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Determinants and Barriers to Micro Irrigation Adoption: Insights from Four Indian States

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ABSTRACT

This study assesses micro irrigation adoption in four Indian states - Punjab, Maharashtra, Gujarat, and Andhra Pradesh - by comparing regions with different cropping patterns to identify key determinants and barriers. It analyzes micro irrigation adoption experiences across four states, specifically examining districts with high adoption rates. From each district, we selected two villages for a total of 16, surveying 827 individuals, with an equal number of adopters and non-adopters, using stratified random sampling. Findings show substantial increases in yield along with savings in water, energy, and fertilizer for adopters compared to non-adopters, with fertilizer savings between 12.89% and 37.51%, and plant protection savings ranging from 37.51% to 48.23%. The results indicate that factors such as family size, mobile phone usage, possession of soil health cards, awareness of crop insurance programs, and ownership of tube-wells positively influence micro irrigation adoption. Access to irrigation infrastructure is crucial for realizing benefits under PMKSY, and farmers with tubewells receive better water supply access, enhancing their likelihood of adopting micro irrigation. In contrast, owning rainfed areas negatively impacts micro irrigation adoption. These factors may play a significant role in advancing micro irrigation practices nationwide.

1 | INTRODUCTION

Water scarcity is more significant in agriculture than in any other economic sector. Globally, agriculture consumes about 70% of freshwater and nearly 90% of its consumptive use. Water withdrawal for irrigation and livestock in India was well above the global average (91%), with about one-third sourced from groundwater in 2010 (FAO, 2012). Ground water resources in India are depleting faster than the natural rate of recharge, particularly in north-western india (Rodell *et al.,* 2007). Over the past decade (2007-2016), the groundwater levels in 61% of wells declined by 0-4 m, primarily due to excessive groundwater extraction (CGWB 2017). The total area covered by MIS across the country is approximately 10.25 mha, which accounts for about 7.6% of the net sown area. The area covered by drip irrigation was highest in Andhra Pradesh (25.3%), followed by Maharashtra (23.6%), Gujarat (13.6%), and Punjab (< 1.17%) (Chand *et al.,* 2020; Srivastava *et al.,* 2014). In contrast, Rajasthan, Gujarat, Maharashtra, and Andhra Pradesh have a larger area covered by sprinklers than Punjab and other states. Understanding the biophysical factors that influence the adoption of micro-irrigation is essential. The socio-economic attributes of adopters are equally important and should be studied in detail when framing policies for micro-irrigation. Therefore, this paper aims to identify the critical determinants of micro-irrigation adoption. At the same time, we need to analyze the socio-economic characteristics of both adopters and non-adopters. This analysis will assist policymakers and researchers in planning micro-irrigation interventions more effectively. With this background, we have planned this study to identify the determinants of micro-irrigation at the grassroots level.

2 | MATERIALS AND METHODS

This study examines the experiences involved in spreading and adopting micro-irrigation in four selected states: Punjab (an unexploited region), Maharashtra, Gujarat, and Andhra Pradesh. We selected two districts from each state, providing background information on the high adoption rates of micro-irrigation in these districts. From each district, we chose two villages, totaling 16 villages. A total of 827 respondents were surveyed, with an equal proportion of adopters and non-adopters. The entire process follows a stratified random sampling procedure.

2.1 | Identification of determinants of micro irrigation adoption

The factors affecting adoption of MI at the farm level have been identified using farm households' data collated through a farm survey in Punjab, Andhra Pradesh, Gujarat and Maharashtra. The key factors affecting the adoption of MI were identified using logit regression analysis. The procedure of logit analysis is given below:

The logit model uses a logistic cumulative distribution function to estimate the linear determinants of the logit (Li) or the logged odds and has the following form:

$$Li(Y) = ln\left[\frac{P_i}{1-P_i}\right] = \beta_0 + \beta_k X \quad ...(1)$$

where, (Pi /1- Pi) is the odds expressing the conditional mean or probability of an occurrence of the event relative to the likelihood of a non-occurrence given X; β_0 is the constant term or intercept, β_k is a vector of regression coefficients to be estimated and X is a set of independent variables determining the probability of the event. The model in terms of Y would then be written as:

$$Y_i = \alpha + \sum_{k=1}^{K} \beta_k X_k + \varepsilon \quad ...(2)$$

where Yi is a binary dependent variable; and Yi equals 1 when a farm household adopted MI system and 0 otherwise, α is the constant term and β_k are regression coefficients of 'k' independent variables to be estimated and 'ε' is the error term. The important thing is to find β that produces the logits and the conditional mean of Y given X values that have the greatest likelihood of producing the observed data.

2.2 | Empirical model specification

The logit model of adoption of MI (Yi) has been specified as a function of all independent variables as follows:

$Y_i = f(X_i) + u$ ...(3)

where, dependent variable (Yi) is adoption of MI and independent variables (Xi) are age (years), family size (number), working labour (number), schooling (years), mobile use (years), caste (Gen or OBC = 1 Otherwise = 0), soil health card (Yes = 1 No = 0), income from food grain (Rs.), income from horticulture (Rs.), total expenditure per month (Rs.), crop insurance (Yes=1 No=0), water table depth (in feet), tube well ownerships (Yes=1 No=0), source of energy to extract water, irrigated area (ha), rainfed area (ha). Logistic regression functions have been fitted separately for each state and for pooled dat.

HIGHLIGHTS

- Family size, mobile phone usage, soil health card ownership, crop insurance awareness, and tube-well ownership are the key determinants of micro irrigation adoption.
- Micro irrigation adopters achieved significant savings in fertilizer and plant protection chemicals, water, and energy use, along with notable yield improvements.
- Reliable access to irrigation markedly improves adoption likelihood.
- Farmers in rainfed regions are less likely to adopt.

3 | RESULTS AND DISCUSSION

The information collected from MIS adopters and non-adopters is presented in this section. Table 1 shows the differences in socioeconomic characteristics between adopters and non-adopters. The application of the t-test indicates that there is a significant difference between adopters and non-adopters of MIS concerning various socio-economic parameters. However, not all parameters considered in the analysis were significant, but there was definitely a mean difference. The age of the family head does not vary much among adopters and non-adopters in the selected states, with farmers averaging between 46 and 54 years of age. The education level was found to be higher for adopters, indicating that educated individuals are more likely to adopt newer technology for the betterment of their farms and environment. The number of agricultural workers available in the family shows a significant difference between adopters and non-adopters (Chand *et al.,* 2020). Although there is no economic interpretation for this phenomenon, a higher number of agricultural workers in the family certainly aids in completing farm work on time, and they may earn off-farm income to support the family. Total income derived from various sources was higher for adopters than for non-adopters. This could be attributed to higher production and reduced cultivation costs associated with MIS adoption. The results also indicate that farmers who adopted micro irrigation are often members of various social organizations in their area. This might have provided them with better information and motivation for adopting MIS.

3.1 | State-level determinants of Micro Irrigation adoption

The relationship between the adoption of micro irrigation and selected explanatory variables, i.e., net sown area, unirrigated area, fruits and vegetables area, fertilizer consumption, electricity use in agriculture, and subsidy availability, has been assessed using the regression analysis technique with state-level panel data (1996-97 to 2016-17). The

TABLE 1 Socio-economic attributes of sample households

Particulars	Punjab		Andhra Pradesh		Gujarat		Maharashtra	
	A	NA	A	NA	A	NA	A	NA
Age of HH (Years)	51.96	50.57	52.10	54.28	46.40	47.71	47.49	48.14
Education of HH	7.67	7.02	8.64	5.94***	7.30	7.57	10.96	10.19*
Family size (No)	6.57	7.03	6.36	5.49***	5.96	5.08***	5.34	5.72
Agriculture worker in family (No)	2.51	2.19*	2.67	2.46*	3.55	3.24**	2.46	2.96***
Land holding Size (ha)	2.27	2.64	1.19	1.17	3.36	2.03***	1.70	2.17**
irrigated area (ha)	2.25	2.55	1.13	1.04	3.36	1.88***	1.67	2.17**
Income from food grain (₹ Lakhs)	0.85	2.21***	0.49	0.79**	1.52	1.81**	1.50	1.32
Income from horticulture (₹ Lakhs)	1.50	0.61**	0.94	0.36***	0.05	0.79***	0.51	0.23*
Income from livestock (₹ Lakhs)	-	-	0.10	0.05**	0.17	0.47***	0.22	0.29
Income from labour (₹ Lakhs)	-	-	0.01	0.02	0.22	3.16***	2.08	2.19
0ff-farm income (₹ Lakhs)	0.83	0.58	0.28	0.35	-	-		-
Total income Lakhs	3.17	3.40	1.82	1.57	3.97	6.24***	4.31	4.03
Food expenditure (₹ 000)	3.69	4.29***	3.81	3.64	3.00	3.03	2.94	3.46**
Non -food expenditure (₹ 000)	3.38	3.86*	3.53	3.89	2.81	2.91	3.48	3.45
Total expenditure per month (₹ 000)	7.07	8.15***	7.33	7.53	5.81	5.94	6.42	6.91**
Loan taken for different purposes (₹ Lakhs)	2.98	3.82	1.25	0.94**	3.81	2.85	2.98	1.67
Mobile use years	9.16	9.15	7.94	6.72**	11.39	7.45***	6.77	7.25
Member of social org (Yes=1 no=0)	12.23***	-	3.82**	-	18.39***	-	5.60**	-
Crop insurance (Yes=1 no=0)	17.86***		4.42**	-	18.52	-	16.74	-
Total number of observations	91	92	103	101	110	110	105	115

*Note: A-Adopter, NA- Non adopter, HH- Household, *** is significant at 1%,** at 5% and * at 10%*

TABLE 2 Multiple regression analysis of adoption of micro irrigation in major states

Explanatory variable	Coefficient	S.E.	t value
Constant	-7.754*	1.547	5.011
Net sown area	0.320*	0.103	3.114
Unirrigated area	0.671*	0.076	8.823
Fruits and vegetables area	0.123*	0.069	1.773
Fertilizer consumtion	0.116	0.165	0.70
Electricity use in agriculture	0.536*	0.067	8.023
Subsidy for micro irrigation	0.509*	0.100	5.115
Number of observations	294		
F (6, 293)	184.908		
R-square	0.794		

*Source: Authors' estimates. Note: *denotes significance at less than 1% level*

results obtained are presented in Table 2. The data indicate that all the explanatory variables (R square value 0.794) jointly contributed 79.4% of variations in the extent of adoption of micro irrigation in key states. The estimated value of F (184.908) was found to be highly significant. Furthermore, the t-test of significance indicated that the coefficients of regression for the explanatory variables, namely net sown area, unirrigated area, fruits and vegetables area, electricity use in agriculture, and subsidy availability, were highly significant at less than 1% level. This means that these variables were more critical for predicting the extent of adoption of micro irrigation. In contrast, the regression coefficient was non-significant for fertilizer use.

The net sown area was positively and significantly associated with the adoption of micro irrigation in major states at a level of significance of less than 1%. It can be inferred that the increasing pressure of population to produce more and feed them is playing a significant role in adopting micro irrigation to expand the irrigated area, which is otherwise difficult to achieve through traditional irrigation methods. Policymakers and researchers are also convinced that the adoption of micro irrigation is more effective in increasing the area under irrigation and making use of precious water resources judiciously, thereby producing agricultural outputs on a sustainable basis (Suresh *et al.,* 2018).

The unirrigated area was positively and significantly related to the adoption of micro irrigation in states at less than a 1% level. This indicates that states with a large unirrigated area were encouraged to bring more land under irrigation by adopting micro irrigation. It shows that the unirrigated area was a driving factor in promoting the adoption of micro irrigation. The regression coefficient of fruits and vegetables area was positive and significant at less than 1%. This implies that an increase in the area under fruits and vegetables will promote bringing more area under micro irrigation. The government is also deliberately promoting the sanctioning of micro irrigation projects for crops like fruits and vegetables, where the returns per drop of water are higher. The regression coefficient for electricity use in agriculture positively and significantly influenced the adoption of micro irrigation at a 1% level of significance. It shows that the assured availability of electricity encourages farmers to adopt micro irrigation and mechanize other farm operations. This may be due to the assured availability of electricity, as its use in agriculture reduces energy costs with increased mechanization and ensures sustainable farm production. Government subsidies have significantly boosted the adoption of improved technology. The subsidy coefficient is positively linked to micro irrigation adoption at below 1% significance. Thus, micro irrigation adoption in major states rose with government subsidy support, as financial assistance lowered installation costs, encouraging farmers to invest in this capital-intensive infrastructure, which they would otherwise find difficult to afford individually.

3.2 | Identification of determinants of micro irrigation adoptions

The adoption of micro irrigation depends on several factors. These factors need to be studied in depth for future planning and to extend the country's micro irrigation for wider coverage. The logit model results revealed that family size, mobile use, possession of a soil health card, availing benefits from crop insurance schemes, and possession of a tubewell positively affect the adoption of MI (Table 3). Possession of an irrigation source is one of the essential eligibility criteria for availing benefits under PMKSY. Farmers with their own tubewell have better access to the water supply, which increases the probability of MI adoption. Farmers who are aware of ongoing schemes like crop insurance schemes and soil health cards showed more interest in the MI scheme. Possession of a rainfed area negatively affects the adoption of MI, though MI is adopted primarily for water saving and to bring unirrigated areas under irrigation with saved water (CWC, 2010; Govt. of India, 2017). In Punjab, an increase in the water table has a positive association with the adoption of MI. This may lead to a positive effect in the future in checking groundwater depletion. Farmers who possess diesel engines have a higher probability of adopting MI. Free electricity connection may discourage farmers from adopting MI, as they can draft groundwater at nominal or no cost. The results are in conformity with various studies conducted by different researchers (Naryanamoorthy *et al.,* 2018, Polak *et al.,* 1997, Kumar *et al.,* 2009, Biswas *et al.,* 2015, Chand *et al.,* 2019, Chandran *et al.,* 2016, and Chandrakanth *et al.,* 2013, Kapur *et al.,* 2015, Salazar and Rand, 2016).

4 | CONCLUSIONS AND POLICY IMPLICATIONS

This study highlights that at the state level, net sown area is positively and significantly associated with micro irrigation (MI) adoption, suggesting that increasing pressure on land and food production drives the shift from traditional to water-efficient irrigation methods. At the village level, factors such as family size, mobile phone usage, possession of a soil health card, awareness of crop insurance schemes, and ownership of a tubewell significantly enhance the likelihood of MI adoption. Access to a reliable irrigation

TABLE 3 Factors affecting adoption of micro irrigation at farm household level

Variables	Punjab		Andhra Pradesh		Gujarat		Maharashtra	
	Coef.	Marginal Effect	Coef.	Marginal Effect	Coef.	Marginal Effect	Coef.	Marginal Effect
Dependent variable: Adoption of MIS (yes=1; no=0)								
Independent variables:								
Family size (no)	-0.137	-0.034	0.205	0.051	-0.009	-0.002	-0.011	-0.002
Family labour available (no)	0.133	0.033	-0.263	-0.065	-0.893	-0.211	-0.621	-0.142
Schooling (years)	0.067	0.017	0.155***	0.038***	-0.115	-0.027	0.001	0.001
Mobile use (years)	0.003	0.001	0.238***	0.059***	0.835***	0.198**	-0.065	-0.015
Caste (Gen+OBC=1 Otherwise=0)	-0.001	0.000	1.152*	0.256**	-2.907	-0.565	1.087	0.215
Soil health card (Yes=1 No=0)	3.502***	0.568***	0.297	0.074	7.095**	0.809***	1.961**	0.453**
Crop insurance (Yes=1 No=0)	1.265***	0.306***	0.643	0.158	8.049***	0.962***	6.03	0.892***
Water table depth (in feet)	0.010***	0.003***	0.005***	0.001***	-0.003	-0.001	0.01***	0.001
Tube well ownership (Yes=1 No=0)	3.366***	0.631***	3.073***	0.592***	3.373	0.520*	2.968***	0.442***
Irrigated area (ha)	0.031	0.008	0.073	0.018	0.646***	0.153**	0.229**	0.052**
Rain-fed area (ha)	-0.627	-0.154	0.611	0.151	-3.6	-0.852	2.52	0.577
Energy (Diesel=1 otherwise=0)	1.671***	0.388***	-1.226*	-0.295**	-1.483	-0.353	-0.522	-0.125
Constant	-2.750**		-9.249***		-10.58		-3.730*	
Number of observation	183	204	220	220				
LR chi2(12)	103.9	151.79	279.59	229.97				
Prob > chi2	0.000	0.000	0.000	0.000				
Pseudo R2	0.409	0.537	0.917	0.750				
Log likelihood	-74.895	-65.497	-12.696	-37.279				

*Source: Authors' estimates; Note: ***, ** and * denote significance at 1%, 5% and 10% level, respectively.*

source, especially tubewells, is crucial, as it is a prerequisite for benefiting from the PMKSY scheme.

Interestingly, farmers in rainfed areas are less likely to adopt MI, despite its potential to bring un-irrigated land under cultivation through water savings. In Punjab, rising water tables are positively associated with MI adoption, indicating the possibility of mitigating groundwater depletion in the long run. However, current subsidy structures under the National Mission on Micro Irrigation (NMMI) apply uniformly across farmer categories, with a cap of 5 hectares. This policy may misalign with land distribution realities, as 15% of medium and large farmers own over 55% of India's agricultural land. There is a pressing need to revisit subsidy caps to ensure equity and broader adoption. Policy recommendations emerging from the study are:

- Tailor subsidy limits based on landholding size and regional needs.
- Strengthen post-installation support and farmer training.
- Establish R&D frameworks at the national/state levels for system recommendations.
- Promote localized demonstrations to showcase region- and climate-specific benefits of MI.

The study also suggests that in-depth regional studies on MI adoption in rainfed and tribal areas are needed. These studies should examine the economic viability and long-term performance of installed systems, conduct behavioural studies on awareness and adoption barriers, and conduct climate-specific performance assessments of drip and sprinkler systems.

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CONFLICT OF INTEREST

The Authors declare there is no conflict of interest.

AUTHOR'S CONTRIBUTION

We declare that both authors have equally contributed to developing the research paper and were part of the original research project.

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