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To conserve or to explore? farm-level strategies to manage groundwater

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Abstract In this paper we have made an attempt to understand farmers' response to the continuing water scarcity. Results show that farmers' education status (primary school and high school level) and plot size are encouraging farmers to go for explorative extraction while farming experience and awareness (about causes of the scarcity) are discouraging it. Explorative extraction results in higher investments, lower gross farm income and shorter well life. Respondents' awareness about human causes of resource scarcity is prompting adoption of conservation measures. Decision to introduce drip irrigation as a major demand management strategy is positively influenced by plot size, government subsidy support and externality cost of well failures.

Keywords Groundwater irrigation, Agriculture, Adaptation, Sustainability

JEL classification Q15 , O13, O33, Q010

1 Introduction

Depletion of groundwater resources is emerging as a big threat to sustainable growth of agriculture in many parts of India. The state of Kerala, although falls in the high rainfall zone, has been experiencing erratic rainfall with increasing number of rain-deficit years enhancing farmers' dependence on groundwater for irrigation (Rao 2008). As a result, the water level in wells has started declining (Shaji et al. 2008).

Farmers' behavioural responses (adaptation strategies) towards water management are influenced by the resource status, the extent of resource scarcity and the awareness about it (Mendelsohn 2000). Such responses are flexible to changes in economic, social, political and institutional conditions (Folke et al. 2002). In cases, adaptations may also worsen resource status and increase social inequality (Jha 2000). The immediate farm-level response to water scarcity is to further explore groundwater by deepening of existing wells and digging new wells. This imposes huge financial burden on farmers (Chandrakanth & Arun 1997; Nagaraj et al. 2003; Tiwari et al. 2009; Vaidyanathan 2013) leading to agrarian crisis (Marothia, 2003). At the same time, improving supply through low-cost soil and water conservation measures are not widely practiced (Sarangi et al. 2004; Alam 2015). Nonetheless, effective groundwater management underlines the need to shift from conventional supply-side to demand-side strategies that improve water-use efficiency (Dziegielewski 1999; Srivastava et al. 2014) such as drip irrigation that besides saving water, has also been proven to yield more, compared to the conventional flood irrigation (Kumar 2012; Chandrakanth et al. 2013; Pramanik et al. 2014).

In this paper, we identity factors that influence farm-level adaptation measures for groundwater management. We discuss in detail the most unsustainable explorative extraction, and the most sustainable drip irrigation practices. A better understanding of their determinants and impacts will help farmers to choose the best water management practices to make farming resilient to adversities.

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2 Data and method

This study was conducted in Palakkad district of Kerala; one of the most water-scarce districts. For selection of the sample households, we identified two block panchayats viz., Chittur and Pattambi. Chittur falls in the category of overexploited groundwater, while Pattambi has the status of semi-critical (CGWB 2014). Chittur receives 1883 mm rainfall, compared to the district average of 2362 mm and the state average of 2817 mm. From each block panchayat we randomly selected 70 groundwater irrigated farms cultivating coconut as the main crop. From these farmers, data were collected in pre-tested structured interview schedules during summer months (February- May 2016) so as to directly observe irrigation practices that farmers follow.

A multinomial logistic regression model was used to understand the factors influencing adoption of water management practices. This model is an extended version of binary logistic regression and is based on the assumption of IIA (Independence of Irrelevant Alternative). To see whether this assumption is satisfied we apply Hausman & McFadden (1984) test that compares full model with restricted model. The null hypothesis is that the full model follows IIA. In other words, the regression coefficients obtained from these models are not significantly different. As the two block panchayats that we selected are climatically and geographically different, we run IIA tests clustering standard errors. Test results given in table A1 and A2 in the appendix fail to reject the null hypothesis; hence there is no evidence against the models not following IIA. The model can be written as:

$$Prob\,(Y_i = j) = P_{ij} = \frac{e^{X_i'\beta_j}}{\sum_{l=1}^{m} e^{X_i'\beta_l}} \quad j = 1, \ldots \ldots m;\ \beta_1 = 0$$

Equation (1) shows probability of outcome 'j' compared to the base category. The restriction $\beta_1 = 0$ means that coefficients corresponding to base outcome are zero. X_is are independent variables and β_js are their corresponding coefficients for j_{th} outcome.

Supply management and demand management strategies were categorised and analysed separately (Model I and Model II respectively). There are four categories of unordered mutually exclusive outcomes (ys) for supply management strategies viz., 'exploration alone' (y1), 'conservation alone' (y2), 'both exploration and conservation' (y3) and none of these (y0). Farms under 'exploration alone' are those digging new wells, deepening existing wells and/or enhancing efficiency of pumping motors for further extraction. Farms practicing only water conservation through rainwater harvesting, mulching and coconut-husk burial are categorised as 'conservation alone' farms. There are three categories of mutually exclusive outcomes (Ys) for demand management strategies viz., drip irrigation (y1), basin irrigation with polythene hose (y2) and no strategy (y0).

Parameters of multinomial logistic regression are interpreted in relation to base category. To obtain magnitude of the response to changes in the independent variables we calculate marginal effects following Cameron and Trivedi (2005).

Our set of explanatory variables includes farming experience, income from sources other than agriculture, education level of the farmers and their awareness about proximate reason of groundwater decline, plot size, plot proximity to permanent water bodies, externality cost of well failure and subsidy on drip irrigation.

Amortisation procedure was used to estimate externality cost of defunct wells and government-subsidy for installation of drip systems. Based on field-level data, annual growth for cost of digging a well is estimated 2%. We reckon it as discount rate for amortisation (Diwakara & Chandrakanth 2007).

Total cost of irrigation = amortised fixed cost + variable cost of irrigation

Amortized fixed cost = (compounded cost of investment) * $\frac{(1+i)^{FL} * i}{(1+i)^{FL} - 1}$

Compounded cost = historical investment * $(1 + i)^{(2016 - year\ of\ investment)}$

For calculating externality cost of defunct wells,

Compounded cost = historical investment * $(1 + i)^{(Year\ of\ defunction\ -\ year\ of\ investment)}$

FL is the average functional life of well/equipment and i is the discount rate. The average functional life of open wells in Chittur and Pattambi is estimated 39 and 53 years, respectively. Similarly, the average functional life of borewells in Chittur and Pattambi is estimated 7 and 10 years, respectively.

3 Results and discussion

Despite being a high rainfall region, groundwater potential of Kerala is low due to peculiarities of soil, high gradient, land-use changes and socio-economic aspects. Irrigated area of the state is low at about 19% of net cropped area of which 50% is served with groundwater (GoK 2016). Surface irrigation methods like flood and basin are very common in the state where area under micro irrigation is low (15885 ha) compared to other states (Chandran & Surendran 2016). Irrigation is mainly protective, used only during summer months for crops like coconut, banana and arecanut. Coconut is the major crop in homesteads, that are representative of the farming system in the state. Arecanut, pepper and banana are grown as intercrops. Coconut, banana, rubber and arecanut are the major garden land crops in Palakkad. About one-third of the net irrigated area in the district is served by groundwater sources (GoK 2016).

3.1 Household and farm characteristics

3.1.1 Household profile

The summary statistics of important socio-economic variables is given in table 1. Majority of the respondents are elderly with average age at 58 years. About 40% of total household income is from sources other than agriculture which enables farmers to meet capital requirement for irrigation investments. The average plot size is 2.7 acres or 1.1 hectares which is higher than the state average of 0.22 ha (GoK 2016). On an average, farms are situated at about 2 km away from permanent water bodies. Framers were asked to state major reason for the groundwater scarcity in the area, as perceived by them. A binary variable was constructed based on their response whether 'natural' or 'man made'. A value zero is assigned to 'natural causes' and 1 to the 'man-made' causes. Fifty five percent respondents pointed out 'natural causes' as major reason for the resource decline. Majority of respondents (39%) have completed middle school level of education.

3.1.2 Cropping pattern and irrigation practices

The two block panchayats studied (Chittur and Pattambi) have distinct climate and soil characteristics. Chittur has black cotton soil and low rainfall similar to Coimbatore district of Tamil Nadu. Pattambi has predominantly laterite and loamy soil and high rainfall similar to that of Kerala. The cropping pattern in both the panchayats is dominated by coconut in garden lands. Banana, vegetables and fodder crops are cultivated as intercrops in Chittur; and arecanut, pepper and banana in Pattambi (table 2). Sugarcane, paddy

Table 1. Description of explanatory variables

Variable	Category/Unit	Mean	S D
Age	Years	57.5	10.7
Farming years	Years	31.7	14.08
Total income	Rs./year	175270	131762
Income from other sources	Rs.000/year	70772	101622.7
Plot size	Acres	2.7	1.9
Plot proximity to permanent water body	km	2.1	1.53
Amortised externality cost of well failures (drying up) per plot	Rs.000/year	2.8	5.8
Amortised subsidy for drip irrigation per plot	Rs.000/year	1.5	4.6
Categorical variables	Category	Share (%)	
Education (standards completed)	0-Up to 4th	17	
	1-Primary school	29	
	2-Middle school	39	
	3-High school	15	
Awareness (2 categories)- based on response about major causes of groundwater decline	0–Natural cause	55	
	1– Man-made cause	45	

Source: Field survey

Table2. Cropping pattern and irrigation methods in sample farms

Crop	Share of cultivated area (%)		Irrigation methods	Share of farms (%)	
	Chittur	Pattambi		Chittur	Pattambi
Paddy	0	3	Flood/basin	30	25
Coconut	68	47	Basin with hose	3	43
Arecanut	0	18	Drip	61	7
Banana	12	11	Sprinkler	6	25
Vegetables	5	10	Total	100	100
Pepper	0	9	Average farm size (ha)	1.44	0.576
Fodder	13	0	Cropping intensity (%)	88	139
Others	2	2			
Total	100	100			

Source: Field survey

and cotton were the traditional crops in black cotton soils of Chittur. Farmers have shifted from these water intensive crops to hardy crops, mainly coconut during the late 1990s and early 2000s on account of water scarcity and high labour cost. Average age of coconut palms in Chittur is about 20 years. Along with this they had shifted to well irrigation (mainly borewells) and there was a spurt of borewells during this period. This competitive well deepening/digging has resulted in lowering of water table and later well failures in the region. Presently, farmers in Chittur are not able to utilise their arable land fully because of water scarcity.

Cropping intensity in Pattambi is higher than that in Chittur owing to better availability of water. Farmers adopt conventional type of flood and basin irrigation and modern type of drip and sprinkler irrigation. Drip irrigation is the main method in Chittur where two-third of the farm households had adopted it. Basin irrigation is the prominent method in Pattambi, and farmers use synthetic hoses and polypropylene pipes for conveyance of water so as to reduce conveyance and transmission loss. In the conventional basin irrigation method, water is conveyed through earthen channels. Drip and micro-sprinkler methods have higher water-use efficiency compared to the conventional flood and basin irrigation systems (CWC 2014).

3.2 Factors influencing supply management strategies

Groundwater supply management strategies include exploration, conservation and a combination of these two. Major explorative strategies followed by farmers include digging of new wells (mainly borewells), deepening of existing wells and intensive extraction of water using high-power electric motors continuously. In such cases, water pumped from borewell is stored in dried-up open wells and re-pumped. Conservative supply management strategies include rainwater harvesting, mulching with coconut leaves and coconut-husk burial. Most of the farms resorted to exploration strategies (48%) (table 3). Only a few farms (9%) have been practicing conservation and 13% farms have been adopting both the explorative and conservative practices.

We have run the multinomial logit function with default, robust and clustered standard errors (results reported in Table A3 in the appendix). The results discussed here correspond to the model with clustered standard errors (Model I). Farmer characteristics (farming experience, awareness and education) and farm characteristics (plot size) are found to be significant for ‘explorative strategies’. Coefficient on ‘farming experience’ is -0.025 (at 1%) indicating that probability of resorting to ‘exploration’ is less among the experienced farmers. Marginal effect of experience is -0.003 implying that for every year of additional experience results in a reduction in probability of ‘exploration’ by 0.3%. Generally, experience increases with age, and hence the elderly respondents may have experienced negative effects of extensive water extraction strategies. Similarly, the risk-taking ability also decreases with age. The perception on the main reasons for groundwater decline (awareness) is

Table 3. Determinants of adoption of groundwater supply management strategies (Model I)

(Base category = No strategy)	Exploration alone (48%)		Conservation alone (9%)		Both (13%)	
	Coefficient	Marginal effect	Coefficient	Marginal effect	Coefficient	Marginal effect#
Farming experience (years)	-0.025***	-0.003***	0.002	0.0006	-0.027*	-0.0015
	(0.001)	(0.0009)	(0.007)	(0.0005)	(0.014)	(0.0012)
Awareness (=1 for aware, 0 otherwise)	-2.368***	-0.482***	15.93***	0.136***	-0.716	0.0501**
	(0.692)	(0.1175)	(1.686)	(0.0523)	(0.651)	(0.0231)
EducationPrimary school	0.274***	0.0935***	-1.481***	-0.478***	-0.549***	-0.764***
(Base = up to class IV)	(0.026)	(0.0099)	(0.055)	(0.0087)	(0.170)	(0.0051)
Middle school	0.079	0.0302	0.786**	0.0493**	-0.359	-0.0604
	(0.801)	(0.157)	(0.049)	(0.195)	(0.221)	(0.0697)
High school	0.995***	0.2006***	-13.62***	-0.701***	-0.090	-0.0694
	(0.088)	(0.0556)	(1.207)	(0.1304)	(1.248)	(0.1325)
Other income (Rs. 000s/year)	-0.002	-9.73e-05	-0.014***	-7.32e-04***	-0.001	1.07e-04
	(0.004)	(3.89e-04	(0.003)	(2.18e-04)	(0.005)	(1.71e-04)
Plot size (acres)	0.185*	0.214*	-0.494	-0.0307	0.253***	0.0210***
	(0.112)	(0.122)	(0.501)	(0.0189)	(0.0005)	(0.0042)
Plot proximity to permanent water	-0.215	-0.044	0.0004***	0.027***	0.044	0.0133
body (km)	(0.261)	(0.047)	(0.005)	(7.07e-03)	(0.035)	(0.0175)
Constant	2.069***		-16.78***		0.052	
	(0.743)				(0.309)	
Block fixed effects	Yes		Yes		Yes	
No. of observations	139				139	

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1, #Marginal effects are calculated at means of the variables.

significant and it indicates that farmers perceiving human exploitation as the main cause of water scarcity are likely to refrain from explorative strategies. These results are in conformity with those reported by Alam (2015) for Bangladesh. Groundwater is a common pool resource enjoyed in association with land ownership rights. The scope of enforcement of norms for digging well is also limited. The results show that awareness creation among farmers on human-related reasons of groundwater decline would make them more cautious and judicious. But, education (primary and high school categories) tend to adopt 'exploration strategies'.

Coefficient on plot size is positive and significant at 10%, indicating the probability of resorting to explorative strategies in larger sized farms .Better resource conditions of large farmers also favour higher investments. Skewed distribution of land holdings leads to inequality in access to groundwater and ownership of the resource in favour of large landholdings (Nayak 2009; Sarkar 2011).

Coefficients on awareness and proximity to permanent water body are positive and significant on adoption of 'conservation alone'. Awareness of farmers about human causes of resource scarcity enables them to adopt conservation strategies. Farms situated away from permanent water bodies opt for water conservation measures. Educated farmers as well as those having better non-farm income are less likely to opt for conservation only as a strategy. Chittur being in the rain shadow region, the annual rainfall is low, and hence 'conservation alone' is not an effective management strategy. According to Pande et al. (2011) the annual net benefit realized from conservation measures is low and long-term benefits are sensitive to discount rate, explaining the low-level of adoption of such measures. Local water conservation programmes with farmers' participation may ensure judicious use of water and reduce its exploitative exploration. Leach et al. (1999) argue that stewardship over natural resources is state responsibility and conservation measures need to be initiated by the state.

3.2.1 Sustainability of explorative supply management

Explorative supply management strategies are capital-intensive and unsustainable. Fifty seven percent farms in Chittur follow 'explorative strategies'. There is competitive deepening of wells, further leading to well failures. The feeble regulations on digging of new borewells, cost effectiveness and practical easiness due to technology advancement are the reasons for spurt in borewells in Kerala (George 2016). Density of permanently defunct wells is higher in Chittur (44/km^2) than in Pattambi (36/km^2) (table 4). Borewells account for major share of defunct wells (89%) due to higher borewell intensity.

The average age of open wells is 39 years in Chittur and 53 years in Pattambi, and average functional life of bore well is 7 and 10 years, respectively. The wells in Chittur are becoming defunct earlier than in Pattambi. Average depth is more in Chittur for both open wells and borewells. Depth of borewells in Chittur (145 mts) is almost twice of that in Pattambi (75 mts). There are several reports of consequences of increasing number of bore wells .Jha (2000) has reported situations of the existing water lifting technology inefficient. Mukherjee (2007) find over-drafting and overcrowding as the two main causes of well failures in areas of groundwater scarcity.

Groundwater is drafted using energized motor pumps. The average power of motors is more (5hp) in Chittur. Deeper water table and higher irrigation requirement in Chittur area demand motors of higher power. Farmers use compressor-cum-motor pumps connected to borewells which could alternatively operate open wells and borewells with a valve and switching over mechanism. Water from borewells is pumped to open wells and further from open wells for domestic and irrigation purposes. There is seepage loss of stored water from open wells and consumption of double the energy (electricity) than direct irrigation with single drafting. The present system of unrestricted provision of subsidised electricity is a disincentive for judicious extraction of groundwater. There are reports of excessive groundwater extraction using subsidized electricity from most parts of the country (Vaidyanathan 2013; Gulati & Pahuja, 2014). Jeevandas et al. (2008) reported that groundwater decline is severe in tube well irrigated areas of Punjab and suggested conjunctive use of tube well+canal irrigation in such areas.

Well failures associated with un-regulated groundwater exploitation has led to poor financial viability (Chandrakanth 2015). Explorative strategies are capital-intensive and may lead to indebtedness and financial insecurity. Average capital investment for a well in Chittur is Rs. 6855/ha/annum (table 5). Amortised cost of non-functional wells accounts for about 36% of total cost of wells (Rs.10789/ha) in the region and it has escalated total cost of irrigation. Major share of irrigation cost (80%) is accounted by fixed cost component and total cost of irrigation is high accounting for about 31% of total cost of cultivation.

Table 4. Well characteristics in Chittur and Pattambi

Sl no.	Particulars	Chittur	Pattambi	Aggregate
1	Share of farms adopting 'exploration alone' (%)	57	39	48.0
2	Open well density/km^2	72.00	229.00	150.50
3	Bore well density/km^2	60.00	125.00	92.50
4	Density of permanently defunct wells/km^2	44.00	36.00	40.00
5	Density of defunct bore well/km^2	39.00	8.00	23.50
6	Share of open wells among defunct wells (%)	11.00	76.00	43.50
7	Share of bore wells among defunct wells (%)	89.00	24.00	56.50
8	Share of wells defunct due to drying-up (%)	78.00	58.82	68.41
9	Average depth of open wells (m)	11.49	8.90	10.20
10	Average depth of bore wells (m)	145.66	75.00	110.33
11	Functional age of open wells (years)	39.00	53.00	46.00
12	Functional age of bore wells (years)	7.00	10.00	8.50

Source: Field survey

Table 5. Comparison of irrigation cost and return among irrigated farms

Sl no.	Particulars	Chittur	Pattambi	Overall
1	Amortised cost of functioning well (Rs./ha)	6855	7008	6932
2	Amortised cost of non-functional wells (Rs./ha)	3934	331	2132
3	Total amortised cost of wells incl. non-functional wells (Rs./ha)	10789	7339	9064
4	Total fixed cost of irrigation (Rs./ha/year)	29449	20150	24800
5	Total cost of irrigation (Rs./ha/year)	36872	28327	32600
6	Share of irrigation cost in total cost of cultivation/ha (%)	31	39	35
7	Total cost of cultivation (Rs./ha)	107419	104482	105898
8	Gross income (Rs./ha)	87664	145256	116460
9	Share of farms adopted drip irrigation (%)	47	7	27

Source: Field survey

The increased cost of cultivation and low returns has resulted in cultivation becoming less profitable in the region.

3.3 Factors influencing demand management strategies

Water-efficient irrigation systems like drip and micro-sprinkler are proven technologies that reduce water use. Drip irrigation has been found to improve yield and profits over the conventional irrigation (Kumar 2012; Chandrakanth et al. 2013; Pramanik et al. 2014). Governments' promotional efforts through financial support have positive and significant influence on adoption of drip irrigation (Adeoti 2009; Dai et al. 2015) and other conservation irrigation methods (Grove & Oosthuizen 2010). Twenty seven percent of the farmers in the study area (46% in Chittur alone) use drip irrigation, and 22% use basin flood system with polythene hose instead of field channels (common in Pattambi).

Results of the regression model (Model II) show that decision to adopt drip irrigation favoured by education class (primary level), plot size, subsidy for drip irrigation and externality cost associated with groundwater decline (table 6). However, farming experience is negatively influencing it. Coefficient on 'income from other sources' is not found significant. Contrary to our expectations, we got awareness and higher level of education as factors discouraging adoption of drip irrigation. Coefficient on farming experience is -0.048 (significant at 1%) indicating an inverse relation between farming experience and probability of adopting drip irrigation. Marginal effect of this variable is -0.0046 indicating that one year increase in farming experience may reduce probability to adopt drip irrigation by 0.46%. Generally, young farmers are innovative and progressive. They introduce capital intensive technologies expecting long term benefits. Coefficient on plot size is positive indicating higher probability of adoption of drip irrigation on larger farms. Positive coefficient of 'subsidy for drip installation' indicates that subsidy support facilitates its adoption. Drip irrigation with subsidy makes it affordable for small and marginal farmers to adopt such water-efficient technologies. Only a few farmers in Pattambi (7%) adopt drip irrigation because of lack of promotional efforts. Moreover farmers also point out clogging of driplets and difficulty in intercultural operations as constraints to adoption. Fine-tuning of drip irrigation technology to make it suitable to climatic conditions (heavy monsoon rainfall) and closely spaced multiple crops is needed to promote this technology in other parts of the state. Chandran & Surendran (2016) also reported heavy rainfall, high initial cost and inadequate subsidy as constraints in adoption of drip irrigation. Average amortised cost for installation of drip irrigation is estimated Rs. 22000/ ha, indicating that drip irrigation system is capital-intensive; hence may not be adopted by the resource poor farmers.

Coefficient on 'amortised cost of digging a defunct well' (externality cost of failed/defunct wells) is 0.17 (significant at 1%) in case of farms adopting drip irrigation. This indicates that, as the cost incurred on digging a well (failed or later became defunct) increases, the probability to introduce water-efficient drip irrigation system increases. As the scope of

Table 6. Factors influencing demand management strategies to manage groundwater decline (Model II)

Variables	Clustered Standard Errors				Default Standard Errors		Robust Standard Errors	
	Drip		Hose		Drip	Hose	Drip	Hose
	Coefficient	Marginal effects#	Coefficient	Marginal effects#				
Farming experience (years)	-0.048*** (0.020)	-0.0046*** (0.0014)	-0.003*** (0.001)	0.0006*** (0.0002)	-0.064** (0.028)	-0.000154 (0.020)	-0.064*** (0.023)	-0.000154 (0.019)
Awareness (=1 for Aware, 0 otherwise)	-1.003** (0.442)	-0.0859 (0.0789)	-0.588** (0.236)	-0.0609 (0.0994)	-1.001 (0.671)	-1.032* (0.605)	-1.001* (0.605)	-1.032 (0.638)
Other income	-0.001 (0.002)	-1.48e-04 (2.37e-04)	4.82e-07 (4.46e-07)	9.8e-05 (3.81e-05)	-0.002 (0.003)	0.0003 (0.003)	-0.002 (0.003)	0.0003 (0.003)
EducationPrimary school (Base = up to Class IV)	0.509*** (0.025)	0.0514*** (0.0072)	-0.182 (0.696)	-0.0369 (0.1322)	0.869 (0.866)	-1.095 (0.976)	0.869 (0.853)	-1.095 (0.927)
Middle school	0.589 (0.628)	0.0601 (0.0494)	-0.236 (1.229)	-0.0461 (0.1947)	1.472 (1.030)	-1.577* (0.917)	1.472 (0.901)	-1.577* (0.868)
High school	-1.250 (0.979)	-0.877*** (0.0166)	0.281 (1.399)	0.0594 (0.1676)	-0.238 (1.399)	-1.474 (1.237)	-0.238 (1.280)	-1.474 (1.305)
Plot size (Acres)	0.361*** (0.015)	0.0444*** (0.0154)	-0.429 (0.310)	-0.0678*** (0.0262)	0.274 (0.168)	-0.255 (0.253)	0.274* (0.161)	-0.255 (0.261)
Subsidy for drip installation	0.85*** (0.218)	0.246*** (0.0639)	-7.53*** (0.527)	-1.0*** (0.3092	0.74*** (0.271)	-3.92 (1067)	0.74*** (0.255)	-3.92*** (0.362)
Externality cost of well failures (drying up)	0.17*** (0.032)	0.0200*** 3.96e-03	-0.159* (0.089)	-0.0259*** (5.33e-03)	0.132** (0.065)	0.652 (0.486)	0.132** (0.59)	0.652 (0.531)
Constant	-0.828 (0.511)		0.779 (0.978)		0.139 (1.258)	-28.41 (1,236)	0.139 (1.180)	-28.41* (16.16)
Block fixed effects	YES		YES		YES	YES	YES	YES
Observations	139		139		139	139	139	139

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1, # Marginal effects are calculated at mean
Source: Estimated by authors

improving water supply is limited, the realistic alternative is to improve water-use efficiency and get 'more crop per drop'. The proportion of farms with drip irrigation is 46% in Chittur owing to low prospectus of supply management strategies. Mainly coconut, banana and vegetables are under drip irrigation. The system has been widely adopted in the recent past mainly on account of growing water scarcity, labour shortage and favourable policy support. Chittur gets advantage of being located near Coimbatore where there are many firms providing drip installation and maintenance services at lower costs. Evidence shows irrigated area as increasing after installation of drip irrigation system. Farms with drip irrigation are able to increase frequency and duration of irrigation even with supply constraints. Farms with flood irrigation have 5 to 10 days of interval between two irrigations (even 15 days during severe water scarcity). Farmers are forced to shift from cultivation of water-intensive crops like paddy and sugarcane to coconut, under severe water scarce situations. Most of the farms are cultivating coconut alone with wider spacing between palms which helps in easy handling of driplets during inter-cultural operations. Flood irrigation using polythene hose for water distribution is practiced by 22% respondents. Farming experience, awareness, subsidy support and externality cost of well failures are found negatively influencing adoption of this method. Farmers have to hold hose at basins and hence farms with sufficient family labour only can adopt this method. Coefficient of plot size is negative and its marginal effect is significant making it not suitable for large sized farms due to labour consuming nature.

4 Conclusion

Erratic rainfall and continuing groundwater decline in Kerala has led farmers to adopt supply driven adaptation strategies. Farm-level interventions to improve availability of water are mainly explorative in nature through well digging, deepening and intensive extraction. Rainwater conservation measures alone are rarely adopted. Our results show that farmers' awareness on 'human-causes' of groundwater decline refrains them from adopting unsustainable exploration strategy. While experience in farming discourages exploration measures, education and farm size encourage to go for such measures. Explorative supply improvement is unsustainable due to well failures and depth increase. Cost measures are also substantiating unsustainability of explorative strategies.

The main groundwater demand management strategy includes water-efficient irrigation methods, mainly drip irrigation. Farming experience and awareness are negatively influencing adoption of drip irrigation. Plot size, externality cost of well failure and subsidy support for drip irrigation are promoting adoption of drip irrigation system. Farms could bring in more areas under irrigation and they could reduce the gap between two irrigations by introducing drip irrigation. Adoption of drip irrigation in Pattambi is very low due to lack of government promotion, subsidy support and low suitability to closely spaced cropping system. Small sized farms with sufficient family labour follow the basin method using polythene pipes to reduce transmission loss. Alternatively farmers are shifting from water-intensive paddy to crops like coconut. Government subsidy support and technology upgradation are suggested for promotion of drip irrigation in other parts of the state.

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Appendix

Table A 1. Table showing results of generalised Hausman Test for IIA (Model I)

I. Unrestricted Model: Model with all four categories [Base=No strategy]
II. Restricted Model: Model without ‘Exploration’ [Base= No strategy]
III. Restricted Model: Model without ‘Conservation’ [Base= No strategy]
IV. Restricted Model: Model 2 without ‘Both’ [Base=No strategy]

Test 1: Comparing I and II	Chi Square	Probability > chi2
	0.27	0.99
Test 2: Comparing I and III	Chi Square	Probability > chi2
	0.22	1.00
Test 3: Comparing I and IV	Chi Square	Probability > chi2
	6.32	0.79

H_O: Assumption of Independence of Irrelevant Alternatives (IIA) holds

Table A 2. Results of generalised Hausman test for IIA (Model II)

I. Unrestricted Model: Model with all three categories [Base=No strategy]
II. Restricted Model: Model without ‘Hose’ [Base= No strategy]
III. Restricted Model: Model without ‘Drip’ [Base= No strategy]

Test 1: Comparing I and II	Chi Square	Probability > chi2
	3.18	0.95
Test 2: Comparing I and III	Chi Square	Probability > chi2
	0.01	1.00

H_O: Assumption of Independence of Irrelevant Alternatives (IIA) holds

Table A 3. Results of determinants of supply management strategies for standard, robust and clustered standard error models

	1			2			3		
	Default Standard Errors			Robust Standard Errors			Clustered Standard Errors		
Base category= No strategy)	Exploration	Conservation	Both	Exploration	Conservation	Both	Exploration	Conservation	Both
Awareness	-2.472***	15.10	-0.917	-2.472***	15.10***	-0.917	-2.368***	15.93***	-0.716
	(0.539)	(1,004)	(0.662)	(0.570)	(1.086)	(0.667)	(0.692)	(1.686)	(0.651)
Farming experience (years)	-0.0214	0.00846	-0.0191	-0.0214	0.00846	-0.0191	-0.0250***	0.00151	-0.0269*
	(0.0190)	(0.0274)	(0.0232)	(0.0176)	(0.0251)	(0.0241)	(0.00119)	(0.00723)	(0.0143)
Plot proximity to permanent	-0.000184	0.000489*	8.91e-05	-0.000184	0.000489	8.91e-05	-0.000215	0.000468***	4.40e-05
water body (km)	(0.000161)	(0.000271)	(0.000198)	(0.000159)	(0.000320)	(0.000210)	(0.000261)	(4.94e-06)	(3.49e-05)
Plot size (acres)	0.319*	0.00237	0.465**	0.319*	0.00237	0.465**	0.185*	-0.494	0.253***
	(0.178)	(0.460)	(0.211)	(0.190)	(0.425)	(0.227)	(0.112)	(0.501)	(0.000503)
EducationPrimary school	0.192	-1.564	-0.666	0.192	-1.564	-0.666	0.274***	-1.481***	-0.549***
(Base = up to class IV)	(0.679)	(1.842)	(0.894)	(0.637)	(1.505)	(0.864)	(0.0264)	(0.0555)	(0.170)
Middle school	-0.126	0.671	-0.654	-0.126	0.671	-0.654	0.0790	0.786***	-0.359
	(0.728)	(1.527)	(0.865)	(0.676)	(1.160)	(0.776)	(0.801)	(0.0492)	(0.221)
High school	0.803	-13.86	-0.407	0.803	-13.86***	-0.407	0.995***	-13.62***	-0.0905
	(0.939)	(1,867)	(1.210)	(0.944)	(1.434)	(1.187)	(0.0881)	(1.207)	(1.248)
Other income	-2.08e-06	-1.57e-05	-1.51e-06	-2.08e-06	-1.57e-05	-1.51e-06	-1.79e-06	-1.41e-05***	-1.16e-06
	(2.46e-06)	(1.09e-05)	(2.96e-06)	(2.92e-06)	(9.87e-06)	(3.00e-06)	(4.49e-06)	(3.43e-06)	(5.20e-06)
Constant	(0.655)	(1,061)	(0.833)	(0.614)	(0.863)	(0.746)	2.069***	-16.78***	0.0519
	1.371	-32.48	-1.245	1.371	-32.48***	-1.245	(0.743)	(1.891)	(0.309)
Block fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
No. of observations	139	139	139	139	139	139	139	139	139

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1