International Journal of the Commons

Bahinipati, C. S., & Viswanathan, P. K. (2019). Can Micro-Irrigation Technologies Resolve India's Groundwater Crisis? Reflections from Dark-Regions in Gujarat. *International Journal of the Commons*, 13(2), pp. 848–858. DOI: https://doi.org/10.5334/ijc.888

AGRICULTURAL AND NATURAL RESOURCES ADAPTATIONS TO CLIMATE CHANGE

Can Micro-Irrigation Technologies Resolve India's Groundwater Crisis? Reflections from Dark-Regions in Gujarat

Chandra Sekhar Bahinipati[1] and P. K. Viswanathan[2]

[1] Department of Humanities and Social Sciences, Indian Institute of Technology Tirupati, Tirupati, IN

[2] Department of Management, Amrita Vishwa Vidyapeetham (Deemed University), Kochi, IN

Corresponding author: Chandra Sekhar Bahinipati (csbahinipati@iittp.ac.in)

Upfront capital costs of micro-irrigation technologies are subsidized across the dark-zone regions of the state of Gujarat, where groundwater was observed as over-extracted, with an anticipation that wide-scale adoption could perhaps reduce pressure on the aquifer. From a macro-perspective, the real water saving potential depends on not only adoption of these technologies but also how best the farmers' get convinced about the looming water scarcity and try to adapt to the new technologies. While there are several plot-level studies with respect to water consumption, very limited research is being carried out at basin-wide and irrigation system level. The onus of this paper, henceforth, is to examine the impact of micro-irrigation adoption on groundwater utilization at the irrigation system level. In the study regions, either an individual or a group of farmers' extract water from the common aquifer, and therefore, it is being considered as a proxy for the irrigation system. Empirical observations were based on an in-depth survey of 430 tubewell owning farmers who have adopted micro-irrigation in the dark zone, and the information were collected by considering common aquifer as the unit of analysis rather than individual farm household. The major findings emerging from the study are: (i) micro-irrigation adoption *per se* was statistically insignificant to make any considerable plunge in the groundwater use, and (ii) technology adoption along with metered power connection leads to a reduction in groundwater extraction. It should be noted that we, based on the finding, do not categorically deny the possibility of declining groundwater use due to large-scale adoption of such technologies since negative coefficient values are found. From a policy angle, the study suggests that the promotion of these technologies may not lead to sustainable groundwater conservation outcomes unless the farmers are made to behave responsibly especially under extreme water scarcity conditions. It is also important that while supporting for the adoption of these innovations, the state also should effectively regulate the pilferages in farm power use by expediting the process of metering of unmetered connections, to achieve the desired goals of sustainable management of groundwater.

Keywords: micro-irrigation; adoption; groundwater extraction; dark-zone region; Gujarat

1. Introduction

Over the years, groundwater is being considered as a major irrigation source in India, and indeed, the dependency has been significantly escalating since the 1970s because diesel and/or electric pump sets become accessible to marginal and small farmers (Maheshwari et al., 2014). On one hand, India is the largest user of groundwater for agricultural purposes in the world which is having a significant contribution to agricultural productivity (i.e., 70–80 per cent of the value of agricultural production) in the recent past decades (Vijay Shankar et al., 2011; Zaveri et al., 2016). Studies, on other hand, are categorically alarming about rapid depletion of groundwater, particularly in the arid and semi-arid regions (Kumar, 2016a, b; Zaveri et al., 2016). This could enhance a number of households in below poverty line and decline food production in rural India (Zaveri et al., 2016). Such implications could further amplify in the foreseeable future due to climate change. Given the barriers in imposing market based instruments (e.g., tariff, subsidy and property right) to save India's groundwater, both policymakers and researchers have been anticipating that a large-scale adoption of micro-irrigation (MI) technologies, i.e., drip and sprinkler irrigation, could potentially reduce over-extraction of groundwater (Dhawan, 2000). Eventually, it would address common-pool externalities, particularly in the arid and semi-arid regions (Kumar, 2016a, b). Therefore, several policy incentives (i.e., institutional innovations and subsidizing upfront capital costs) have been introduced in the recent past years for rapid diffusion of MI technologies across the Indian states (Bahinipati and Viswanathan, 2017). For instance, '*Pradhan Mantri Krishi Sinchayee Yojana*' was enforced in 2014 with the objective of 'more crop per drop'. Three strands of studies have so far emerged: (i) determinants of adoption of MI, (ii) cost-benefit analysis, and (iii) evaluating positive benefits such as reduce water and energy footprints, increase productivity, decline labour and use of fertilizers, etc. (Bahinipati and Viswanathan, 2016, 2017).

In reference to assess farmers' behavioral shift on water use scenarios during post-adoption, several studies have been carried out at plot-level,[1] however, very limited research is being conducted at the basin-wide and the irrigation system level; a study by Ward and Pulido-Velazquez (2008) for Mexico is a noteworthy exception. Extrapolation based on the plot-level estimation could over-estimate potential saving of water at the aggregate level, i.e., irrigation system. While the plot-level estimations are mainly based on the technological potential, farmers' ex-post adoption behaviour matters for calculation of realistic saving of water and energy at a larger scale (Fishman et al., 2015). Given such assessments are largely socially relevance with respect to stabilizing groundwater level, this study aims to examine the impact of MI adoption on the groundwater extraction at the irrigation system level in the dark regions, known for over-exploitation of groundwater, of the state of Gujarat. The state government had demarcated 57 water scarce talukas[2] as dark-zone in 2003, where new power connection and groundwater extraction were banned in the interest of geo-hydrology and public since 2001,[3] and such restrictions have again withdrawn in 2012 (Bahinipati and Viswanathan, 2017). In these regions, farmers are mostly depending on groundwater for irrigation purposes, and they are obtaining water from a common tubewell/aquifer; this is considered as a proxy for the irrigation system, henceforth.

The marginal cost of water and energy (subsidized energy price per unit/levied at a flat rate) use is often less or negligible for Indian farmers (Dubash, 2007; Shah et al., 2012), and on other hand, a large proportion of land still remains un-irrigated,[4] wanting a major breakthrough in the expansion of water saving irrigation systems. Concurrently, given the reckless nature of farmers' behaviour in using irrigation water in Indian conditions, it may be very unlikely that the levels of groundwater extraction could be significantly reduced (thus sustaining the groundwater pool reserve) due to the wide-scale promotion of MI. In fact, few studies also pointed out that adoption of water-efficient technologies, in turn, lead to higher water use and faster resource depletion – 'Jevon's Paradox', i.e., resource efficiency curse (e.g., Ward and Pulido-Velazquez, 2008). This study also notes that the adoption of more efficient technologies reduces valuable return flows and limits aquifer recharge (e.g., Ward and Pulido-Velazquez, 2008). In an urge to maximize profit, farmers often undertake several options after MI adoption, such as: (i) expansion of irrigated area, (ii) increase frequency of irrigation, (iii) shifting to water intensive crops, and (iv) sharing [selling] water with [to] neighbourhood farmers (Fishman et al., 2014). These responses coincided with a sheer lack of knowledge to maximise the potential of MI could offset its social objective intended at a reduction of water extraction, and thus, saving the groundwater commons. Hence, arguably, the net effect of the adoption of MI on water use could be nil or insignificant at the irrigation system level. There is a dearth of empirical research, particularly in the water deficit regions of Gujarat.

Namara et al., (2007) and Fishman et al., (2014) point out, without robust empirical analysis, that farmers objective is not to conserve groundwater by adopting MI, but to increase irrigation intensity and/or provide more water to the irrigated crops. Fishman et al., (2015) compare between 'naïve' (no change) and 'realistic' (irrigated area expanded until the baseline level of water extraction reached or until the cultivated area saturated) behavioral scenarios of water efficient technologies, i.e., drip, sprinkler and laser land leveling, across the Indian districts. It notices an evidence of an increasing number of over-extraction districts in the later scenario and the total amount of unsustainable water extraction drops by half (Fishman et al.,

[1] Saleth and Amarsinghe (2010) conclude, based on several empirical studies, that adoption on MI reduces water requirement between 48 per cent and 67 per cent in India.

[2] Taluka means sub-division of a revenue district, comprising of a group of villages.

[3] see GR. (Government Resolution) no. GWR-2003-14J1, dated 16/12/2003.

[4] Around 52% of the total net sown area is irrigated in India as of 2013–14, and across the states, it varies from 9% (Jharkhand) to 99% (Punjab) (Government of India, 2016).

2015). However, it fails to capture farmers' actual behaviour. A recent study by Birkenholtz (2017) observes that farmers in the Rajasthan state of India adopt MI to enhance yield, particularly to cultivate commercial crops, rather than reducing pressure on groundwater. Thus, it may be pertinent to understand the post-MI technology adoption scenario, especially, the changes in farmer behaviour in using the new technology to efficiently utilize the groundwater in water scarce regions. Some of the pertinent questions here are: 'What farmers do with the saved water following the adoption of MI? Do the increased levels of adoption of MI lead to a significant reduction in the pressure on groundwater resources?'. Based on a survey of 430 tubewell owning farmers, who have adopted MI systems across the dark zone talukas in Gujarat state, this paper addresses these questions. The paper is organized as follows. Section II discusses data and methods and section three explains the results. Section IV presents concluding remarks with some policy suggestions.

2. Data and Methods

The study had conducted a primary survey across the dark-zone talukas in Gujarat, to empirically examine the effect of MI adoption on groundwater use. All the dark-zone talukas are falling under the six agro-climatic zones: north Gujarat (36 talukas), south Saurashtra (5 talukas), middle Gujarat (4 talukas), north Saurashtra (2 talukas), south Gujarat (3 talukas) and north-west arid (4 talukas). A purposive random sampling approach was adopted to select districts, talukas, and villages for the survey, and then, stratified random sampling has been followed to select tubewell owners for an in-depth interview. First, we have classified these agro-climatic zones into three categories based on the stage of groundwater development (SGWD[5]), e.g., (i) over-exploited and critical categories, (ii) semi-critical and (iii) safe categories. Whereas talukas in north Gujarat are notified as over-exploited and critical regions, the talukas in south Saurashtra, north Saurashtra, and north-west arid regions are known as semi-critical, and the talukas in the remaining zones like middle Gujarat and south Gujarat fall under the safe category. After this, the study districts, talukas, and villages were selected on the basis of adoption status of MI, and we have selected those villages where a higher adoption was noticed.[6] We have purposefully done this as the aim is to survey only the MI adopted tubewell owners. While we have purposively selected two districts from the first category, e.g., Banaskantha and Sabarkantha,[7] one district each has been picked out from second and third categories, viz., Junagadh and Bharuch.

One taluka from each district has been chosen: Dhanera (Banaskantha), Idar (Sabarkantha), Mangrol (Junagadh) and Ankleshwar (Bharuch). According to district-wise groundwater brochure published by Central Ground Water Board in 2014, the aquifers in Dhanera and Ankeleshwar are covered by soft rock, while it is a hard rock in Idar and shallow in Mangrol (see Appendix 1). Based on the respondents, the depth of borewell/tubewell is high in Dhanera taluka, i.e., on an average 256 feet, followed by Idar (155 feet), Mangrol (107 feet) and Ankleshwar (31 feet). With reference to the stage of groundwater development (SGWD), both Mangrol and Ankleshwar are falling under the safe category, whereas Idar and Dhanera talukas are in semi-critical and over-exploited categories, respectively (see Appendix 1). Within these talukas, 10 villages were chosen for the primary survey, namely, Nenava, Dhakha, Gorol, Mudeti, Shepa, Divrana, Diva, Mandvabuzarg, Kansiya, and Andada (see **Figure 1** and appendix 2 for land use and irrigation scenario across the villages). We have specifically selected four villages in Ankleshwar since the adoption of MI is lower across the villages as compared to the talukas in other categories. In these villages, we first stratified all the tubewell owners according to their land holding, and then, select respondents from each stratum. By doing this, we would have a representative sample for the dark-zone regions. In sum, we have surveyed 430 tubewell owning farmers, and in fact, all of them adopted MI at least one year before. It should be noted that these farmers have no other sources of irrigation except borewell and tubewell.

We had used a structured questionnaire to elicit responses from the farmers regarding their resource utilization behaviour during pre[8]- and post-adoption (2015–16) contexts. The tubewell specific information related to irrigation practices, cropping patterns, energy consumption, and extraction of water were also

[5] Over exploitation: SGWD > 100%; critical: SGWD is between 85–100%; Semi-critical: SGWD is between 65–85%; and safe: SGWD < 65% (Government of India, 2014).

[6] Village level analysis was carried out based on information collected from Gujarat Green Revolution Company Limited for the period between 2006 and 2014, i.e., number of people adopted MI and area under MI.

[7] Around 67% of total dark-zone talukas are falling under this category, and therefore, two districts were considered for survey purposes.

[8] The reference year varies among the respondents, and this represents previous year of the MI adopted in the surveyed tubewell. Around 72 per cent of the farmers adopted MI at most five years before the survey was conducted. Although we can't deny the possibility of recall bias, but the likelihood would be low as most of the farmers adopted MI post 2010.

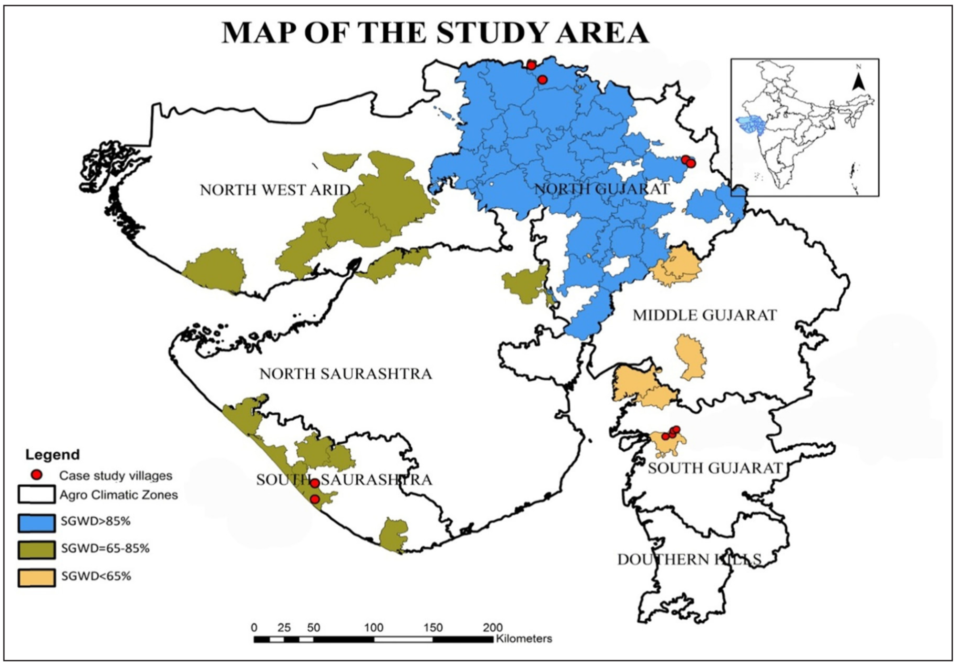

Figure 1: Map of the Study Villages.
Note: this figure not to scale and depict authentic boundaries.

collected. Respondents were particularly asked to provide data for the entire agricultural land irrigated under the survey tubewell. We have also gathered detailed socio-economic information of the farmers, and in addition, they were asked to share their opinion/perception on the impact of MI adoption on resource utilization, i.e., water and energy. In order to capture the rate of groundwater extraction before and after adoption, we have taken proxy variables as a change in depth of water level,[9] a number of added column pipes (the length of column pipe varies between 10ft and 20ft) and change in pump set HP (horsepower); these are the dependent variables. The information for these three variables were collected from the respondents. In order to capture the impact of MI adoption, the variables like the proportion of gross irrigated area (GIA) under MI and number of years since MI adoption were included as explanatory variables in the regression model. The effect of these variables on extraction of groundwater resources may be confounded with the effect of other drivers such as gross irrigated area before MI adoption, electricity meter connection, GIA under MI multiplied with meter connection, water recharge measures, depth of the groundwater level before MI adoption, age of tubewell, years of schooling of tubewell owner, and tubewell owners' age. Further, we have also taken binary dummy variable for surveyed villages to capture unobserved heterogeneity effects at the village level.[10] Obtaining reliable estimates requires controlling for these factors.

The estimated equation is specified as:

$$\begin{aligned}\Delta DWL_i/\Delta CP_i/\Delta Pump_i = \beta_0 + \beta_1 GIAMI_i + \beta_2 YearMI_i + \beta_3 GIABMI_i + \beta_4\, Meter_i \\ + \beta_5 (GIAMI{*}Meter)_i + \beta_6 WRM_i + \beta_7 Ln(DWater)_i \\ + \beta_8 AgeTubewell_i + \beta_9 EduOwner_i + \beta_{10} AgeOwner_i + \beta_{11} V_i + \varepsilon_i\end{aligned}$$

Table 1 provides a description and summary statistics of the variable (both dependent and explanatory) used in the econometric analysis of this study. While the average depth of groundwater level has increased by 11 feet between the surveyed year and before adoption, around 2 column pipes were added and HP of the pump set has enhanced by 2 during the same reference period. The empirical analysis of this study has taken confounded variables related to MI adoption, farm and tubewell characteristics, water regulatory measures

[9] Farmers are frequently altering location of the submersible pump set and adding column pipes with respect to change in depth of water level, and therefore, they are having an idea about the depth of water level at different time periods. For robustness check, we compared self-reported average depth of water level in each taluka with the figures mentioned in CGWB (2014).

[10] The confounders like amount and variation of rainfall, number of tubewells/aquifers in the village, community level water recharge activities, etc. are also major determinants for the observed groundwater level. Due to non-availability of village-level rainfall information, this variable was not directly taken into model, but the influence of it could have been captured by the village-level effect variables. Similarly, it also captures the effect of number of tubewells in village.

Table 1: Descriptive Statistics of the Variables used in the Analysis.

Sl. No.	Dependent Variables	Description	Mean (SD)
1	ΔDWL_i	ΔDepth of Water Level (in feet)	11.47 (17.07)
2	ΔCP_i	ΔColumn Pipe (in no.)	2.09 (4.61)
3	$\Delta Pump_i$	ΔPump set HP	2.19 (4.16)
	Independent Variables		
	Adoption of MI		
4	$GIAMI_i$	GIA under MI (%)	0.76 (0.23)
5	$YearMI_i$	No. of years adopted MI	4.41 (2.84)
	Farm and Tubewell Characteristics		
6	$GIAMI_i$	Gross Irrigated Area Before MI adoption	6.03 (4.67)
7	WRM_i	Water Recharge Measures	0.60 (0.49)
8	$Ln(DWater)_i$	Ln(Depth of water level before MI adoption)	4.48 (0.89)
9	$AgeTubewell_i$	Age of the Tubewell	18.09 (9.87)
	Water Regulatory Measures		
10	$Meter_i$	Meter Connection (Yes/No)	0.35 (0.48)
11	$(GIAMI{*}Meter)_i$	Gross Irrigated Area under MI*Meter Connection	2.31 (4.54)
	Tubewell Owners' Characteristics		
12	$EduOwner_i$	Years of schooling of Tubewell Owner	7.13 (4.87)
13	$AgeOwner_i$	Tubewell Owners' Age	51.47 (12.34)
14		N	430

Note: SD - Standard Deviation.
Source: Authors' Computation.

and tubewell owner's characteristics. Given the objective for wide scale diffusion of these technologies, it is expected that the indicators representing MI adoption status, e.g., proportion of GIA under MI and number of years of MI adoption, could have a negative impact on groundwater extraction. A substantial number of studies have empirically estimated that these technologies reduce the use of water at the plot-level as compared to the conventional method of irrigation across the regions as well as crops (Saleth and Amarasinghe, 2010; Kumar, 2016b). On the basis of this, we are expecting to have similar findings in the case of irrigation system level and basin wise. It is found that the mean of 76% of the total irrigated area under MI, and the average number of years the farmers have undertaken MI are four at the time of the survey, with a minimum of 1 year and a maximum of 15 years. Farm characteristics include GIA before MI adoption and water recharge measures. The variable $GIABMI_i$ was taken to control the water extraction scenario at the baseline level. Various water recharge measures, (e.g., check dams, bori bundhs,[11] farm ponds,[12] etc.), have been undertaken at the individual- and community levels across the state over the years (Kishore, 2013). There is a provision to avail incentives from the state government to construct these measures (Kishore, 2013). These activities could enhance groundwater recharge and improving the water supply at the basin level. In the present study context, around 60% of farmers have undertaken water recharge measures. The factors representing tubewell characteristics are $Ln(DWater)_i$ and $AgeTubewell_i$. The variable $Ln(DWater)_i$ captures baseline water level which could influence the individual farmer's extraction behaviour.

In 1989, Gujarat Electricity Board had moved to flat-rate tariff system in the case of farm power in order to avoid high transaction costs due to the significantly increased number of aquifers during the 1970s and 1980s (Shah et al., 2008). It is apparently remaining as too low over the years since it is one of the main agenda for the electoral campaign (Mukherji et al., 2009). Earlier studies, hence, ascertain that the marginal cost for pumping groundwater is almost negligible, and this, in turn, increased the demand for

[11] It is a type of check dams made of sand bags.
[12] The state government had launched Sardar Patel participatory water conservation scheme in January 2000, and it was planned to construct a large number of check dams, especially in the water scarce regions (Kishore, 2013).

electricity connections for tubewells, resulting over-extraction of groundwater (Dubash, 2007; Shah et al., 2012; Fishman et al., 2016). Particularly in the arid and semi-arid regions where there is a less potential for groundwater recharge due to hard rock aquifers, the flat tariff is considered as a major determinant for over-extraction (Mukherji et al., 2009). As part of the power sector reforms, Asian Development Bank had advised the government of Gujarat for increasing performance efficiency of the power supply system through metering of farm power supply during the early last decade, and it also becomes mandatory according to the Indian Electricity Act of 2003 (Fishman et al., 2015). Due to political resistance, the government move was very slow in fixing meter on the old connections but made meter tariff mandatory for all new connections for tubewells (Shah and Verma, 2008; Shah et al., 2012). Because of this, a large percentage of farmers across the state are still charged on the basis of flat-rate tariff linked to the HP of pumps (Viswanathan, 2014). About 35% of the total surveyed tubewell, for example, had a meter connection, and it seems around three out of five tubewell owners are paying based on the flat electricity pricing. Having a meter connection expected to reduce the extraction of groundwater – because, the marginal cost of extracting groundwater is higher for a farmer with meter connection than that of a farmer with unmetered connections who pays at a flat rate (Shah et al., 2008; Mukherjee et al., 2009). According to economic theory, the efficient allocation of water could be achieved, if farmers are charged as per the marginal cost pricing of water including full social cost – this reflects scarcity value of resources and may slow down depletion of water resources (Mukherjee et al., 2009; Shah et al., 2012; Fishman et al., 2016). Previous studies emphasize to account water at the depletion point rather than plot level (Ward and Pulido-Velazquez, 2008), and pricing farm power based on meter could capture the rate of groundwater use (Mukherji et al., 2009).

In this regard, empirical studies by Kishore and Verma (2004) and Fishman et al., (2016) have not observed a significant influence of meter connection on farmers' groundwater use behaviour. This could be because of subsidized electricity pricing per each unit, and farmers do not find it as significantly different from the flat rate (Mukherji et al., 2009). Further, 'Jyotirgram Scheme'[13] was introduced during mid of the last decade, and the aim is to separate out the agricultural feeders and provide power for pre-announced 6–8 hours per day (Shah et al., 2008; Mukherji et al., 2010; Kishore, 2013). Shah et al., (2008) conclude that increasing water price charges after the implementation of '*Jyotigram*' scheme diminishes groundwater extraction. Likewise, Mukherji et al., (2010) observe that electricity demand for agriculture, which is considered as a proxy for groundwater extraction as around 90 per cent of tubewells are having electricity connection, has been plunged in the state during the following years after the scheme was enacted. It deems an inconclusive finding in the case of the causal relationship between meter-based pricing and groundwater consumption. In order to capture the influence of meter connection, the variable like $Meter_i$ is taken in the model. Therefore, more empirical studies are required in this regard. Under the backdrop of the above discussion, it is anticipated that both adoption of MI technologies and meter connection independently could reduce groundwater footprint in agriculture. What will happen to groundwater extraction if a farmer is having access to both MI and meter connection? This is being less explored in the research arena, especially in the context of Gujarat state; previous studies largely focused on either of them. In order to estimate the effect of both together, we have taken an interaction variable, i.e., $(GIAMI*Meter)_i$.

This study has considered two proxy variables to capture tubewell owning farmers' characteristics those could have a possible impact on water extraction, namely, $EduOwner_i$ and $AgeOwner_i$. Both multicollinearity and heteroscedasticity problems, in general, arise for cross-section econometric analysis (Wooldridge, 2010). A variance inflation factor (VIF) for all the confounders was calculated to check former, and the latter was eradicated by estimating robust standard error. The VIF value for the explanatory variables was below 10 (i.e., 2.51, spreading between 1.11 and 4.96) and hence, negate the problems of multicollinearity.

3. Results and Discussions

Previous studies pointed out that MI enhances water use efficiency as compared to the conventional method of irrigation (Saleth and Amarasinghe, 2010), and as a consequence, it is anticipated that we can reduce water footprint in agriculture by adopting such technologies at a larger scale (Kumar, 2016b). Nevertheless, the impact of MI adoption on water extraction at the irrigation system level is less explored, while several studies have investigated this at the plot-level (Kumar, 2016b). Technological potential could reduce water footprint at the plot-level, but the overall extraction of groundwater mostly depends on

[13] This scheme was implemented between 2004 and 2007, and the onus is effective rationing of the power supply to the agriculture sector. Under this, a separate three phase high voltage electricity connection has been provided to agriculture sector for pre-announced 6–8 hours per day (see Kishore, 2013).

farmers' post-adoption behaviour. It is found that farmers change agricultural management practices after adopting MI; some of them are outlined in the introduction section. These measures could offset the real potential saving of water, i.e., a strategic externality. Estimating water saving potential based on the technical capacity is a clear cut example of asymmetric information bias. Based on the primary survey, it is found that 26% of farmers have increased the GIA, and enhanced frequency of irrigation by 80% of the tubewell owners (**Table 2**). While post-adoption cropping intensity is increased by 32%, around 37% of farmers diversified towards water-intensive crops (**Table 2**). Similar observations are also obtained by the earlier studies, such as Namara et al., (2007), Fishman et al., (2014) and Birkenholtz (2017). These ex-post activities could offset the water saving potential which would have otherwise achieved due to the adoption of water conservation technologies.

The results of the impact of MI adoption on groundwater extraction are presented in **Table 3**. Columns (iii), (iv) and (v) show the coefficients of the explanatory variables for three dependent variables, e.g., change in depth of water level, change in column pipes and change in capacity of pump set (HP), respectively. In these models, it is found that the goodness of fit (R^2) varies between 0.39 and 0.46, i.e., these models explain 39–46% of the total variation in the dependent variables. When the main thrust of the empirical analysis is with the covariates of MI adoption, the coefficients of $GIAMI_i$ were found as non-significant. The sign is observed as negative for depth of water level and column pipes, and this indicates that groundwater use declines with an increasing area under MI; but, the association is not statistically significant. This could be because of availability of large chunk of un-irrigated area and existence of informal water market for irrigation purposes. Surprisingly, we observed a positive relationship for the covariate $YearMI_i$ with column pipes added, and it is also statistically significant. This reveals that an additional year under MI enhances the probability of adding column pipes by 13%. In contrast to the expected results, these findings suggest that the adoption of MI alone does not have a significant impact on the reduction of groundwater – the major policy onus for wide-scale diffusion of these technologies is to stabilize groundwater level in arid and semi-arid regions of India (Dhawan, 2000; Birkenholtz, 2017).

Several studies assumed that charging electricity price as per the meter is likely to mitigate the rate of groundwater extraction (Dubash, 2007; Shat et al., 2012). Empirical studies conducted across Indian states such as Gujarat and West Bengal, however, have not found any evidence of change in farmers' behaviour towards pumping groundwater after meter connection (Kishore and Verma, 2004; Mukherji et al., 2009). Testing an alternative voluntary approach, i.e., invite farmers to install electricity meters and receive compensation for every unit they save, Fishman et al., (2016) found no impact on water usage, while there was an unprecedented voluntary shift to meter based billing. Such a large shift could be anticipated as farmers are expecting pay lower electricity bill in the case of meter connection due to high subsidized unit rate and power connection for a fixed time period in a day (Mukherji et al., 2009, 2010). Moreover, Mukherji et al., (2009) pointed out that regulating farm power supply through metering certainly improves water use efficiency, and it is subtle with respect to water saving behaviour. We find a negative coefficient value for two outcomes, namely, change in depth of water level and power of pump set, but these reported coefficients are not statistically significant. This does not deny the possibility of getting positive societal benefits due to metering farm power connection. Findings from this study reveal that neither the MI not the meter connection independently having a statistically significant coefficient value. Based on this, it would not be viewed that both the options are not reducing pressure on groundwater, however, the fact is that their association is not statistically significant. In the case of joint effect, i.e., $(GIAMI*Meter)_i$, we have observed a negative relationship with statistically significant. For instance, it reduces the likelihood of increasing depth of water level by 49%, and additional column pipes by 15%. This finding suggests that the

Table 2: Tubewell Owners' Behaviour after adopting MI (Percentage of respondent).

Sl. No.	Post Adoption Behaviour	Mean (SD)
1	Increase Gross Irrigated Area (GIA)	0.26 (0.44)
2	Increase frequency of Irrigation	0.80 (0.40)
3	Increase Cropping Intensity	0.32 (0.47)
4	Shifting Water Intensive Crops	0.37 (0.48)

Note: SD - standard deviation.
Source: Authors' table based on the field survey.

Table 3: Impact of MI adoption on Groundwater Extraction at common aquifer level.

Sl. No.	Independent Variables	ΔDWL_i	ΔCP_i	$\Delta Pump_i$
		Coef. (Robust SE)	Coef. (Robust SE)	Coef. (Robust SE)
(i)	(ii)	(iii)	(iv)	(v)
	Adoption of MI			
1	$GIAMI_i$	–5.08	–0.42	0.59
		(3.43)	(0.91)	(0.81)
2	$YearMI_i$	0.38	0.13**	0.05
		(0.24)	(0.06)	(0.05)
	Farm and Tubewell Characteristics			
3	$GIABMI_i$	0.37**	0.09*	0.03
		(0.18)	(0.05)	(0.04)
4	WRM_i	1.19	0.44	0.04
		(1.81)	(0.51)	(0.46)
5	$Ln(DWater)_i$	0.23	0.97**	0.27
		(1.68)	(0.41)	(0.30)
6	$AgeTubewell_i$	–0.03	0.01	0.01
		(0.07)	(0.02)	(0.01)
	Water Regulatory Measures			
7	$Meter_i$	–0.08	0.41	–0.44
		(1.96)	(0.45)	(0.43)
8	$(GIAMI*Meter)_i$	–0.49**	–0.15***	–0.05
		(0.19)	(0.06)	(0.05)
	Tubewell Owners' Characteristics			
9	$EduOwner_i$	–0.04	–0.00	–0.01
		(0.16)	(0.04)	(0.04)
10	$AgeOwner_i$	–0.02	0.01	0.02**
		(0.06)	(0.01)	(0.01)
11	Constant	27.79***	0.54	4.77***
		(9.86)	(2.63)	(1.73)
12	R^2	0.39	0.46	0.46
13	F (19, 410)	17.56***	9.67***	14.92***
14	Village Effects	Yes	Yes	Yes
15	N	430	430	430
16	Model	OLS	OLS	OLS

Source: Authors' Computation.
Note: Robust standard errors are in the parentheses; *** p < 0.01, ** p < 0.05 and * p < 0.1 respectively.

wide-scale adoption of MI does not have a significant impact on the reduction of groundwater extraction, as long as the connection is not metered. In other words, adoption of MI with metered connection reduces the depletion of groundwater. Tubewell owners pay electricity charges as per the groundwater use if the aquifer is having a meter connection, and this could have influenced farmers' behaviour towards the withdrawal of groundwater. Further, plots with MI require comparatively less amount of water. Thus, when the farmers are having both concurrently, a significant reduction of groundwater is observed.

This indicates that accounting water at the source point acts as a strong determinant in reducing extraction of groundwater along with adoption of MI technologies. From a broader policy perspective, it advocates accounting water at the source (extraction) point rather than at the application point. The specific policy suggestion here is that the government may expedite the process of fixing meters for all the agricultural power connections in order to reduce the groundwater extraction, in addition to the diffusion of MI. The other covariates found as significant are: gross irrigated area before MI adoption, depth of water level before adoption and tubewell owner's age. It can be inferred that the probability of groundwater extraction is higher if water depth level was high before the adoption of MI. This invariably suggests that farmers given an access to water, may behave rationally to themselves (and socially irrational and irresponsible) and not necessarily have the motivation to conserve it for any future use. Such actions could exemplify hyperbolic discounting, i.e., farmers are more myopic about short-term gains rather than long-term sustainability. The net result is that the groundwater resource in question would continue to face the challenges of over-extraction, irrespective of the new technological paradigm. Besides, the variables like gross irrigated area and depth of water level before MI adoption are found as having a positive association with outcome, and the coefficients are statistically significant.

4. Concluding Observations and Policy Suggestions

While a large number of studies have been constantly warning about the looming water scarcity in the state of Gujarat, an unsustainable extraction of groundwater is being observed due to the common-pool nature and the absence of regulatory mechanisms (Kumar, 2016a, b). It is difficult to enact market instruments to correct distortions in groundwater. As a result, overdraft of groundwater is being observed in many parts of the state. Thus, several policies are being undertaken to promote MI technologies which perhaps reduce water footprint in agriculture. The water saving potential of these technologies is largely explored at the plot level, but there is a sparse at the irrigation system level and basin-wise (Kumar, 2016b). With interviewing 430 tubewell owners in the dark-zone where farmers use common aquifer to irrigate, the onus of this study is to empirically examine the impact of MI adoption on groundwater utilization at the tubewell level. The results of this study infer two major conclusions: (i) MI adoption and pricing farm power based on meter do independently reduce groundwater use, but their relationships are statistically insignificant, and (ii) there is a strong possibility of reducing groundwater extraction, if the tubewell is having both MI and meter connection concurrently – in fact, the causal association is found as statistically significant. Both, for example, reduce the probability of increasing the depth of water level and additional column pipes by 49% and 15%, respectively. The results of this study also need to be interpreted with some caution. The first has to do with proxy variables identified to capture groundwater extraction and analysis based on a cross-section survey. There could also be a possibility of recall bias while farmers are asked to report some specific questions for before adoption of MI, e.g., depth of water level, gross irrigated area – second limitation of this study.

An important policy suggestion emerging from the study is that the government should continue to provide an additional subsidy for a large-scale diffusion of MI in the dark zone areas as these technologies perhaps reduce water footprint in agriculture. In particular, with a clear focus on achieving a greater success with its ongoing process of metering of unmetered connections on a priority basis so as to make sustainable impacts to reduce the over-extraction of groundwater in water scarce regions. This has also another advantage of reducing rampant power thefts in the case of un-meter connection across the state (Viswanathan, 2014). From a broader policy perspective, we suggest that it is imperative to design institutions and accounting measures in order to achieve the objective of real water saving with the net impact that the groundwater commons are conserved and sustained. We also need to rethink of widely held belief that irrigation efficiency alone will not solve the water crisis and the problems of water commons. Instead of focusing on water application, it is important to define water rights, water use and water accounting as already suggested by scholars (Ward and Pulido-Velazquez, 2008). In sum, MI technologies have the advantage of enhancing irrigation efficiency and food security (Mukherji et al., 2009; Kumar 2016a, b), but not necessarily lead to a perceptible impact in saving groundwater at the system level. It is also important that while supporting for the adoption of micro irrigation systems, the state also should effectively regulate the pilferages in farm power use by expediting the process of metering of unmetered connections, to achieve the desired goals of sustainable management of groundwater commons in the state.

Additional Files

The additional files for this article can be found as follows:

- **Appendix 1.** Depth of Well in the Study Talukas. DOI: https://doi.org/10.5334/ijc.888.s1
- **Appendix 2.** Village-wise land-use and irrigation scenario. DOI: https://doi.org/10.5334/ijc.888.s2

Acknowledgements

The research was possible by a research grant from the South Asian Network for Development and Environmental Economics (SANDEE), Nepal [SANDEE/2014-10]. We are thankful to Jean Marie Baland for his constructive suggestions and for mentoring the research. We have benefited from discussions with E. Somanathan, Tushar Shah, R. Parthasarathy and Unmesh Patnaik. The earlier versions were presented at the 4th Annual GGKP conference, TAAS-IFPRI-ICAR conference on 'sustainable development goals: preparedness and role of Indian agriculture', AERC-IWMI conference on 'water governance in India: sustainable management of water resources in agriculture', 15th GLOBELICS international conference and Waterfuture conference 2019. We also acknowledge the suggestions and comments provided by the participants of inception and dissemination workshops held at Gujarat Institute of Development Research, India. All views, conclusions and recommendations made in this paper are those of the authors and not of those of the supporting or collaborating institutions. Usual disclaimers apply.

Competing Interests

The authors have received a research grant from the South Asian Network for Development and Environmental Economics (SANDEE), Nepal [SANDEE/2014-10] to carry forward this study.

References

Bahinipati, C. S., & **Viswanathan, P. K.** (2016). Determinants of Adopting and Accessing Benefits of Water Saving Technologies: A Study of Public Tube Wells with MI Systems in North Gujarat. In P. K. Viswanathan, M. Dinesh Kumar, & A. Narayanamoorthy (Eds.), *Micro Irrigation Systems in India: Emergence, Status and Impacts in Select Major States* (pp. 133–154). Singapore: Springer-Verlag. DOI: https://doi.org/10.1007/978-981-10-0348-6_8

Bahinipati, C. S., & **Viswanathan, P. K.** (2017). Adoption and diffusion of micro-irrigation in Gujarat, Western India: Do institutions and policies matter? In P. Mukhopadhyay, N. Nawn, & K. Das (Eds.), *Global Change, Ecosystems and Sustainability* (pp. 204–224). New Dehli: Sage Publication. DOI: https://doi.org/10.4135/9789353280284.n17

Birkenholtz, T. (2017). Assessing India's drip-irrigation boom: efficiency, climate change and groundwater policy. *Water International, 42*, 663–677. DOI: https://doi.org/10.1080/02508060.2017.1351910

CGWB. (2014). District Groundwater Brochure (study districts), Technical Report Series, Central Ground Water Board, Ministry of Water Resources, Government of India, Ahmedabad.

Dhawan, B. D. (2000). Drip irrigation: evaluating returns. *Economic and Political Weekly, 35*, 3775–3780.

Dubash, N. K. (2007). The electricity-groundwater conundrum: case for a political solution to a political problem. *Economic and Political Weekly, 42*(52), 45–55.

Fishman, R., Devineni, N., & **Raman, S.** (2015). Can improved agriculture water use efficiency save India's groundwater. *Environmental Research Letters, 10*(8). DOI: https://doi.org/10.1088/1748-9326/10/8/084022

Fishman, R., Gulati, S., & **Li, S.** (2014). Should resource efficient technologies be subsidized? Evidence from the diffusion of drip irrigation in Gujarat. *Paper presented at the ISI*, Delhi. Retrieved from http://www.isid.ac.in/~epu/acegd2014/papers/RamFishman.pdf

Fishman, R., Lall, U., Modi, V., & **Parekh, N.** (2016). Can electricity pricing save india's groundwater? field evidence from a novel policy mechanism in gujarat. *Journal of the Association of Environmental and Resource Economists*, *3*(4), 819–855. DOI: https://doi.org/10.1086/688496

Government of India. (2014). Dynamic groundwater resources in India (as on 31st March 2011). *Published by Central Groundwater Board, Ministry of Water Resources, River Development & Ganga Rejuvenation*, Faridabad.

Government of India. (2016). Agricultural statistics at a Glance 2016. *Published by Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare*, New Delhi.

Kishore, A. (2013). Supply- and demand-side management of water in Gujarat, India: what can we learn? *Water Policy, 15*, 496–514. DOI: https://doi.org/10.2166/wp.2013.161

Kishore, A., & **Verma, S.** (2004). What determines pumping behaviour of tubewell owners: marginal cost or opportunity cost? *Water Policy Research Highlight #6*. Anand, Gujarat, India: IWMI-Tata Water Policy Program.

Kumar, D. (2016a). Water saving and yield enhancing micro irrigation technologies in India: theory and practice. In P. K. Viswanathan, M. Dinesh Kumar, & A. Narayanamoorthy (Eds.), *Micro Irrigation Systems in India: Emergence, Status and Impacts in Select Major States* (pp. 13–36). Singapore: Springer-Verlag. DOI: https://doi.org/10.1007/978-981-10-0348-6_2

Kumar, D. (2016b). Distressed elephants: policy initiatives for sustainable groundwater management in India. *IIM Kazhikode Society & Management Review, 5*(1), 51–62. DOI: https://doi.org/10.1177/2277975215617266

Mukherji, A., Das, D., Majumdar, N., Nayak, N. C., Sethi, R. R., & **Sharma, B. R.** (2009). Meeting of agricultural power supply in West Bengal, India: Who gains and who loses? *Energy Policy, 37*, 5530–5539. DOI: https://doi.org/10.1016/j.enpol.2009.08.051

Mukherji, A., Shah, T., & **Verma, S.** (2010). Electricity reforms and its impact on groundwater use: evidence from India. In L. Martinez-Cortina, A. Garrido, & E. Lopez-Gunn (Eds.), *Re-thinking Water and Food Security* (pp. 299–306). Leiden, Netherlands: CRC Press. DOI: https://doi.org/10.1201/b10541-21

Namara, R. E., Nagar, R. K., & **Upadhyay, B.** (2007). Economics, adoption determinants and impacts of micro-irrigation technologies: empirical results from India. *Irrigation Science, 25*, 283–297. DOI: https://doi.org/10.1007/s00271-007-0065-0

Saleth, R. M., & **Amarasinghe, U. A.** (2010). Promoting irrigation demand management in India: options, linkages and strategy. *Water Policy, 12*(6), 832–850. DOI: https://doi.org/10.2166/wp.2010.038

Shah, T., Bhatt, S., Shah, R. K., & **Talati, J.** (2008). Groundwater governance through electricity supply management: assessing an innovative intervention in Gujarat, western India. *Agricultural Water Management, 95*, 1233–1242. DOI: https://doi.org/10.1016/j.agwat.2008.04.006

Shah, T., Giordano, M., & **Mukherji, A.** (2012). Political economy of the energy-groundwater nexus in India: exploring issues and assessing policy options. *Hydrogeology Journal, 20*, 995–1006. DOI: https://doi.org/10.1007/s10040-011-0816-0

Shah, T., & **Verma, S.** (2008). Co-management of electricity and groundwater: an assessment of Gujarat's Jyotirgram scheme. *Economic and Political Weekly, 43*(7), 59–66.

Vijaya Shankar, P. S., Kulkarni, H., & **Krishnan, S.** (2011). India's groundwater challenge and the way forward. *Economic and Political Weekly, XLVI*(2), 37–45.

Viswanathan, P. K. (2014). *Trends and Determinants of Agricultural Power Consumption and Distribution Losses: An analysis of agricultural feeders across power distribution companies in Gujarat*. Gandhinagar, Gujarat: Gujarat Electricity Regulatory Commission.

Ward, F. A., & **Pulido-Velazquez, M.** (2008). Water conservation in irrigation can increase water use. *Proceedings of National Academy of Science, 105*(47), 18215–18220. DOI: https://doi.org/10.1073/pnas.0805554105

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. Cambridge, MA: MIT Press.

Zaveri, E., Grogan, D. S., Fisher-Venden, K., Frolking, S., Lammers, R. B., Wrenn, D. H., Prusevich, A., & **Nicholas, R. E.** (2016). Invisible water, visible impact: groundwater use and Indian agriculture under climate Change. *Environment Research Letters, 11*. DOI: https://doi.org/10.1088/1748-9326/11/8/084005

How to cite this article: Bahinipati, C. S., & Viswanathan, P. K. (2019). Can Micro-Irrigation Technologies Resolve India's Groundwater Crisis? Reflections from Dark-Regions in Gujarat. *International Journal of the Commons*, 13(2), pp. 848–858. DOI: https://doi.org/10.5334/ijc.888

Submitted: 13 April 2018 **Accepted:** 02 February 2019 **Published:** 30 October 2019

]u[*International Journal of the Commons* is a peer-reviewed open access journal published by Ubiquity Press. OPEN ACCESS