	[0.0329]	[0.0410]	[0.0325]
1.125-1.875 Deviations Below Mean	**0.128*** **	**0.0955*** **	**0.0731** **	**0.0957*** **
	[0.0273]	[0.0261]	[0.0353]	[0.0265]
.375-1.125 Deviations Below Mean	**0.0706*** **	**0.0500** **	0.0102	**0.0450***
	[0.0252]	[0.0243]	[0.0333]	[0.0251]
.375-1.125 Deviations Above Mean	**-0.0952*** **	**-0.0832*** **	-0.0489	**-0.0748*** **
	[0.0281]	[0.0276]	[0.0361]	[0.0276]
1.125-1.875 Deviations Above Mean	**-0.222*** **	**-0.195*** **	**-0.187*** **	**-0.179*** **
	[0.0364]	[0.0364]	[0.0460]	[0.0366]
1.875-2.625 Deviations Above Mean	**-0.325*** **	**-0.283*** **	**-0.286*** **	**-0.251*** **
	[0.0505]	[0.0516]	[0.0689]	[0.0521]
>2.625 Deviations Above Mean	**-0.393*** **	**-0.333*** **	**-0.316*** **	**-0.292*** **
	[0.0712]	[0.0717]	[0.0983]	[0.0707]
Observations	2330	2330	2330	2330
Districts	466	466	466	466
R-Squared	0.1690	0.1900	0.434	0.2310
Controls:				
Year Fixed Effects	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes
District Time Trends	No	No	Yes	No
Temperature and Rainfall	No	Yes	Yes	Yes
Demographics	No	No	No	Yes
Clustered Standard Errors	Yes	Yes	Yes	Yes

Notes: Independent variable is the distance from the district level 1985-1996 mean groundwater level in terms of district specific standard deviations. The demographic controls are percent literate, percent employed, percent of scheduled caste population, percent female population, percent population working, and total population interacted with year indicators. *** indicates significance at 1 % level, ** at 5 %, and * at 10 % level.

Table III.D : Non- Linearity in Estimates of Deviations of Groundwater Depth from Mean

	Foodgrains Production			
	(i)	(ii)	(iii)	(iv)
Log Food grain Production				
>2.625 Deviations Below Mean	**0.197*** **	**0.139*** **	**0.108***	**0.132*** **
	[0.0495]	[0.0458]	[0.0641]	[0.0481]
1.875-2.625 Deviations Below Mean	**0.180*** **	**0.132*** **	**0.121*** **	**0.143*** **
	[0.0390]	[0.0364]	[0.0456]	[0.0353]
1.125-1.875 Deviations Below Mean	**0.182*** **	**0.141*** **	**0.135*** **	**0.144*** **
	[0.0353]	[0.0334]	[0.0435]	[0.0323]
.375-1.125 Deviations Below Mean	**0.117*** **	**0.0930*** **	**0.0701** **	**0.0842*** **
	[0.0271]	[0.0261]	[0.0326]	[0.0261]
.375-1.125 Deviations Above Mean	**-0.131*** **	**-0.116*** **	**-0.0750***	**-0.101*** **
	[0.0308]	[0.0297]	[0.0393]	[0.0288]
1.125-1.875 Deviations Above Mean	**-0.281*** **	**-0.247*** **	**-0.228*** **	**-0.226*** **
	[0.0391]	[0.0382]	[0.0504]	[0.0364]
1.875-2.625 Deviations Above Mean	**-0.446*** **	**-0.395*** **	**-0.364*** **	**-0.353*** **
	[0.0537]	[0.0529]	[0.0626]	[0.0500]
>2.625 Deviations Above Mean	**-0.462*** **	**-0.392*** **	**-0.359*** **	**-0.339*** **
	[0.0693]	[0.0682]	[0.0847]	[0.0641]
Observations	2330	2330	2330	2330
Districts	466	466	466	466
R-Squared	0.2450	0.2690	0.53	0.3220
Controls:				
Year Fixed Effects	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes
District Time Trends	No	No	Yes	No
Temperature and Rainfall	No	Yes	Yes	Yes
Demographics	No	No	No	Yes
Clustered Standard Errors	Yes	Yes	Yes	Yes

Notes: Independent variable is the distance from the district level 1985-1996 mean groundwater level in terms of district specific standard deviations. The demographic controls are percent literate, percent employed, percent of scheduled caste population, percent female population, percent population working, and total population interacted with year indicators. *** indicates significance at 1 % level, ** at 5 %, and * at 10 % level.

Table III.E : Non- Linearity in Estimates of Deviations of Groundwater Depth from Mean

	Cash Crops Production			
	(i)	(ii)	(iii)	(iv)
Log Cash Crops Production				
>2.625 Deviations Below Mean	-0.0222	-0.0472	-0.119	-0.0566
	[0.0521]	[0.0535]	[0.0921]	[0.0573]
1.875-2.625 Deviations Below Mean	-0.00619	-0.0238	-0.0458	-0.0221
	[0.0446]	[0.0449]	[0.0516]	[0.0480]
1.125-1.875 Deviations Below Mean	0.00165	-0.016	-0.0631	0.00568
	[0.0409]	[0.0417]	[0.0455]	[0.0435]
.375-1.125 Deviations Below Mean	-0.00242	-0.0175	-0.0697	-0.00124
	[0.0454]	[0.0446]	[0.0582]	[0.0442]
.375-1.125 Deviations Above Mean	-0.0264	-0.02	0.0199	-0.0351
	[0.0444]	[0.0443]	[0.0556]	[0.0438]
1.125-1.875 Deviations Above Mean	**-0.128***	**-0.114***	**-0.124***	**-0.130***
	[0.0538]	[0.0553]	[0.0524]	[0.0543]
1.875-2.625 Deviations Above Mean	-0.125	-0.0987	-0.132	-0.101
	[0.0861]	[0.0865]	[0.0936]	[0.0846]
>2.625 Deviations Above Mean	**-0.195***	-0.152	-0.162	**-0.163***
	[0.0946]	[0.0962]	[0.123]	[0.0944]
Observations	2325	2325	2325	2325
Districts	465	465	465	465
R-Squared	0.0170	0.0300	0.381	0.0840
Controls:				
Year Fixed Effects	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes
District Time Trends	No	No	Yes	No
Temperature and Rainfall	No	Yes	Yes	Yes
Demographics	No	No	No	Yes
Clustered Standard Errors	Yes	Yes	Yes	Yes

Notes: Independent variable is the distance from the district level 1985-1996 mean groundwater level in terms of district specific standard deviations. The demographic controls are percent literate, percent employed, percent of scheduled caste population, percent female population, percent population working, and total population interacted with year indicators. *** indicates significance at 1 % level, ** at 5 %, and * at 10 % level.

Table III.F : Non- Linearity in Estimates of Deviations of Groundwater Depth from Mean

	Water Intensive Crops Production			
	(i)	(ii)	(iii)	(iv)
Log Water Intensive Crop				
>2.625 Deviations Below Mean	**0.141****	0.0852	0.0599	0.0722
	[0.0583]	[0.0573]	[0.0819]	[0.0597]
1.875-2.625 Deviations Below Mean	**0.0977****	0.0528	0.0602	0.0592
	[0.0490]	[0.0483]	[0.0549]	[0.0473]
1.125-1.875 Deviations Below Mean	**0.130*****	**0.0912*****	**0.0958****	**0.0990*****
	[0.0344]	[0.0332]	[0.0432]	[0.0340]
.375-1.125 Deviations Below Mean	**0.0574***	0.034	0.00723	0.0326
	[0.0326]	[0.0318]	[0.0413]	[0.0328]
.375-1.125 Deviations Above Mean	**-0.109*****	**-0.0947****	-0.0368	**-0.0866****
	[0.0373]	[0.0371]	[0.0478]	[0.0367]
1.125-1.875 Deviations Above Mean	**-0.276*****	**-0.243*****	**-0.228*****	**-0.227*****
	[0.0486]	[0.0493]	[0.0574]	[0.0492]
1.875-2.625 Deviations Above Mean	**-0.347*****	**-0.298*****	**-0.289*****	**-0.265*****
	[0.0651]	[0.0673]	[0.0856]	[0.0671]
>2.625 Deviations Above Mean	**-0.447*****	**-0.378*****	**-0.348*****	**-0.341*****
	[0.0920]	[0.0927]	[0.128]	[0.0907]
Observations	2330	2330	2330	2330
Districts	466	466	466	466
R-Squared	0.1140	0.1310	0.433	0.1690
Controls:				
Year Fixed Effects	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes
District Time Trends	No	No	Yes	No
Temperature and Rainfall	No	Yes	Yes	Yes
Demographics	No	No	No	Yes
Clustered Standard Errors	Yes	Yes	Yes	Yes

Notes: Independent variable is the distance from the district level 1985-1996 mean groundwater level in terms of district specific standard deviations. The demographic controls are percent literate, percent employed, percent of scheduled caste population, percent female population, percent population working, and total population interacted with year indicators. *** indicates significance at 1 % level, ** at 5 %, and * at 10 % level.

Table IV. A: Estimates of Transitions of Groundwater Depth from Below to Above 8m

	Production				
	(i)	(ii)	(iii)	(iv)	(v)
Total Log Production	**-0.0620****	-0.0385	0.0241	-0.0198	0.0338
	[0.0313]	[0.0314]	[0.0389]	[0.0305]	[0.0386]
Observations	2330	2330	2330	2330	2330
Districts	466	466	466	466	466
R-Squared	0.0870	0.1380	0.403	0.1900	0.4340
Foodgrains	**-0.135*****	-0.109**	-0.0481	-0.0791*	-0.0312
	[0.0449]	[0.0442]	[0.0486]	[0.0420]	[0.0485]
Observations	2330	2330	2330	2330	2330
Districts	466	466	466	466	466
R-Squared	0.1270	0.1900	0.488	0.2590	0.5250
Cash Crops	-0.0483	-0.0281	0.043	-0.0435	0.0216
	[0.0377]	[0.0396]	[0.0496]	[0.0416]	[0.0512]
Observations	2325	2325	2325	2325	2325
Districts	465	465	465	465	465
R-Squared	0.0100	0.0250	0.373	0.0780	0.4050
Water Intensive Crops	**-0.0842****	-0.0598	0.00134	-0.0455	0.0024
	[0.0382]	[0.0384]	[0.0486]	[0.0385]	[0.0483]
Observations	2330	2330	2330	2330	2330
Districts	466	466	466	466	466
R-Squared	0.0510	0.0910	0.407	0.1360	0.4280
Controls:					
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes	Yes
District Time Trends	No	No	Yes	No	Yes
Temperature and Rainfall	No	Yes	Yes	Yes	Yes
Demographics	No	No	No	Yes	Yes
Clustered Standard Errors	Yes	Yes	Yes	Yes	Yes

Notes: Independent variable is an indicator equal to one if groundwater depth increases from less than 8m from the surface to more than 8m from the surface within the district in a given year. The demographic controls are percent literate, percent employed, percent of scheduled caste population, percent female population, percent population working, and total population interacted with year indicators. *** indicates significance at 1 % level, ** at 5 %, and * at 10 % level.

Table IV.B: Estimates of Transition of District Groundwater Depth from Below to Above 8m

	Area				
	(i)	(ii)	(iii)	(iv)	(vi)
Overall Log Area	**-0.0505***	**-0.0447**	-0.0263	**-0.0342***	-0.0253
	[0.0187]	[0.0187]	[0.0211]	[0.0184]	[0.0214]
Observations	2330	2330	2330	2330	2330
Districts	466	466	466	466	466
R-Squared	0.0320	0.0420	0.376	0.1400	0.4230
Foodgrains	**-0.0837***	**-0.0789***	**-0.0650**	**-0.0647***	**-0.0621**
	[0.0239]	[0.0238]	[0.0285]	[0.0235]	[0.0289]
Observations	2330	2330	2330	2330	2330
Districts	466	466	466	466	466
R-Squared	0.0440	0.0530	0.4	0.1550	0.4380
Cash Crops	0.0014	0.0153	0.0471	0.0037	0.0306
	[0.0282]	[0.0289]	[0.0378]	[0.0297]	[0.0386]
Observations	2325	2325	2325	2325	2325
Districts	465	465	465	465	465
R-Squared	0.0080	0.0310	0.343	0.0840	0.3860
Water Intensive Crops	**-0.110***	**-0.103***	**-0.0704**	**-0.0907***	**-0.0727**
	[0.0266]	[0.0266]	[0.0297]	[0.0263]	[0.0297]
Observations	2330	2330	2330	2330	2330
Districts	466	466	466	466	466
R-Squared	0.0220	0.0300	0.46	0.0960	0.4910
Controls:					
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes	Yes
District Time Trends	No	No	Yes	No	Yes
Temperature and Rainfall	No	Yes	Yes	Yes	Yes
Demographics	No	No	No	Yes	Yes
Clustered Standard Errors	Yes	Yes	Yes	Yes	Yes

Notes: Independent variable is an indicator equal to one if groundwater depth increases from less than 8m from the surface to more than 8m from the surface within the district in a given year. The demographic controls are percent literate, percent employed, percent of scheduled caste population, percent female population, percent population working, and total population interacted with year indicators. *** indicates significance at 1 % level, ** at 5 %, and * at 10 % level.

Table V: Effect of Decadel Average Groundwater Transitions on Operational Holdings

	Percentage of Farms in Size Category		Percentage of Area in Size Category	
	(i)	(ii)	(i)	(ii)
Marginal Farms	-1.191	-1.537	-1.083	-1.517
(0-1 ha)	[2.100]	[1.859]	[1.432]	[1.403]
Small Farms	0.421	0.246	0.633	0.544
(1-2 ha)	[0.628]	[0.672]	[1.293]	[1.296]
Medium Farms	0.8200	1.2410	3.7160	5.6640
(2-10 ha)	[1.441]	[1.240]	[7.226]	[5.983]
Large Farms	-0.0502	0.0499	-0.5060	1.3920
(>10 ha)	[0.563]	[0.589]	[10.30]	[11.07]
Controls:				
Year Fixed Effects	Yes	Yes	Yes	Yes
District Fixed Effects	Yes	Yes	Yes	Yes
Temperature and Rainfall	No	Yes	No	Yes
Clustered Standard Errors	Yes	Yes	Yes	Yes

Notes: Independent variable is an indicator equal to one if the decadel average groundwater depth is more than 8m .
*** indicates significance at 1 % level, ** at 5 %, and * at 10 % level.

Table A1: Classification of Crops in Different Categories

Crop Category	Crops
Food Grains	Rice
	Wheat
	Maize
	Ragi
	Small Millets
	Barley
	Gram
	Arhar (Tur)
	Urad
	Moong
	Masoor
	Horse Gram
	Other Kharif Pulses
	Other Rabi Pulses
	Peas & Beans (Pulses)
	Kesari
	Moth
	Jowar
	Bajra

Crop Category	Crops
Cash Crops	Groundnut
	Sesamum
	Rapeseed & Mustard
	Linseed
	Castor Seed
	Safflower
	Niger Seed
	Coconut
	Sunflower
	Soyabean
	Cotton (lint)
	Mesta
	Sannhamp
	Dry Chillies
	Dry Ginger
	Turmeric
	Arecanut
	Coriander
	Potato
	Tapioca
	Garlic
	Sweet Potato
	Banana
	Onion
	Sugarcane
	Jute
	Black Pepper
	Cardamom
	Guar Seed

Crop Category	Crops
Water Intensive Crops	Arhar (Tur)
	Kesari
	Other Kharif Pulses
	Other Rabi Pulses
	Peas & Beans (Pulses)
	Groundnut
	Barley
	Rapeseed & Mustard
	Tobacco
	Garlic
	Onion
	Black Pepper
	Cardamom
	Coriander
	Dry Chillies
	Moong
	Sugarcane
	Turmeric
	Urad
	Potato
	Sweet Potato
	Tapioca
	Banana
	Coconut
	Dry Ginger
	Rice

Note: Water Intensity has been determined based on the evapotranspiration Index of the crops.

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