Way Down in the Hole: Adaptation to Long-Term Water Loss in Rural India

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Introduction

- Groundwater depletion in southern India
- Why is it important?
  - Groundwater depletion is a critical threat to agriculture-dependent livelihoods
  - Socioeconomic impacts of environmental degradation
  - Inform sustainable development policies
- Quasi-random variation in geological factors causing borewell failure as exogenous shock
- Compare HH with functional borewells to HH with failed borewells
- How do rural households in India adapt to long-term water loss caused by groundwater depletion?
- What role does labor reallocation to non-agricultural sectors play in maintaining household income?

Methodology

- Hard-rock geology: spatially random subsurface pockets $\Rightarrow$ quasi-random groundwater access
- HHs within the same village
- Divide HHs into successful or failed first borewell, to avoid confounding effects of wealthier households
- Compare outcomes between HHs with currently active and inactive borewells
- Specialized cameras confirm geological differences drive borewell failures, validate exogeneity
- Robustness tests show no pre-existing correlation between borewell age, depth, or cost and household socioeconomic conditions
- Regress outcomes (e.g., income, labor shifts) on borewell failure, using household controls, fixed effects for village and year of drilling

Data

- Household survey data: 1,408 households from 102 villages in Karnataka that rely primarily on groundwater for irrigation
- Data on every borewell drilled, its functionality status, costs, depths, and drilling year
- Household characteristics, including cropping patterns, income sources (farm and off-farm), assets
- Supplementary village-level data from the 2013 Economic Census, used to measure the presence of firms and local industry

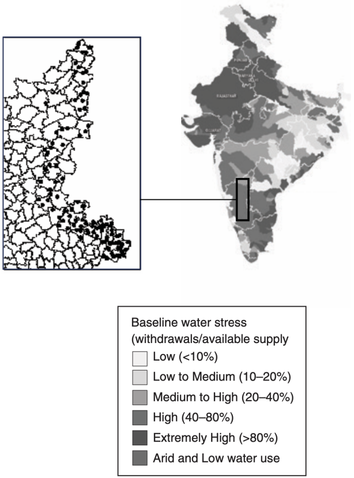


Figure Baseline water stress (withdrawals/available supply)

Results

- Significant drop in farm income with no agricultural adaptation
- Households shifted labor to off-farm employment to offset income losses, mediated by presence of large firms
- Increased debt and asset liquidation
- Older children enrollment decreased to supplement income, younger children enrollment increased

Literature Review (in 30 seconds)

- Detrimental effects of climate change on agricultural livelihoods and social outcomes
  - Auffhammer et al. 2013
  - Dell, Jones, and Olken 2014
  - Carleton and Hsiang 2016
- Households' coping strategies in response to transient income shocks, including asset sales, income diversification, and migration
  - Alderman and Paxson 1994
  - Morduch 1995
  - Dercon 2002
- Shifts to non-agricultural employment in response to transient weather shocks
  - Kochar 1999
  - Macours, Premand, and Vakis 2012
  - Colmer 2016

Overview

1. Background
2. Data
3. Empirical Strategy
4. Results
5. Conclusion
6. Thesis

Background

- Groundwater use has grown by 105% since the 70s, in contrast to 28% growth in surface water use
- Access, use, and depletion is dependent on characteristics of the subsurface hydrogeology
- Over-extraction is largely concentrated in two parts of India:
  - The Northwest, where aquifers are deep and alluvial
  - Central-southern India, where aquifers occur within a hard-rock geology

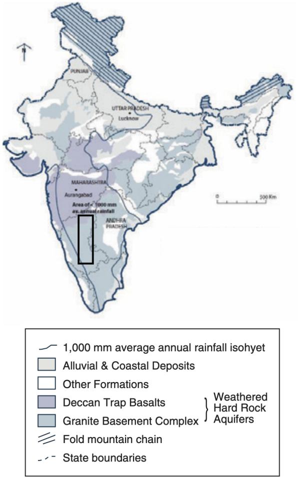


Figure Classification of aquifer systems; light grey shades mark alluvial aquifers, else: hard-rock aquifers

Background

- Most subsurface consists of impermeable rock with networks of fractures and pockets of permeable material (where groundwater is stored)
- Borewells drilled into the hard rock tap into these water-bearing pockets, intersect 0—5 sources; each borewell is just a few decimeters thick
- Fractures' exact location and spacing cannot be determined by surface features; their patterns are highly heterogeneous and unpredictable
- Until 60s: mostly shallow, dug wells. Late 60s: "down-the-hole" (DTH) drilling enabled access to deeper sources of water at high cost. 90s: rising incomes enabled a proliferation of DTH

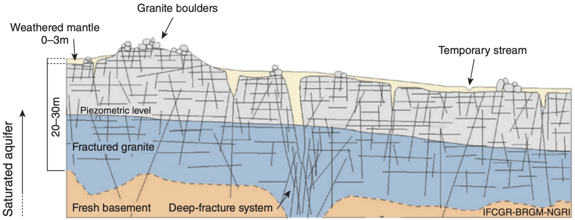


Figure 2. Hard Rock Hydrogeology

Notes: Simplified geological profile of a hard rock aquifer. Water accumulates in fractures (solid lines) that are interspersed within the subsurface at varying locations and depth, and are being recharged from various sources.

Background

- Important to our study:

1. Local aquifers have limited storage, exhaust more rapidly than alluvial aquifers of NW India; water levels dropping since 90s, many dried up
2. High degree of quasi-random spatial variation, even at small distances, in rate of hitting water and operation time before it dries up
3. Drilling is costly (more than x2 median household annual income) and a risky investment

Data

- 2016 survey: 1,408 land-owning households from 102 villages randomly selected from 31 districts in Karnataka, not served by surface irrigation
- Supplemented with village-level admin data from 2013 Economic Census, which provides information on the number and size of firms within each village and in adjacent area

TABLE 1—DESCRIPTIVE STATISTICS

Panel A. Sample sizes	
Number districts	10
Number villages	102
Number households	1,408
Number HHs ever drilled BW	893
Panel B. First borewell characteristics	
Year drilled	2001 [10]
Depth (feet)	423 [225]
Cost (10,000 Rs)	7.463 [5.690]
Failed	0.615 [0.487]
Year failed	2006 [8]

Data

- Households with functioning borewells have much higher farm and total income, and own more land and other assets
- Greater wealth can enable households to retain access to water by drilling more and deeper wells
- Therefore, these differences cannot be interpreted as being caused by access to water

Panel C. Household characteristics

	Household has functional borewell		
	Yes	No	Difference
HH head non-marginal caste	0.532	0.476	−0.055 [0.032]
HH head literate	0.643	0.577	−0.067 [0.027]
HH head age	51.961	51.548	−0.413 [0.809]
Brick house	0.437	0.340	−0.098 [0.028]
Electricity	0.974	0.968	−0.006 [0.010]
Below poverty line (BPL)	0.871	0.892	0.020 [0.020]
Inherited land (acres)	5.720	4.554	−1.166 [0.408]
Asset value without land (10,000 Rs)	28.529	17.465	−11.064 [2.044]
Income, 2015 (1,000 Rs)			
Total	85.374	54.711	−30.663 [7.276]
On-farm	61.005	24.817	−36.188 [4.775]
Off-farm	24.369	29.894	5.525 [4.814]
Fraction of HH members (dry season)			
Own-farm	0.492	0.301	−0.191 [0.023]
Off-farm, agricultural labor	0.126	0.229	0.103 [0.016]
Off-farm, non-agricultural labor	0.041	0.111	0.069 [0.011]
Not working	0.097	0.147	0.050 [0.011]
Working outside village	0.074	0.098	0.024 [0.010]
Semi-permanent migrant	0.015	0.021	0.006 [0.005]

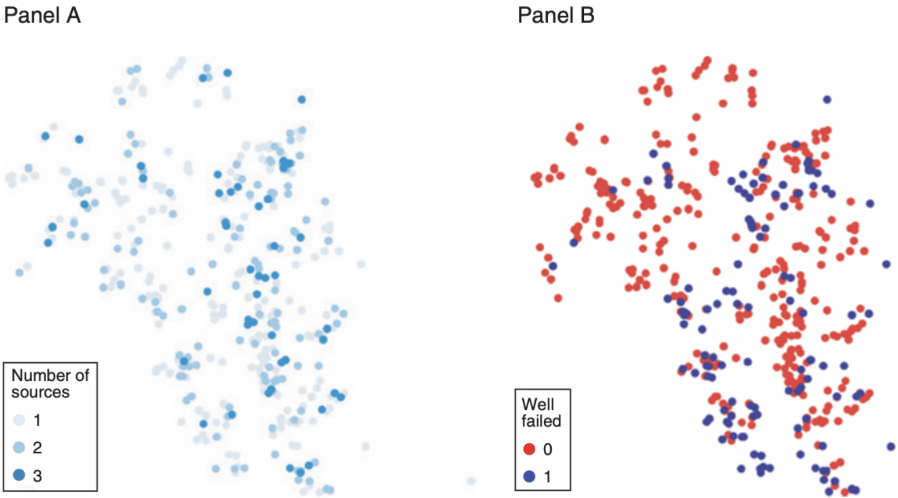
Empirical Strategy

- Regression:

$$y_{i,v} = \alpha_1 + \underbrace{\alpha_2 F_i}_{\text{effect of borewell failure}} + \underbrace{X_i \Phi}_{\text{household characteristics}} + \underbrace{A_v}_{\text{village fixed effects}} + \underbrace{B_t}_{\text{year fixed effects}} + u_i \quad (1)$$

- Household characteristics include age, caste, literacy, total land inherited
- Robustness tests: depth and cost of the first borewell, alternative specs of first borewell age
- All regressions incorporate sampling weights for the relative share of HH with/without first borewell in the village
- Identifying assumption: conditional on year of drilling, failure of first borewell is exogenous to any other correlates of the outcomes
- Remaining determinants of failure primarily depend on highly variable and quasi-random hydrogeological characteristics (such as number of sources the well intersects)

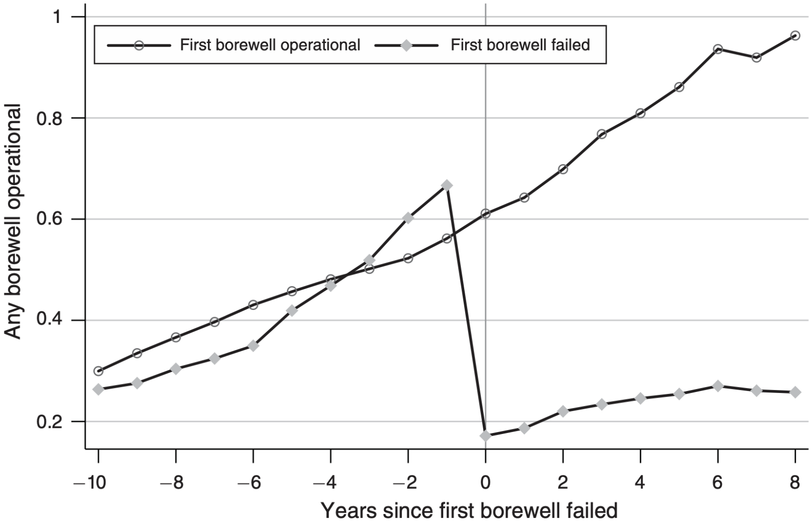
Results



Results

	First borewell		Difference		
	Operational	Failed			
	(1)	(2)	(3)	(4)	(5)
HH head					
Hindu	0.969	0.965	−0.004 [0.014]	0.001 [0.013]	−0.003 [0.014]
Non-marginal caste	0.497	0.565	0.068 [0.039]	0.023 [0.039]	0.014 [0.041]
Male	0.765	0.797	0.032 [0.030]	0.017 [0.027]	0.017 [0.027]
Age	51.377	51.682	0.305 [1.058]	0.013 [1.098]	−0.068 [1.184]
Literate	0.629	0.658	0.030 [0.034]	−0.009 [0.034]	−0.021 [0.036]
Education: none	0.371	0.339	−0.032 [0.034]	0.008 [0.034]	0.020 [0.036]
Education: primary	0.118	0.100	−0.018 [0.026]	−0.021 [0.030]	−0.009 [0.029]
Education: secondary	0.107	0.142	0.035 [0.023]	0.027 [0.025]	0.025 [0.027]
Education: post-secondary	0.298	0.331	0.034 [0.033]	0.015 [0.032]	−0.012 [0.036]
Number children					
Aged 6–11	0.614	0.490	−0.124 [0.065]	−0.068 [0.066]	−0.038 [0.075]
Aged 12–18	0.718	0.711	−0.008 [0.069]	0.018 [0.072]	0.015 [0.077]
Adult sons	0.767	0.795	0.027 [0.032]	0.015 [0.033]	0.030 [0.033]
Assets (at time 1st BW drilled)					
Seed drill	0.392	0.350	−0.042 [0.043]	0.029 [0.039]	0.029 [0.039]
Tractor	0.032	0.040	0.008 [0.013]	0.006 [0.014]	0.013 [0.014]
Thresher	0.004	0.009	0.005 [0.006]	0.001 [0.006]	−0.001 [0.007]
Motorcycle	0.123	0.121	−0.002 [0.023]	−0.019 [0.026]	0.006 [0.026]
Inherited land (acres)	5.625	5.318	−0.307 [0.443]	0.480 [0.398]	0.184 [0.435]
Agriculture (at time 1st BW drilled)					
Cash crops	0.249	0.274	0.024 [0.037]	0.007 [0.039]	0.020 [0.039]
Irrigation	0.392	0.350	−0.042 [0.043]	0.029 [0.039]	0.029 [0.039]

Results



First borewell operational
First borewell failed
Any borewell operational
1
0.8
0.6
0.4
0.2
−10
−8
−6
−4
−2
0
2
4
6
8
Years since first borewell failed

Results

TABLE 3—WATER ACCESS AND AGRICULTURE

	Control mean	Impact of BW failure	
	(1)	(2)	(3)
Panel A. Water use			
Operational borewell	1.000	−0.626	−0.634
		[0.027]	[0.026]
Irrigation, rainy season (any)	0.701	−0.443	−0.458
		[0.031]	[0.029]
Irrigation, dry season (any)	0.508	−0.332	−0.336
		[0.035]	[0.034]
Irrigation, dry season (pct. land)	0.317	−0.218	−0.210
		[0.028]	[0.028]
Panel B. Rainy season			
Any cultivation	0.993	−0.020	−0.021
		[0.009]	[0.009]
Total land (acres)	4.451	−0.093	−0.124
		[0.219]	[0.266]
Field crops (acres)	3.730	0.190	0.179
		[0.209]	[0.250]
Horticulture (acres)	0.720	−0.282	−0.303
		[0.096]	[0.099]
Panel C. Dry season			
Any cultivation	0.596	−0.286	−0.303
		[0.037]	[0.038]
Total land (acres)	1.204	−0.466	−0.479
		[0.239]	[0.249]
Field crops (acres)	0.826	−0.291	−0.286
		[0.182]	[0.211]
Horticulture (acres)	0.378	−0.175	−0.193
		[0.098]	[0.089]
Village fixed effects		Yes	Yes
First-BW year-drilled fixed effects			Yes

Results

Table 4—Labor Reallocation

	Control mean	Impact of BW failure	
	(1)	(2)	(3)
Panel A. Rainy season			
Occupations per member	1.380	−0.005	−0.013
		[0.047]	[0.044]
Fraction of HH members			
Working on own farm	0.527	−0.040	−0.048
		[0.024]	[0.024]
Working off-farm, agriculture	0.102	0.049	0.048
		[0.019]	[0.020]
Working off-farm, non-agriculture	0.038	0.026	0.027
		[0.011]	[0.012]
Not working	0.100	0.014	0.019
		[0.012]	[0.012]
Panel B. Dry season			
Occupations per member	1.375	−0.025	−0.026
		[0.047]	[0.044]
Fraction of HH members			
Working on own farm	0.489	−0.094	−0.104
		[0.025]	[0.025]
Working off-farm, agriculture	0.119	0.061	0.064
		[0.021]	[0.021]
Working off-farm, non-agriculture	0.045	0.040	0.042
		[0.012]	[0.014]
Not working	0.102	0.022	0.029
		[0.014]	[0.014]
Panel C. Location			
Fraction of HH members			
Semi-permanent migrant	0.010	0.013	0.014
		[0.006]	[0.007]
Non-migrant working outside village			
Rainy season	0.058	0.030	0.027
		[0.013]	[0.014]
Dry season	0.060	0.028	0.028
		[0.013]	[0.014]
Village fixed effects		Yes	Yes
First-BW year-drilled fixed effects			Yes

Results

Table 5—Child Employment and Schooling

	Control mean	Impact of BW failure	
	(1)	(2)	(3)
Children, 6–11 years old			
Fraction enrolled	0.542	0.120	0.122
		[0.058]	[0.060]
Fraction employed	0.005	–0.002	–0.004
		[0.003]	[0.005]
Children, 12–18 years old			
Fraction enrolled	0.817	–0.096	–0.110
		[0.043]	[0.042]
Fraction employed	0.130	0.052	0.073
		[0.034]	[0.037]
Village fixed effects		Yes	Yes
First-BW year-drilled fixed effects			Yes

Results

TABLE 6—INCOME

	Control mean	Impact of BW failure	
	(1)	(2)	(3)
Any income			
On-farm	0.800	0.002	0.003
		[0.024]	[0.026]
Government transfers	0.204	0.004	0.028
		[0.031]	[0.033]
Business	0.039	−0.004	−0.010
		[0.012]	[0.012]
Remittances	0.062	0.002	0.009
		[0.019]	[0.020]
Off-farm employment	0.291	0.084	0.118
		[0.038]	[0.038]
Income (1,000 Rs.)			
On-farm	59.141	−16.684	−14.083
		[5.854]	[6.325]
Off-farm	21.850	8.623	12.182
		[5.549]	[6.017]
Total	80.991	−8.061	−1.900
		[8.773]	[9.500]
Village fixed effects		Yes	Yes
First-BW year-drilled fixed effects			Yes

Results

TABLE 7—ASSETS AND DEBT

	Control mean	Impact of BW failure	
	(1)	(2)	(3)
Assets			
Total land (acres)	5.510	0.091	0.045
		[0.216]	[0.226]
Land value (10,000 Rs)	316.816	−18.289	10.593
		[60.519]	[64.742]
Brick house	0.412	−0.055	−0.059
		[0.036]	[0.037]
Number rooms	3.160	−0.062	−0.075
		[0.114]	[0.119]
Asset value without land (10,000 Rs)	27.758	−6.523	−6.750
		[2.363]	[2.464]
Debt			
Any	0.352	0.074	0.073
		[0.032]	[0.031]
Size of total debt (10,000 Rs)	9.270	4.599	5.572
		[2.271]	[2.294]
Village fixed effects		Yes	Yes
First-BW year-drilled fixed effects			Yes

Conclusion

- Evidence of long-term impacts of large-scale, permanent environmental deterioration in a developing country
- Loss of access to irrigation water reduces agricultural viability with minimal adaptation
  - Affected land often left fallow or cultivated with low-value crops
  - Raises concerns about aggregate food production
- Households offset agricultural income losses by reallocating labor to off-farm employment
  - Regions with many large firms: higher off-farm employment, slight total income increase
  - Regions with few large firms: total income declines slightly
- This adaptation involves trade-offs:
  - Asset liquidation, debt accumulation, reduced food expenditures
  - Lower human capital investments for older children

Thesis

- Micro Irrigation (drip and sprinkler systems) can improve agricultural efficiency by saving 30—70 percent of water compared to conventional methods
- Adoption levels remain low in India due to a lack of incentives for efficiency; water and electricity is unpriced or heavily subsidized
- All-India dataset: village-level panel data from the Minor Irrigation Census (1993—2017), used to assess adoption patterns and water scarcity correlations; will be merged with climatic data, socio-economic indicators, and satellite-based irrigation estimates
- Gujarat dataset: high-resolution data tracks 400,000 geo-referenced MI adopters (2006—2013), includes detailed subsidy variations, enabling analysis of adoption determinants, social learning effects, and water conservation outcomes

Figure Map of India

Thesis

- Working Hypotheses:
  1. Adoption rates are correlated, across villages and farmers, with indicators of economic development and water scarcity, and these correlations are higher at early stages of diffusion. Earlier adopters are larger farmers, but MI diffuses to smaller farmers in the village over time.
  2. Variation in water scarcity has causal impacts on the rate of adoption.
  3. Variation in (subsidy driven) MI cost has causal impacts on the rate of adoption and particularly by smaller farmers.
  4. Subsidized adoption has spillover effects on adoption in adjacent areas (presumably through social learning), but these are limited by crop type and social groups (castes).
  5. Subsidized adoption has varying effects on water and power use for pumping, depending on the extent of overall irrigation coverage in the village and the existence of informal water markets.