Adapting Or Chasing Water? Crop Choice And Farmers' Responses To Water Stress In Peri-Urban Bangalore, India

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Abstract:

Unregulated groundwater extraction has led to declining water tables and increasing water scarcity in the Indian subcontinent. Understanding how farmers respond to this scarcity is important from multiple perspectives - equity in access, livelihoods security and resource sustainability. We present a case from the rapidly urbanizing Arkavathy sub-basin near Bangalore city in Southern India where irrigation is fully groundwater dependent. Using cross-sectional data from a stratified random sample of 333 farmers from 15 villages, we investigated the factors that determine their choice of crops under conditions of water scarcity and urbanization. Binary logit analysis showed that the high land holding farmers respond by tapping deep groundwater using borewells. Multinomial logit analysis revealed that access to groundwater, variation in the proximity to the product market (city) and labour availability influence crop choice decisions. We observe that current responses indicate what has been characterized in literature as chasing strategies. These largely favour the well-off farmers and hence inequitable. While choice of water intensive crops and unregulated pumping have aggravated water stress, the uptake of water saving technologies among irrigated farmers has been low, showing that resource sustainability may not be a concern where non-farm diversification opportunities exist.

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ABSTRACT

Unregulated groundwater extraction has led to declining water tables and increasing water scarcity in the Indian subcontinent. Understanding how farmers respond to this scarcity is important from multiple perspectives - equity in access, livelihoods security and resource sustainability. We present a case from the rapidly urbanizing Arkavathy sub-basin near Bangalore city in Southern India where irrigation is fully groundwater dependent. Using cross-sectional data from a stratified random sample of 333 farmers from 15 villages, we investigated the factors that determine their choice of crops under conditions of water scarcity and urbanization. Binary logit analysis showed that the high land holding farmers respond by tapping deep groundwater using borewells. Multinomial logit analysis revealed that access to groundwater, variation in the proximity to the product market (city) and labour availability influence crop choice decisions. We observe that current responses indicate what has been characterized in literature as chasing strategies. These largely favour the well-off farmers and hence inequitable. While choice of water intensive crops and unregulated pumping have aggravated water stress, the uptake of water saving technologies among irrigated farmers has been low, showing that resource sustainability may not be a concern where non-farm diversification opportunities exist.

KEY WORDS: agriculture; urbanization; groundwater stress; livelihoods; India

INTRODUCTION

Tapping groundwater using borewells has been a significant breakthrough in efforts at enhancing farm productivity and improving livelihoods in the wake of water stress in agriculture (Shah, 2012). This is particularly true of India where currently groundwater accounts for 62% of the net area under irrigation (World Bank, 2010). However, groundwater is a finite resource and unabated drilling of borewells has led to increased groundwater pumping for irrigation over and above recharge rates, resulting in depletion. Groundwater depletion has adversely impacted agriculture and agrarian livelihoods (Fishman, 2013) and raised questions of resource sustainability and future global food security (Madramootoo, 2012). Groundwater regulation is politically contentious, and even impossible in the short term (Fishman *et al*., 2015) and hence the water future of countries like India is completely dependent on farmers' responses to water scarcity, the crops that they choose to grow, the decisions on how much water they apply and if they choose to drill deeper or go for water saving technologies like drip when groundwater declines.

While water scarcity is a major factor influencing agriculture and farmers' crop choice decisions (Kaur and Vatta, 2015), it has not been given as much importance as climate variability in recent studies on farmer responses to risks and adaptation (Alam, 2015). While climate change can lead to or accentuate water scarcity, this may also be the result of climate unrelated factors such as population growth and urbanization (Vörösmarty *et al.*, 2000). As India's population rises toward 1.5 billion by 2030, the country faces a critical challenge of adapting to a future where demand for water is accelerating but where supply remains essentially fixed, or increasingly variable under climate change. India is also experiencing rapid urbanization and is projected to double its urban population between 2014 and 2050 (United Nations, 2015). As urbanization progresses, there will be increasing integration of the rural labour and commodity markets with cities. Proximity to urban areas offers possibilities for diversification into non-farm employment as well as increasing demand for high value crops (Rao *et al.*, 2006). However, the implications of urbanization are mixed. On the one hand, income generation and diversification opportunities open up. But on the other, the demand from urban areas are usually for water intensive crops such as vegetables and fruits putting additional pressure on water resources.

Responses of farmers to groundwater scarcity has been dealt with and characterized in different ways in existing literature. Berahmani *et al.* (2012) argue that farmers adopt two types of strategies, chasing and adaptive, when faced with declining groundwater. Chasing strategies are less sustainable responses where the farmers do not change their groundwater use in accordance with declining water levels, whereas adaptive strategies involve adoption of water conservation technologies and move to shorter duration and less water demanding crops. Adoption of water efficient technologies such as drip irrigation have been advocated as a means to conserve water (Pereira *et al*., 2002). However, their impact is limited because there are no legal or institutional regulations on groundwater pumping. Even as water conservation through drip irrigation is promoted on the one side, governments also have to cater to the interests of farmers by providing subsidized irrigation which offsets efforts at water conservation (Fishman *et al*., 2015). It has also been pointed out that while farmers may make concerted adjustments to respond to declining water levels by augmenting supplies, undertaking conservation efforts and reallocating available water, individual strategies may be uncoordinated, and add up to having adverse impacts on the environment (Molle *et al*., 2010).

We studied the Arkavathy sub-basin in Southern India that has witnessed a steady decline in groundwater tables alongside rapid urbanization with the expansion of Bangalore city. We investigated how farmers responded and what factors determined their choice of crops and water use under conditions of water scarcity and urbanization. To see if water stress has prompted the farmers to adopt water conservation we also looked at the uptake of drip irrigation technology and the factors behind this. The rest of the article is structured as follows. The next section introduces the location of the study and methods. This is followed by an outline of the analytical framework for the study and the model description. The results of the econometric analysis are presented next. The article concludes with a discussion of the implications of the study.

LOCATION AND METHODS

The Arkavathy sub-basin (Figure 1) with a catchment area of 4,169 sq. km. is part of the Cauvery river basin that straddles three states in Southern India. The sub-basin has been experiencing rapid urbanization, and comprises of roughly one third of Bangalore, one of the largest cities in India, four small towns and over 1000 villages (Lele *et al*., 2013). While the villages are still agriculture based, many villagers are engaged in non-agricultural activities and farm incomes are increasingly being supplemented by industrial and city based jobs. At the same time, the urban areas also provide a market for high value agricultural products such as vegetables, fruits and flowers. Irrigated agriculture has always been a small fraction of the landscape. However, over the past four decades, it has shifted from being based on surface irrigation from several hundred small reservoirs to being entirely groundwater dependent. The advent of borewell technology led to this shift, which initially may have increased and diversified the area under irrigation but has now led to groundwater depletion. There have been increasing instances of borewells failing and not yielding water anymore, and farmers resorting to digging more and deeper borewells (Thomas *et al*., 2015).

-- FIGURE 1 ABOUT HERE --

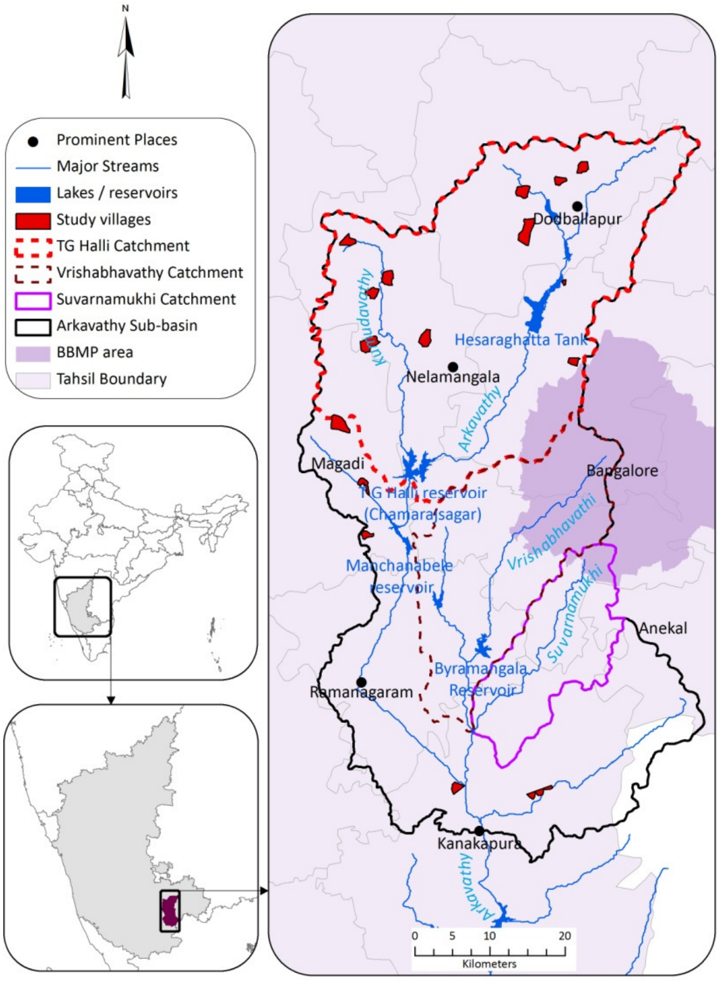

Figure I. The Arkavathy sub-basin, India

We undertook a multidisciplinary socio-hydrological research project during 2012-16 to look at the changes in water use in the Arkavathy sub-basin, the reasons for the drying of the Arkavathy river and exploring the responses of farmers, urban and rural households and other sectors. The project included detailed analyses of climatic, hydrological, water quality, institutional and socio-economic aspects in the sub-basin, based on available secondary data and original field data. For this article, we have used a component in this project that focused on farmer crop choice. The study covers the entire basin except for a small catchment immediately south-west of Bangalore city which received wastewater from the city and hence water abundant (Thomas *et al.,* 2017).

One of the reasons put forward by local communities and decision makers for the drying of Arkavathy river and consequent water stress, which also has implications on farmers' crop choice decisions, was climate change. As part of the project, Srinivasan *et al*. (2015) examined empirically the trends in climatic parameters over time, specifically trends in rainfall between 1934 and 2010, and in estimated evapotranspiration between 1961 and 2010. It was concluded that temperature and rainfall could not explain the decline in the water levels in Arkavathy river. Instead, human induced factors such as increased groundwater pumping, with the advent of borewell technology, and the expansion of eucalyptus plantations led to the fall in water levels and eventually the drying of the Arkavathy river. Therefore, with historical climate change ruled out, we wanted to see what impact do water stress and impact of urbanization, manifested through labour scarcity, have on farmers' crop choice.

We conducted a stratified random sample household survey among farmers in the entire sub-basin between November 2013 and January 2015. The analysis reported here pertains to 333 farmers including both farmers having access to irrigation (henceforth called irrigated farmers), which was invariably groundwater-based, and those without (henceforth called rainfed farmers) from 15 water-stressed villages. It may be noted that, given the scarcity of water, irrigated farmers also have some land under rainfed cultivation. We selected randomly 20% each of the irrigated and rainfed farmers in each sample village.

ANALYTICAL FRAMEWORK

From planting to harvesting of crops, farmers make a series of decisions. Based on preliminary observations from fieldwork we developed a framework of farmer decision making to help structure our analysis and findings (Figure 2). In a given situation, a farmer in the Arkavathy sub-basin can cultivate the land, use it for non-agricultural activities, or just leave it fallow. With multiple industrial and non-agricultural employment opportunities close by, there has been a gradual shift of labour away from agriculture in the region. Land use analysis using remote sensing done separately as part of the project showed fallowing of farmland, resulting from labour and water shortage and in anticipation of rising land prices, which is not unexpected in peri-urban areas. However, our household survey did not capture fallowing since the focus was on current agriculturists and agricultural water management.

-- FIGURE 2 ABOUT HERE --

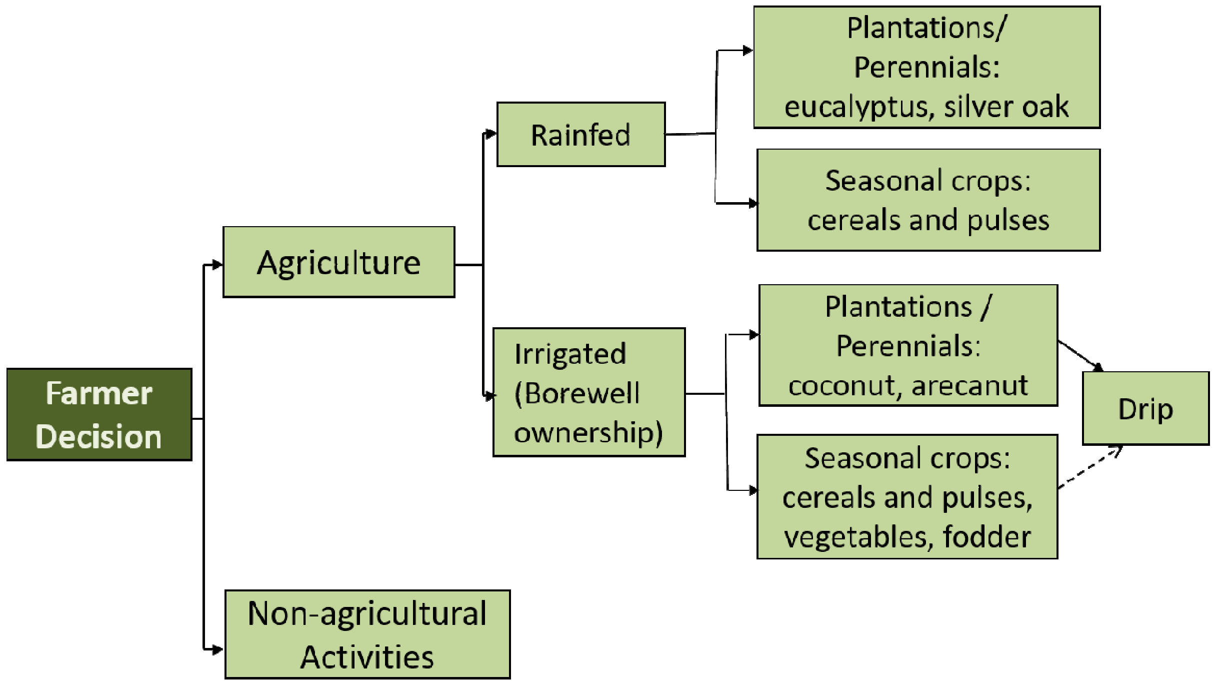

Figure II. Analytical framework

Once a farmer has decided to continue agriculture, the next steps are contingent upon availability and access to water, which is the biggest constraint. Access to water in turn is dependent upon whether the farmer owns a borewell or not, since as we saw earlier, there is no surface water available for agriculture in the region. Moreover, unlike in areas where borewells have high yields, the borewell yields in this region are low, usually insufficient to irrigate the entire land owned by the farmer, resulting in water markets being non-existent. Hence, ownership of borewells is equivalent to water access, and will therefore directly influence the type of crops that a farmer chooses to grow. Further, since the area is facing severe water stress and there are several government policies subsidising water conservation measures, some farmers would have opted for water efficient technologies, such as drip irrigation. In terms of the sequence of decision making, the choice to invest in drip irrigation would come after farmers have moved to borewell irrigation and began specialising in certain crops. But to the extent that drip irrigation technology is capital intensive, it can also be seen as a decision similar to digging of borewells, that determines the farmer's water asset and then influences crop choice. In the analysis that follows, we treat drip irrigation as a prior decision to crop choice.

Given a certain level of access to groundwater, based on ownership of borewells and irrigation technology, the farmer decides which crops to grow and in what area. The farmer also factors in borewell yield, but we did not have a reliable way of estimating yields and had to leave it out of the analysis. Based on our preliminary observations, we expected that the farmers who decide to practice rainfed agriculture would cultivate seasonal crops like cereals and pulses, or perennial plantation crops like eucalyptus and silver oak, which have lower water and labour requirement. On the other hand, those farmers who could afford to own borewells and access groundwater for irrigation, might cultivate irrigated seasonal crops such as vegetables or irrigated perennial crops such as coconut and arecanut.

Having outlined the sequence of decisions, the next question is what factors are likely to influence these decisions, especially in an urbanizing context. Drilling a borewell is an expensive investment costing anywhere between 200,000 and 300,000 Indian Rupees (3,000-4,000 USD) which is more than a year's income for many farmers. Thus wealth matters in deciding who can drill and who cannot. Similarly, investing in drip irrigation also requires capital (even if the government provides subsidies). Educational levels and socio-economic status (caste) are also likely to influence the ability to invest in borewell drilling and drip irrigation technologies.

In the case of crop choice, the major challenge was how to analytically accommodate the fact that all farmers cultivate multiple crops. We used a multinomial logit (MNL) model, widely used in crop choice studies (see for example, Seo and Mendelsohn, 2008) where the dominant crop is taken as the ‘base crop’. In terms of factors affecting crop choice, other than groundwater acccess and irrigation technology, one would expect urbanization to influence crop choice through proximity to product markets (Bangalore city), as also the availability of labour. In addition to these village-level variables, we might expect household-level variables such as labour available within the household, access to non-agricultural income, landholding (as a proxy for wealth) and educational and caste variables to also have influence.

The farmers in our sample cultivated a total of 82 distinct crops during the survey period. In terms of area under cultivation, the major crops cultivated were ragi (finger millet), maize, coconut, arecanut, mulberry (used for silkworm rearing), fodder, eucalyptus, a variety of vegetables, fruits, and pulses, and other plantation crops. For analysis, this large variety of crops was reduced to six broad categories based on water and labour requirement, commercial or subsistence type, and seasonality. These six categories were ‘cereals and pulses’[1], ‘vegetables’[2], ‘maize’, ‘plantations’[3], ‘horticultural crops’[4] and ‘fodder’. When farmers cultivated a combination of any of these categories, crop choice was defined as the single crop with the largest gross cropped area among the six broad categories (Table 1).

[1] 'Cereals and pulses' includes ragi, pigeon pea, green gram, Bengal gram, and cowpea.
[2] 'Vegetables' includes tomato, chilli, onion, cucumber, leafy, and other vegetables and flowers.
[3] 'Plantations' includes eucalyptus, silver oak, teak, neem, Malabar neem wood, and pongamia.
[4] 'Horticultural crops' include coconut, areca nut and fruits like guava, mango, sapota, papaya, and banana.

-- TABLE I ABOUT HERE --

Table I. Primary crop choice during 2013

Crops	Frequency	Percent	Mean	SD	Min	Max
Cereals and pulses	144	43.24	0.56	0.37	0.02	2.02
Vegetables	45	13.51	1.01	0.76	0.16	3.74
Maize	65	19.52	0.78	0.70	0.04	4.45
Plantations	27	8.11	1.41	2.10	0.05	9.51
Horticultural crops	36	10.81	0.96	0.84	0.20	4.30
Fodder	16	4.80	0.72	0.42	0.20	1.64
Total	333	100				

Note: Mean, SD, min, and max columns show the figures of gross area under particular crop in hectare.

ECONOMETRIC SPECIFICATION AND MODEL DESCRIPTION

We use binary discrete choice approach to analyse the factors influencing borewell ownership and adoption of drip method with no ownership/adoption as a base category (set to 0) and ownership/adoption as a main category (set to 1). The probability of owning borewells or adopting drip method condition on independent variables (X) is the logistic cumulative density function (CDF) of a random error term (ε) evaluated at Xβ, where β is a vector of coefficients (Cameron and Trivedi, 2009).

$$\Pr(y=1 \mid X) = F(X\beta)$$

Where *F* is the logistic CDF. Unlike in linear regression models, it is difficult to interpret from estimated coefficients the magnitude of the effect of independent variable in a logit model. Therefore, the coefficients are transformed into marginal effects for meaningful interpretation of magnitude of a variable's effect.

Model I: Binary logit analysis of borewell ownership

As noted earlier, the wealth of the farmer influences owning a borewell. Therefore, we need a variable for wealth, and in the absence of reliable economic measures, we use land holding (LAND) which is an approprite proxy for wealth in rural settings. In addition, we also look at the role of non-agricultural income (NON-AG INCOME), groundwater level in the area (WELL DEPTH), access to major product markets (DISTANCE) and household characteristics like education (EDUCATION) and caste (CASTE). The final borewell ownership model takes the form:

$$\Pr(\text{BW\_OWNERSHIP} = 1|x) = F(\alpha + \beta_1\text{LAND} + \beta_2\text{DISTANCE} + \beta_3\text{NON-AG INCOME} + \beta_4\text{WELL DEPTH} + \beta_5\text{CASTE} + \beta_6\text{EDUCATION})$$

Model II: Binary logit analysis of drip adoption

Adoption of drip could be influenced by landholding (LAND), number of wells (WELLS), depth of wells (WELL DEPTH), non-agricultural income (NON-AG INCOME), proportion of non-agricultural labour in the village (NON-AG LABOUR), labour availability in household (AG LABOUR) and demographic variables like caste (CASTE) and education (EDUCATION). We used Census 2011 data and calculated the 'proportion of other workers to total workers in a village' to represent non-agricultural labour. The final model for drip adoption takes the form:

$$\Pr(\text{DRIP\_ADOPTION} = 1|x) = F(\alpha + \beta_1\text{LAND} + \beta_2\text{WELLS} + \beta_3\text{AG LABOUR} + \beta_4\text{NON-AG-LABOUR} + \beta_5\text{NON-AG INCOME} + \beta_6\text{WELL DEPTH} + \beta_7\text{CASTE} + \beta_8\text{EDUCATION})$$

The MNL model, applied to analyze the factors influencing farmers' crop choice, estimates the probability that a farmer chooses a particular crop as compared to the assigned base crop category. The model takes the form:

$$\ln \Omega_{m|b}(\text{X}) = \ln \frac{\Pr(y = m|\text{X})}{\Pr(y = b|\text{X})} = \text{X}\beta_{\text{m}|b} \text{ for } m = 1 \text{ to } J$$

Where *b* is the base crop category. *J* number of outcome categories have *J* equations which are solved to estimate the probability for each outcome by:

$$\Pr(y = m|\text{X}) = \frac{\exp(\text{X}\beta_{\text{m}|b})}{\sum_{j=1}^{J} \exp(\text{X}\beta_{j|b})}$$ (Cameron and Trivedi, 2009).

Model III: Multinomial logit analysis of crop choice

As noted earlier, MNL model requires choosing a 'base' crop against which to evaluate the effect of independent variables on choosing other crops. As vegetables are high water and labour intensive commercial crops and have relatively high demand in peri-urban areas, we chose it as the base category. This allows for better comparison of other crop categories with the vegetables crop category, with respect to farmers' access to resources and other factors. As access to water and water technology could significantly influence the farmer's crop choice decision, the number of functioning wells per hectare (WELLS), and water conserving irrigation technique(s) used (TECHNOLOGY) were used as explanatory variables. Wealth, labour availability, income sources, cattle holding, and access to product market could also influence crop choice. We used land holding (LAND) as a measure of wealth. Fodder and associated crops will be grown if farmers possess cattle holdings and hence we considered cattle ownership (LIVESTOCK). Distance to Bangalore city was used as a proxy for access to product market (DISTANCE). In addition, we considered number of family labour available per hectare for agriculture (AG LABOUR), proportion of non-agricultural labour in the village (NON-AG LABOUR) and per capita non-farm income (NON-AG INCOME). We also added education of the household head (EDUCATION) and caste (CASTE) as explanatory variables to take into account household characteristics that could affect crop choice. We ran several iterations of the model to come up with the model that provided the best fit. The final model for crop choice of farmers takes the form:

$$\Pr(\text{CROP\_CHOICE} = 1 | x) = F(\alpha + \beta_1\text{LAND} + \beta_2\text{WELLS} + \beta_3\text{AG LABOUR} + \beta_4\text{NON-AG LABOUR} + \beta_5\text{NON-AG INCOME} + \beta_6\text{LIVESTOCK} + \beta_7\text{TECHNOLOGY} + \beta_8\text{DISTANCE} + \beta_9\text{EDUCATION} + \beta_{10}\text{CASTE})$$

The complete description of variables and descriptive statistics is provided in Table 2.

-- TABLE II ABOUT HERE --

Table II. Descriptive statistics

Variable	Description	Mean	SD	Min	Max
LAND	Total landholding of the household (in hectare)	1.08	1.26	0.05	14.58
WELLS	Number of functioning borewells (per hectare)	0.38	0.80	0.00	6.50
AG LABOUR	Number of household labour available per hectare for agriculture	4.00	5.40	0.14	57.03
NON-AG LABOUR	Proportion of other workers to total workers in a village (data from 2011 census)	30.00	17.84	5.00	88.00
NON-AG INCOME	Per capita non-agricultural income in a household (in 1000 Indian Rupees)	20.34	24.03	0.00	162.67
LIVESTOCK	Number of cattle and buffaloes in a household	2.00	2.03	0.00	10.00
TECHNOLOGY	=1, drip/sprinkler, and =0, conventional irrigation	0.06	0.24	0.00	1.00
DISTANCE	Distance of the centre of the village to Bangalore (in kilometres)	46.00	9.14	23.00	57.00
EDUCATION	Years of education of the household head (=0, illiterate, =1, for 10 years and =2, for more than 10 years)	0.69	0.54	0.00	2.00
CASTE	=1, backward (scheduled caste or scheduled tribe), and =0 other caste	0.23	0.42	0.00	1.00
WELL DEPTH	Average depth of borewells in the village (in feet below ground level)	702	144.36	548	1024

RESULTS

Model I: Binary logit analysis of borewell ownership

Using binary logit model, we investigated which factors significantly influence farmers' borewell ownership. The coefficients in the second column in Table 3 are in log odds form, i.e., they indicate the change in the log odds of the outcome for a small change in the independent variable, which do not provide meaningful interpretation for conveying the magnitude of effects. As indicated earlier, these coefficients are transformed to marginal effects that estimate the change in probability of owning borewells for change in a particular independent variable, keeping other variables constant at specific values (mean). For continuous variables, marginal effects measure the change in probability of owning borewells for infinitely small change in a particular independent variable. For categorical variables, marginal effects measure the change in probability for discrete changes in an independent variable.

-- TABLE III ABOUT HERE --

Table III. Who owns borewells?

Variables	Coefficients	Marginal effects
LAND	1.679***	0.360***
	(0.257)	(0.062)
DISTANCE	-0.052***	-0.011***
	(0.016)	(0.004)
NON-AG INCOME	-0.032***	-0.007***
	(0.009)	(0.002)
WELL DEPTH	0.001	0.0002
	(0.001)	(0.0002)
CASTE	-1.401***	-0.251***
	(0.483)	(0.065)
EDUCATION_1	0.607*	0.121*
	(0.338)	(0.064)
EDUCATION_2	2.670***	0.583***
	(0.991)	(0.158)
Constant	-0.220	-
	(1.212)	
Observations	333	333
Pseudo R2	0.342	-
Wald Chi2 (Prob> chi2)	0.000	-

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; All predictors (marginal effects) at their mean value

The results indicate that borewell ownership depends on farmer's socio-economic characteristics, groundwater depth, and distance to the city. The effects of land holding and education of household heads on borewell ownership are significant and positive, suggesting that wealthy and educated farmers are more likely to own borewells. Whereas, the effects of distance from Bangalore and annual per capita non-agricultural income are significant and negative indicating that the effects of urbanisation also play an important role in borewell ownership, which we will discuss in detail later on. In addition, as expected, households that belong to upper castes have relatively higher probability of owning a borewell as compared those who belong to the lower castes indicating the inequality in borewell ownership among farmers of different social categories.

Model II: Binary logit analysis of drip adoption

The results of the logit estimation of who adopts drip irrigation method are presented in Table 4. The coefficients are transformed to marginal effects for meaningful interpretation. The results show that land holding, the number of borewells that farmers own, and the number of family members available for agriculture are significant and negatively influence the likelihood of adopting drip irrigation. Average depth of groundwater is significant and positively influence the likelihood of adopting drip irrigation, indicating that drip adoption is scarcity driven. Overall, these results show that farmers who have large land holding, more number of borewells per hectare and more family members available for agriculture are less likely to adopt drip method for irrigation. The results also indicate that farmers in villages where the average depth of groundwater is more are more likely to adopt drip method than those who are in villages where average depth of groundwater is less.

-- TABLE IV ABOUT HERE --

Table IV. Who adopts drip irrigation?

Variables	Coefficients	Marginal effects
LAND	-0.954***	-0.096**
	(0.350)	(0.037)
WELLS	-1.205*	-0.121*
	(0.720)	(0.073)
AG LABOUR	-0.722*	-0.073*
	(0.431)	(0.039)
NON-AG LABOUR	0.013	0.001
	(0.012)	(0.001)
NON-AG INCOME	0.006	0.0006
	(0.014)	(0.002)
WELL DEPTH	0.005***	0.0005***
	(0.002)	(0.0002)
CASTE	1.296	0.195
	(1.060)	(0.215)
EDUCATION_1	0.223	0.0212
	(0.646)	(0.059)
Constant	-2.239	-
	(1.609)	
Observations	108	108
Pseudo R2	0.169	-
Wald Chi2 (Prob> chi2)	0.042	-

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; EDUCATION_2 dropped as it predicts failure perfectly; marginal effect for factor levels is the discrete change from the base level.

Model III: Multinomial logit analysis of crop choice

The results of the MNL crop choice model, presented in Table 5, should be interpreted as the effect of each explanatory variable on each crop category relative to the base category (in this case, vegetables). We found that the effect of increase in land holdings is significant on the probability of farmers choosing cereals and pulses, maize, and plantations as compared to vegetable crops. Land holding is positively associated with the likelihood of choosing plantations but is however negatively associated with the likelihood of choosing cereals and pulses, and maize as compared to vegetables. That is to say, as landholding increases, the dominant crop becomes eucalyptus (plantations), whereas when landholding declines, the dominant crop becomes cereals/pulses/maize. As the number of functioning borewells per hectare increases, farmers are less likely to choose cereals and pulses, maize, and plantations as their dominant crops as compared to vegetables. Increase in the proportion of non-agricultural workers in a village increases the likelihood of farmers choosing maize as their dominant crop as compared to vegetables. Increase in per capita non-farm income of households reduces the likelihood of choosing cereals and pulses as their dominant crops as compared to vegetables, suggesting that farmers can then afford to invest in vegetables. Farmers using water conserving irrigation technologies (drip irrigation, in this case) are less likely to choose cereals and pulses, maize and horticultural crops as compared to vegetables. Increase in the distance from Bangalore city increases the likelihood of farmers choosing maize and horticultural crops as their primary crops as compared to vegetables, suggesting that the primary market for vegetables is Bangalore city.

-- TABLE V ABOUT HERE --

Table V. Multinomial logit regression of crop choice

Variables	Cereals and pulses	Maize	Plantations	Horticultural crops	Fodder
LAND	-0.912***	-0.500*	0.464	0.004	-0.525
	(0.317)	(0.284)	(0.292)	(0.283)	(0.593)
WELLS	-2.239***	-2.494***	-5.224***	-0.345	0.002
	(0.417)	(0.541)	(1.863)	(0.329)	(0.366)
AG LABOUR	0.006	-0.019	0.051	-0.106	-0.054
	(0.063)	(0.070)	(0.066)	(0.120)	(0.146)
NON-AG LABOUR	-0.007	0.045***	-0.005	-0.019	-0.124***
	(0.013)	(0.015)	(0.018)	(0.017)	(0.033)
NON-AG INCOME	-0.022**	-0.0014	-0.005	-0.015	0.001
	(0.011)	(0.010)	(0.012)	(0.012)	(0.013)
LIVESTOCK	0.236*	0.247*	-0.050	-0.105	0.181
	(0.132)	(0.145)	(0.185)	(0.154)	(0.198)
TECHNOLOGY	-3.662***	-3.130***	-17.460	-1.483*	-0.053
	(1.217)	(1.159)	(3,291)	(0.777)	(1.031)
DISTANCE	0.029	0.134***	0.0413	0.061**	0.037
	(0.025)	(0.033)	(0.036)	(0.030)	(0.033)
EDUCATION_1	0.841	1.917***	0.892	0.946	0.143
	(0.515)	(0.601)	(0.669)	(0.621)	(0.739)
EDUCATION_2	1.612	0.957	-1.874	2.086	-16.240
	(1.348)	(1.721)	(3.035)	(1.324)	(3,186)
CASTE	0.988	0.121	0.445	-0.188	-13.880
	(0.650)	(0.736)	(0.804)	(0.855)	(730.30)
Constant	1.521	-7.101***	-1.844	-1.834	0.511
	(1.398)	(1.969)	(2.008)	(1.715)	(2.010)

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Vegetables taken as the base category. Total observations 333; Pseudo R^2=0.29

The estimated coefficients in Table 5 are non-linear (log of odds ratio form) which provide only the direction of the effect but not the scalar effects of independent variables on crop choice. Hence marginal effects are estimated for meaningful interpretation of the expected change in probability of a particular choice being made with respect to a unit change in an independent variable, which are presented in Table 6. This shows that for one hectare increase in landholding the probability of farmers choosing plantations and horticultural crops increases by 0.1 and 0.04 respectively, whereas the probability of choosing cereals and pulses reduces by 0.15. As borewells per hectare increases by 1, probability of farmers choosing vegetables, horticultural crops, and fodder crops increases by 0.18, 0.11, and 0.05respectively, while the probability of choosing cereals and pulses, maize, and plantations reduces by 0.17, 0.10, and 0.08 respectively. An increase in the proportion of non-agricultural workers by 1 per cent has slight positive influence on the probability of choosing maize crop and negative influence on the probability of choosing cereals and pulses. Per capita non-agricultural income has slight positive influence on the probability of choosing maize, while it is negative on cereals and pulses. As livestock holding size increases by 1, the probability that farmers choose cereals and pulses increases by 0.03,while the probability of choosing plantations and horticultural crops decreases by 0.01 and 0.02 respectively. For 1 km increase in the distance from Bangalore city, the probability of farmers choosing maize increases by 0.01, while the probability of choosing vegetables decreases by 0.004, due to high demand for vegetables in Bangalore city and the perishable nature of the crop.

-- TABLE VI ABOUT HERE --

Table VI. Marginal effect estimates of MNL model

Variables	Cereals and pulses	Vegetables	Maize	Plantations	Horticultural crops	Fodder
LAND	-0.146 ***	0.034	-0.013	0.098 ***	0.036 *	-0.009
WELLS	-0.169 ***	0.180 ***	-0.098 ***	-0.078 ***	0.113 ***	0.052 ***
AG LABOUR	0.005	0.002	-0.002	0.004 **	-0.008	-0.001
NON-AG LABOUR	-0.002 *	0.001	0.007 ***	-0.000	-0.001	-0.004 ***
NON-AG INCOME	-0.003 **	0.001	0.002 **	0.001	-0.000	0.000
LIVESTOCK	0.026 *	-0.010	0.014	-0.014 *	-0.019 **	0.004
TECHNOLOGY	-0.311 ***	0.372 ***	-0.098	-0.082 ***	0.026	0.093
DISTANCE	-0.009 ***	-0.004 ***	0.013 ***	-0.001	0.001	-0.000
EDUCATION_1	-0.048	-0.080 *	0.137 ***	-0.006	0.019	-0.023
EDUCATION_2	0.140	-0.105	-0.027	-0.082 ***	0.141	-0.067 ***
CASTE	0.185 ***	-0.018	-0.064	-0.007	-0.039	-0.057 ***
Av. predictions (Pr (y | base))	0.432	0.135	0.195	0.081	0.108	0.048

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

DISCUSSION

In the first stage of our analysis, we asked what influences access to groundwater. This was driven by the fact that the survey showed a limited level of borewell ownership of only about 15% if adjusted for sampling density. The analyses reveal that large, educated, upper caste farmers are more likely to own borewells. The model results also show that farmers who have more non-farm income are less likely to have borewells. It is unclear which way the causality goes - whether farmers quit agriculture because their borewells stop functioning, or stop drilling deeper because they have alternative income opportunities. Historical data nevertheless show that a number of farmers lost access to irrigation during the last two decades as their wells dried up and they could not invest in new borewells (Thomas *et al.*, 2015). So, only some farmers are able to exploit groundwater, others have to back off and engage in rainfed crops alone, and diversify sources of income through non-agricultural employment, or quit farming altogether. The impact of urban markets also shows up in borewell ownership. Farmers closer to the city seem to be more willing to invest in them, for reasons that become clear in the crop choice analysis.

Regarding adoption of drip irrigation technology, one must note that the overall adoption level is low, about 37% for all irrigated farmers. And this is in spite of the obvious water scarcity on the one hand and significant government subsidies on the other. Those who do adopt drip appear to be driven by water scarcity - more wells mean less adoption and deeper wells mean more adoption - as well as labour scarcity - family members available for agriculture. But the variation that is explained is rather low, suggesting that there may be other factors influencing adoption or its absence. Based on our focus group discussions, we can speculate that the adoption of drip may be endogenous to the crop choice decision, that not all crops can be irrigated by drip, and that other problems with the technology such as short life because of clogging of holes due to salt deposition from the hard water may be responsible for non-adoption.

It is clear that access to groundwater drives crop choice. To an extent, this relationship is blurred by the MNL approach. A simple correlation between irrigated crops on the one hand and borewell ownership on the other shows a strong correlation. Horticultural and vegetable crops are only grown by borewell owners, while those without borewell only grow cereals/pulses, eucalyptus and other tree crops. Only maize is grown in both situations. But what the MNL analysis shows is the influence of other factors. Larger farmers prefer to put a large part of their landholding under eucalyptus plantations, which could be because of labour scarcity and insufficient availability of water in their borewell(s) that is unable to cover their entire land and so they prefer eucalyptus in the remaining unirrigated area. Eucalyptus plantations are harvested once in 3-4 years by contractors. Placing the land under eucalyptus allows the farmer to pursue non-farm occupations. Thus, farmers are essentially separating the return from land and labour. The smaller farmers tend to prefer cereals and pulses, which our focus group discussions revealed are mostly for self-consumption. The adoption of drip irrigation is clearly correlated with choosing vegetables as the dominant crop. The choice of maize and cereals/pulses over vegetables seems to be associated with labour scarcity and water scarcity (lack of or inadequately functioning borewells) but also results in more diverse incomes. Maize is preferred by farmers who also have some livestock (for dairy) and can use it for fodder. Thus, by process of elimination, farmers who grow vegetables have functioning borewells, access to labour and live close to the city (product market), suggesting that it is demand driven.

One contradiction in the survey findings appears to be that farmers closer to the city are more likely to own borewells. On the face of it, the association between higher non-farm income and lower borewell ownership seems to contradict the association between proximity to the city and higher borewell ownership. In fact, both are true. To resolve this contradiction, we reference the land use maps, which show higher levels of land-fallowing but also higher fraction of irrigation close to the city. We argue that farmers close to the city adopt a 'go deep or quit' strategy. In other words, there are no purely rainfed farmers close to the city. If farmers still farm close to the city, they are either growing high value crops with a borewell or most of their income is from non-farm sources. Farmers who remain in agriculture can only justify the decision if they have a borewell and grow high value vegetable crops. They can extract a higher value from their land due to prices for vegetables driven by high demand from urban dwellers.

Overall, when taken along with qualitative data from focus group discussions and historical data, it appears that farmers respond in the following different ways to increasing groundwater scarcity and urbanization. The larger landholders with better socio-economic and caste status intensify by digging more borewells, however short-lived, and grow high-return crops such as vegetables. At the same time, they put the rest of their land under plantations like eucalyptus. Smaller farmers, coming mostly from weaker socio-economic backgrounds, grow rainfed cereals and pulses, along with some eucalyptus. Farmers further away from the city may prefer irrigated horticultural crops such as coconut or areca nut that are not highly perishable.

CONCLUDING REMARKS

Using a survey both irrigated and rainfed farmers from 15 water stressed villages in the Arkavathy sub-basin near Bangalore city in Southern India we tried to understand and explain the responses of farmers to water stress in an urbanising region. The study points to three main findings. First, the current strategy of responding to water stress is mainly drilling deeper in search of groundwater. These are inequitable and largely adopted by larger, well-off farmers. Smaller, poorer farmers tend to leave agriculture or diversify their income from non-farm sources. Second, the predominant crop choices are eucalyptus plantations for non-borewell owning farmers and water intensive vegetable and horticultural crops for borewell owning farmers. Both these choices raise questions on long-term sustainability of water resources in the region. Third, in spite of facing water scarcity and steadily declining water tables, uptake of water saving technologies among irrigated farmers has been low, due to the non-existence of incentives to conserve water as well as employment opportunities that exist outside agriculture.

Understanding farmer responses to declining groundwater and increasing urbanisation is valuable from multiple perspectives. From a social equity perspective, the question is whether these stressors affect farmers uniformly and the answer is clearly in the negative. Access to groundwater is neither universal nor randomly distributed. Even though the fractured rock hydrogeology introduces some randomness in the location of yielding fractures, the ability to invest in deeper borewells is highly contingent upon socio-economic class and status. Groundwater irrigation and adoption of water efficient technologies require huge capital investments by individual farmers. As Dubash's (2002) political economic analysis shows, it is largely the well off farmers who are able to make use of technologies that can help adapt to declining water availability and continue in agriculture, while the marginal and less privileged farmers lose out. Compared to smaller farmers, large farmers are able to invest in both water appropriation and water conservation technologies (Frija *et al.,* 2016).

From a hydrological sustainability perspective, the question is whether farmers continue to pump groundwater and how other crop choices they make affect water consumption in agriculture. In this study, we find that across socio-economic classes, farmers have extensively adopted eucalyptus and other plantation crops, which increases water consumption as compared to single season rainfed crops. Simultaneously, the larger landholders have continued to pump groundwater and cultivate irrigated crops, thereby aggravating groundwater depletion significantly. Hydrological research conducted as part of our larger research project showed that eucalyptus plantations and irrigated agriculture explained to a large extent the decline in baseflows and in groundwater levels in the upper reaches of the Arkavathy sub-basin (Srinivasan *et al*., 2015).

As Amichi *et al* (2012) note, access to groundwater is an important factor in increasing socio-economic differentiation, furthering land concentration in a few hands and forcing small farmers out of agriculture. Urbanization may be leading to abandonment of agriculture in favour of real-estate to some extent, but urbanisation has a much wider impact in terms of increasing the demand for and cultivation of water intensive vegetable and fruit crops that dominate farmer crop choices, as long as they have access to groundwater. From a farm livelihoods sustainability perspective, the strategy of farmers in the Arkavathy sub-basin seems to be to chase water and not adapt, drawing upon the characterization put forward by Berahmani *et al.* (2012). Farmers are aware of and might be prepared to exploit the opportunities that lie outside agriculture. In an open access situation with unregulated groundwater use, till water runs out, they can visualise short-term earnings, and then sell land or shift to non-agricultural jobs - so chase water and quit farming.

In conclusion, when there is no regulation of groundwater exploitation nor other mechanisms to provide feedback to farmers as to the cumulative hydrological effects of individual crop choices, the long-term impacts are inequities among the farming population, and unsustainability, both of water resources and farm-based livelihoods.

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