Ecology, Economy and Society–the INSEE Journal 2 (2): 45–74, July 2019

RESEARCH PAPER

Groundwater Extraction, Agriculture and Poverty in Godavari River Basin

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Abstract: This study analyses the relationship between access to groundwater irrigation, agricultural development, and poverty in Godavari river basin with heterogeneous hydrogeological resource conditions, and their implications for resource governance, using primary data from 825 farm households. The analysis showed that households with access to groundwater earn relatively higher household and per capita incomes. The large farmers seemed to have better access to water resources. Although poverty headcount ratio is high among the upper reach farmers, depth, and severity of poverty is more among middle reach farmers. Land size *per se* is not a significant variable in determining access, but the access is conditioned by sources of non-farm income, credit facility, education and caste hierarchy. While small farmers used more water per acre for irrigation without commensurate economic productivity, the differences in their economic productivity in comparison to large farmers was found to be associated with inequality.

Keywords: Well Ownership, Groundwater Access, Per Capita Income, Poverty and Inequality, Water Use and Productivity

1. INTRODUCTION

Groundwater irrigation, driven by both demand side and supply side factors, has experienced explosive growth during the past few decades, and now it plays an important role in the agricultural development of India (Shah, Singh and Mukherji 2006; Shah 2009; World Bank 2010; GoI 2014;

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Published by Indian Society for Ecological Economics (INSEE), c/o Institute of Economic Growth, University Enclave, North Campus, Delhi 110007.

ISSN: 2581-6152 (print); 2581-6101 (web).

Kulkarni and Shankar 2014; Zaveri *et al.* 2016). Availability of better drilling and pumping technologies, subsidised energy for extraction, flexibility and timeliness of supply, and poor delivery of public water supply system have contributed to raising groundwater consumption in farming. This helped the farmers optimise input use, diversify to high value crops, and achieve higher water productivity (Shah *et al.* 2007; World Bank 2010). While this led to reduction in rural poverty through various pathways (Hussain and Hanjra 2004; Narayanamoorthy 2007), the highly intensive development of groundwater also resulted in over exploitation, decline in groundwater levels in certain areas and sea water intrusion in coastal areas (Dhawan 1989; Chopra 2003; Bhandhopadhyay 2007). According to recent estimates, out of 6584 groundwater assessment units, 1034 are over exploited, 253 units are critical, 681 units are semi-critical, 4520 units are safe, and 96 units are saline in the country. The overall stage of groundwater development in the country is 62% and in several states like Punjab, Rajasthan, Haryana, and Delhi it is over 100% — implying that annual groundwater consumption is more than annual groundwater recharge and is unsustainable (GoI 2017).

The implications of groundwater depletion are many and serious, as there is already an inherent inequality in groundwater accessibility due to skewed distribution (Sarkar 2011). With falling water tables and reduced well yields, users must pump water from greater depths, often using high capacity pumps, thus increasing the cost of extraction while making the resource out of reach for small and marginal farmers (Saleth 1996; Kulkarni *et al.* 2015). This, together with heterogeneous hydrogeological conditions, implies that resource endowment conditions are inequitable even within a typical village (Kulkarni and Thakkar 2012). The situation perpetuates with further scarcity, leading to unequal economic returns and finally taking the most exploitative form where the 'large landlords' emerge as 'water lords' through surplus accumulation forcing the small and marginal landholders to become landless agricultural labourers (Ballabh 2003; Sarkar 2011). This leads to water conflicts, which are becoming endemic at all levels in India in its various social, economic, and ecological dimensions (Joy *et al.* 2008). Studies in India have shown that the small landowners are also likely to go deeper and poach water from their neighbouring farmers by lowering the water table under their own lands (Foster and Rosenzweig 2008).

The pathways through which irrigation can impact poverty reduction are not only direct and indirect but are often also complex and diverse. Not all the poor are water-poor and not all water-poor are poor. The influence of water and agricultural activity on poverty is strongly dependent on the overall development trajectory within the basin[1] (Woolley *et al.* 2009; Cook *et al.* 2009). The effect of water stress on livelihoods, hence poverty, can be felt in a variety of ways (Cook and Gichuki 2009). A lack of consensus on the linkages between irrigation and poverty reduction is evident: studies based on macro data tend not to find significant links between investment in irrigation and poverty, while micro-data tends to establish a robust relationship between access to irrigation and poverty reduction (Gebregziabher *et al.* 2009).

Contrary to the long-prevalent consensus on Gisser-Sanchez effect (GSE) that states that benefits of optimally managed groundwater are insignificant, Koundouri (2004) found that groundwater management significantly increases welfare in many situations. An inverse relation between access to irrigation and poverty has been observed in India (Narayanamoorthy 2007; Sekhri 2014). Evidence from Sub-Saharan Africa shows that equitable distribution of income is critical for poverty reduction and that nationwide policy may inadvertently overlook high inequality at sub-regional and commune levels (Manero 2017). Participation in small-scale irrigation was found to reduce poverty by 50% among users relative to non-users in Northern Ethiopia (Zeweld *et al.* 2015). While irrigation for small landowning farmers is seen as an important vehicle to promote (especially rural) poverty alleviation, food security (at various scales, from local to global) and land and labour productivity, as well as rural employment and general economic development, adaptation to climate variability (Ngigi 2009 cited in Villoth 2013), the implications of spatially heterogeneous resource availability are important, too. Research also needs to focus on differential impact on various categories of farmers as farm size is a significant determinant of both groundwater-irrigated farm acreage and groundwater irrigation application rates per unit of land area; besides, spatial variability in groundwater use has important implications for policies to correct common property externalities and for welfare maximisation (Koundouri 2004; Saak and Perterson 2012).

On one hand groundwater use by millions of small landholders of developing countries has reduced poverty in the rural side (Shah 2005), on the other, its depletion and degradation have increased poverty (Janakrajan and Moench 2006). Studies have found a significant contribution of

[1] The Basin Focal Projects (BFP) of the CGIAR Challenge Programme on Water and Food conducted large number of studies in ten river basins, including the Indo-Ganges, in various countries to study these relationships.

groundwater irrigation in production[2] and productivity[3] (Grogan *et al.* 2015; Srivastava *et al.* 2014). However, the direct positive impacts hinge on the availability of other factors like availability of hydrogeological, institutional, technological, and policy frameworks (Koundouri and Xepapadeas 2004; Janakrajan and Moench 2006; Zeweld *et al.* 2015; Srivastava *et al.* 2014; Woolley *et al.* 2009). Therefore, this is an empirical issue that needs to be analysed in a specific context.

Further, the literature has focused more on the river basins in the Indo-Gangetic Plain; there is little analysis of the peninsular region. While the former covers 1.09 million km^2 of area, Godavari river basin covers 0.31 million km^2 of area forming 10 per cent of India's geographical area. Interestingly, despite the surface irrigation made available in these river basins, large share of irrigated land in all the basins depend on groundwater (Shah *et al.* 2009). In the arid and semi-arid regions, where livelihood is based on groundwater socio-ecologies (GwSEs), it is the demand-pull that leads to unsustainable extraction from relatively poor groundwater endowments (Shah 2005). There is a knowledge gap in how groundwater systems are exploited in the drier parts of South Asia and how they impact livelihoods (Bandyopadhyay 2007). The Basin Focal Projects of the CGIAR that analyse different basins indicate specific linkages (Cook *et al.* 2009; Woolley *et al.* 2009), which again point to the need for basin-wise studies on the nature of linkages.

Against this background, this study aims to contribute to understanding of the relationship between access to groundwater irrigation, agricultural development, poverty and inequality in a multi-crop farming system in a river basin with heterogeneous hydrogeological and resource availability conditions and its implications for the resource governance. Based on the user recall, we estimate groundwater use at farm level from irrigation hours for each crop and the type of pumps used for irrigation. We define access to groundwater irrigation as the farming households' ability to irrigate their crops, fully or partially, either from their own irrigation wells or through water markets or their social and kinship networks. Here, the focus on 'ability' is intended to include a wide range of social relationships that can constrain or enable people to benefit from resources without focusing on property relations alone (Ribot and Peluso 2004). Those who have been identified as having access to groundwater irrigation during the reference

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[2] Grogan *et al.* (2015) found, using hydrological model, that mined groundwater contributed to 15-27% of national total crop production in China during 1981-2000.

[3] Using panel data analysis from India, Srivastava *et al.* (2014) concluded that irrigation increased yields by 15% in cereals and 3% in oilseeds.

agricultural year 2012-13 are referred to as 'users' and others as 'non-users'.[4] As the past studies pointed out inequity in groundwater access by small and marginal farmers and those belonging to the marginalised communities (Shah 2009; Prakash 2005), we first confirmed whether their access had improved or not using our data. For analytical purposes, farmers have been categorized into two groups based on land size: small (less than 5 acres) and large (above 5 acres).

While small farmers among the users are found to use more water per acre for irrigation without commensurate economic productivity, the difference in economic productivity among large farmers was found to exist along with higher inequality. While poverty headcount ratios were high among the upper reach farmers, depth, and severity of poverty was more among the middle reach farmers who were becoming agricultural labourers. Improving access to groundwater irrigation and adopting measures to address problems associated with groundwater depletion are necessary to reduce the gap in economic productivity of small and large farmers as well as inequality and poverty in the study area.

The rest of the paper is divided into the following sections: Section 2 briefly describes the study area, data sources and analytical tools. Household income, inequality and poverty are analysed in Section 3. Groundwater access, utilisation and determinants are examined in Section 4.The final Section concludes with policy implications.

2. STUDY AREA, DATA AND METHODOLOGY

2.1. Study Area

The study sample is drawn from the Godavari river basin (Figure 1), which extends over 3,12,800 km^2 across the states of Maharashtra, Andhra Pradesh, Telangana, Chhattisgarh, Madhya Pradesh, Odisha, and small parts of Karnataka. Divided into 12 sub-basins by the Central Water Commission (CWC), the basin is characterised by high variability in the average annual rainfall—from 400 to 2500 mm; in the spatial distribution, nearly 15% of the basin area received less than 800 mm and another 12% received more than 1600 mm of rainfall during 1971-2005 (NRSC 2011). The estimated average water resource potential of the basin is 110.540 billion cubic meters (BCM) of which the utilisable surface water is 76.3 BCM and replenishable groundwater is about 40.65 BCM (CWC, 2011). Hydrogeologically, this

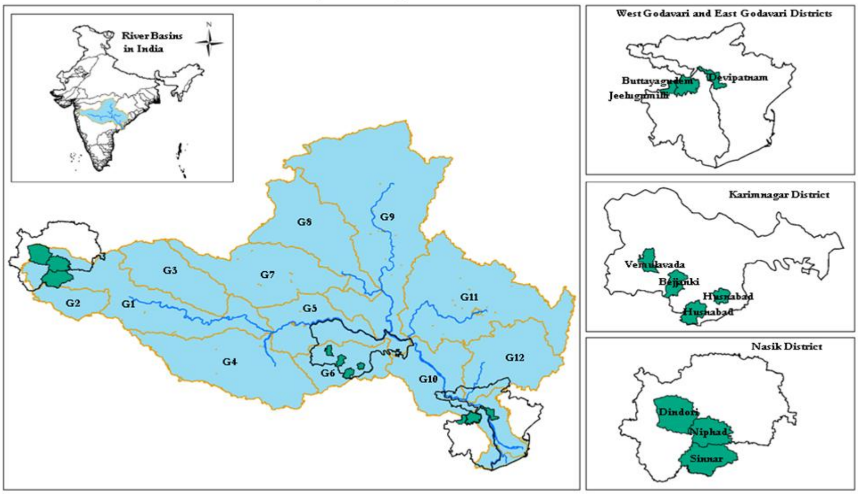
[4] Since farming is considered the major groundwater-based livelihood, landless who depend on other groundwater-based livelihood, if any, are not considered as 'users' in the study.

basin is predominantly under basalt (42.54%) and banded gneissic complex (17.38%) aquifer system. The upper reaches of the basin are mostly occupied by the Deccan Traps, the middle part is principally Archean granites and the Eastern Ghats dominate the lower part of the drainage basin and are formed mainly from the Khondalites (GoI 2011). The basin has agriculture (59.7%) and forests (30%) as major land uses. As much as 46% of the net irrigated area of the basin is irrigated by ground water sources, 37 % by canals, 11% by tank and the rest 6% by other sources (CWC 2011). Other socio-economic characteristics of the basin show that nearly 14.3% and 16.6% of the estimated population of 75.83 million belongs to the socio economically marginalised Scheduled Caste (SC) and Scheduled Tribe (ST) communities, respectively, according to the Census of India 2011. The basin is also characterised by severe district level rural poverty, ranging from 36% to 70% (Chaudhari and Gupta 2009; Mohanty *et al.* 2016). In the typology of Shah *et al.* (2003), the upper reaches are marked by rise in the use of ground water, while the middle reaches in the study area fall in the early symptoms of groundwater overexploitation.

Primary data collected from farming households in the Godavari river basin includes both users and non-users of groundwater. It covers Nashik, Karimnagar and West and East Godavari districts from Maharashtra, Telangana and Andhra Pradesh that belong to G1, G6, and G10 sub-basins or river systems corresponding to the upper, middle, and lower reaches (GoI 2013)· as most of the socio-economic information is available at administrative boundary level only (Figure 1). From each of these districts, three *mandals* or sub-districts were selected based on the stage of ground water development, viz. overexploited (>100%), critical (70-100%), and safe (<70%)[5]. In a similar manner, three to four villages were selected from each of these sub-districts and a survey was conducted to list out all groundwater user and non-user households for in-depth survey. The groundwater users and non-users were randomly selected from these villages in the ratio of 60:40 from the census list till a pre-decided sample size of 100 households from each *mandal* and 300 for each district was reached. However, for the lower reaches the sample had to be limited to 225. The final sample consisted of 825 households (494 users and 331 non-users) covering a total population of 10,064. The household surveys were carried out by trained investigators using structured questionnaires and administered to the head of the households. User and non-user weights

[5] The stage of groundwater development has been 58% in Nashik, 70% in Karimnagar and 25 and 45% respectively in East and West Godavari districts with considerable variations across *mandals* in 2011 (CGWB 2014).

Figure 1: Location Map of Study Areas in the Godavari Basin



Source: The figure is prepared based on the map given by CWC (2011)

were used in the calculation of averages. STATA and SPSS software were used for data analysis.

2.2. Methodology

To assess poverty and inequality in the region, we estimated total household income, comprising both agricultural and non-agricultural incomes. Crop and livestock were important components of household agricultural income. Net returns from agriculture was estimated by taking the difference between gross value of output produced and the total paid out costs of variable inputs for each crop separately and then aggregated for all crops for the household. Similarly, expenses incurred for the upkeep of animals were deducted from gross returns (asset value of livestock not included) to arrive at net returns from livestock. Non-agricultural incomes from salary, wage or self-employment for each member of the household, social security allowances, and remittances from migrated family members were included for the reference year of the study. In addition to these, sale of water for drinking and irrigation purposes was also found to be a source of income for some of the households. Total annual household income was used to estimate the monthly per capita income of the household.

Inequality in the distribution of land and incomes was measured using Gini coefficient for the users and non-users from small and large farmers both reach-wise and for the entire basin. The Gini coefficient measures the extent to which the distribution of wealth within a group deviates from a perfectly equal distribution, with values from 0 to 1 (Foster *et al.* 2013). Poverty was estimated using Foster Greer and Thorbecke (1984) measures such as the head count ratio, poverty gap and squared poverty gap.[6]

$$P\alpha = \frac{1}{N}\sum_{i=1}^{q}\left(\frac{(z - y_i)}{z}\right)^{\alpha} \qquad (1)$$

In the above equation α is a measure of the sensitivity of the index to poverty; the poverty line is z; the value of per capita monthly income for the i^{th} households is y_i ; and q is the number of people who were poor or below poverty line. When parameter $\alpha = 0$, P_0 is simply the head count index, when $\alpha=1$, the index is the poverty gap index P_1, and when $\alpha=2$, P_2 is the poverty severity index. This study measured poverty using all three measures of poverty separately for the users and non-users and by land size classes.[7] The study reference for the poverty line was Rs 860 per capita per month for the state of undivided Andhra Pradesh for middle and lower reaches and Rs 967 per capita per month for Maharashtra for the upper reaches, as per the erstwhile Planning Commission of India[8] for 2011-12 for identifying poor households (Planning Commission 2014).

We analysed the sampled households by size of landholding and examined their access to groundwater across different reaches using descriptive statistics. This was followed by an analysis of the determinants of sample households' access to ground water using a logit model as specified here.

$$Y = \frac{1}{1 + e^{-z}} \qquad (2)$$

where the dummy dependent variable Y represents whether farmers have access to groundwater or not and on the right hand side, Z is the linear combination of the explanatory variables X_1, X_2, X_3,….X_k; $Z=a+ b_1X_1+ b_2X_2+\ldots+ b_kX_k$; and a, b_1, b_2, b_3…b_k are the coefficients. The independent variables included those related to socio economic and demographic characteristics of the households such as family size, age, gender social

[6] While estimating poverty and inequality, we also faced problems due to negative net incomes. We adopted the 'equalisation' method in which individual income components with negative values were set to zero before computing the total income of each household (Sandoval and Urzua 2009).

[7] Sandoval and Urzua (2009) show that almost all poverty measures cannot cope with the possibility of some incomes being negative. While the problem is less relevant in the case of head count ratio, other measures could behave abnormally in extreme cases.

[8]The Planning Commission of India was replaced by NITI Aayog by the BJP-led NDA government in 2014.

category, farm size, occupation, and literacy status of the head of the household, whether they own livestock, whether household head owns the property right to land or not, have access to credit, knowledge of aquifer, rainfall in the region etc.

Water use was measured in terms of the quantity of water applied for each crop at various stages of crop growth and was estimated using the number of irrigation hours, type and horsepower of pump used, depth of the well etc. (Srivastava *et al.* 2015).[9] Crop-water productivity is defined as the ratio of crop yield or crop value, to groundwater applied in the process of growing a crop. If the same crop is grown in more than one cropping season, then all the seasons were taken into account. In this study, we mostly used average economic water productivity of crop which is defined for individual farmer household as:

$$WP_C = \sum_{c=i}^{N} \frac{YiPi}{WAi} \qquad (3)$$

Where WP_C represent he average economic water productivity of crops and C represents the crops from *i to N*. Y_i is the physical yield of crop *i,* and P_i is the price realized by the farmer household, while WA_i represents the water applied for crop *i* in cubic meter per acre.[10]

The determinants of water use and productivity are then estimated using log-linear model that was found to be suitable based on the distribution. The independent variables represent the socio-economic characteristics of farm households and other factors that may influence their water use (or productivity), which included land, crop and irrigation related factors as well as other factors (Table 1).

[9] It was assumed that one horsepower pump can pump 30 litres of water per second, and the efficiency of pump was taken as 83.5 %. Based on this assumption, we first estimated the water pumped in litres per second for a pump of a certain horsepower from a certain depth at the above efficiency. This was converted to cubic meter per hour depending on the irrigation hours.

[10] We are not estimating marginal productivity of water and therefore not addressing the question of optimality.

Table 1: Description of Variables Included in the Regression Models (N=825)					
Variable	Definition	Mean	Std. Dev	Min	Max
User_nonuser	1 if farmer household (HH) is user, else ‘0’	0.61	0.49	0	1
Age_hh	Age of the HH head (years)	49.11	12.84	20	90
SC	‘1’ if household belong to Schedule Caste and Schedule Tribe, else ‘0’	0.29	0.46	0	1
Gender	‘1’ if gender of the head of the HH is male, else ‘0’	0.93	0.26	0	1
Fam size	Number of family members	4.63	1.98	1	16
Illiterate	‘1’ if HH head is illiterate, else ‘0’	0.33	0.47	0	1
Land_size_class	‘1’ if HH is a small farmer, else ‘0’	0.55	0.49	0	1
Livestock_owned	‘1’ if HH has livestock assets; else ‘0’	0.65	0.48	0	1
No_plots	Number of plots owned by HH	1.45	0.79	0	6
No_crops	No. of crops cultivated by HH	1.69	0.82	0	5
Occupation	‘1’ if main occupation of HH head is own farm agriculture; else ‘0’	0.82	0.38	0	1
Mobile_ph	‘1’ if HH has mobile, else ‘0’	0.88	0.33	0	1
Credit	‘1’ if HH has access to credit, else ‘0’	0.74	0.44	0	1
Aquifer	‘1’ if HH has knowledge of aquifer, else ‘0’	0.52	0.49	0	1
Depth_well	Depth of open or bore well in metres	25	35	0	201
Dripsprinkler	‘1’ if HH use drip or sprinkler or drip irrigation, else ‘0’	0.07	0.26	0	1
Energy_cost	Annual energy (diesel/electricity) cost in Rupees	1987	5304	0	63600
Water use per acre	Amount of water used for irrigation in cubic meters per acre	2379	5375	0	73671
Water productivity per acre	Water productivity in Rupee per cubic meter of water used	83	921	0	23900
Dis_out_mkt	Distance to nearest output market in kms	16.49	8.13	1	35
Hi_value_crops	‘1’ if HH cultivate high value crops, else ‘0’	0.52	0.49	0	1
Property right	‘1’ if farmland is in the name of head of HH, ‘0’ otherwise	0.75	0.43	0	1
Rainfall	Rainfall in millimetres per year	566	122	431	795
Source_borewell	‘1’ if the main source of irrigation is borewell, else ‘0’	0.31	0.4[illegible]	0	1
Water mkts	‘1’ if HH participates in water markets, else ‘0’	0.08	0.2[illegible]	0	1
Source: Field Surveys					

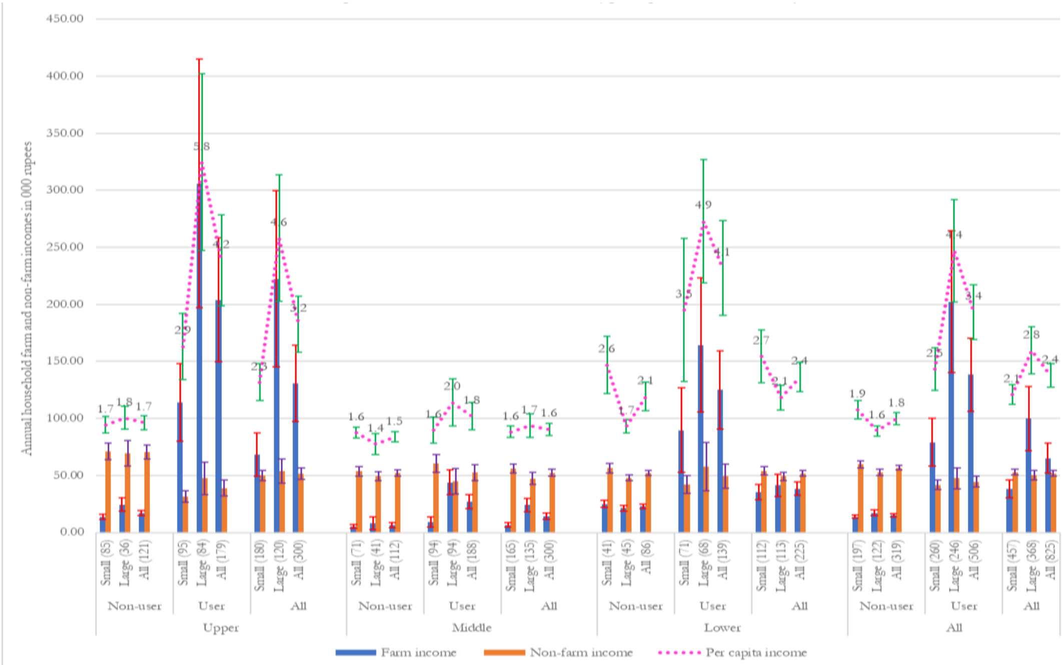
3. INEQUALITY AND POVERTY IN THE RIVER BASIN

The households' average annual and monthly per capita incomes show wide variations in the share of agricultural and non-agricultural incomes in relation to the relative abundance or scarcity of groundwater resources and its access across the reaches (Figure 2). Higher average annual and per capita incomes as well as higher share of agricultural incomes have been observed among all users in the upper reaches and among large farmers with access to groundwater across other reaches. While the average annual household income for non-users was less than one lakh rupees, it was over two lakh rupees for users in the basin. Though the average incomes of non-user small and large farmers did not differ considerably, the same was not true in the case of users where the incomes of large farmers were much higher than that of small farmers. Statistically, the users in all the reaches of the river earned higher farm income as well as total household and per capita income vis-à-vis those who did not have access to ground water. The large farmers among the users also had significantly higher household and per capita income by virtue of better farm earnings.

The upper reaches reported the highest average annual farm household income for groundwater users small (Rs 1.64 lakhs) and large (Rs 4.15 lakhs). Around 70% of their total income came from agricultural sources. However, farm household income for the non-users was very low along with low share of agricultural income in total income for both small (25%) and large (38%) farmers. Interestingly, middle reaches reported the lowest levels of average annual household as well as per capita incomes for all, including large farmers for whom share of non-agricultural income in total income was over 40%. This part of the river basin is in the fourth stage of groundwater socio-ecologies (GwSE) with agrarian distress.[11] This naturally increases the cost of water extraction as well as borewell failures, as was found by Narayanamoorthy (2015). In our sample, about 20% of the households in the middle reaches reported well failure as compared to 9% and 5% respectively in the upper and lower reaches. However, considerable difference in the average incomes between users and non-users and between small and large farmers was observed in the lower reaches, where the users had about 75% of their income from agricultural sources and non-users had just 35% share from agricultural sources as they were not able to cultivate high value crops like tobacco.

[11] Shah *et al.* (2003) explained the stages of groundwater socio-ecologies in four different stages.

Figure 2: Average Annual Household Income and Monthly Per Capita Income in the Study Area



Source: Field surveys
Note: I indicates standard errors

When all farmers are considered, the income inequality was found to be higher than the inequality in farm size in general among farmers in the upper reaches. Similar observation was also made in the case of users as compared to non-users across all reaches. While the inequality in the farm size averaged around 40%, per capita income inequality was 54% (Table 2). Contrary to what was observed in the study by Foster and Rosenzweig (2008), farm-size inequality was associated with higher income inequality in the Godavari river basin, perhaps due to the differences in the economic productivity of water, which we discuss in the latter section of this paper. The Gini coefficients of small and large farmers within the user and non-user subgroups were at comparable levels except for per capita income of large farmers among the users in the upper reaches who had higher levels of inequality as compared to others. This could also be due to the difference in the age of grapevines grown by large farmers, some of which may not have started giving yields. The overall inequality of the users and non-users in the middle and lower reaches was comparable, though there were differences between the small and large farmers in both cases.

Coming to the poverty levels, the estimated head count ratio shows higher levels of poverty in the upper reaches (33%), followed by middle (25%) and lower reaches (7%) with discernible difference across the user and non-user groups and farm size wise. These figures are comparable with district level poverty estimates based on NSSO data by (Mohanty *et al.* 2016). The head count ratio was relatively high for small farmers in the upper reaches followed by the large farmers in the middle reaches among both the users and non-users. The upper and middle reaches with the highest levels of poverty had the contrasting characteristics with respect to groundwater availability and access. While the availability of groundwater was better in the upper reaches, the status of groundwater has been far from being safe in most parts of the middle reaches rendering them to seek non-agricultural activities, mostly wage labour as their supplementary source of income. Moreover, the poverty gap index and squared poverty gap shows that poverty is both deeper and severe in the middle reaches as compared to the other two reaches.

Interestingly, poverty is more severe among the users in the middle reaches, where farm households depend on agriculture as their major source of income. From the estimates of poverty gap index, it was seen that while 14% of the poverty line amount is required to take the poor out of poverty, for large farmers among the users in the middle and upper reaches it was over 26% and 22%, respectively. Depth of poverty was also found to be very high among the large user farmers in the middle reaches. On the other hand, poverty levels were found to be very low in the lower reaches.

Table 2: Inequality in the Distribution of Land and Income (Gini Coefficients)

Reach of river	User/ Non-user	Category of farmer	Gini coefficient (in percentage)		Poverty measures (in percentage)		
			Land	Per capita Income	Head count ratio	Poverty gap index	Squared poverty gap index
Upper	Non-user	Small (85)	19	36	35.3	10.1	3.9
		Large (36)	22	34	27.8	12.2	6.8
		All (121)	34	35	33.1	10.7	4.8
	User	Small (95)	20	56	36.8	22.6	17.1
		Large (84)	29	70	28.6	18.1	14.7
		All (179)	42	65	33	20.5	16
	All	Small (180)	39	63	36.1	16.7	10.9
		Large (120)	39	71	28.3	16.3	12.3
		All (300)	39	65	33	16.5	11.5
Middle	Non-user	Small (71)	21	30	23.9	8.5	5.7
		Large (41)	18	38	29.3	20.1	33.8
		All (112)	35	33	25.9	12.8	16
	User	Small (94)	24	34	21.3	18	35.5
		Large (94)	24	45	28.7	26.3	35.6
		All (188)	40	40	25	22.1	35.6
	All	Small (165)	25	37	22.4	13.9	22.7
		Large (135)	25	44	28.9	24.4	35
		All (300)	40	42	25.3	18.6	28.3
Lower	Non-user	Small (41)	18	40	2.4	1	0.4
		Large (45)	16	26	17.8	7.9	9.6
		All (86)	29	36	10.5	4.6	5.2
	User	Small (71)	25	46	5.6	6.9	21.2
		Large (68)	24	49	4.4	2.7	1.8
		All (139)	40	44	5	4.9	11.7
	All	Small (112)	25	46	4.5	4.8	13.6
		Large (113)	24	39	9.7	4.8	4.9
		All (225)	40	44	7.1	4.8	9.2
All	Non-user	Small (197)	43	35.5	24.4	7.6	3.8
		Large (122)	40	35.3	24.6	13.3	16.9
		All (319)	41	35.5	24.5	9.8	8.8
	User	Small (260)	32	57.6	22.7	16.7	24.9
		Large (246)	37	57.4	22	17	19.1
		All (506)	34	57.6	22.3	16.8	22.1
	All	Small (457)	39	54	23.4	12.8	15.8
		Large (368)	39	54	22.8	15.7	18.4
		All (825)	39	54	23.2	14.1	17

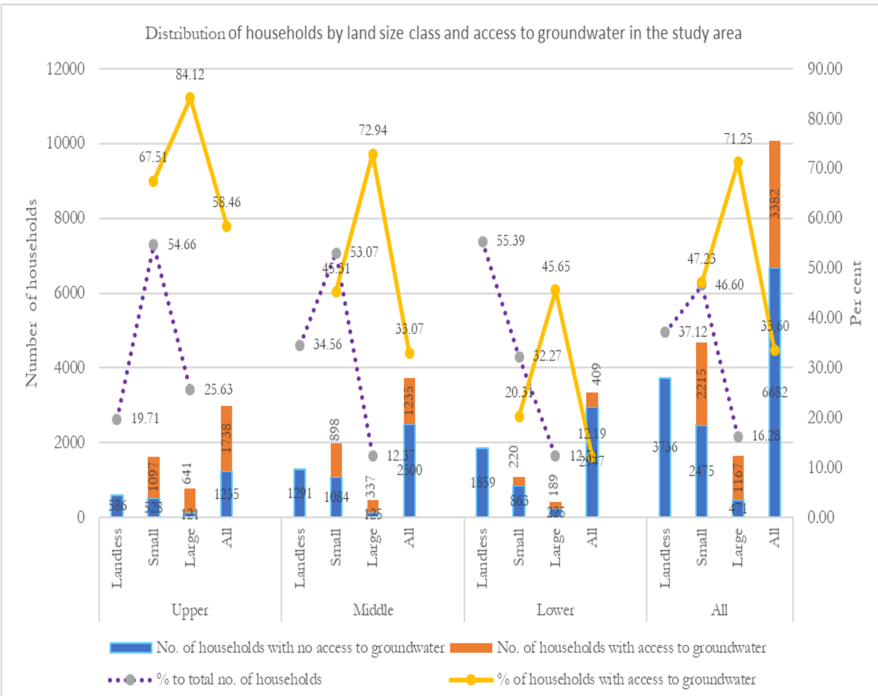
Source: Field Survey
Note: Figures in the parentheses are respective sample sizes.

4. GROUNDWATER ACCESS, UTILIZATION AND DETERMINANTS

4.1. Water use Profile of Farmers in Selected Villages

We will have a look at the groundwater access from the census of the selected villages before turning to the detailed analysis of the sampled households. Among the 10,064 households enumerated in the census survey, 37% were landless, 47%smallandthe rest large farmers (Figure 3).

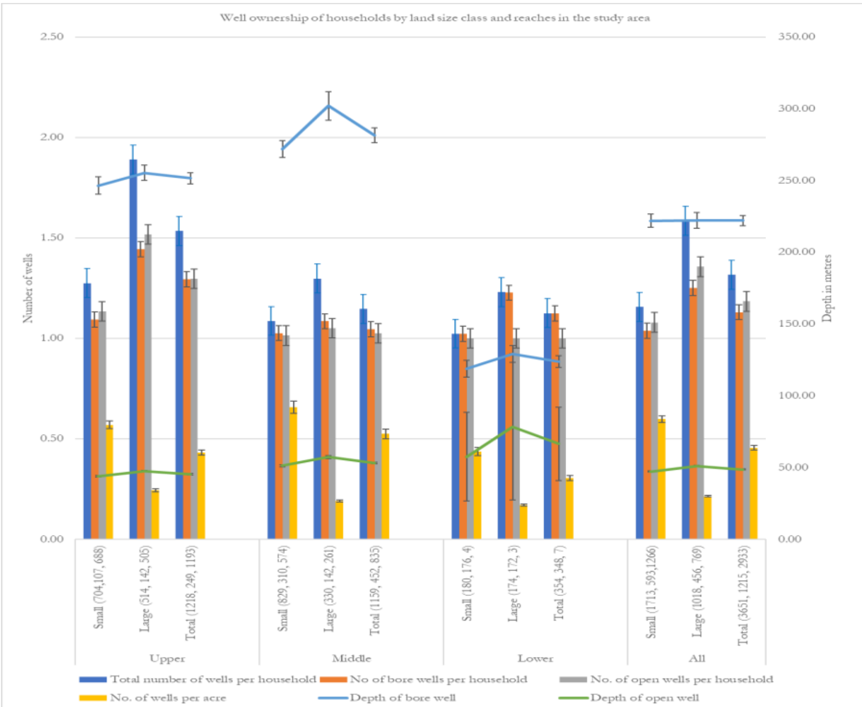
Figure 3: Distribution of Households by Land Size-class and Access to Groundwater in Godavari River Basin



Source: Census survey of field surveys
Note: I indicates standard errors

Landlessness ranged from 20% in the upper reaches to as high as 55% in the lower reaches. Even when access to groundwater was primarily tied to land ownership in India, only 34% of the surveyed land-owning farmers reported access to it with considerable heterogeneity across reaches and categories of farm sizes. While the large farmers reported better access, ranging from 46% to 84% from the lower to upper reaches, small farmers in the lower reaches (20%) and middle reaches (45%) had relatively poor access to groundwater.

Figure 4: Well Ownership in the Study Area by Land Size-class in Godavari River Basin



Source: Field surveys

Note: 1. I indicates standard errors

2. Figures in the brackets represents the following:

First: Number of households reporting total number of wells and no. of wells per acre;

Second: Number of households reporting bore well and its depth;

Third: Number of households reporting open well and its depth.

4.2. Land and Well Ownership

The sampled households on an average owned 4.68 acres of land and 1.3 wells (bore plus open wells) in the Godavari river basin. In other words, there existed one well for approximately every three and half acres of land. Surprisingly, each well serviced 2.236 acres in case of small farmers, while the same was 6.12 acres for large farmers. Across all reaches, it was seen that the average number of bore wells, open wells and both put together were higher among large farmers as compared to small farmers (Figure 4).

A t-test confirmed that these differences were statistically significant at one per cent level of significance, except in the case of open wells in the lower reaches. The average depth of bore wells was found to be around 220 m, whereas it was around 48 m for open wells in the study area. The depth of open wells was more for the large farmers in the upper and middle reaches, whereas the depth of bore wells was more only for the large farmers in the middle reaches where groundwater scarcity was found to be more severe. These differences were statistically significant. It was also seen that about 15%of all non-users in the study area attempted digging wells at some point of time, and encountered problems of well failure.

More than 80% of such well failures were reported from the middle reaches at an average depth of 200 m or so for bore wells. Almost 60 % of those who reported well failures were small farmers. This implied that as water levels go down, it was mostly the large farmers who are able to construct deeper wells and extract groundwater. In other words, the larger the land area owned, greater was the possibility of striking groundwater and that the heterogeneity in access to groundwater irrigation observed in some of the earlier studies (Shah 2009; Prakash 2005; Janakarajan and Moench 2006) exists even today. While the analysis of census data using descriptive statistics seem to show that the large farmers are better placed than small farmers in terms of their access to groundwater and ownership of wells, it was not clear what factors determined a household's access to groundwater.

4.3. Determinants of Access to Groundwater

An analysis of the sample survey data using the earlier specified logit model shows that access to groundwater is determined by a host of social, economic, climatic and hydrogeological factors along with the households' access to information and communication technologies (Table 3). Interestingly, farm size per se was not a significant variable in determining the access, but the access was conditioned by the factors like sources of non-farm income, credit facility, education, and social and caste hierarchy with better access among the forward communities. Households belonging to scheduled castes and scheduled tribes and illiterate household heads were less likely to have access to groundwater as compared to others. The number of individual plots owned by the households was a significant factor influencing access across all reaches. This could be due to the possibility that the households owning a greater number of plots might be owning them in diverse local hydrogeological conditions and groundwater endowment thus increasing the prospects of striking water when a well is dug. The coefficient and marginal effects of the variable for awareness of

Table 3: Determinants of Access to Groundwater in Godavari River Basin

	Upper reaches (N=300)		Middle reaches (N=300)		Lower reaches (N=225)		All (N=825)	
Variable	Co-eff	Marginal	Co-eff	Marginal	Co-eff	Marginal	Co-eff	Marginal
Constant	-5.757** (-1.839)	-	-3.168** (-1.232)	-	-0.41 (-2.04)	-	-4.10 (-0.82)	-
Fam_ size	0.083 (-0.079)	0.193 (-0.018)	0.174* (-0.096)	0.038* (-0.021)	0.008 (-0.110)	0.002 (-0.025)	0.078** (-0.046)	0.180** (-0.011)
Occupa-tion	-0.612 (-0.477)	-0.134 (-0.097)	0.501 (-0.352)	0.113 (-0.082)	1.741*** (-0.636)	.409*** (-0.129)	0.332 (-0.212)	0.079 (-0.051)
Illiterate	-0.468 (-0.430)	-0.112 (-0.105)	-0.363 (-0.301)	-0.080 (-0.067)	-0.563 (-0.373)	-0.129 (-0.086)	-0.414** (-0.191)	-0.097** (-0.045)
SC	-1.625*** (-0.457)	-0.384*** (-0.099)	-0.687** (-0.322)	-0.156** (-0.075)	-1.797*** (-0.538)	-0.343*** (-0.078)	-0.898*** (-0.185)	-0.21*** (-0.043)
Age_hh	-0.002 (-0.015)	-0.001 (-0.004)	0.003 (-0.012)	0.001 (-0.003)	0.020 (-0.015)	0.005 (-0.003)	0.009 (-0.007)	0.002 (-0.002)
Gender	0.682 (-0.728)	0.167 (-0.181)	0.394 (-0.599)	0.090 (-0.143)	-0.523 (-0.573)	-0.110 (-0.109)	-0.058 (-0.325)	-0.013 (-0.074)
Land_size _class	0.018 (-0.326)	0.004 (-0.076)	0.251 (-0.314)	0.546 (-0.069)	0.714** (-0.359)	0.169** (-0.079)	0.105 (-0.172)	0.024 (-0.040)
No_plots	.431* (.257)	.100* (.059)	1.413*** (.313)	.306*** (.062)	.344 (.197)	.0778546* (.04431)	.530*** (.125)	.122*** (.028)
Property right	0.397 (-0.453)	0.095 (-0.111)	-0.047 (-0.337)	-0.010 (-0.072)	0.180 (-0.378)	0.041 (-0.086)	-0.038 (-0.198)	-0.009 (-0.045)
Aquifer	1.326*** (-0.439)	0.264*** (-0.071)	-0.406 (-0.309)	-0.856 (-0.063)	0.328 (-0.412)	0.076 (-0.097)	0.284 (-0.179)	0.065 (-0.041)
Rainfall	0.004** (-0.002)	0.001** (0.000)	-	-	-0.002 (-0.002)	-0.001 (0.000)	0.002*** (-0.001)	0.001*** (0.000)
Livestock owned	2.124*** (-0.359)	0.486*** (-0.070)	0.64** (-0.310)	0.142** (-0.070)	0.291 (-0.349)	0.066 (-0.080)	0.851*** (-0.170)	0.200*** (-0.040)
Credit	1.314*** (-0.304)	0.298*** (-0.065)	-0.814* (-0.480)	-0.153** (-0.076)	0.133 (-0.447)	0.031 (-0.104)	0.779*** (-0.185)	0.186*** (-0.045)
Mobile ph	0.924 (-0.744)	0.226 (-0.180)	1.169*** (-0.456)	0.278*** (-0.110)	0.812** (-0.407)	.192** (-0.091)	1.076*** (-0.255)	0.261*** (-0.061)
	LR chi2 120.42; Prob > chi2=0.000 Pseudo R =.298 Probability (user) 0.631		LR chi2 79.43; Prob > chi2=0.000 Pseudo R.200 Probability (user) 0.683		LR chi2 61.16; Prob > chi2=0.000 Pseudo R 0.204 Probability (user) 0.655		LR chi2 =170.930; Prob > chi2=0.000 Pseudo R 0.155 Probability (user) 0.639	

Source: Estimated from the field survey data

Notes:

1. Figures in the parenthesis are standard errors; ***, ** and * are significance levels at 1%, 5% and 10% respectively.
2. Co-eff indicates co-efficient; Marginal indicates Marginal effects.

the type of aquifer and rainfall were found to be positive and significant in the upper reaches. Rainfall was found to be a determinant of access in the upper reaches as well as in the entire basin. While access to credit was found to influence access to groundwater positively in the upper reaches as well as when all the reaches were taken together, it showed an unexpected negative relation in the middle reaches. It was noted that the highest groundwater usage in the Godavari river basin was recorded in the middle reaches. The access to mobile phones, which might be helping households to reach out to different sources of information and other support services like technical and credit services, was also found to be a significant factor in determining the household access to groundwater in the study area except in the upper reaches.

4.4. Water use, Productivity and Determinants:

The average groundwater consumption per acre of farm was the lowest in the upper reaches of the river basin with the highest economic water productivity (Figure 5).

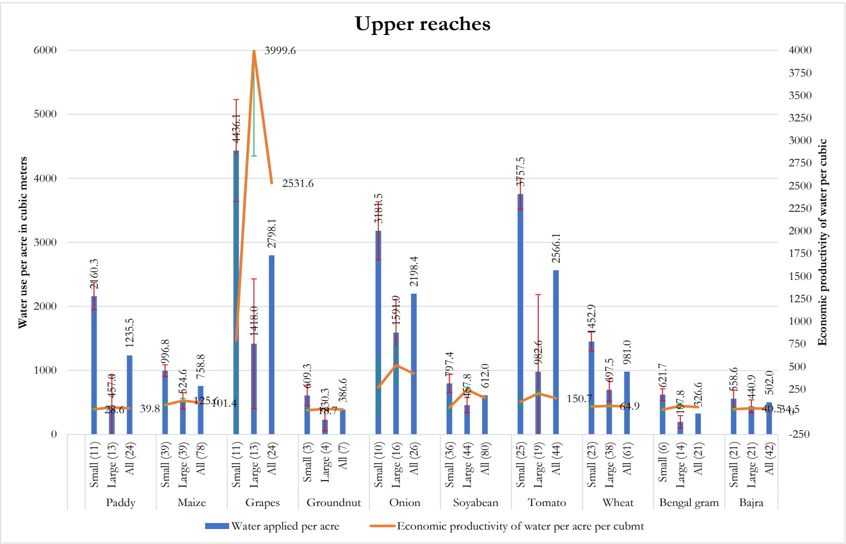
It is worth mentioning here that grapes, onion, soybean, maize, wheat, and tomato are cultivated in the upper reaches, while paddy, cotton, maize are the mainstay in both middle and lower reaches. Tobacco was the major crop for the users in the lower reaches and cotton for the non-users.[12] Owing to water intensive crops, the highest per acre water usage was found in the middle reaches followed by the lower reaches. Overall, the water usage by the small farmers was found to be significantly higher without significant difference in productivity.

Before analysing the results of econometric models on the determinants, we present the descriptive statistics of the variables. The farm households on average had 4.82 members per family. The average age of the head of the household was 49 years (Table 1). The average farm size per household was 4.68 acres that utilised 2379 cubic meters of water per acre. The average rainfall was 566mm. The depth of average well was 25m (201 m-maximum). A household on an average incurred an amount of Rs 1987 per year as cost of energy for irrigation. The sample households cultivated two crops on average, and they had to trudge 17km to reach the nearest market for selling their agricultural produce. The formulation of several binary variables is explained in the table.

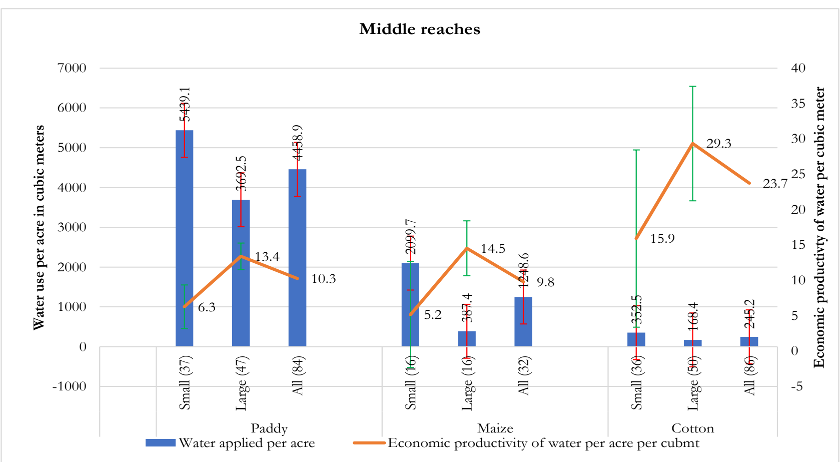
[12] Crop-wise water use calculated was comparable to those of Srivastava *et al.* (2015) with minor variations.

Figure 5: Water use and Economic Productivity of Groundwater for Irrigation in Godavari River Basin

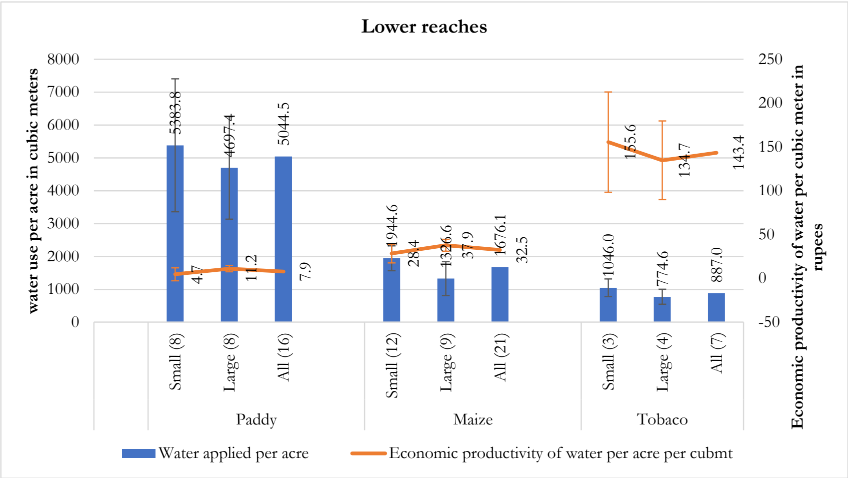
(a) Upper Reaches



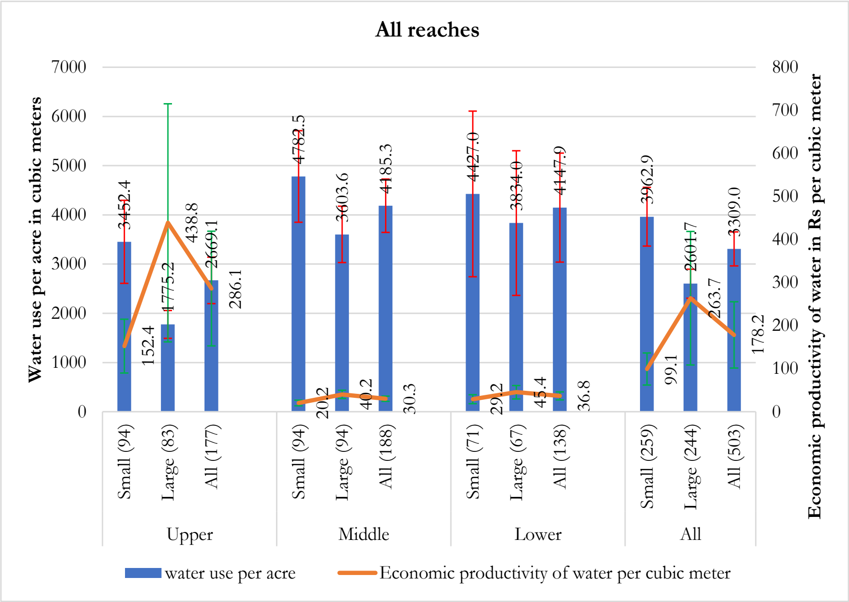
(b) Middle Reaches



(c) Lower Reaches



(d) All Reaches



Source: Field surveys
Note: I indicates standard errors

Using the regression model specified earlier, the determinants of water use and productivity showed that farm size was inversely related with water use per acre and directly with economic productivity of water in the sample as a whole and also in all the reaches of the river basin (Table 4). In other words, large farmers apply significantly lesser amount of water per acre and attain higher levels of economic productivity as compared to small farmers. This was a very important result to observe when we consider the fact that majority of the farms in India are small and marginal. The sign and significance of the coefficient of the variable for number of crops cultivated indicates that while addition of crops results in additional water usage, it

Table 4: Determinants of Per Acre Water Use and Productivity in the Study Area (contd.)

	Upper reaches (N=172)		Middle reaches (N=170)	
Variable	Water use	Water productivity	Water use	Water productivity
Constant	7.146*** (0.909)	1.679* (0.966)	7.270*** (0.628)	2.368*** (0.649)
Fam_ size	0.005 (0.043)	-0.026 (0.045)	-0.044 (0.047)	0.020 (0.049)
Occupation	-0.248 (0.277)	0.022 (0.294)	-0.266 (0.253)	0.397 (0.262)
Illiterate	0.073 (0.261)	-0.049 (0.277)	0.108 (0.183)	0.049 (0.190)
SC	0.166 (0.345)	-0.573 (0.367)	0.155 (0.208)	-0.273 (0.215)
Age_hh	-0.016* (0.009)	0.020** (0.010)	-0.009 (0.007)	0.001 (0.007)
Gender	-		-	-
Land_size_class	0.628*** (0.204)	-0.660*** (0.216)	0.196 (0.177)	-0.325* (0.183)
No_plots	0.006 (0.117)	-0.105 (0.124)	0.118 (0.097)	-0.140 (0.100)
Rainfall	0.000 (0.001)	0.001 (0.001)	-	-
Livestockowned	-0.222 (0.265)	0.198 (0.282)	-0.102 (0.208)	0.0451 (0.215)
Credit	0.235 (0.188)	-0.061 (0.199)	-0.487** (0.250)	0.423* (0.262)
Water_mkts	0.472 (0.393)	-0.231 (0.418)	-0.326 (0.345)	0.326 (0.356)
No_crops	0.609*** (0.102)	-0.190* (0.108)	1.170*** (0.163)	-0.803*** (0.169)
Drip sprinkler	0.380 (0.324)	0.268 (0.344)	-	-
Source_borewell	0.563 (0.322)	-1.155*** (0.342)	0.397** (0.199)	-0.325 (0.206)
Energy_ cost	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)
Depth_ well	-0.030*** (0.004)	0.035*** (0.005)	-0.014*** (0.002)	0.013*** (0.002)
Dis_out_mkt	-0.008 (0.010)	-0.023** (0.011)	0.014 (0.011)	0.000 (0.011)
Hi_value_crops	0.083 (0.248)	0.845*** (0.264)	-0.572 (0.223)**	1.048*** (0.231)
	F (18, 153) = 9.42 Prob>F = 0.000 Adj R^2 = 0.470	F(18, 153) = 10.46 Prob>F = 0.000 Adj R^2 = 0.499	F(16,153)=7.62 Prob>F = 0.000 Adj R^2 = 0.385	F(16,153)=6.81 Prob>F = 0.000 Adj R^2 = 0.355

Table 4: Determinants of Per Acre Water Use and Productivity in the Study Area (from pre-page)

	Lower reaches (N=127)		All (N=469)	
Variable	Water use	Water productivity	Water use	Water productivity
Constant	7.895*** (0.930)	2.396** (1.061)	6.975*** (0.518)	1.739*** (0.559)
Fam_ size	-0.002 (0.043)	-0.011 (0.049)	-074*** (0.028)	0.054* (0.030)
Occupation	-	-	-0.113 (0.164)	0.058 (0.177)
Illiterate	0.299* (0.160)	-0.220 (0.182)	0.347*** (0.130)	-0.260* (0.141)
SC	-0.099 (0.167)	-0.163 (0.190)	0.146 (0.128)	-0.253* (0.138)
Age_hh	-0.002 (0.006)	0.008 (0.006)	-0.013*** (0.005)	0.013** (0.005)
Gender	0.240 (0.231)	-0.140 (0.263)	0.033 (0.236)	-0.150 (0.254)
Land_size_class	0.516*** (0.139)	-0.605*** (0.158)	0.377*** 0.114)	-0.441*** (0.123)
No_plots	0.084 (0.072)	-0.261*** (0.082)	0.152** (0.062)	-0.280*** (0.067)
Rainfall	-0.004*** (0.002)	0.004*** (0.002)	0.001 (0.001)	0.002*** (0.001)
Livestockowned	0.016 (0.144)	0.065 (0.164)	-0.113 (0.131)	-0.032 (0.141)
Credit	-0.353* (0.211)	0.261 (0.241)	0.231* (0.135)	-0.083 (0.145)
Water_mkts	-0.276* (0.171)	0.364* (0.195)	0.089 (0.184)	0.106 (0.199)
No_crops	1.093* (0.124)	-0.804*** (0.141)	0.609*** (0.070)	-0.280*** (0.075)
Drip sprinkler	.0191 (0.232)	-0.093 (0.265)	0.186 (0.184)	0.181 (0.198)
Source_borewell	0.334 (0.251)	-0.186 (0.286)	0.371*** (0.137)	-0.338** (0.148)
Energy_ cost	0.000 (0.000)	0.000 (0.000)	-0.000*** (0.000)	0.000*** (0.000)
Depth_ well	-0.035*** (0.005)	0.038*** (0.006)	-0.019*** (0.001)	0.0186*** (0.002)
Dis_out_mkt	0.095** (0.030)	-0.115*** (0.034)	-0.002 (0.007)	-0.009 (0.007)
Hi_value_crops	-0.404 (0.172)	0.873*** (0.197)	0.109 (0.123)	0.623*** (.0133)
	F(18,108)=12.87 Prob>F = 0.000 Adj R^2 = 0.629	F(18,108)=11.97 Prob>F = 0.000 Adj R^2 = 0.611	F(19,449)= 15.14 Prob>F = 0.000 AdjR^2 =0.365	F(19,449)=14.55 Prob>F = 0.000 Adj R^2 = 0.355

Source: Estimated from the field survey data
Note: Figures in the parenthesis are standard errors; ***, ** and * are significance levels at 1%, 5% and 10% respectively

results in decline of productivity. This finding was consistent across all reaches of the basin. It implies that specialization might help in reducing water usage per acre and increasing economic productivity of water.

The economic productivity of those who cultivated high value crops including vegetables and fruits was found to be better in all reaches. Access to borewell and subsidized power for water lifting devices encouraged elevated water use with lower productivity. In other words, higher the user cost of power, lower the water use and better utilization. Participation in water markets did not impact water use or water productivity in the sample. The coefficient for water productivity for modern irrigation technologies was insignificant. This could possibly be because these technologies are used mostly in the upper reaches for grape gardens and many of them are still in the vegetative phase. The difficulty in accessing the markets in the lower reaches of the river basin seems to have resulted in higher water usage and lower water productivity. The vibrant water markets in the lower reaches resulted in lower water use with higher economic productivity.

As expected, those with deeper wells in all the reaches of the river basin used less water and achieved higher productivity. As water extraction from deeper depths becomes more difficult, the users tend to extract less and use it better. In other words, the scarcity of the resource might be driving them to efficient resource utilisation and better returns.

5. CONCLUSIONS AND POLICY IMPLICATIONS

This study examined the access to groundwater for irrigation and its impact on agriculture, poverty, and inequality against the backdrop of heterogeneous conditions of groundwater availability in the Godavari basin and its implications for resource governance. It uses data collected from 825 farm households that included 494 groundwater users in the upper, middle and lower reaches of the basin. Data was analysed using various statistical and econometric methods that yielded important results at both aggregate (basin level) and disaggregate levels. At the aggregate level, large farmers were found to have better access to groundwater vis-à-vis small farmers. Households with access to groundwater earned higher household and per capita income compared to those without access. However, reaches-wise disaggregate level analysis, including those done separately for farm size as well as user-non-user categories, shows that in addition to access to groundwater, the amount of value that the farmers tend to generate out of groundwater irrigation is an important factor in determining household income or poverty levels. It may be noted that farmers with access to groundwater expectedly had a higher share of agricultural income to total income but also had higher levels of inequality. The poverty headcount ratios were at higher levels in the upper reaches, which had better groundwater access and availability conditions. However, the poverty levels were both severe and deeper in the middle reaches where groundwater scarcity conditions were more widespread as compared to others. The experience of the middle reaches also shows that as depletion or scarcity of groundwater increases, it is mostly the large farmers who tend to reap better productivity. The small farmers drift towards non-agricultural sources of income including wage labour that can be termed distress-driven diversification.

A detailed analysis of the determinants of access to groundwater showed that access was determined by a host of social, economic, climatic and hydrogeological factors along with households' access to information and communication technologies. Even though farm size *per se* was not found to be a significant variable in determining access, it was a significant variable in determining per acre groundwater usage as well as economic productivity of water. Basin level analysis showed that farm size was inversely related to water use per acre and directly related to economic productivity. The higher per acre usage of water by small farms without commensurate economic productivity was perhaps a major concern for a country like India where majority of farms are small and marginal. Reaches-wise disaggregate level analysis pointed to the lowest groundwater usage per acre by the farmers in the upper reaches with the highest levels of economic productivity in contrast to the middle reaches with high per acre water usage irrespective of farm size and low levels of economic productivity of water. These differences could be due to the choices of crops adopted by farmers, including the number and types of crops grown. The upper reaches were characterized by a diverse variety of crops, which include high-value and less water consuming crops in contrast to the high-water consuming, less diverse and low-value crops in the middle reaches. It was observed that in the upper reaches mere addition of a number of crops led to higher per acre water usage and a decline in economic productivity, thus pointing towards the need for crop specialization to reduce per acre water usage to spur economic productivity of water. While ownership of borewells had a differential impact on water use and productivity across reaches, the depth of borewells, an indicator of groundwater depletion, was found to be significant in determining water use and productivity. Farmers seem to adopt measures to economize water use and improvements in productivity when they face actual scarcity situation rather than when they just foresee it happening. The case of lower reaches showed that difficulty in accessing output markets often resulted in higher water usage and lower water productivity, whereas vibrant water markets tend to help in reducing water use and increasing economic productivity of water.

To sum up, this study attempted to throw some light on the complex and diverse relationship between groundwater irrigation, agriculture, poverty and inequality under heterogeneous conditions of groundwater availability in the Godavari river basin. Understanding and incorporating them in policy are of paramount importance not only for the conservation of groundwater resources but also to reduce the gap in economic productivity of water and reduction of poverty and inequality across different size classes of farmers in the study region. While the overall policy should be directed towards more equitable access to groundwater resources, measures to economise groundwater use per farm acre as well as improvement in economic productivity across regions and size classes of farmers, considering regional specificities, are equally important. Otherwise, situations like middle reaches will be more widespread, and as Manero (2017) points out, national policy may inadvertently overlook the complex relationship of agriculture, water use, economic farm productivity, and poverty, which is critical for the reduction of poverty and inequality and for the promotion of agricultural growth and development at the sub-regional levels.

ACKNOWLEDGEMENTS

This study was funded by Jamsetji Tata Trust through erstwhile Research Unit for Livelihoods and Natural Resources (RULNR) of the Centre for Economic and Social Studies, Hyderabad. The suggestions by the two anonymous reviewers of the journal helped in improving the analysis, and the authors sincerely thank them. The authors are also grateful to Himanshu Kulkarni for his inputs on hygrogeological data for the selection of field sites. The assistance by V Srinivas is gratefully acknowledged. The authors alone are responsible for any errors in the paper.

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