

# **Do rehabilitated canals influence irrigation technology choices? Evidence from smallholders in Madhya Pradesh, India**

**Ranu Sinha<sup>a,b</sup>, Edoardo Borgomeo<sup>c</sup>, Christian Fischer<sup>a</sup>, and Robert Hope<sup>d</sup>**

<sup>a</sup>School of Geography and the Environment, University of Oxford, UK,

<sup>b</sup>Oxford India Centre for Sustainable Development, Somerville College, Oxford, UK.

<sup>c</sup> Environmental Change Institute, School of Geography and the Environment, University of Oxford, UK.

<sup>d</sup>School of Geography and the Environment and Smith School of Enterprise and the Environment, University of Oxford, UK.

## **Corresponding author contact details:**

Ranu Sinha

Email: [Ranu.Sinha@ouce.ox.ac.uk](mailto:Ranu.Sinha@ouce.ox.ac.uk)

## **Abstract**

Investments to rehabilitate and modernize irrigation systems as well as price subsidies to incentivize adoption of drip and sprinkler irrigation technologies are promoted to enhance agricultural productivity and sustainability of on-farm water use across India. We examine the effect of these two policies on farmer irrigation choices in surface irrigated farms in Madhya Pradesh. A logistic regression based on novel survey data from 918 farmers estimates a 3% reduction in the probability that farmers will adopt drip or sprinkler technologies if they are located on farms serviced by irrigation schemes where 30% or more of the irrigated area was rehabilitated. Results also reveal that, on average, farmers are 12% more likely to continue using irrigation technologies if they had adopted them prior to the start of rehabilitation works. Quantitative results are complemented with semi-structured interviews of farmers to better understand drivers of adoption, which suggest that: (1) open, gravity canals do not always restrict drip or sprinkler adoption, (2) water scarcity appears to be a strong driver for farmers to adopt, despite financial constraints, (3) socio-economic factors such as caste, education, and house ownership does not seem to influence a farmers' choice of adoption, and (4) social networks provide a stronger incentive for adoption as smallholders struggle to access government subsidies. Understanding the role of social networks in influencing the irrigation practices of farmers can complement supply-side infrastructure investments and financial incentive policies to enhance the water security of smallholders facing climatic risks to food production.

## **Keywords**

Canal rehabilitation; irrigation technology; subsidies; farmer behavior; India

## 1. Introduction

Meeting rising food demands while maintaining the sustainability of land and water resources is one of the greatest policy challenges of the 21st century (Hoekstra and Chapagain, 2008; Hoekstra and Mekonnen, 2012). Irrigation is the largest water consumer in the world, accounting for 70% of global annual freshwater withdrawals (FAO, 2018). Based on current water use patterns, water demand for food production is predicted to increase by 70 to 90% by 2050, far exceeding available freshwater resources (De Fraiture et al., 2007; Odegard and Van Der Voet, 2014). As such, interventions to grow more food with the same or reduced volumes of water, commonly known as ‘more crop per drop’, while rehabilitating and modernizing canal irrigation systems are being promoted worldwide (Scheierling et al. 2016; Giordano et al. 2019). These interventions are also encouraged to adapt irrigated agriculture to some of the inevitable impacts of climate change (Kahil et al. 2015; Zaveri and Lobell, 2019) and, increasingly, returning water to ecosystems (Crossman et al. 2010). Surface irrigation infrastructure rehabilitation and subsidies for modern irrigation technologies such as drip and sprinkler irrigation are two key policy actions adopted to accomplish these twin goals of increased productivity and resilience in the face of water scarcity and climate change.

While rehabilitation and increased irrigation efficiency by means of technology adoption can provide benefits, such as reduced labor requirements and improved crop yields, they also have some well-known limits. Ward and Velazquez (2008) highlight that incentivizing farmers to switch from flood to drip irrigation by raising the subsidy on drip irrigation can produce higher crop yields, reduce the total water applied to farmlands, and decrease groundwater pumping for irrigated agriculture. However, they argue that a progressively increasing public subsidy of drip irrigation increases overall water use (Ward and Velazquez, 2008). These findings align with others who find that adoption of modern irrigation technologies tends to result in increased on-farm water consumption, groundwater extractions, and higher water consumption per hectare as farmers switch to more water intensive crops (Venot, et al., 2017; Song et al. 2018; Grafton et al., 2018). Pérez-Blanco et al. (2020) reviewed over 230 studies to determine whether the higher physical irrigation efficiency achieved by means of water conservation technologies (e.g., sprinkler or drip systems among other interventions) conserves water. Overall, they conclude that unless water conservation technologies are coupled with behavioral policy tools, agricultural water conservation technologies increase water consumption, thereby reducing water availability for

alternative uses (Pérez-Blanco et al., 2020). Finally, while rehabilitation and subsidy programs often use water productivity (i.e., amount of crop production, either mass or monetary value divided by amount of supplied irrigation water) as a key indicator to measure performance, the literature also highlights that it cannot be pursued in isolation from other water management dimensions (e.g., ensuring equal access to subsidies and extension services, equality in water allocation) (Wichelns, 2015; Zhu et al. 2019).

These studies highlight the importance of understanding the complex issues involved in water use on surface irrigated farms, policy interactions, and the behavioral responses of irrigators to diverse policy instruments (Garrick et al. 2020). Simply encouraging irrigators to adopt more efficient irrigation technologies via subsidies may not achieve intended outcomes (Wheeler et al. 2015). In fact, the benefits of behavior change through financial incentives encouraging adoption of improved agricultural technologies and practices are often overestimated (Thornton et al., 2017; Wheeler et al. 2020). This is in part due to the inherent limitations of supply-led approaches to development and the lack of understanding of the effects of policy actions on the behavior of irrigators, including limited attention to context-specificity and to farmers' priorities beyond increased agricultural productivity, and lack of appreciation of the socio-cultural contexts within which smallholder farmers operate (Orr, 2012; Lankford, 2009; Levidow et al., 2014; Venot et al., 2017; Liyama et al., 2018; Pilarova et al., 2018). In addition, little is known about the effects of multiple policy actions (e.g., irrigation rehabilitation and subsidies) on farmers' water use and choices for irrigation technologies. Lankford (2013) points out that understanding the complexities of water management within irrigation systems has significance for resource efficiency complexity and debates around efficiency, which he argues reinforces the need to understand the details of water management at the spatial scale of the field and from the perspective of the farmer (Lankford, 2013, Chapter 3, pg. 45).

This paper examines farmers' choices for irrigation technology adoption in the context of two types of policy interventions in Madhya Pradesh, India. First, physical irrigation rehabilitation interventions are examined as part of the Madhya Pradesh Water Sector Restructuring Project (MPWSRP), a 400 million USD program funded by the World Bank in the Indian state of Madhya

Pradesh aimed at improving water productivity<sup>1</sup>. Second, financial incentives are examined as part of a state-wide subsidies program promoting the use of modern irrigation technologies (i.e., sprinklers and drip systems) among farmers in Madhya Pradesh. The paper aims to explore changes in adoption choices for modern irrigation technologies among smallholder farmers in the context of these two policies, enabling us to examine farmers' behavioral responses to infrastructure and technology subsidies. To achieve this aim, it employs a mixed methods approach combining logistic regression analysis of household survey data of 918 farmers with semi-structured interviews.

To our knowledge this is the first study applying a mixed method approach to understand how farmers' irrigation technology adoption changes in response to irrigation rehabilitation interventions and subsidies. We explore whether these policies are negatively or positively correlated with the choice of adoption of drip and sprinkler technologies among a sample of farmers in central India. The mixed methods approach helps us to better understand *how* and *why* farmer choices for irrigation technologies differ after surface systems are upgraded and the implications of these behavioral responses on on-farm irrigation practices. In turn, this offers an analytical basis to comprehend the drivers of water use behaviors among smallholders, contributing knowledge on the impacts of financial incentives and irrigation investments for achieving water and food security, with implications for India and beyond.

## **2. Study Area**

### **2.1. Irrigation policy in India**

India has the second largest irrigated area in the world after China (ICID 2018), with irrigation playing a major role in meeting national food demand (Manjunatha et al., 2016). Surface irrigation canals established during British rule have historically been the main policy instrument for addressing hunger and famine risk across India (Jurriens, Mollinga, & Wester, 1996). Following independence, from the 1950s to 2001, the proportion of surface water to net irrigated area

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<sup>1</sup> In the context of the MPWSRP, water productivity is defined as “the sum of the net multi-sectoral benefits per unit of water use in a river basin framework. This would include the net benefits of irrigated agriculture, fisheries, hydropower, drinking water, industries, navigation, and environmental or other uses of water” (World Bank, 2005).

decreased and, in the 1990s, it decreased by 23 % as growing reliance on groundwater irrigation contributed to the increase in net irrigated area (Bhaduri et al., 2006). Shah et al. (2009) argue that the main factors behind the rapid decline in canal irrigation across India were the poor performance of surface irrigation systems, market failures, failure of participation of irrigation communities, and failure of public-sector agencies to deliver irrigation water. Agricultural sector growth in India, known as the 'Green Revolution' during 1967–68 and 1977–78, as a result, was largely dependent on groundwater irrigation with 55–60 % of the Indian population directly or indirectly relying on groundwater for their livelihoods (Shah et al., 2003). Although groundwater irrigation contributed to the crop productivity gains of the Green Revolution, it was also associated with negative environmental externalities (e.g., groundwater depletion, waterlogging, salinity of soil, water pollution, and biodiversity loss (Alauddin and Quiggin, 2008; Rasul, 2016).

Considering these environmental challenges, since the early 2000s irrigation policy priorities across Indian states shifted from canal construction to large-scale public investments to rehabilitate and modernize aging irrigation systems to reduce dependence on unsustainable groundwater abstraction (Sinha et al., 2018). In particular, state governments across India focused on policies of irrigation rehabilitation and modernization, defined here as the technical and managerial upgrading of irrigation schemes (including rehabilitation of physical infrastructure) combined with institutional reforms, with the objective to improve resource utilization (notably water) and water delivery services to farms (Burt 2013; Biswas and Venkatachalam, 2015). Rehabilitation and modernization of irrigation service delivery was also accompanied by subsidies to incentivize farmers to adopt modern irrigation technologies such as drip or sprinklers to promote on-farm irrigation efficiency (Narayanamoorthy, 2009a, b). Priorities of international donors shifted accordingly, with the World Bank providing support to multiple Indian states for canal rehabilitation as well as capacity building for state irrigation agencies, institutional support to farmers to create Water Users Associations (WUAs) within the context of Participatory Irrigation Management (PIM). Water User Associations are a group of water users, such as irrigators, who pool their financial, technical, material, and human resources for the operation and maintenance of an irrigation system (FAO 2012). As a result, irrigation engineers within Indian public sector agencies began focusing on the physical infrastructure part of canal rehabilitation, which consists of canal lining and upgrading control structures, among other solutions. These

measures aimed to improve irrigation system efficiency and reliability of water delivery to farmers (Yu, 2021).

In terms of demand management, modern irrigation technologies (e.g., drip, sprinklers) have been widely promoted across India under the assumption that widespread adoption may enhance farm-level irrigation efficiencies, thereby benefiting the farmer with respect to reduced costs of labor, precision application of fertilizers and chemicals, minimizing leaching of nitrates and other pollutants, diversifying crops, and reduction in on-farm water use (Ministry of Water Resources, 2006; Narayanamoorthy, 2009a; Singh, 2017; Arya et al., 2017). However, Indian government subsidy policies to promote large scale demand for precision irrigation technologies have failed to take off (Government of India, 2011; Venot et al., 2014; Malik et al., 2018). Suresh et al. (2018) estimate that only 10 % of the total modern irrigation potential in India has been achieved.

## **2.2 Irrigation rehabilitation in the state of Madhya Pradesh**

In 2005, the Madhya Pradesh government initiated a large-scale irrigation rehabilitation program—the Madhya Pradesh Water Sector Restructuring Project - funded by the World Bank. The purpose of the project was to improve the productivity of water in the state through institutional reforms and technical upgrading of physical infrastructure across 26 districts in six out of the ten river basins of the state (Betwa, Chambal, Ken, Sindh, Tons, and Wainganga) (see Figure 1). A second-level objective was to increase the reliability of canal water in the state and reduce dependence on withdrawal of groundwater resources. Agriculture is one of the main sources of employment and economic growth. In Madhya Pradesh, with more than 70 % of its labor force employed in agriculture (Sapre, 2014; World Bank 2016).

Upon closure in 2015, the project's impact evaluation reported that water productivity had been maximized in all target areas: 495,000 hectares of designed potential irrigation Culturable Command Areas (CCA)<sup>2</sup> was achieved within the six basins (Sinha et al., 2018). The project made a total investment of USD 443 million to rehabilitate 202 minor, 21 medium, and 5 major irrigation schemes for a total of 228 projects across 26 districts within the six river basins (Figure 1). Major projects are defined as projects with a CCA of more than 10,000 ha, medium

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<sup>2</sup> Culturable Command Area (CCA): The area that can be irrigated from an irrigation scheme and are fit for cultivation.

projects have a CCA between 2000 to 10,000 ha, and minor projects have a CCA less than 2000 ha. MPWSRP investments in physical infrastructure included repair works on dams and embankments, reducing seepage, improving drainage, adding boundary stones, and fixing sluice and radial gates on irrigation tanks and canals that were no longer operational (Sinha et al., 2018).



**Figure 1.** Map of Major & Medium Irrigation Schemes Rehabilitated by the Madhya Pradesh Water Sector Restructuring Project<sup>3</sup>.

The project also created and trained over 400 Water User Associations to operate and maintain these systems in the project area. Kumar (2016) finds that following closure of the MPWSRP in 2015 and as a result of over 10-12 years of public investments in canal rehabilitation, there was a substantial increase in the area irrigated by surface systems in MP. For instance, in

<sup>3</sup> Colors in Figure 1 delineate the river basins of Madhya Pradesh



the Chambal basin, the area irrigated by canals increased from 150,000 ha to 290,000 ha (Kumar 2016). This contributed to high levels of growth in the agriculture sector and a reduction in the relative area under groundwater irrigation from 28.2 % in 2002-03 to 16.2 % in 2012-13 during the *kharif* cropping season<sup>4</sup> (Kumar, 2016).

### **2.3 Subsidy policy for promoting adoption of modern irrigation technologies in Madhya Pradesh**

The Indian government invested heavily in state-wide subsidy programs to promote the adoption of sprinkler, drip, and other relevant modern irrigation technologies by launching the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) in 2015 (Government of India, 2017). This program was an extension of a previous scheme called the National Mission on Micro-irrigation (NMMI), which was implemented from 2010-2014. The objective of the PMKSY program is to target investments in the irrigation sector at the field level and provide subsidies for the adoption of modern irrigation technologies within Indian states. The scheme aims to assist Indian states to: a) increase the area under modern irrigation technology (e.g., drip/sprinkler systems) to enhance water use efficiency; b) increase productivity of crops and income of farmers through precision water management; and c) promote relevant modern irrigation technologies in water intensive crops such as sugarcane, banana, cotton, as well as incentivize farmers to extend coverage of field crops under applicable modern irrigation technologies (e.g., sprinkler systems) (Government of India, 2017). Coinciding with World Bank funding for MPWSRP, Madhya Pradesh benefited from central government funds for promoting modern irrigation from PMKSY.

In 2014-15, the central government allocated USD 12.8 million to Madhya Pradesh for promoting on-farm water management and subsidizing adoption of modern irrigation technologies. The main objective of the state *Micro-irrigation Scheme* launched by the Government of Madhya Pradesh is to increase agricultural production by maximizing available irrigation water. Within this program, farmers are given financial assistance for purchasing modern irrigation technologies for their farms based on the following: a) sprinklers – 80 % subsidy up to a total maximum cost of Rs 12,000 Indian Rupees (approximately USD 160) per hectare, b) drip irrigation – 80 % subsidy up to a total maximum cost of Rs 40,000 (approximately USD 530)

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<sup>4</sup> The '*kharif*' cropping season is the summer growing season in India (June-September) and coincides with the southwest monsoon. The '*rabi*' growing season is the post-monsoon cropping period (October-November), and continues through to the following spring or early summer (Krishna Kumar et al., 2004).

per hectare, and, c) mobile rain gun – 50 % subsidy up to a total maximum cost of Rs 15,000 (approximately USD 200) per hectare (Government of Madhya Pradesh, 2020). The required eligibility conditions for applying for the state *Micro-irrigation Scheme* (which was funded by the national Government of India PMKSY) are one or both of the following criteria: a) all farmer residents of Madhya Pradesh are eligible, and b) all owners of agricultural land in Madhya Pradesh are eligible (Government of Madhya Pradesh, 2020).

The total land suitable for modern irrigation technology coverage in Madhya Pradesh is 1.38 million hectares, however, in 2015, the total area under sprinkler and drip irrigation against potential penetration was only 2.3 %, below the national average of 5.5 % (Grant Thornton India, 2016). As of 2008, the state's total drip irrigated area was 20,432 ha (about 1 % of the potential) and as of 2015 this went up to 352,117 ha (Grant Thornton India, 2016; Malik et al., 2018).

Some studies find that drip and sprinkler technology adoption rates are limited in India because farmers with low levels of education, from vulnerable castes and at low poverty levels do not have the resources to adopt these technologies (Namara et al., 2007; Narayanamoorthy, 2009b; Suresh et al., 2018). In addition, global literature on the adoption of water-saving irrigation technologies has, to a large extent, focused on irrigators as rational agents, thus explaining adoption only in terms of its effects on utility (i.e., irrigators adopt technologies because of their profitability) (Perez Blanco et al. 2020). Subsidies play a role on this decision by increasing expected profit (Grafton et al. 2018). However, these past studies analyzing drivers of irrigation technology, globally and in India, often overlook perceptions towards irrigation technologies “through the eyes of farmers” (Lankford et al., 2020; Lankford et al. 2013) as well as fail to analyze the nuances of adoption choices among farmers in areas where canal systems are rehabilitated compared to areas where systems are not, which is the focus of this paper.

#### **2.4. Policy interactions**

While the World Bank funded the MPWSRP infrastructure rehabilitation program (infrastructure reforms for enhanced canal water supply) and the Government of India PMKSY funded the state subsidy program (financial incentives for technology adoption), both policies aimed to improve water productivity. However, there was no *explicit* attempt by the Government of Madhya Pradesh to integrate these different policy approaches to harmonize interventions at the farm, system, and basin-scales. Despite being two distinct policy interventions, both programs shared

the common goals of enhancing water productivity and were implemented within the same districts, and targeted land-owning rural farmers with access to surface, ground, and/or rain-fed irrigation. Hence, these two distinct policy instruments provide a good case study to examine the interplay of infrastructure rehabilitation and technology subsidy policies and their impact on farm-level irrigation technology choices.

To understand the impact of these policies on farmer irrigation choices in command areas with and without rehabilitated canal irrigation systems, we conducted surveys of farming households in six river basins in MP. We sampled farmers within command areas with irrigation systems where MPWSRP investments were made as well as in command areas where irrigation systems were not rehabilitated. Across all districts in the sample, state-wide subsidies for drip and sprinklers were available. It is important to note that the state subsidy program was technically available to all farmers in Madhya Pradesh, agnostic of their source of water (canal, tank, tube well, well, or rain-fed) or their socio-economic status. Farmers in our study area, including farmers in command areas with irrigation schemes which were upgraded by the MPWSRP were equally eligible to access the government subsidy program as farmers in command areas without rehabilitated canals. This implies that all farmers in our study sample, regardless of their irrigation profiles could technically avail the subsidy.

Next, in addition to MPWSRP and the state micro-irrigation scheme, a number of other government-funded programs that focused on promoting horticulture crop adoption, soil health, organic farming, rainwater harvesting, and other agriculture sector efficiency interventions were also available to the same farmers in the same river basins, districts, and command areas as the study area. However, in order to tease out behavioral responses by farmers to the combination of rehabilitated irrigation canals and financial subsidies for irrigation technology adoption, we restrict our focus to two policy interventions, which directly target the management of water supply and demand in surface irrigated farms and exclude analysis of additional agricultural interventions at this stage.

### 3. Data and Methods

#### 3.1 Household survey

##### 3.1.1 Sampling strategy for household surveys

A cross sectional survey of 918 farmer households was conducted in late 2015. To identify households to be surveyed, we classify them based on the attributes and size of irrigation investments they received, following earlier work (Sinha et al., 2018):

- *No rehabilitation.* Households farming in surface command areas where irrigation schemes (e.g., canals and tanks) were not rehabilitated by the MPWSRP. All households have access to the state-wide micro-irrigation subsidy. This set of households is the control group in our empirical analysis.
- *Low Rehabilitation.* Households farming in surface command areas where irrigation schemes have less than 10% of the irrigated area rehabilitated by MPWSRP. All households have access to the state-wide micro-irrigation subsidy. This group of households is taken as treatment group 1 in our empirical analysis.
- *High Rehabilitation.* Households farming in surface command areas where irrigation schemes have 30% or more of the irrigated area rehabilitated by MPWSRP. All households have access to the state-wide micro-irrigation subsidy. This group of households is taken as treatment group 2 in our empirical analysis.

For the treatment groups (treatment groups 1 & 2), our sample frame consisted of 228 projects which were rehabilitated in 2015 by MPWSRP. Out of these 228, 14 schemes were exposed to a “high degree of rehabilitation”, and 214 were exposed to a “low degree of rehabilitation” (Sinha et al., 2018). This is the reference population. To further stratify this population, we used two criteria: a) selection of MPWSRP projects where irrigation rehabilitation works were completed for at least three years and where farmers would have access to rehabilitated irrigation infrastructure for a minimum of three years (at the time of the survey) and b) inclusion of major, medium, and minor irrigation schemes as well as schemes from *both* the high rehabilitation and low rehabilitation irrigation schemes. This criteria for selection reduced the reference population size from a total of 228 irrigation schemes across 21 districts to 27 projects across 10 districts, 34 WUAs, and 485 farming households (Table 1). The sample size of 27 “treatment” projects consists of 1 major, 3 medium, and 23 minor irrigation schemes from a mix of high rehabilitation and low rehabilitation schemes (Table 1).

For the control group, 15 irrigation schemes were randomly selected across five districts, 14 WUAs, and 433 households (Table 2). The sample size of 15 “control” irrigation schemes were selected roughly within the same districts as the treatment schemes, however, with the stipulation that the selected “control” irrigation scheme was never rehabilitated by the MPWSRP (or any other government or donor funded program). The control sample of irrigation schemes consists of 4 medium and 11 minor irrigation schemes (Table 2). Control and treatment samples purposively focus on the distribution of infrastructure investments from large to small irrigation schemes. Random selection of schemes in each category cannot eliminate endogeneity issues or selection bias in this approach. Recognizing this limitation in the sampling design, we include district fixed effects in the modelling specification.

In principle, within both control and treatment groups, all sample farmers participating in the survey had the following common characteristics: (i) farms located in command areas where an irrigation scheme is present, (ii) membership in WUAs, (iii) access to groundwater irrigation (through private tube or bore wells), and (iv) access to modern irrigation technology (micro-irrigation) subsidies through the state-wide subsidy scheme, in which all districts of the state were eligible to participate.

**Table 1.** Summary of stratified sample for treatment irrigation schemes.

Name of irrigation scheme (27)	Scheme type	Name of District (10)	Number of Water User Associations (34)	Number of farmers surveyed (485)
Harsi	Major	Gwalior	9	125
Paronch tank	Medium	Shivpuri	2	29
Kethan medium tank	Medium	Vidisha	2	29
Bardha tank	Minor	Vidisha	1	14
Ghaterapura tank	Minor	Vidisha	1	14
Jajon minor tank	Minor	Vidisha	1	14
Morwan tank	Medium	Neemuch	1	15
Langarpura tank	Minor	Bhopal	1	15
Ghuwara tank	Minor	Sagar	1	15
Kudiyala tank	Minor	Tikamgarh	1	15
Bhitarwar tank	Minor	Tikamgarh	1	15
Bilwari tank	Minor	Tikamgarh	1	15
Shahpur tank	Minor	Tikamgarh	0	Linked to Bilwari tank
Chhutaki tank	Minor	Tikamgarh	1	15
Gidwasan tank	Minor	Tikamgarh	1	15
Kandwa tank	Minor	Tikamgarh	1	15
Kharon tank	Minor	Tikamgarh	1	15
Morpariya tank	Minor	Tikamgarh	0	Linked to Kharon tank
Para tank (Badagaon)	Minor	Tikamgarh	1	14

Siloda tank	Minor	Shajapur	1	14
Koyalkhedi tank	Minor	Ujjain	1	14
Laxmipura tank	Minor	Ujjain	1	14
Silarkhedi tank	Minor	Ujjain	1	14
Bhartala tank	Minor	Katni	1	14
Pabra tank	Minor	Katni	1	14
Pali tank	Minor	Katni	0	Linked to Pabra tank
Bhonhari	Minor	Katni	1	14

**Table 2.** Summary of stratified sample for control irrigation schemes.

Name of irrigation scheme (15)	Scheme type	Name of District (5)	Number of Water User Associations (WUA) (12)	Number of farmers surveyed (433)
Bahadurpur canal	Medium	Gwalior	1	37
Ramowa canal	Medium	Gwalior	1	36
Himmatgarh tank	Minor	Gwalior	1	36
Sirsa dam project	Minor	Gwalior	1	36
Muradpur tank	Minor	Vidisha	1	36
Naren tank	Medium	Vidisha	0	Linked to other tanks
Bani tank	Minor	Neemuch	1	36
Dhangaon tank	Minor	Neemuch	1	36
Malgarh and Lasur tanks	Minor	Neemuch	1	36
Kervan tank	Medium	Bhopal	1	36
Hataikheda tank	Minor	Bhopal	1	36
Jastakhedi tank	Minor	Ujjain	1	36
Undadasa tank	Minor	Ujjain	1	36
Tankaria	Minor	Ujjain	0	Linked to other tanks



We also examine annual average rainfall availability for each district. The rainfall analysis was incorporated to ascertain whether there is a relationship between sub-basin rainfall, which influences local water availability, and farmer irrigation technology choices. Spatial rainfall variability across Madhya Pradesh is high, and we group the 10 sample districts according to three rainfall zones following Sinha et al. (2018): low rainfall, average rainfall, and high rainfall (Table 3).

**Table 3. Results of interannual rainfall analysis<sup>5</sup>**

District-wise Breakdown into Rainfall Zones		
Low	Average	High
Shivpuri, Tikamgarh, Gwalior	Ujjain, Shajapur, Katni, Neemuch	Bhopal, Sagar, Vidisha

### 3.1.2 Survey approach and focus

The purpose of the household survey was to determine a change (if any) in a farmers' choice of irrigation technology and irrigation methods before and after the MPWSRP irrigation rehabilitation interventions. This was achieved by comparing farmer irrigation methods and technology choices observed at the time of the survey (coinciding with MPWSRP project closure and start of the subsidy scheme program in 2015) and self-reported recall of a farmer's irrigation practices as the project began in 2005.

Due to the absence of baseline household data at the start of MPWSRP, farmers were asked to provide two responses to each question: first, a response based on their current choices (in 2015 at the time of the survey) and second, a response based on their past choices (in 2005 at the start of the MPWSRP). All farmers were asked to respond to questions based on their current choices and then recall their choices in the past (e.g., approximately ten years ago in 2005 or

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<sup>5</sup> Sinha et al., (2018) find evidence of heterogeneity in the sub-basin hydrological climate among districts in Madhya Pradesh. Multiple districts within a single river basin in MP have diverse rainfall patterns within a single year and within one monsoon season. This can range from extremes of wet monsoons to dry monsoons within one cropping season. As Sinha et al. (2018) determine there is significant diversity in the interannual rainfall patterns among districts in Madhya Pradesh, thus we incorporate the three rainfall zones into the regression model.

later). We recognize that testing farmer choices based on memory has potential recall bias (Eisenhower et al., 1991; Arthi et al., 2018, Dillman et al., 2014). Given the presence of recall bias, it was important for us to include a control group to whom we asked the same questions as to the treatment cohort. This approach attempts to limit recall bias by comparison with the control group.

The survey focused on three main themes: (i) primary source of irrigation for the last *rabi* or winter cropping season (bore well, tube well, or canal water); (ii) main method of irrigation for the last *rabi* season (flood, drip or sprinkler, ridge and furrow, border strip, or check basin); and (iii) adoption of modern irrigation technology (either mini sprinkler, sprinkler or drip) for all crops across both cropping seasons (yes or no). In addition, farmer demographic, socio-economic data were also gathered to better understand the poverty profile of surveyed households. The sample survey questionnaire is available in Appendix A<sup>2</sup>.

### 3.2 Logistic regression

To assess the impact of the MPWSRP irrigation rehabilitation program (the treatment) on farmers' choice of irrigation technology, we construct a multivariate model using a logistic regression. The model is constructed to test the effect that rehabilitated irrigation infrastructure exert on technology choices after controlling for specific household, hydrological, socio-economic, irrigation, farm location, and well-being characteristics that could potentially be associated with the choice of irrigation technology for the farmers in our sample. A logistic regression is suitable for the analysis as it enables measurement of the difference between the expected change in the outcome variable of interest (whether a farmer uses modern irrigation technologies) among the farmers in the treatment vs. control groups.

Acknowledging potential biases in the random selection of districts in the treatment sample, we construct a logit model with district fixed effects which allow controls for time

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<sup>2</sup> The Madhya Pradesh Water and Land Management Institute (WALMI) was responsible for conducting the survey. To execute the household survey, a strict code of ethics was followed in alignment with the University of Oxford Central University Research Ethics Committee requirements (see <https://researchsupport.admin.ox.ac.uk/files/policyontheethicalconductofresearchinvolvinghumanparticipantsandpersonaldatapdf>). Prior to the start of the household surveys, the lead author led a one-day enumerator training in Bhopal, Madhya Pradesh in November 2015 in partnership with WALMI and Water Resources Department officials, to prime the enumerators from WALMI on the objectives, approach, and questions related to the survey.

invariant district characteristics. We take note of each farmer's self-reported response to the survey question related to the choice of adoption of drip and/or sprinkler technologies by constructing a binary dependent variable for technology adoption. The responses were combined into a single variable labelled “microcurrent” = 1 if farmers reported “yes” to using irrigation technologies in 2015 and “microcurrent” = 0 if farmers reported “no” to using drip or sprinkler irrigation technologies on their farm in 2015 (at the time of the survey). The basic specification is presented in Equation 1.

$$Pr(Microcurrent_{i,d} = 1) = F(\alpha + \beta HighRehab_{i,d} + \beta LowRehab_{i,d} + Micropast_{i,d} + \vartheta X_{i,d} + u_d + e_{i,d}) \quad (1)$$

where  $Microcurrent_{i,d}$ , our binary dependent variable, indicates the probability that a farmer chooses to use drip or sprinkler technologies, where  $i$  indicates the farmer respondent and  $d$  the district location of their farm plot. This variable is equal to 1 if the farmer responds yes to using drip or sprinkler technologies for irrigation on their farm. In Equation 1,  $\alpha$  represents the constant,  $u_d$  stands for the district fixed effects which are included to remove the impact on the choice of irrigation technology due to fixed district-specific characteristics, which could be potentially correlated with our main regressor.  $e_{i,d}$  is a random error term, which we assume to follow a logistic distribution.

The variable  $HighRehab_{i,d}$  is an indicator variable which is equal to 1 if the farm plot of the farmer respondent is located in Treatment Group 2, implying that he has a farm plot in the command area of an irrigation scheme where 30 % or more of the irrigated area was rehabilitated by investments from MPWSRP. The variable  $LowRehab_{i,d}$  is an indicator variable which is equal to 1 if the farmer respondent is in Treatment Group 1, implying that he has a farm plot in an irrigation scheme where 10 % or less of the irrigated area was rehabilitated by investments from MPWSRP. These two variables represent our main explanatory or treatment variables. Comparing the choice of adoption by adding treatment variables with differing degrees of “investment in rehabilitation” by MPWSRP to farmer technology choices in control irrigation schemes (with no MPWSRP investment) allows us to capture the effect of “treatment” on a farmer's choice of adoption.

Based on reports from the World Bank and the Madhya Pradesh Water Resources Department; the following two criteria were used to select irrigation schemes for investment: a) location - MP has 10 river basins (Mahi, Chambal, Sindh, Betwa, Ken, Tons, Son, Narmada, Wainganga and Tapi); irrigation systems were selected from 6 out of the 10 river basins in the state (Chambal, Sindh, Betwa, Ken, Tons and Wainganga) as four river basins were out of the scope of the World Bank project and thus irrigation schemes that were located in Mahi, Son, Tapi, and Narmada river basins were not considered for 'treatment'; and b) the secondary justification was to address the physical engineering needs of the systems, so irrigation schemes that were 20 years or older, which had not been adequately maintained by the WRD and were no longer operating at optimal standards, were selected to receive investment for rehabilitation (Sinha et al., 2018; World Bank, 2005).

Thus, our empirical analysis assumes that 'treatment' (or selection of schemes for rehabilitation investment by the MWPSRP) is randomly assigned, conditional on the (unobserved) level of deterioration of existing irrigation infrastructure that are located in selected intervention river basins within the project area. However, there may be cases where specific investment projects were selected based on socio-economic or political grounds rather than solely on the 'degree of deterioration' of a system. In these cases, we assume that treatment would not be randomly assigned, and this could lead to selection bias due to the 'non-random' targeting of irrigation schemes. Thus, potential issues of endogeneity in the model from 'non-random' scheme selection as well as farmers' unobserved characteristics in their decision to adopt drip/sprinkler cannot be ruled out. These sources of endogeneity represent a limitation of the study, which implies that the effect that the treatment variable exerts on the probability that a farmer will choose to use sprinkler/drip technologies will likely be lower. We interpret the results in terms of potential associations rather than causal linkages between treatment and the choice of adoption of sprinkler and drip technologies.

Next, we include a dummy variable for the choice of adoption of irrigation technologies in the "past" into a single variable labelled "micropast" =1 if farmers reported "yes" to using micro-irrigation in the past (recall of their past technology choices in 2005) and "micropast" = 0 if farmers reported "no" to using drip or sprinkler irrigation technologies in the past. This variable

is included as an independent explanatory variable to determine whether a farmers' choice to use modern irrigation technologies "in the past", is associated with their choice to adopt in 2015.

$X_{i,d}$  identifies a vector of controls. We seek to ascertain the degree to which rehabilitated irrigation systems are correlated with the choice to adopt sprinkler or drip systems in comparison to other important individual, physical, household, socio-economic, hydrological, and irrigation characteristics and practices. To account for varying degrees of socio-economic vulnerability among farmers in our sample, we include a diverse set of farming household characteristics, which are related to household poverty in India (education level, ownership of a BPL card<sup>3</sup>, Kisan credit card<sup>4</sup>, caste classification) and which could also identify whether differing degrees of socio-economic poverty is a determinant of whether households will adopt irrigation technologies (Namara et al. 2007). Indeed, the literature on irrigation technology adoption suggests that a range of socio-economic factors, such as level of education, asset ownership, and farm characteristics help explain adoption of modern irrigation technologies (Genius et al. 2013; Koundouri et al. 2006; Foster and Rosenzweig 2010). We employ information on type of house owned as an additional indicator of household poverty, as research indicates that households that are asset-poor are more likely to be economically poor and vice versa (i.e., owning a house or the type of house structure implies economically better-off households) (Filmer and Pritchett, 2001). Finally, we include other indicator variables related to farm characteristics such as being located at the head of an irrigation canal (ensuring first rights of access to irrigation water), types of preferred irrigation methods (e.g., using flood irrigation, ridge and furrow, or check basin over using sprinkler or drip systems), a farmer's degree of well-being which may contribute to improved agricultural outputs and thus contribute to increased preference for adopting irrigation technologies (Makate et al., 2019; Ogundari and Bolarinwa, 2019), and rainfall zone of the district where the irrigation scheme is located.

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<sup>3</sup> The Food and Supplies Departments of state governments in India issues "Below Poverty Line" ration cards to individuals who are earning an income below the official Government of India poverty line of \$1.90 per day. This card entitles individuals holding these cards to be given subsidized allocations of rice and wheat by the state governments Public Distribution Scheme.

<sup>4</sup> Kisan Credit Card is a credit card to provide affordable credit for farmers in India. It was started by the Government of India, Reserve Bank of India (RBI), and National Bank for Agriculture and Rural Development (NABARD) in 1998-99 to help farmers obtain access to timely and adequate credit for farming.

To select a subset of independent variables from the full list of controls that might influence the outcome variable, we perform a set of specification tests. First, as a screening step, a backward stepwise<sup>5</sup> logistic regression was used to identify possible predictors of a farmer's choice to adopt sprinkler or drip technologies out of 2 treatment variables (High and Low Rehabilitation) and the full set of all 11 candidate variables. To perform the backward elimination stepwise regression, a significance-based stopping rule is employed such that only variables with a significance level of less than 0.20 are retained, thereby eliminating predictor variables considered to have none or negligible effect on the outcome. However, variable selection procedures such as backward stepwise regression are well known to have several shortcomings, such as high instability and a possible bias in parameter estimates (Copas and Long, 1991; Miller, 2002). To investigate model stability and variable selection procedures, methods based on bootstrap resampling are recommended (Sauerbrei and Schumacher, 1992).

Thus, second, we use bootstrap model averaging to consider the stability of the backward stepwise regression selection. We used 1000 bootstrap sub-samples drawn from the original dataset (with replacement) and performed a backward stepwise selection procedure for the different pseudo-samples. We retain variables that have a higher frequency of inclusion in these sub-samples for the final preferred logit regression model. Focusing on the frequency of inclusion of the variables in models derived from the backward stepwise regression and the bootstrap pseudo-samples allows a better understanding for the final model, the importance of the different variables, and their interrelationship (Sauerbrei and Schumacher, 1992). In addition, to test the robustness of the regression results, we checked for multicollinearity against all control dummy variables by using the variance inflation factor (VIF) test (Graham, 2003; Lin, 2008; Marquardt, 1980).<sup>6</sup>

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<sup>5</sup> A stepwise logistic regression procedure involves selection and stopping criteria, and the stepwise approach is a method in which variables are selected either for inclusion or exclusion from the model in a sequential fashion. There are many variations on this approach, but the three main versions of the stepwise procedure are: forward selection (FS), backward elimination (BE), and Efroymson's procedure (a combination of FS and BE; Efroymson, 1960) (Wang et al., 2007). In this article, backward elimination is used as a specification test.

<sup>6</sup> A variable that has a VIF greater than 10 merits further investigation. To check for collinearity, a tolerance value is calculated. This is defined as  $1/\text{VIF}$ . A tolerance value lower than 0.1 is comparable to a VIF of 10. This indicates that the variable could be considered a linear combination of other independent variables.

### 3.3. Semi-structured interviews

In August-September 2018 we conducted telephone interviews with a smaller sub-sample of farmers from the 918 households to develop a qualitative understanding of the drivers of irrigation adoption choices and nuance the quantitative regression results<sup>8</sup>. We pre-selected all farmers who had previously been surveyed in 2015, who responded “yes” to sprinkler/drip use and a small percentage of farmers who had responded “no” to sprinkler/drip use. Out of the total sample of 918 farmers surveyed, 49 farmers (5.3%) reported using either sprinklers (mini and normal) or drip technologies. A total of 80 farmers were selected at random to participate in the telephone interviews (49 farmers out of the 918 who replied “yes” and 31 farmers who replied “no”). All farmers who participated in the telephone surveys are male and members of WUAs. Out of the 80 farmers contacted for the telephone surveys, 26 (32.5%) survey responses were successfully recorded and analyzed, due to issues of availability.

An overview of the profile and location of each of the 26 farmers interviewed is provided in Appendix C. All farmers were interviewed directly by the main author in Hindi, following clearance from the University of Oxford’s Central University Research Ethics Committee. Interviews were recorded and transcribed verbatim. Each interview lasted between 30-45 minutes as each question was designed in an open-ended manner to enable respondents to provide as much detail as they wished. The questionnaire utilized for the semi-structured telephone interviews is provided in Appendix B. While the sample of semi-structured interviews (n=26) is small and does not represent a robust sample size for statistical tests to determine causality and isolation of the effects of the two policies under review in this study, it does provide nuance to our statistical and household survey results. This allows us to build a multi-faceted analysis of the drivers of irrigation practices among a sample of farmers.

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<sup>8</sup> While face-to-face interviews would have been preferred, due to resource and time constraints semi-structured interviews were conducted over the telephone. These interviews enabled us to have the opportunity to discuss factors driving farmer choices for modern irrigation technology adoption, broader farming practices, and develop a better understanding of the social context of farming households in the study area.

## 4. Results

### 4.1 Sample characteristics

#### 4.1.1 Socio-economic characteristics and well-being perceptions

Table 4 presents descriptive statistics results related to the socio-economic and well-being characteristics of farmers in the household survey. We present characteristics by dividing the sample among the farmers who reported never using modern irrigation technologies (e.g., this sample constitutes farmers who reported using flood irrigation, border strip, ridge and furrow, or check basin irrigation methods and never using drip/sprinklers on their farms) (n=866) and those adopting drip or sprinkler technologies (n=49), with three responses dropped for lack of data.

Farmers who never adopt modern irrigation technologies are more likely to live in a permanent house, to be a member of the General caste group, and to report better-off and the same well-being perceptions in comparison to farmers who adopt modern irrigation technologies (Table 4). Farmers who report using drip or sprinkler irrigation are more likely to hold a BPL card, live in a temporary house, and are more likely to be a member of the Scheduled Caste group, compared to farmers who never use modern irrigation technologies. Literature evidence highlights the hierarchical complexity of caste in India. Work by Berchoux and Hutton (2019) in India shows that members of socio-economically deprived caste groups (e.g., Other Backwards Caste (OBC), Scheduled caste and Scheduled tribe) suffer from social and economic exclusion, from a lack of access to certain types of assets and even from a social unacceptability to undertake some activities. Thus, we include controls for possible non-linear effects between specific socio-economic vulnerability variables (e.g., the caste of the farmer, whether the farmer owns a BPL card or a Kisan Credit card, and the number of years of education he received) and the probability that a farmer will choose to use modern irrigation technologies on his farm. This type of analysis enables us to test whether a farmers' degree of poverty (e.g., owning a BPL card, years of education, membership in a socio-economically deprived caste group such as Scheduled caste or tribe) is correlated with the choice of modern irrigation technology in comparison to the sample that are relatively 'non-poor' (e.g., members of the General caste, who do not own BPL cards, etc.).



More than half (52%) of farmers adopting modern irrigation technologies perceive their well-being to be worse off when compared to the past (e.g., recall of their well-being status in 2005). In contrast, a greater share (43%) of non-adopting farmers perceive their well-being to have improved (column A, Table 4). These initial results suggest that farmers adopting sprinklers or drip systems on their farms are relatively more impoverished or socio-economically vulnerable than farmers not using modern irrigation technologies.

**Table 4.** Farmer socio-economic status and well-being perceptions by technology adoption. *Italicized p-values denotes cases where p-values are less than 0.05 and the mean between columns A and B is non-zero.*

Independent Variables	A. No adoption (n=866)	B. Adoption (n=49)	C. Difference in mean (%)
	Mean (st.dev)	Mean (st.dev)	(A-B) (p-value)
Age (years)	47 (12.2)	44 (12.5)	2 (0.18)
Holds Below Poverty Line Card	0.25 (0.43)	0.52 (0.50)	-27 (0.00)
Holds Kisan Credit Card	0.29 (0.45)	0.20 (0.41)	8 (0.22)
Highest Education (years)	8 (3.52)	9 (2.94)	-0.8 (0.16)
<b>House Type</b>			
Permanent House	0.54 (0.50)	0.35 (0.48)	20 (0.00)
Semi-permanent house	0.11 (0.31)	0.16 (0.37)	-6 (0.21)
Temporary house	0.35 (0.48)	0.49 (0.51)	-14 (0.05)
<b>Caste</b>			
General	0.33 (0.47)	0.16 (0.37)	17 (0.01)
Other Backwards Caste	0.58 (0.49)	0.65 (0.48)	-8 (0.29)
Scheduled Tribe	0.01 (0.08)	0.00 (0)	0.5 (0.60)
Scheduled Caste	0.08 (0.28)	0.18 (0.39)	-10 (0.02)
<b>Well-being perceptions</b>			
Worse off with respect to the past	0.19 (0.39)	0.52 (0.51)	-34 (0.00)
Same with respect to the past	0.38 (0.49)	0.20 (0.41)	18 (0.02)
Better off with respect to the past	0.43 (0.50)	0.27 (0.45)	16 (0.04)

#### 4.1.2 Quality of irrigation infrastructure, irrigation source, and technology adoption

Tables 5 and 6 present descriptive statistics results related to the irrigation sources, quality of irrigation infrastructure, and preferred modern irrigation technology of farmers in the sample. Table 5 shows that in the control irrigation schemes, farmers are more likely to use groundwater (45%) (defined as the use of dug wells or bore wells or both in our survey) for irrigation compared to 18% of farmers residing in areas where MPWSRP investments were made (treatment schemes). Farmers in the treatment schemes are more likely to rely on canal irrigation (57%) compared to farmers in the control schemes (41%). Reliance on surface irrigation from canals in treatment schemes increased from 41% (in 2005) to 57% (in 2015), with t-test results in 2015 showing statistically significant p-values for use of canal irrigation if a farmer is located within a treatment irrigation scheme. This signals that the MPWSRP rehabilitation investments did lead to some change in the primary source of irrigation for farmers located in treatment schemes, with more farmers relying on surface irrigation and reducing their groundwater use compared to 2005. On the other hand, reliance on groundwater irrigation remained the same (45%) in the control schemes from 2005 to 2015.

**Table 5.** Main source of irrigation in 2005 and 2015. *Italicized p-values denotes cases where p-values are less than 0.05 and the mean between columns A and B is non-zero<sup>9</sup>.*

Independent Variables	A. Control No rehabilitation  Mean (st.dev)	B. Treatment Rehabilitation  Mean (st.dev)	C. Difference in mean (%)  (A-B) (p-value)
<b><i>Primary Source of Irrigation (rabi cropping season) 2005</i></b>			
Groundwater (dug well and/or bore well) (n=295)	0.45 (0.50)	0.21 (0.41)	24 (0.00)
Canal water (n=363)	0.38 (0.49)	0.41 (0.49)	-3 (0.37)
<b><i>Primary Source of Irrigation (rabi cropping season) 2015</i></b>			

<sup>9</sup> Values in Table 5 do not sum to 100% as farmers had the option to choose “I do not know” as a potential response to the query asking them about their main source of irrigation in the past (2005) and the option to choose river or pond as additional irrigation sources along with “I do not know” in the present (2015) in the questionnaire (see Annex A). The results reflected in Table 5 are indicative of the sample which selected groundwater or canal water in their response to this query (n values are specified) but excludes data from farmers who selected “I do not know” or river/pond as the response to this query.

Groundwater (dug well and/or bore well) (n=278)	0.45 (0.50)	0.18 (0.38)	27 (0.00)
Canal water (n=456)	0.41 (0.49)	0.57 (0.50)	-16 (0.00)

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Table 6 presents details about the differences in irrigation sources and irrigation methods, farm plot location, and the quality of irrigation infrastructure availability between adopting and non-adopting farmers. As is expected, for main irrigation method, adopting farmers are more likely to use drip/sprinkler technologies (column B, Table 6). In addition, a small percentage of adopting farmers are more likely to use check basin irrigation methods compared to non-adopting farmers. Adopting farmers are also more likely to experience a) deteriorated irrigation flow in their canals, b) canal breaches that are unchanged, and c) deteriorated conditions of siltation in their surface irrigation canals. Although, farm plot location t-test values are not significant, more adopting farmers are situated at the tail-end of the canal system (45%), where traditionally water availability is limited if the canal networks are poorly maintained, compared to non-adopting farmers (33%) (Table 6).

Non-adopting farmers are evenly distributed at the head (32%), middle (35%) and tail-end (33%) of the canal (column A, Table 6). Non-adopting farmers are more likely to use canal irrigation as their main source of irrigation and use flood irrigation as their main irrigation method, have improved irrigation water flow in their canals, canal breaches that are repaired, and improved silt conditions of their irrigation canals compared to non-adopting farmers. Rainfall profiles are not associated with outcomes for both adopting and non-adopting farmers.

In summary, the results indicate that farmers are more likely to use drip and/or sprinkler technologies when they have limited surface water availability and thus face higher production risk, due to the lack of surface irrigation from deteriorated canal water flow, breached, and silted canals. The results also indicate, however, that 20% of the sample of adopting farmers report canal irrigation as their primary source of irrigation, while also using drip or sprinklers on their farms (column B, Table 6). Conversely, farmers who report never using sprinkler/drip irrigation technologies are more likely to be located on farms in districts where canal systems have been rehabilitated by the MPWSRP, as they are more likely to have improved water flow in their canals, breaches that are repaired and reduced silt in their canals. This initial result implies that readily

available canal water reduces farmers' perceptions of production risks arising from water scarcity, thus potentially lowering incentives to adopt modern irrigation technologies.

**Table 6.** Difference in irrigation source, irrigation methods, and quality of irrigation infrastructure by technology adoption (*Italicized p-values denotes cases where p-values are less than 0.05 and the mean between columns A and B is non-zero*).

<b>Independent Variables</b>	<b>A. No adoption (n=866)</b>	<b>B. Adoption (n=49)</b>	<b>C. Difference in mean (%)</b>
	<b>Mean (st.dev)</b>	<b>Mean (st.dev)</b>	<b>(A-B) (p-value)</b>
<b><i>Farm Plot Location in Command Area</i></b>			
Head of canal	0.32 (0.47)	0.31 (0.47)	1 (0.86)
Middle of canal	0.35 (0.48)	0.24 (0.43)	10 (0.14)
Tail-end of canal	0.33 (0.47)	0.45 (0.50)	-12 (0.10)
<b><i>Primary Source of Irrigation (rabi cropping season)</i></b>			
Groundwater (dug well and/or bore well)	0.30 (0.46)	0.37 (0.46)	-7 (0.32)
Canal	0.51 (0.50)	0.20 (0.41)	31 (0.00)
<b><i>Main Irrigation Method (rabi cropping season)</i></b>			
Flood irrigation	0.86 (0.35)	0.59 (0.36)	27 (0.00)
Drip/sprinkler	0.00 (0.00)	0.24 (0.43)	-24 (0.00)
Ridge & furrow	0.02 (0.12)	0.04 (0.20)	-3 (0.18)
Border strip	0.12 (0.32)	0.08 (0.28)	4 (0.43)
Check basin	0.01 (0.07)	0.04(0.20)	-4 (0.00)
<b><i>Irrigation Water Flow in Canals</i></b>			
Improved irrigation flow	0.29 (0.45)	0.10 (0.31)	19 (0.00)
Deteriorated irrigation flow	0.38 (0.49)	0.71 (0.46)	-33 (0.00)
Flow unchanged	0.23 (0.42)	0.12 (0.33)	11 (0.09)
<b><i>Repair of Canal Breaches</i></b>			
Breaches repaired	0.24 (0.43)	0.02 (0.14)	22 (0.00)
Breaches worsened	0.34 (0.48)	0.37 (0.49)	-2 (0.72)

Breaches unchanged	0.26 (0.44)	0.59 (0.50)	-34 (0.00)
<b><i>Siltation Condition of Canals</i></b>			
Improved condition	0.27 (0.44)	0.04 (0.20)	23 (0.00)
Deteriorated condition	0.34 (0.48)	0.57 (0.50)	-23 (0.00)
Siltation condition unchanged	0.22 (0.42)	0.31 (0.47)	-9 (0.16)
<b><i>Rainfall Zones of Farm Location</i></b>			
Low	0.46 (0.50)	0.43 (0.50)	3 (0.66)
Average	0.30 (0.46)	0.27 (0.45)	4 (0.58)
High	0.24 (0.43)	0.31 (0.47)	-7 (0.27)

## 4.2 Regression analysis

### 4.2.1 Results of specification tests

Starting with 2 treatment variables and 11 control variables that might theoretically be good predictors of whether a farmer chooses to adopt drip or sprinkler technologies (column 1), we report the estimated regression coefficients and associated 95% confidence intervals for all specification tests in Table 7. The backward stepwise logistic regression model with a significance level of 0.20 for variable retention, retains 1 treatment variable (high rehabilitation) and 6 predictor variables (column 2); while the bootstrap model averaging procedure (with backwards elimination) retains the treatment variable for ‘high rehabilitation’ and 7 predictor variables (column 3, Table 7). We note that in column 3, well-being is retained whereas it was dropped in the conventional backward stepwise regression in column 2. We also note that the treatment variable ‘Low Rehabilitation’, and the control variables of Years of Education, Holds Kisan Credit Card, Caste, and House Type are never retained in the conventional backwards stepwise regressions or the bootstrap model averaging pseudo-samples.

In comparing the estimated regression coefficients, Table 7 indicates that coefficient estimates are never identical, but for all retained variables, the bootstrap model averaging variable coefficients (column 3) are closer to those of the backward stepwise variable selection model (column 2), except in a few instances (e.g. high rainfall). The result of the bootstrap model averaging among 1000 sub-samples with backwards elimination results in a better estimation of

regression coefficients and confidence intervals compared with that of the logistic regression model prior to specification tests (in column 1) and from the logistic model obtained using conventional backwards variable elimination (column 2). Thus, we rely on the model specification from column 3 for building our final preferred logit model and for further interpreting the results of our main explanatory variable. The final preferred logit model includes the treatment variable for high rehabilitation and the controls related to micro-irrigation adoption in the past, Holds BPL Card, Farm Location, Rainfall Zones, irrigation methods, well-being, and district fixed effects. We note that this final preferred specification includes a diversity of predictors to include as control variables including technology use in the past, socio-economic poverty variables, farm plot location, type of irrigation method, and hydrological variables.

**Table 7.** Results of estimated coefficients and 95% confidence intervals for all specification tests

Variable	Logit model (pre-specification tests) (13 main effects) (1)	Backwards stepwise elimination regression results (2)	Bootstrap model averaging selection results (3)
Micro-irrigation adoption in the past	4.09 (2.30, 5.87)	3.05 (1.23, 4.86)	3.11 (1.42, 4.79)
High Rehabilitation	-0.67 (-1.73, 0.39)	-0.93 (-1.72, -0.14)	-0.91 (-1.54, -0.27)
Low Rehabilitation	0.11 (-2.22, 2.43)		
Years of Education	-0.09 (-2.86, 0.10)		
Holds BPL Card	0.63 (-0.38, 1.65)	0.42 (-0.13, 0.96)	0.39 (-0.47, 1.26)
Holds Kisan Credit Card	-0.59 (-1.67, 0.48)		
<b>Caste</b>			
Scheduled caste	0.63 (-0.64, 1.91)		
Scheduled tribe			
General caste	-0.42 (-2.25, 1.40)		
<b>Farm location</b>			
Head of canal	0.22 (-0.80, 1.234)		
Middle of canal	-1.08 (-2.63, 0.47)	-0.82 (-1.64, 0.002)	-0.83 (-1.59, -0.08)
Tail-end of canal			
<b>Irrigation method</b>			

Drip and sprinkler technologies			
Border strip	0.17 (-0.62, 0.97)		
Ridge and Furrow	1.21 (-0.09, 2.51)	1.09 (-0.72, 2.89)	1.13 (-0.56, 2.81)
Check basin			
<b>Rainfall zone</b>			
Low Rain			
Average Rain	-2.80 (-4.90, -0.71)	-0.49 (-2.26, 1.29)	
High Rain	2.10 (0.77, 4.12)	1.93 (1.07, 2.80)	2.26 (1.00, 3.52)
<b>House type</b>			
Permanent	-0.06 (-0.89, 0.76)		
Semi-permanent	-0.04 (-1.22, 1.13)		
Temporary			
<b>Well-being</b>			
Better-off than the past			
Same as the past	-0.87 (-2.24, 0.51)		-0.66 (-1.63, 0.31)
Worse-off than the past	-0.64 (-2.47, 1.19)		
<b>District</b>			
Gwalior	1.24 (-0.35, 2.83)	0.99 (0.24, 1.74)	1.13 (0.36, 1.90)
Ujjain	5.13 (2.12, 8.13)	1.49 (-0.66, 3.63)	1.46 (0.20, 2.71)
Neemuch	5.28 (2.29, 8.27)	2.37 (0.37, 4.38)	2.22 (1.18, 3.26)
Vidisha	0.38 (-1.66, 2.42)	-0.84 (-1.01, -0.67)	-0.45 (-1.18, 0.27)
Katni	3.82 (-0.12, 7.76)	1.69 (-0.85, 4.22)	1.32 (-0.46, 3.09)
Sagar	0.43 (-2.49, 3.35)	0.18 (-1.27, 1.64)	0.08 (-1.53, 1.68)
Tikamgarh	2.75 (-0.83, 6.33)	2.51 (1.89, 3.14)	2.95 (1.86, 4.03)
Shajapur			
Shivpuri			

**Note:** Each cell contains the estimated regression coefficient and the associated 95% confidence interval. Empty cells indicate no values.

#### 4.2.2 Final logit regression estimation

We present results for the effect of irrigation rehabilitation on the probability of a farmer adopting modern irrigation technologies based on our preferred logit model in Table 8. The unit of observation is for an individual farmer, and different columns add different control variables to the initial regression (column 1, Table 8). Robust standard errors, which are clustered at the district-level, are reported in parentheses below each coefficient at the 10, 5 and 1% levels of significance.

The use of drip or sprinkler technologies in the past is included as a first level of control in the regression. The coefficient for farmers adopting modern irrigation technologies in the past remains stable, positive and significant at the 1% level with district fixed effects and after controls for rainfall, BPL card ownership, farm plot location, irrigation methods, and well-being are added (columns 1-6, Table 8). This result reveals that past use of modern irrigation technologies is positively associated with a farmer's willingness to continue using sprinklers or drip systems on their farms in 2015, at the time of the survey. These results also indicate that the effect of "past adoption choices" on present irrigation technology choices for farmers increases gradually as more controls are added, illustrating that despite different parameters for measuring socio-economic poverty, geographic, hydrological, and irrigation practices among households, once a farmer starts using modern irrigation technologies, he is likely to continue doing so. We explore the potential causes driving this choice in Section 4.3, which presents the results of the qualitative interviews.

The first column is the basic specification with district fixed effects, which reveals that the coefficient for a high degree of rehabilitation is not significant. In columns 2-6, we include controls for the rainfall zone of the district where the farmers' farm plot is located, whether he owns a BPL card, the location of the farm plot, choice of irrigation methods, and relative change in well-being with respect to the past. Like column 1, the results in columns 2-3 indicate that the coefficient for "high rehabilitation" is not significant after controlling for rainfall and BPL card ownership. However, in columns 4-6, the coefficient for high rehabilitation is negative and significant, after additional controls for farm location, irrigation methods, and well-being are added with district fixed effects. As more controls are added, the degree of significance goes up from 10% (column 4) to 1% (column 6). This reveals that a higher degree of rehabilitation of an irrigation system is potentially correlated with a reduction in the probability that a farmer will use sprinkler or drip



systems on his farm compared to farmers without access to rehabilitated irrigation canals, after controlling for district-specific, past technology use, socio-economic, hydrological, farm location, irrigation practices, and well-being characteristics.

Controls related to rainfall zones reveal that farmers that reside in districts with above average or high levels of rainfall are more likely to adopt modern irrigation technologies, regardless of the types of controls included in columns 2-6. Although, the summary statistics revealed that rainfall zone variables are not associated with the adoption preferences for farmers, the logit estimation reveals that high rainfall is positively associated with the probability that a farmer will use sprinkler/drip systems on their farms.

Column 3, Table 8 shows that having a BPL card has a positive and significant correlation with the probability that a farmer will adopt modern irrigation technologies at the 10% level which aligns with descriptive statistics results (Table 4). However, once additional controls for farm location, irrigation methods, and well-being are included, this coefficient is no longer statistically significant. In addition, the coefficient for 'well-being', is not statistically significant (column 6, Table 8). This implies that factors related to household poverty are not necessarily correlated with modern irrigation technology adoption preferences among the farmers in our sample. These results are contrary to what has been observed in the microeconomics literature (Koundouri et al. 2006; Foster and Rosenzweig, 2010; Abdulai and Huffman, 2014) where human capital and higher income levels are found to generally increase the probability of farmers adopting new technologies. This finding raises important questions around what is causing this effect in our sample, which was outside of the scope of this study, and warrants further exploration in future studies.

Columns 4 and 5, Table 8 reveals that the coefficient for farm plot location, specifically if a farmers' plot is in the middle of the canal command area, is negative and significant at the 10% level, for whether a farmer chooses to adopt modern irrigation technologies. The significance level is negative and significant at the 5% level (column 6, Table 8), when additional controls are included. Although summary statistics did not indicate significant results with adoption trends and farm plot location, this finding reveals that farm plot location in the middle of an irrigation canal is negatively associated with a farmers' choice to adopt modern irrigation technologies. We note that the variable for choice of irrigation methods, specifically the coefficient for ridge and furrow irrigation methods, are never significant in the model, regardless of the types of controls

included (columns 5 and 6, Table 8). Overall, we found no evidence of multicollinearity with any of the control variables in any of the model specifications, after running the VIF tests.

**Table 8.** Results of logit estimation with controls.

Dependent variable: Microirrigation adoption in 2015 with (1)-(6) model specifications						
	District FEs (1)	Including rainfall (2)	Including BPL card (3)	Including farm location (4)	Including irrigation methods (5)	Including well-being (6)
Microirrigation adoption in 2005	2.85*** (1.11)	2.86*** (1.06)	2.99*** (1.01)	3.02*** (0.96)	3.02*** (0.95)	3.11*** (0.86)
High Degree of Rehabilitation	-0.17 (0.37)	-0.58 (0.47)	-0.67 (0.47)	-0.81** (0.41)	-0.93** (0.40)	-0.91*** (0.32)
High Rain		1.94*** (0.54)	1.97*** (0.53)	2.02*** (0.55)	2.05*** (0.56)	2.26*** (0.64)
Holds a BPL Card			0.46* (0.24)	0.39 (0.26)	0.42 (0.28)	0.39 (0.44)
Middle of canal				-0.78* (0.44)	-0.81* (0.42)	-0.83** (0.38)
Ridge and furrow					1.08 (0.94)	1.13 (0.86)
Same with respect to past						-0.66 (0.49)
Constant	-3.35*** (0.09)	-5.27*** (0.56)	-5.38*** (0.60)	-5.16*** (0.69)	-5.19*** (0.70)	-5.37*** (0.80)
District FEs	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo $R^2$	0.28	0.29	0.30	0.31	0.31	0.33
Observations	873	873	865	829	804	781

Standard errors in parentheses  
Robust standard errors clustered at the district level.  
\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

To interpret the results in Table 8, we present the Average Marginal Effects in Table 9 for coefficients that are significant (either negative or positive). The difference in the AME results illustrates that, keeping all factors constant, areas with a higher degree of rehabilitation are correlated with a 3-4% reduction in the probability that farmers would adopt modern irrigation technologies compared to farmers where irrigation schemes were never rehabilitated, once additional controls related to farm plot location, irrigation methods, and well-being are included (columns 4-6, Table 9). Results for high rehabilitation, which are not statistically significant, are included in columns 1-3 (Table 9). This is complemented by the results for farm location, which

indicates that farms located in the middle of an irrigation canal command area are, on average, correlated with a 3% reduction in the probability that a farmer would chose to adopt modern irrigation technologies. These results are stable and consistent despite additional controls added to the model and supports the result that improved irrigation supply by means of rehabilitation is likely associated with a reduced willingness among farmers to invest in irrigation technologies.

**Table 9.** Average Marginal Effects (AME) of the effect of high degree of rehabilitation on the probability of adopting modern irrigation technologies and other variables

Variables	Basic logit estimation with District FE (dy/dx) (Standard error)	Full estimation with rainfall (dy/dx) (SE)	Full estimation with BPL card ownership (dy/dx) (SE)	Full estimation with farm location (dy/dx) (SE)	Full estimation with irrigation methods (dy/dx) (SE)	Full estimation with well- being (dy/dx) (SE)
	(1)	(2)	(3)	(4)	(5)	(6)
High Rehabilitation	-0.01 (0.03)	-0.02 (0.02)	-0.03 (0.02)	-0.03** (0.01)	-0.04** (0.01)	-0.03*** (0.01)
Micro- irrigation adoption in the past	0.11*** (0.03)	0.11*** (0.03)	0.12*** (0.03)	0.12*** (0.02)	0.13*** (0.03)	0.12*** (0.02)
Rainfall – High rain		0.08*** (0.02)	0.08*** (0.02)	0.08*** (0.02)	0.09*** (0.02)	0.09*** (0.03)
Holds BPL Card			0.02* (0.01)			
Farm location – middle of canal				-0.03* (0.02)	-0.03* (0.02)	-0.03** (0.02)
N	873	873	865	829	804	781

The AME for adoption of modern irrigation technologies in the past, shows that there is a 12% increase, on average, in the probability that a farmer will use modern irrigation technologies in 2015, if he was using them in the past (columns 1-6, Table 9). The results in Table 9 reveal that the variable for adoption in the “past” is strong and stable and its magnitude is even

higher than that of the treatment variable. This implies a strong path dependency in technology adoption. For example, this could be due to some of the following factors: once farmers start using the technologies, they experience the benefits of adoption firsthand and continue using them on their farms.

The AME for rainfall levels reveals that there is an 8-9% increase, on average, in the probability that a farmer will use modern irrigation technologies in 2015, if the areas where his farm plot is located receives above average rainfall, coinciding with the results in columns 2-6 (Table 8). Further exploration, which was out of the scope of this paper, is needed to better understand why farmers in areas with high rainfall are more likely to adopt modern irrigation technologies.

#### **4.3. Attitudes, perceptions, and beliefs: evidence from semi-structured interviews**

Of the 26 farmers interviewed in 2018, 18 (69 %) reported “never” having used drip or sprinklers either in the past or at present, 7 (27 %) reported “always” using modern irrigation technologies (prior to 2015 and continuing to the present), and only 1 (4 %) farmer was not using drip or sprinklers in 2005 but was using it at the time of the interview. All adopting farmers self-reported using sprinkler systems (either mini or large sprinklers) and only 2 farmers out of the 8 reported using both drip and sprinkler systems simultaneously. Interviewees reported that they have farm plots ranging from less than 1 ha, 1.5 ha to 3-5 ha, and up to 10 ha in size. Adopting farmers reported growing wheat with sprinklers during the *rabi* season along with crops such as chickpeas, mustard, onions, garlic, and coriander. Those using drip systems reported growing chilies and 1 farmer reported growing a variety of golden apples with mini sprinklers.

In terms of geographical distribution of farms, 18 of the farmers interviewed come from treatment irrigation schemes and eight are from control irrigation schemes (see table in Appendix C). Out of the 18 farmers from the treatment irrigation schemes, 14 (78 %) report never using sprinkler/drip irrigation technologies and four (22 %) are adopters. Out of the eight farmers from the control irrigation schemes, four (22 %) report adopting sprinkler/drip technologies and four are non-adopters.

Among the non-adopting farmers, farm plots ranged from small sizes of less than 1 ha (5 farmers), to 4-5 ha, to larger plots ranging from 10 ha up to a maximum of 20 ha. These farmers

reported growing a mixture of soybeans, lentils, corn, peanuts and/or rice during the *kharif* or summer cropping season and wheat and/or chickpeas during the *rabi* or winter cropping season – with some growing crops such as mustard and peas, in addition to wheat. Five common themes emerged from analysis of the interviewee responses and are described below, supplemented with direct quotes from the interviews.

Water stress incentivizes adoption: A majority of adopting farmers (7 out of 8) stated that one of the main reasons for adoption was due to deficient monsoons resulting in limited irrigation water and/or inadequate availability of water from canal systems. Water stress, therefore, seems to be influencing farmers' decisions to start using sprinkler or drip systems, which enables them to continue to farm the same basket of crops while experiencing reduced water availability for irrigation. In contrast, non-adopting farmers (15 out of 18) decided not to use sprinkler or drip systems because of the increased and more reliable irrigation water availability following rehabilitation, which enabled them to flood irrigate their farms. Non-adopting farmers who have farms in irrigation schemes with MPWSRP investments all reported using flood irrigation methods.

*When the rains were deficient, farming became very difficult for me. Now there are new technologies for irrigation even when there is deficient rain, I use modern irrigation systems. For example, this monsoon season, rainfall is very deficient, and I see that my sprinkler systems are very effective - I can still grow my crops. Now I see that many farmers are using this technique on their farms in my village* (Farmer in Neemuch, no rehabilitation scheme, average rainfall).

*I have adequate surface irrigation canals and I get good access to water and I don't need to do micro-irrigation* (Farmer in Katni, low rehabilitation scheme, average rainfall).

Adoption leads to time and efficiency gains: Adopting farmers reported time and efficiency gains, as they found that they could irrigate a larger area of land in less time. In contrast, farmers using flood irrigation reported spending more time on their farm to ensure water flows into their fields and physically move pipes.

*I decided to switch to sprinklers - because it was hard to always do flood irrigation and it used to take a lot of hard work, now I can set the sprinklers and do my own house work and I can just leave them to irrigate my farm field; they take less time to irrigate and I*

*don't have to be continuously sitting at my farm field and wait for the water to flood the field” (Farmer in Katni, low rehabilitation scheme, average rainfall).*

Information changes behavior: Information about modern irrigation technologies, its utility and benefits, and state subsidy opportunities, emerged as a key factor influencing adoption. Non-adopting farmers, especially farmers that self-reported good surface irrigation supply, stated that they had received little to no information on how to use sprinklers or drip technologies and their benefits. Farmers also pointed out the difficulties they faced in accessing information about the state subsidy, which contributed to reduced willingness to adopt. Lastly, farmers claimed that improved knowledge and training about irrigation technology would increase their willingness to adopt.

*No one has explained modern irrigation techniques to us - we do not know how to use them, and we don't have any information about them - no one in our local market has explained anything about the subsidies we can receive from the government. I am currently doing flood irrigation in my farm – all farmers in my village are doing irrigation in the same way (Farmer in Tikamgarh, low rehabilitation scheme, low rainfall).*

*We are very stressed from big farmers (like me) to small farmers in my village, as we have not received any information on the government subsidy programs for purchasing irrigation technologies and I have tried in several places to find out how it works but I have not been able to find out anything. I want to find out how to get the subsidy, so I can start using modern irrigation techniques (Farmer in Shivpuri, WUA president, low rehabilitation scheme, low rainfall).*

Social networks influence farmer irrigation choices: The power of personal family and social networks emerges as a key driver influencing adoption. All eight adopting farmers reported first meeting a family member, relative, neighbor, or friend using drip/sprinkler systems and benefiting from the use, which encouraged them to subsequently adopt. Non-adopting farmers stated that they did not adopt these technologies because they did not know anyone in their social network or village using them and preferred using flood irrigation. Farmers indicated that their irrigation choices are heavily influenced by the behavior of their neighbors. Specifically, among close knit farming communities, farmers reported that they preferred to watch, learn, and imitate one another.

*If no one is using sprinklers or drip technologies then I am not doing it - my big brother who has a farm next to mine - doesn't use these technologies - so I also don't do it (Farmer in Gwalior, High rehabilitation scheme, low rainfall).*

*I first saw that my relative was using sprinklers and he lived close to me (about 15-20 km away) and I went to see his farm and he has been using irrigation technologies since 2001. He taught me how to do it and then I saw it and started doing it as well. In 2010, I bought the equipment in the market and there was no information on the subsidy then, so I bought it at full price (Farmer in Katni, low rehabilitation scheme, average rainfall zone).*

*Yes, neighbors we watch each other – we all see each other's techniques easily because we have a small village - we copy each other, and we see what the other is doing and then we imitate it. We all have the same techniques; we are all using mini-sprinklers now on our farms. (Farmer in Neemuch, no rehabilitation scheme, average rainfall).*

Access to the state subsidy matters: Several farmers reported issues of affordability, restrictions to subsidy access, and high upfront costs required to purchase modern irrigation equipment as factors prohibiting adoption. Specifically, lack of access to the state-wide subsidy scheme emerged as a major barrier to adoption. Out of the farmers that were aware of the subsidy, many reported that they were unsuccessful as local government officers in charge of administering the subsidy often asked for a bribe.

*Buying the equipment from the market at full price is not possible for me, I would need to get access to the subsidy from the government, but I have no information about the subsidy (Farmer in Katni, low rehabilitation scheme, average rainfall zone).*

*Yes I would think about using modern irrigation technologies - in the past some people have come to tell us about the subsidy for purchasing drip or sprinklers and have told us this is what you need to do to get the subsidy but I went to the Tehsil village leader and I wanted to access the subsidy - I couldn't get access to the funds because they wanted a "cut" from all the farmers [he refers to local officials who are in charge of providing the subsidy] - as I refused to pay the bribe they refused to give me the subsidy. This issue is everywhere, if you don't pay the bribe to the official - you don't get the benefits. I would use modern irrigation technologies if the subsidy were provided to me (Farmer in Katni, low rehabilitation scheme, average rainfall).*

## 5. Conclusion and Policy Implications

Governments and donors around the world spend millions of dollars improving irrigation infrastructure and subsidizing sprinkler and drip irrigation technologies to incentivize farmers to enhance the productivity and sustainability of water use in the face of climate change. This study takes the case of a World Bank and Government of Madhya Pradesh irrigation rehabilitation and subsidy program to understand how these policy actions interact with farmers' water use behaviors and choices for adopting modern irrigation technologies.

The findings suggest that MPWSRP rehabilitation investments were successful in achieving the intended objective of reducing farm dependence on groundwater irrigation and increasing reliance on surface water from canals for food production. However, results suggest that, once there is a higher degree of rehabilitation, farmers are less likely to adopt modern irrigation technologies compared to areas where systems are not rehabilitated. This result allows us to conclude, that rehabilitated irrigation canals are potentially associated with a decrease in the probability that a farmer will use irrigation technologies on his farm, compared to farmers with canal systems that were never rehabilitated. However, a low degree of investment in rehabilitating irrigation canals covering a smaller irrigated area does not seem to matter for technology adoption.

Although multiple factors contribute to farmer adoption decisions, insights from the descriptive statistics and semi-structured interviews generally support the quantitative results, revealing that better quality of canals and adequate quantity and timing of surface irrigation water to farm fields, which are associated with a high degree of rehabilitation, may contribute to the reduced likelihood that farmers will adopt sprinkler or drip systems. From the farmer interviews, we learn that the availability of canal water influences farmers' perceptions of water shortages impacting future yields: as water becomes more readily available, farmers have fewer incentives to hedge water scarcity risks through purchasing modern irrigation technologies that use less water but require more upfront financial investment. This is supported by existing findings from the global literature, which highlights the role of production risk in influencing an irrigators' decision to adopt technologies (Dinar and Yaron, 1990; Koundouri et al. 2006). In addition, the qualitative findings expose that in the absence of observing someone in their social network adopt or receiving information about the subsidy program or experiencing the benefits of modern



irrigation technologies firsthand, farmers perceive that sprinkler and drip technologies are not relevant for them once access to surface water supply is improved.

These findings have four policy implications. First, the finding that “past” adoption is strongly correlated with the likelihood of “present” adoption implies that once farmers begin using modern irrigation technologies on their farms, irrespective of the degree of rehabilitation of the canal or other hydrological or socio-economic controls, there is an increased probability that they will continue using them. This finding is likely associated with the net marginal benefits that farmers experience after adopting the technologies, which are also supported by the benefits that adopting farmers described to us during the interviews (e.g., yield, time, and efficiency gains), which appear to outweigh the upfront costs of purchasing and maintaining modern irrigation technologies. The results from the model specifications are reflected in the qualitative interviews as we note that 7 out of 8 “adopting farmers” in our sample, indicated that they had started using sprinkler/drip technologies in the “past” and all of them confirmed they first learned about the technology benefits from someone within their personal network. This finding aligns with existing literature that cites the profit maximizing attribute of irrigator decision-making around technology adoption (e.g., Perez-Blanco et al. 2020). However, the caveat of this finding is that overall adoption rates are still quite low (below average) in Madhya Pradesh, reflected by the fact that only 5% of the overall sample in this study adopted sprinkler/drip technologies. The implication of this result for policy is that once the right set of incentives are in place to enable adoption at scale, farmers in Madhya Pradesh are likely to continue using the technologies over time as evidence of the benefits gained from adoption outweighs cost, infrastructure, hydrological, farm location, and related socio-economic factors. However, the robustness of this finding would need to be tested in future panel studies that do not rely on recall of past preferences and do not suffer from other potential sources of endogeneity in the model findings.

Second, analysis of the irrigation profiles of the adopting farmers in our sample reveals that a minority of farmers adopting sprinkler or drip systems did report gravity-fed, open surface canals as their main source of irrigation. Nearly a fifth (20%) of the adopting farmers reported canal water as their main source of irrigation, with a trend towards reduction in groundwater use over time as canal systems were upgraded by the MPWSRP. Although this is a relatively low number, our results reveal that irrigation technology adoption is relevant for farmers in gravity systems where farmers are growing cereal crops. Next, farmer interviews revealed that all

adopting farmers self-reported using sprinkler systems (either mini or large sprinklers). These farmers were evenly split in terms of geographical distribution of their farms, with 4 coming from irrigation schemes that were upgraded by the MPWSRP and 4 from farms where irrigation schemes were not rehabilitated by the MPWSRP. Farmers reported using sprinklers to irrigate wheat crops in the *rabi* season, with farm plots ranging from less than 1 ha in size up to 9 ha. This finding reveals that open, gravity-fed surface canals and irrigation technologies can be complementary water management options for smallholder farmers growing cereal crops in rural India instead of substitutes. However, these research findings raise additional questions on the factors influencing a limited number of farmers in areas with improved, open (and non-pressurized) irrigation canals to transition away from traditional flood irrigation methods towards sprinklers compared to a majority of farmers in the same areas who did not adopt.

The third policy implication that emerges from the analysis is that socio-economic factors such as the number of years of education, or whether a farmer is a member of a socially deprived caste group, whether they own a Kisan credit card, or own a permanent house are not retained as significant predictors of whether a farmer chooses to adopt sprinkler or drip technologies, once specification tests are applied. In addition, variables such as well-being and ownership of a BPL card, which were included in the model specifications were not correlated with adoption of modern irrigation technologies, in the final model with all control variables included. This indicates that the degree of socio-economic poverty is not necessarily a predominant factor in determining whether a farmer chooses to use sprinkler/drip technologies in our study area. Thus, our study finds that the choice of adoption is welfare neutral, contrary to studies that argue that wealth factors are the most dominant in driving technology adoption among Indian farmers (Namara et al., 2007). Although, understanding the nature of what is causing this effect was outside the scope of this study, this conjecture deserves further investigation in subsequent studies.

Next, as the Government of Madhya Pradesh subsidy program did not specifically target socio-economically vulnerable farmers, the study exposes that water stress (too little water in terms of scarcity and too much water in terms of high rainfall levels) appears to be a strong driver for farmers to adopt, despite difficulties in accessing the state subsidy for purchasing the technologies. This is aligned with evidence from other parts of the world suggesting that production risks arising from water stress are an important factor influencing farmers' decisions

to adopt new irrigation technologies (Koundouri et al. 2006), which we find are more relevant than socio-economic poverty factors in our study sample. This result reveals that as surface water increases in availability, farmers are less likely to pump groundwater reducing farming costs as farmers no longer need to pay for the associated energy costs of groundwater pumping. Hence, the net marginal benefit (net of the marginal cost) from capital investment in drip and sprinkler technologies is higher for farmers in areas which did not benefit from improved surface water supply from MPWSRP rehabilitated canals, indicating higher rates of adoption of modern irrigation technologies in non-MPWSRP irrigation schemes, where water availability from surface canals is much more limited and dependence on groundwater is greater.

The fourth policy implication is that farmer learning through social ties appears to be a strong incentive driving a farmer to adopt, in some cases more than financial subsidy programs, which fail to reach most poor farmers, due to high barriers of access. When farmers in our sample learned about the benefits of sprinklers or drip systems from their neighbors, friends, family (both in close physical proximity as well as in more remote locations to their farms) they chose to adopt despite limited access to state subsidies for purchasing irrigation equipment, and other financial and socio-economic constraints. They also chose to adopt “in the past” when they did not have access to rehabilitated irrigation canals. This confirms findings from other studies showing that knowledge sharing of agricultural technologies through interpersonal ties leads to higher rates of adoption (Thaler and Sunstein, 2009; Guiteras et al., 2015; Beaman et al., 2016; Wang et al. 2016). This presents emerging evidence that raises further queries; for example: would aligning delivery of technology subsidy policies through farmer networks specifically in areas where irrigation systems are rehabilitated to a higher degree play a positive role in influencing rates of adoption? At present, subsidy policies and infrastructure rehabilitation programs across Indian states are developed without adequate consideration of the social dynamics of adoption among irrigating farmers. Demand for water among farming communities is not homogenous or stationary, it is complex and changing – and much more emphasis on understanding demand behaviors among different segments of farming communities is needed prior to designing rehabilitation programs or price-based incentives such as subsidies in canal irrigated areas in India. As Lankford (2013) points out fluctuations in irrigation water demand is “*created by a complex mix of soil type, moisture content, crop type and stage, and farmer influence on distribution*” (Lankford, 2013, Chapter 3, pg. 43). Yet, few studies have analyzed how “*social influence among farming*

*communities*” changes in command areas after irrigation systems are upgraded. Laboratory and field experiments could provide greater insights into the social contexts and behaviors of farmers in target areas (for an example, see Pham et al. 2019).

These findings raise additional questions about whether upgraded irrigation systems are contributing to relative increases in on-farm water demand (as most farmers preferred flood irrigation methods in MPWSRP schemes) compared to farmers in non-MPWSRP or groundwater irrigated areas who are adopting drip or sprinkler systems. Existing evidence for Madhya Pradesh suggests that flood irrigation methods (even the optimal approaches to flood irrigation) are relatively less yield enhancing and entail higher consumptive water use per crop when compared to drip or sprinkler technologies. Studies on Madhya Pradesh by Mandal et al., (2019) show that grain yields average 5.5 tons/ha with 6316 m<sup>3</sup> water used (irrigation plus rainfall) in sub-surface drip irrigation compared to 5.5 tons/ha with 8420 m<sup>3</sup> water used with traditional flood irrigation with water productivity of 0.88 and 0.59 kg/m<sup>3</sup> respectively as recorded in 2014-15 in Morena district of Madhya Pradesh. While drip or sprinkler technologies typically result in higher water productivity (i.e., crop yield per unit of water used kg/m<sup>3</sup>), they can lead to increased water use, either at a basin-scale (Lankford et al., 2020) or as farmers increase their cultivated areas, shift to more high value water intensive crops, and/or increased adoption leads to reduced return flows and reduced aquifer recharge (Dinar and Zilberman, 1991; Massarutto, 2002; Ward and Velazquez, 2008; Balasubramanya and Stifel, 2020; Fishman et al., 2021). This underscores the need for future studies and adaptive policy measures to: (1) develop comprehensive water accounts to fully quantify the water productivity gains/losses associated with different types and combinations of irrigation methods and technologies; and, (2) applying direct caps on water offtakes or on the irrigated area in tandem with measures to promote irrigation efficiency, such as drip and sprinkler irrigation technologies.

Overall, our study supports existing literature which calls for a better understanding of the social dynamics driving adoption behaviors (Balasubramanya and Stifel, 2020). For instance, this necessitates further exploration of whether changes in irrigation practices among farmers in India can be catalyzed by diffusion of knowledge about irrigation technologies and farm-level innovations through trusted social networks. This may include coupling infrastructure and financial subsidy investments with technology awareness programs targeted to the social norms of farming communities such as a) sprinkler/drip knowledge campaigns specifically focused on

farmers in command areas after canals are rehabilitated, and b) phasing and scaling demonstration programs about irrigation technologies, their related benefits, and financial subsidy programs through 'early adopters' who are already using sprinkler/drip technologies instead of through external consultancies, NGOs, or government extension workers. This study presents evidence of the need to rethink the design and sequencing of infrastructure and financial incentive policies for promoting water and food security on surface irrigated systems in India.

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**Appendix A. Sample questionnaire of farmer survey and summary of stratified sample size for survey districts**

**I. General Information**

- a. Name of district
- b. Name of Tehsil
- c. Name of block
- d. Name of village
- e. Name of irrigation project
- f. Name of WUA

**II. Personal Details**

- a. Name of respondent
- b. Telephone/mobile
- c. Sex (Male/Female)
- d. Age (years)
- e. Highest educational qualification
- f. Caste (specify one)
  - General
  - Other Backwards Caste (OBC)
  - Scheduled Tribe
  - Scheduled Caste
  - Don't know or prefer not to say
- g. Farm location in canal system (Tick one)
  - Head
  - Middle
  - Tail

**h.** Are you the main farmer in the household?

- Yes
- No

**i.** Status of Farming (Select One - for the respondent)

- Owned plot
- Rented plot
- Farm labourer

**j.** Do you hold a BPL card? (Select One – for the respondent) <sup>7</sup>

- Yes
- No
- Don't know

**III. Socio-economic Details**

**a.** Total number of members in the family

**b.** Number of family members (specify numbers)

- Age less than 6 years
- Between 6 and 15 years
- Age 16 years or more

**c.** What is the type of house?

Before Rehabilitation of scheme

1. Permanent

---

- 2. Semi-permanent
- 3. Temporary
- 0. Don't Know

Current Status

- 1. Permanent
- 2. Semi-permanent
- 3. Temporary
- 0. Don't Know

**IV. Land Holding Details**

**a. Total land owned (acres)**

Before rehabilitation

Current status

**b. Land taken on lease (acres)**

Before rehabilitation

Current status

**c. Land leased out (acres)**

Before rehabilitation

Current status

**V. Irrigation Details**

- a.** In your village, which is/was the primary source of irrigation during the *rabi* cropping season?

Before Rehabilitation of scheme:

1. Dug well
2. Bore well
3. Canal
0. Don't Know

Current Status:

1. Dug well
2. Bore well
3. River
4. Pond
5. Canal
0. Don't Know

- b.** What is the status of the canal condition post-rehabilitation of the scheme?  
(Perception based question for individual survey respondent, one tick to be given for each parameter)

Parameter	Improvement	Deterioration	No change	Don't Know
Amount of flow				
Siltation/Vegetation				
Canal breaches				



Seepage alongside canal banks				
Condition of Canal structures				
Quality of maintenance				
Other (please specify) 1..... 2.... 3.... 4.....				

c. Please describe your well-being? Is this perception different prior to the rehabilitation works?

1. My well-being is better-off from the past
2. No, my well-being is the same as before
3. My well-being is worse-off from the past
0. Don't know

i. Please specify the main method of irrigation for last main *rabi* cropping season:

Before rehabilitation of scheme (please tick one)

1. Flooding
2. Drip/sprinkler
3. Ridge & Furrow

4. Border strip
5. Check basin

Current status (please tick one)

1. Flooding
2. Drip/sprinkler
3. Ridge & Furrow
4. Border strip
5. Check basin

## **VI. Agriculture Details**

- a. Adoption of modern irrigation technology by farmers in general for all crops for both *rabi* and *kharif* seasons

Before rehabilitation of scheme

1. Modern irrigation technology (yes/no/don't know)

Current status

1. Micro-irrigation technology (yes/no/don't know)

- b.** Do you hold a Kisan credit card? (Select One – for the respondent) <sup>8</sup>
- Yes
  - No
  - Don't know

**VII. Questions on accuracy and comprehension (for enumerators)**

a. Do you think the respondent's answers were answered accurately?

- Yes, in all cases
- Yes, but not in all cases
- No, not at all

b. Do you think the respondent understood all the questions asked?

- Yes, in all cases
- Yes, but in some cases
- No, not at all

## **Appendix B. Farmer Telephone Interview Survey Questionnaire: WUA members previously surveyed in 2015**

This questionnaire will provide insights into farmer choices for using modern irrigation technologies as well as insights into how farmers interact with one another, access subsidies, and the other related aspects around their agricultural practices.

*NB: This survey was conducted in August 2018.*

### **I. Personal and Geographic Information**

- a. What is the name of the farmer?
- b. What is the name of the WUA of the farmer?
- c. What is the name of the district?
- d. What is the name of the village?
- e. What is the name of the irrigation project?
- f. Did the irrigation project receive investments from the MPWSRP for rehabilitation?
  1. Yes
  2. No

### **II. Farm Characteristics**

- a. What is average plot size of your farm? (Ha) \_\_\_\_\_
- b. What is the average distance between your farm and neighbouring farms around you? \_\_\_\_\_

### **III. Modern irrigation Category of the Farmer (select one):**

Category (A) – I was using modern irrigation technologies in 2015 and I am still using them?

Category (B) – I didn't use modern irrigation technologies in 2015 but now I do use them.

Category (C) – I was using modern irrigation technologies in 2015 but now I have stopped using all such technologies.

Category (D) – I never used modern irrigation technologies in 2015 and I still do not use them.

**IV. Modern irrigation technologies (For category A & B farmers only)**

- a. Which type of modern irrigation technology are you using? \_\_\_\_\_
- b. What types of crops do you irrigate with modern irrigation technologies?  
\_\_\_\_\_

**V. Pre-Modern Irrigation Technology Use Questions (Only for Farmers in Category A, B, C)  
(Open-ended questions)**

- a. What type of irrigation methods was the farmer using before adopting modern irrigation?
- b. For farmers who do not use modern irrigation technologies at all, what type of irrigation methods do you use on your farm? (Category D farmers only)
- c. When did you start using modern irrigation technologies on your farm? (Provide the year (estimate))
- d. How and why did you switch to using modern irrigation technologies?
- e. Who helped you to start using modern irrigation technologies? (Select all that apply and ask the farmer to speak about why they chose that response)
  - 1. **The Government:** I was offered a subsidy from a government scheme in 2015
  - 2. **Civil Society:** Local NGOs helped me

3. **Private Firm:** A private firm helped me
4. **Community:** I saw my neighbors/family/friends using it and benefiting from it
5. **Ambition:** I wanted to improve my crop yields
6. **Economic:** I wanted to improve my income
7. **Hydrological distress:** I wanted to reduce my water usage as I faced severe water shortages for irrigation
8. **Other reasons** – please specify why

**VI. Factors driving farmers to use modern irrigation technologies (Only for Farmers in Category A, B, C) (Open-ended questions)**

- a. **Income:** When I decided to use modern irrigation technologies, getting a satisfactory income was and is important to my decision (ask them to rank on a scale of 1-10)

0: This aspect has no impact on my decision

1

2

3

4

5: This aspect has some impact on my decision

6

7

8

9

10: This is the aspect that most affects my decision

- b. **Community and Local Norms:** When I decided to use modern irrigation technologies, adhering to local norms was and is important to my decision (ask them to rank on a scale of 1-10)

0: This aspect has no impact on my decision

1

2

3

4

5: This aspect has some impact on my decision

6

7

8

9

10: This is the aspect that most affects my decision

- c. **Legal:** When I decide how or when to use modern irrigation technologies, adhering to local laws is important to my decision (ask them to rank on a scale of 1-10)

0: This aspect has no impact on my decision

1

2

3

4

5: This aspect has some impact on my decision

6

7

8

9

10: This is the aspect that most affects my decision

- d. **Personal reputation:** When I decide to use modern irrigation technologies, making sure my personal reputation is not negatively impacted is important to my decision (ask them to rank on a scale of 1-10)

0: This aspect has no impact on my decision

1

2

3

4

5: This aspect has some impact on my decision

6

7

8

9

10: This is the aspect that most affects my decision

**VII. Post adoption experiences (Only for Farmers in Category A and B) (Open-ended questions)**

- a. How have your costs of cultivation changed since you started using modern irrigation technologies? (Provide estimate of monthly costs now that you are using them vs before when you were not using them)
  1. Costs estimates now
  2. Has this gone up? If yes, why?
  3. Has this gone down? If yes, why?
  4. Costs have remained the same? If yes, why?
- b. What input differences has modern irrigation technologies made in terms of labour needs? (select one and explain why)
  1. More labour needed
  2. Less labour needed
  3. Labour is the same



- c. What differences has modern irrigation technologies made in terms of the time needed to cultivate your crops? (select one and explain why)
  - 1. More time needed (how much more – days, hours, etc)
  - 2. Less time needed (how much less – days, hours, etc)
  - 3. Time is the same
- d. What differences has modern irrigation technologies made in terms of the inputs you use to farm?
- e. What differences has modern irrigation technologies made in terms of yield outcomes you have seen? (specify for which crops you are talking about) (Question refers to quantity of crops produced in T/Ha)
  - 1. Quantity of crop is more
  - 2. Quantity of crop is less
  - 3. Quantity of crop is the same
- f. What differences have you experienced in the quality of your crops since using modern irrigation technologies? (specify for which crops you are talking about) (Question refers to crop quality)
  - 1. Quality of crop is better
  - 2. Quality of crop is worse

3. Quality of crop is the same
- g. Would you say you have more “income” (Kamai) from farming because of your choice to use modern irrigation technologies?
1. Yes, I do (please explain why)
  2. No, I do not (please explain why)
  3. My funds are the same – no change (please explain why)
- h. **Income Satisfaction:** Tell me a little about your choices (please explain your response)
1. I have a minimum income target that I need to achieve every month (yes/no)  
If yes, what is the minimum target \_\_\_\_\_?
  2. If I earn less than my target, it has been an unsatisfactory month (yes/no)
  3. If you had knowledge of the income of your neighbors, and if your income was below the average income of your neighbors, would this be unsatisfactory for you? (response: yes/no)
  4. If you had knowledge of the income of the highest earner in your village, and if your income were below that amount, would this be unsatisfactory for you? (response: yes/no)

5. I know which farmers in my village are using modern irrigation technologies?  
(response: yes/no)  
If yes, how many (rough estimate is OK)

i. **Sharing Information on Income:**

1. I share information about my income with my friends? (yes/no)  
If yes, how many friends (0-100)
2. I know how much farmers in my local community earn on average (yes/no)  
If yes, how much do they earn (approximate)
3. I know how much the farmer who earns the most in my local community earns  
(yes/no)  
If yes, how much do they earn (approximate)

- j. Why have you kept using modern irrigation? Can you tell us the top three factors that have influenced you to keep using it?

- k. What challenges have you experienced in using modern irrigation? Can you tell us the top three challenges that you have faced?

- l. How did you address these three challenges identified in the previous question, if any?

**VIII. Community-level norms among farmers (All categories) (Open-ended questions)**

- a. I know the farming techniques of farmers in my local community? (yes/no)
- b. If yes, what do you think are the main reasons, your neighbours and local farmers in the command have NOT used modern irrigation technologies? (Category C and D farmers only)
- c. Do you share information about your farming techniques (including your irrigation methods) with your friends in the village and/or command area (yes/no)

If yes, how many friends (0-100)

- d. Is imitation of other farmers' techniques in your village socially acceptable? (yes/no)

**IX. Future irrigation technology adoption scenario (Only for Farmers in Category A & B)**

- a. Do you intend to keep on using modern irrigation technologies? (Yes/No)
  - 1. If Yes, why?
  - 2. If No, can you give three reasons why not?

**X. Non-Adoption Questions (Only for Farmers in Category C & D)**

- a. Why did you never use modern irrigation technologies? (Can you give us three main reasons) – Only for farmers in Category D
- b. Why did you stop using modern irrigation technologies? (Can you give us three main reasons) – Only for farmers in Category C
- c. Instead of modern irrigation technologies, what irrigation methods do you prefer? For *rabi*? For *kharij*?
- d. Are there factors that would help you to start using modern irrigation technologies? (Select all that apply)

1. Government support – specify
2. Financial support – specify
3. Knowledge and informational support – specify
4. Agricultural support – specify
5. Irrigation support - specify
6. Social support - specify
7. Other – specify

**Appendix C. Summary of farmer profiles who completed telephone survey**

<b>No.</b>	<b>District</b>	<b>Name of Village</b>	<b>Name of Irrigation Scheme</b>	<b>MPWSRP Rehabilitated Scheme (Yes/No)</b>
1	Bhopal	Bandarua	N/A	No
2	Bhopal	Langarpura	Langarpura Tank	Yes
3	Gwalior	Gram Bajna	Harsi	Yes
4	Gwalior	Adampur	Harsi	Yes
5	Katni	Bhartala	Bhartala Tank	Yes
6	Katni	Bhartala	Bhartala Tank	Yes
7	Katni	Bhartala	Bhartala Tank	Yes
8	Neemuch	Bani	Bani Tank	No
9	Neemuch	Bani	Bani Tank	No
10	Neemuch	Bani	Bani Tank	No
11	Neemuch	Dhangaon	Dhangaon Tank	No
12	Neemuch	Barada	Bani Tank	No
13	Neemuch	Dhangaon	Dhangaon Tank	No
14	Neemuch	Morwan	Morwan Tank	Yes
15	Sagar	Bamhori	Bhonhari Tank	Yes
16	Shivpuri	Gram Miliya	Paronch Tank	Yes
17	Shivpuri	Gram Miliya	Paronch Tank	Yes
18	Shivpuri	Mahaubath	Paronch Tank	Yes
19	Tikamgarh	Dhimar Pura	Chhutaki Tank	Yes
20	Tikamgarh	Chhutaki	Chhutaki Tank	Yes
21	Tikamgarh	Mudara	Bilwari Tank	Yes
22	Tikamgarh	Bari	Gidwasan Tank	Yes
23	Tikamgarh	Bari	Gidwasan Tank	Yes
24	Tikamgarh	Kharon	Kharon Tank	Yes
25	Ujjain	Kirkhipur	Undasa Tank	No
26	Vidisha	Bamankhedi	Kethan Medium Tank	Yes