Final report

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Adaptation to persistent drought and groundwater depletion

Evidence from Karnataka

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Adaptation to Persistent Drought & Groundwater Depletion: Evidence from Karnataka – Final Report

Introduction

Water stress is becoming the leading constraint on Indian agriculture. Groundwater resources, on which the country's food production is critically dependent, are being rapidly depleted; while the rainfall disruptions expected to result from climate change may already be underway, with dry spells and drought events becoming more frequent. These two trends are both projected to have large negative impacts, and to reinforce each other, with the lack of access to irrigation limiting farmers' capacity for adaptation to precipitation shortfalls. Understanding how farmers are affected by, and adapt to, this dual challenge is crucial not only for India's agricultural growth, but also for India's structural transformation and urbanization, as farmers under stress may be an important source of rural-urban migration.

In the semi-arid parts of the Karnataka, a persistent drought over the last 3-4 years, coupled with a rapid depletion of the region's hard rock aquifers, has left a clear imprint on the area's conspicuously parched countryside. A multi-year drought is a rare event, akin to the permanent shifts in precipitation that may result from climate change; and it is likely to gradually erode the effectiveness of traditional income-smoothing mechanisms, which have evolved primarily to protect households against short-term (annual) weather shocks. Few studies have rigorously examined the impacts of persistent environmental change on households in developing countries, with most studies focusing instead on the impacts of short-term (annual) weather shocks and environmental disasters. This study presents an opportunity to address this gap in literature by investigating the combined impacts of the multi-year drought and continuing groundwater depletion afflicting Karnataka on various household outcomes; and the adaptation strategies adopted by farmers in response. This study seeks to do so by: first, utilizing large-scale variation in groundwater access driven by finer scale geological differences occurring even across farms within the same village; second, and perhaps more importantly, utilizing precipitation data of unprecedented quality and resolution that exhibits fine spatial and temporal variation in rainfall and drought exposure; and, finally, examining a rich collection of household indicators.

Unique features of Karnataka's geology and climatology create exogenous variation in groundwater access and drought exposure. In particular, variation in access to water is driven in substantial part by variation in local hard rock geology that occurs at small geographical distances, with even directly adjacent households experiencing radically different access to groundwater. Such variation in geology provides a unique opportunity for causal identification of the effects of access to water on household economic outcomes. Similarly, high-quality rainfall data has been collected by KSNDMC at unprecedented spatial and temporal resolution (hourly/*hobli* level), which shows considerable variation in rainfall even across neighboring villages. This will enable us to exploit variation in rainfall and drought exposure over short geographical distances to provide causal estimates of the combined effects of drought and groundwater depletion on household outcomes and coping strategies.

Methodology

In an unprecedented undertaking, the Government of Karnataka, through KSNDMC, has been installing a dense network of rainfall gauges around Karnataka, which relay hourly precipitation data to a centralized depository. Currently, rainfall data is available at the *Hobli* level (there are 4-6 Hoblis in a sub-district, or taluka). In the semi-arid climate characteristic of this region, variation over small geographical distances is common, as confirmed by both existing data and anecdotal accounts from field visits by the researchers. While past studies of rainfall impacts have relied upon on district-level rainfall data, the fine-scale data provided us by KSNDMC captures plausibly exogenous variation in drought exposure at the sub-district, and even sub-sub-district, levels.

We have utilized this fine-scale data collected by KSNDMC to identify (exogenous) exposure to drought. Using this data to help establish a sampling frame, we conduct a cross sectional survey for 1,500 households across 100 villages in 10 of the region's districts.

Exogenous variation in groundwater access is generated using retrospective data on borewell history, including more recent drilling efforts (e.g., expenditure, depth of drilling, etc.), as well as household wealth, agricultural practices, and so on. In the hard rock geology of this region, these "groundwater shocks" are the result of sub-surface geological variation in the presence of fractures in the rock strata where groundwater accumulates. As wells are deepened, hitting water is a function of the probability that there is a fracture in the rock below the fracture that was already depleted. The presence of such a fracture deeper down under the household land, is random, plausibly exogenous to household characteristics, and unknown to the household prior to the attempt to deepen the well following the previous drying of the well. This residual probability will provide us with a novel source of exogenous variation in access to groundwater.

Having gathered this data, the estimation strategy to be used is straightforward. Household outcomes will be regressed on exposure to drought and to groundwater "shocks" to determine the separate and combined impacts of these two forms of hydrological stress. These estimates should provide us a complementary and comprehensive analysis of the issues at hand.

Sampling Strategy

The sampling strategy to select households entailed the following:

- Collecting a list of farmers in each village from *Bhoomi*, an online repository for Karnataka land records; identifying the borewell status of each of these farmers with prominent people in the village (i.e. prominent farmer of the village, the local dairy manager); and, finally, verifying the borewell status of identified farmers through household visits.

- Households were identified and grouped into three categories: those have a functioning borewell; those having only a non-functioning borewell; and those who have never dug a borewell.
- For each village, 5 households were randomly selected from each of the 3 groups to be part of the study sample.

Data Collected

Household surveys: For the households selected according to the sampling strategy outlined above, information was collected on the history of groundwater wells for each household, including well failures and deepenings. The survey also collected information about a host of standard household outcomes, including income-generation activities and migration by household members, income, consumption, and assets.

Timeline

Following the pilot, which was carried out in March, 2016, the household surveys were administered between May and July, 2016. One key logistical challenge confronted by the team was the considerable distance between survey villages. In addition, some villages which were initially part of the study sample had to be replaced due to their having alternative sources of irrigation, such as canals and rivers, which disqualified them from inclusion in the study. These two factors were the principal reasons for the timeline extension required for the completion of field operations. Finally, some additional delay occurred due to the need to revise the protocols for identifying and verifying the borewell status of the households, as the original protocols led to instances of the borewell status being misidentified.

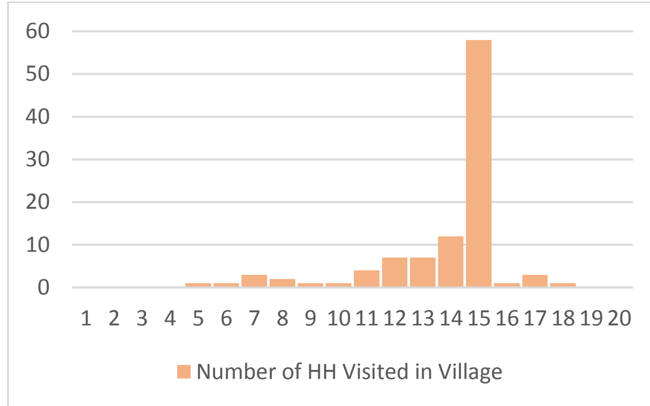
Summary Tables and Preliminary Insights

The study covers 10 districts in Karnataka: Bellary, Bidar, Chikkaballapur, Chitradurga, Gulbarga, Kolar, Koppal, Raichur, Tumkur and Yadgir. As per the sampling strategy described above, 2000 households wer chosen to participate in the study, across 130 villages in these districts. With 27 of the villages being ultimately disqualified from inclusion due their having alternative sources of irrigation, the final sample was reduced to 1409 households across 103 villages, with an average of 14 households per village.

Table 1. Study Geography

Unit	Number
Districts	10
Taluks	33
Villages	103
Households	1409

Graph 1. Number of HH visited per village



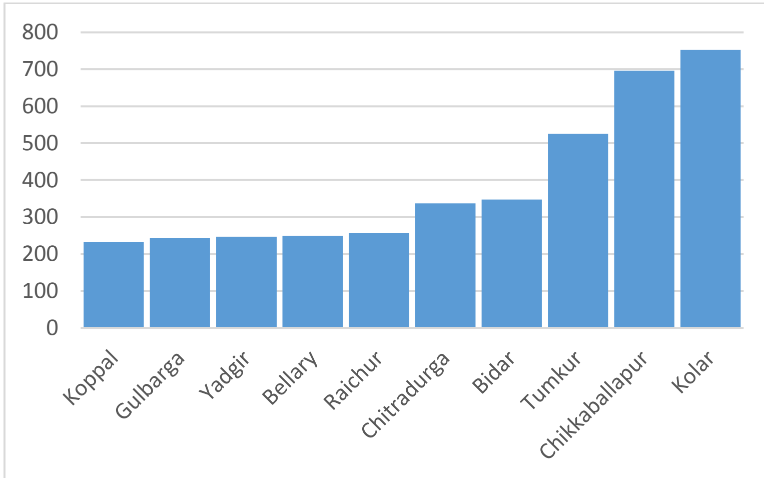
Approximately 35% of the sample households in each district report having a currently-functioning borewell, while just under 30% report having dug borewells that are currently non-functional, and 37% report having never attempted to dig a borewell. Districts in northern Karnataka (Bidar, Gulbarga, Yadgir and Raichur) have the highest share of households which have never attempted to dig a borewell, generally over 40%.

Table 2. Sample Distribution & Borewell Status

District	No. of HH	Functioning Borewell (% of HH)	Non-functioning Borewell (% of HH)	Never attempted to dig Borewell (%of HH)
Bellary	84	37%	30%	33%
Bidar	130	30%	27%	43%
Chikkaballapur	280	39%	26%	35%
Chitradurga	131	36%	28%	36%
Gulbarga	55	20%	33%	47%
Kolar	317	35%	30%	34%
Koppal	60	33%	30%	37%
Raichur	94	36%	22%	41%
Tumkur	213	36%	28%	36%
Yadgir	45	33%	29%	38%

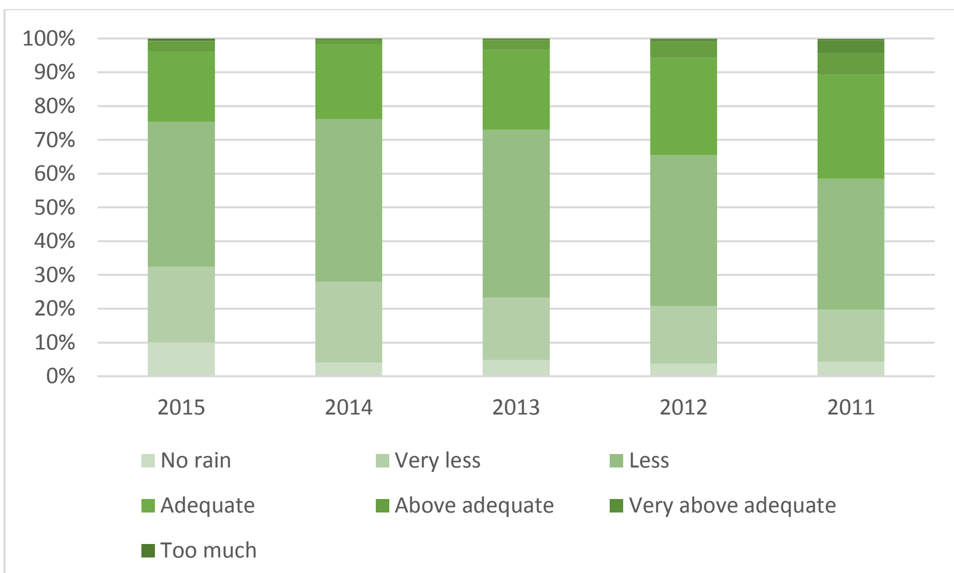
We also observe marked variation in the depth of the borewells across the study geography: while the mean borewell depth is just over 200 ft in districts like Koppal and Gulbarga, it increases to 700 feet and more in districts like Kolar and Chikkaballapur.

Graph 2. Average depth of wells (in Feet)



All respondents were asked to rate the rainfall in each of the years 2011-2015, on a scale ranging from 'no rain' at all, to 'too much' rainfall. Strikingly, for each of the years at least 60% of the sample rated the rainfall as being below adequate. In 2014 and 2015, close to 80% of the sample rated rainfall as being below adequate, while almost 10% of the sample reported no rainfall at all in 2015, indicative of the perceived persistence of drought-like conditions across multiple years.

Graph 3. Rainfall (2011-2015)



A large share of the sampled households depend primarily on farming and dairying for their incomes, as can be seen from the tables below, with casual labor also generating significant income for many households. Since we have collected data on the current status of wells on respondents' lands, we can explore income variation according to the current status of wells. As expected, this income variation according to well status is most pronounced for agricultural and livestock-based income. Income from casual labor and government schemes, in contrast, is similar across all three well-status categories.

It is not surprising that incomes in 2015 (a year of acute rainfall shortage, as seen earlier) are highest for those households having operational borewells, as irrigation access both increases agricultural incomes, and allows farmers to better adapt to shortfalls in precipitation.

Table 3. Household Income (Category wise and Total), by well status

In INR	Farming land			Own livestock			Casual work by household members		
	Never tried	Failed	Operational	Never tried	Failed	Operational	Never tried	Failed	Operational
Mean	15,727	28,171	40,807	23,252	30,461	32,871	20,470	20,934	19,718
SD	(26,962)	(45,329)	(55,676)	(24,703)	(28,753)	(37,098)	(20,663)	(25,444)	(25,240)
N	509	192	396	161	64	163	247	73	118

Table 3. Contd.

In INR	Government Schemes			Total Income		
	Never tried	Failed	Operational	Never tried	Failed	Operational
Mean	6,946	6,915	6,280	51,362	53,510	68,856
SD	(10,374)	(4,217)	(4,278)	(134,444)	(78,526)	(87,420)
N	199	61	122	509	181	383

Similar patterns can be seen in (self-reported) asset ownership, with households possessing operational wells reporting higher asset ownership across all categories. In the case of gold, we see households with operational wells having 70% more gold than those households that have never tried to dig a well, and close to 150% more gold than those who have have a failed well on their land.

Because households lacking access to groundwater possess so few assets, they may struggle to make the necessary investments to successfully adapt to climate change, or to transition to income-generating activities that are less environmentally sensitive. Indeed, the lack of groundwater access may lead to a depletion of existing assets and resources as households try to cope with hydrological stress.

Table 4. Asset Ownership (Selected Categories), by well status

Asset		Never tried	Failed	Operational
Cows	Mean	0.60	0.74	0.96
	SD	(0.98)	(1.08)	(1.61)
Bullock	Mean	0.29	0.40	0.48
	SD	(0.72)	(0.86)	(0.89)
Tractor	Mean	0.01	0.08	0.13
	SD	(0.12)	(0.28)	(0.34)
Cars	Mean	0.02	0.02	0.06
	SD	(0.15)	(0.14)	(0.29)
Gold (in grams)	Mean	17.33	12.35	29.81
	SD	(72.26)	(93.90)	(132.93)

To further explore variations in income and capabilities across households according to well status, we next report statistics on household expenditure, specifically the critical categories of food, education, and health. Data is recorded on both the actual expenditures in the preceding month/year, as well as the hypothetical expenditures that would have occurred had rainfall been "normal."

Table 4. Expenditure, by well status

		Food		Education		Health	
In INR		**Last Month**	**In event of normal Rainfall**	**Last Year**	**In event of normal Rainfall**	**Last Year**	**In event of normal Rainfall**
Never tried	Mean	3,947	5,682	20,946	26,124	31,516	34,425
	SD	(3,937)	(9,362)	(38,278)	(105,785)	(88,894)	(187,577)
	N	501	501	375	375	501	501
Failed	Mean	4,925	11,880	29,427	25,500	36,470	36,258
	SD	(5,424)	(40,850)	(63,315)	(80,519)	(62,644)	(68,682)
	N	187	187	155	155	186	186
Operational	Mean	5,295	6,826	55,615	45,228	45,757	51,333
	SD	(4,908)	(7,506)	(224,974)	(140,602)	(179,479)	(212,611)
	N	373	373	296	296	373	373

As seen in Table 4, households having operational wells report the highest expenditures, both actual and hypothetical, in the health and education categories. The largest differences between the actual and hypothetical expenditures are seen food expenditures in households having failed borewells, indicating that they may suffer greater losses during bad monsoons than househols with borewells, though the magnitude of the difference requires further inspection.

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