Pathways to Water Security: Evaluating the Impacts of Irrigation Investments in Madhya Pradesh, India

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Abstract

It is widely accepted that countries facing water-related risks should invest in infrastructure and institutions to improve national water security and increase economic growth. However, the majority of existing analysis is based on national-level impacts, which can mask localised variations and impacts. This thesis explores whether investments in irrigation infrastructure enhance water security and welfare benefits at a sub-national scale by drawing on data from a decadal, World Bank funded, irrigation investment program in Madhya Pradesh, India. Using district-level rainfall anomaly analysis, this research first analyses whether irrigation investments can both improve district-level crop yields, and protect yields from rainfall variability. Secondly, using a survey of 918 farmers in districts that received investments in irrigation infrastructure and districts which did not, it assesses whether the investments made a positive impact on the perceived welfare of farmers.

The results from the first question counter the established understanding that investments protect crop yields from localised monsoon variability; districts with irrigation investments did not always achieve higher crop yields compared to districts with no investments. Nor did investments always de-couple yields from variations in localised rainfall patterns in intervention districts. The second question showed that investments are a significant determinant of welfare improvements for vulnerable farmers. However, only a limited number of farmers adopted sustainable agriculture practices. The results suggest that a small, minority of farmers switched to micro-irrigation technologies and high-value crop production, while a majority of farmers in intervention districts continued to use flood irrigation methods and grow low-value crops. This thesis recommends coupling future investment decisions with district-level rainfall variability analysis and localised capacity building measures to enhance investment returns and overall water security.

Keywords: Irrigation; infrastructure investments; India; Madhya Pradesh; water security; rainfall variability; subjective welfare; sustainable agriculture

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Acronyms

AC	Acres
BPL	Below Poverty Line
CCA	Culturable Command Area
CUREC	University of Oxford Central University Research Ethics Committee
GDP	Gross Domestic Product
GWP	Global Water Partnership
GoMP	Government of Madhya Pradesh
GSDP	Gross State Domestic Product
Ha	Hectares
HH	Household
HR	High Rehab
IWMI	International Water Management Institute
LR	Low Rehab
MP	Madhya Pradesh
MPWSRP	Madhya Pradesh Water Sector Restructuring Project
MR	Medium Rehab
NABARD	National Bank for Agriculture and Rural Development
NIA	Net Irrigated Area
NR	No Rehab
NSDP	Net State Domestic Product
OBC	Other Backwards Caste
OECD	Organisation for Co-operation and Development
OLS	Ordinary Least Squares
O&M	Operation & Maintenance
PICU	Project Implementation Coordination Unit
RBI	Reserve Bank of India
SC	Scheduled Caste
SD	Standard Deviation
ST	Scheduled Tribe
WALMI	Water and Land Management Institute
WRD	Water Resources Department
WUA	Water Users Association

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CHAPTER 1: INTRODUCTION

1.1 Water Security & Infrastructure

The link between growth and hydro-climatic variability is firmly established, particularly in low-income countries. The Global Water Partnership (GWP) and Organisation for Economic Co-operation and Development (OECD) Task Force report '*Securing Water, Sustaining Growth'*, confirms that water and water-related hazards can have a statistically significant effect on economic growth in developing countries, perhaps even stronger than temperature effects (Sadoff et al., 2015). The influences of hydro-climatic variables on growth are strongest in countries that are poor (low-income) with high water stress and high dependence on agriculture (more than 20% of the Gross Domestic Product (GDP) from agriculture) (Sadoff et al., 2015). Brown et al. (2013) conclude that precipitation is closely linked with whether countries grow successfully or not. Their results suggest that a 1% increase in drought area is associated with a 2.8% reduction in economic growth per year (Brown et al., 2013). A 1% increase in flood-impacted area is associated with a 1.8% reduction in economic growth in that year, with possible important lagged effects (Brown et al., 2013). Therefore, managing sustainable usage of water resources and ensuring water security for growing populations is one of the main development challenges facing emerging economies.

Sadoff et al. (2015) identify South Asia as the region with the largest global concentration of water-related challenges, including severe impacts across the full range of hydrological risks. Grey et al. (2013) argue that India is one of the countries in South Asia that is hypothesized to be in a "water insecure: low-level equilibrium trap". Mekonnen and Hoekstra (2016) state that 66% of the globe (4 billion people) lives under severe water scarcity at least 1 month of the year, and out of these 1 billion live in India.

Measures to address these challenges include making better use of available water in agriculture (in particular investments in irrigation systems, drought management, and related natural and artificial water storage), investment in institutions and information as well as economic diversification (Grey et al., 2013, Hall et al., 2014). "Policies and infrastructure investments are needed to enhance water security; to allocate water between alternative uses; to deliver water at specific times, places, and prices; to ensure water quality; and to protect people and assets from water-related hazards. This, in turn, can have a profound impact on economic growth, inclusiveness, and the structure of economies" (Sadoff et al., 2015). Therefore it is recommended that India, with an agriculture-dependent economy that faces high levels of water insecurity, should make investments that de-couple economic growth from hydro-climatic variability. Of the multiple options recommended, investment in irrigation has been found to play a critical role in improving water security and reducing rural poverty (Balooni et al., 2016).

Since the 1950s, investment in irrigation infrastructure has been one of the key pillars of the Government of India's policy to reduce variability in water availability for agriculture and thus address water security challenges. However, despite India's large-scale investments in irrigation across multiple states, there is an absence of systematic empirical evidence on the localised impacts of these investments on agricultural productivity and welfare of the rural poor. Most of the current and past literature on the impacts of investing in surface irrigation systems focuses on regional and national outcomes (Turral et al., 2010). Although these findings are relevant at a macroeconomic level, they may not reflect the dynamics of rainfall variability at a local and spatial level. Spatial variability of rainfall and its implications for growth at a local level is poorly understood and generally overlooked in the literature (Ghosh et al., 2016). There is, therefore, a critical need to question the assumptions that investments in irrigation result in increased water security at a micro-level. Meinzen-Dick (2007) points out that if hydrological problems are to be solved, the belief that "solutions" such as irrigation investment always lead to enhanced water security needs modification. The purpose of this thesis, therefore, is to examine the dynamics of irrigation investments on district-level rainfall variability, on crop yields, and on household welfare in the context of an Indian state.

1.2 Research Aims & Objectives

The overall objective of this research is to explore linkages between investments in irrigation infrastructure, rainfall variability, and welfare at the household level among poor, rural farmers in the Indian state of Madhya Pradesh (MP). MP represents a present day example of a relatively water insecure Indian state that implemented necessary reforms towards greater water security by investing in water-related infrastructure and institutions. However, there is a major gap in evidence indicating how the irrigation investments made by the Government of Madhya Pradesh (GoMP) impacted welfare at the household level, crop yields at a district-level and whether or not investments protected yields from fluctuations in localised rainfall.

As water-related risks tend to principally impact poor households, it is critical to understand and quantify these risks at a household level, particularly in agriculture-dependent regions (Hope et al., 2012). Furthermore, scholars working on policy prescriptions for water security have developed theoretical frameworks to analyse aspects of resource problems at regional or global levels but not at a more granular, district (sub-state) or household levels (Pritchett & Woolcock, 2004). This thesis, therefore, is one of the first studies on India to analyse the agriculture productivity impacts of modernized irrigation systems at a district and household level. Researchers have also cited the need for analysis of how water-related infrastructure (e.g. irrigation) impacts poverty rather than just crop output (Smith, 2004). In this context, the aim of this thesis is to provide empirical evidence of the impacts of irrigation investments: a) on district-level crop yields; b) to buffer yields against variability in district-level rainfall; and, c) on welfare changes of farming households.

Specifically, within the scope of the research aim specified above, the following research questions guide the analysis and results presented in this thesis:

1a. Do investments in irrigation infrastructure lead to higher crop yields compared to districts without investments; and,

1b. Do investments buffer crop yields from fluctuations in rainfall levels at a district-level compared to districts without investments?

2. Do investments in irrigation infrastructure improve perceived welfare of farmers compared to farmers living in districts without investments?

1.3 Overview of Research Papers & Thesis Structure

Each of the research questions posed in this thesis has been addressed in two papers written to the specifications of the journals, *Water Policy* and *Agricultural Water Management* respectively. Paper one was submitted to *Water Policy* and is under review. This paper addresses both parts of the first research question by exploring changes in rainfall variability and crop yields of districts with and without irrigation investments in MP. It tests the assumptions that investments in irrigation infrastructure lead to higher agricultural yields and improved resilience of crops against rainfall variability.

Paper two was submitted to *Agricultural Water Management* and is under review. This paper addresses the second research question and provides empirical evidence on how subjective measures of welfare of farming households are impacted as a result of investments in irrigation rehabilitation. Paper two relies on new, primary household survey data to understand whether investments in irrigation infrastructure were successful in improving subjective measures of farmer welfare. Both papers derive data from the ten-year irrigation investment project funded by the World Bank in Madhya Pradesh.

This thesis is structured as follows: Chapter 2 presents a literature review and assesses the key gaps in the literature in the context of India as well as provides background information on Madhya Pradesh. Chapter 3 provides an overview of the methodological approach and data analysis methods used for each of the research papers along with limitations of the analysis. Chapter 4 presents paper one and Chapter 5 presents paper two. The conclusions of the thesis are presented in Chapter 6 along with recommendations regarding future areas of research.

CHAPTER 2: LITERATURE REVIEW

This chapter reviews the literature on the role of irrigation infrastructure in improving water security in developing countries, particularly India. In order to effectively answer the research questions posed in this thesis, the following topics are explored in the literature review:

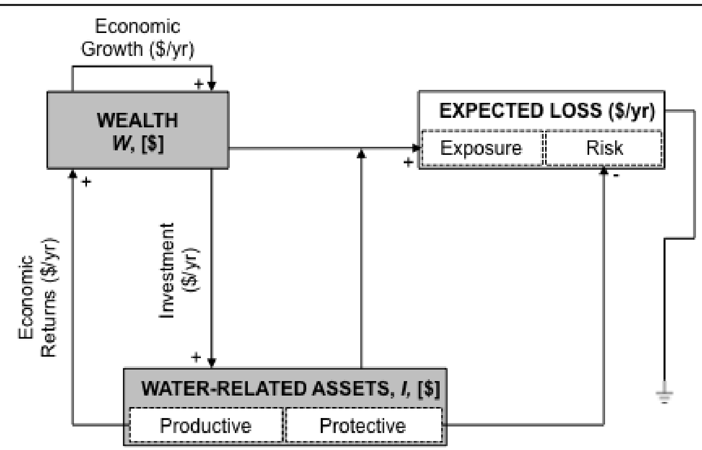
1. the role of infrastructure in improving water security, growth and poverty within a country;
2. the need to include subjective measures of welfare when measuring impacts of irrigation investments on poverty;
3. the dynamics of water and poverty in the agriculture sector in India; and,
4. the effects of rainfall variability on agricultural growth in Madhya Pradesh.

These topics of exploration led to insights into where research is limited in the context of India. Although there is a wide body of literature that examines the linkages between irrigation schemes, growth, poverty, and welfare, there is a need to expand the analysis of the implications of investments made in irrigation at a micro-scale in India. Findings on district and household level impacts from irrigation investments can provide useful insights on factors influencing water security at a local level. Secondly, these results can contribute knowledge on how to design future water-related investments in order to maximise agriculture productivity and poverty outcomes. Identification of these literature gaps provides the justification for the development of the two main research questions in this thesis and the subsequent analysis conducted.

2.1 Role of Irrigation & Growth

Water security is defined as “the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies” (Grey and Sadoff, 2007). Dadson et al. (2015) find that countries that lack sufficient wealth to improve their water security can as a result be trapped in a low-equilibrium and high poverty development pathway. Therefore, the recommendations for water insecure nations are that investments in infrastructure and institutions are key to enabling a nation to evolve from water insecurity to security. In order to capture the dynamics between water security and growth within a country, Dadson et al. (2015) developed a growth model relating country wealth to investment in both protective and productive water-related assets. Figure 1 illustrates how each country starts with a level of wealth and that wealth is ultimately diminished by hazard-related losses. The losses depend on exposure (wealth) and risk, where risk can be managed by investing in water-related assets. The model illustrates how some places need more investment to reduce their risk to a tolerable level and the more critical water security is, the more will be invested, and investment will level off as water security is achieved (Dadson et al., 2015). Therefore, they conclude that investment in water-related assets has two roles; it generates returns to the economy and it reduces losses.

Figure 1: Growth model relating country wealth to investment in protective and productive water-related assets (Dadson et al., 2015)

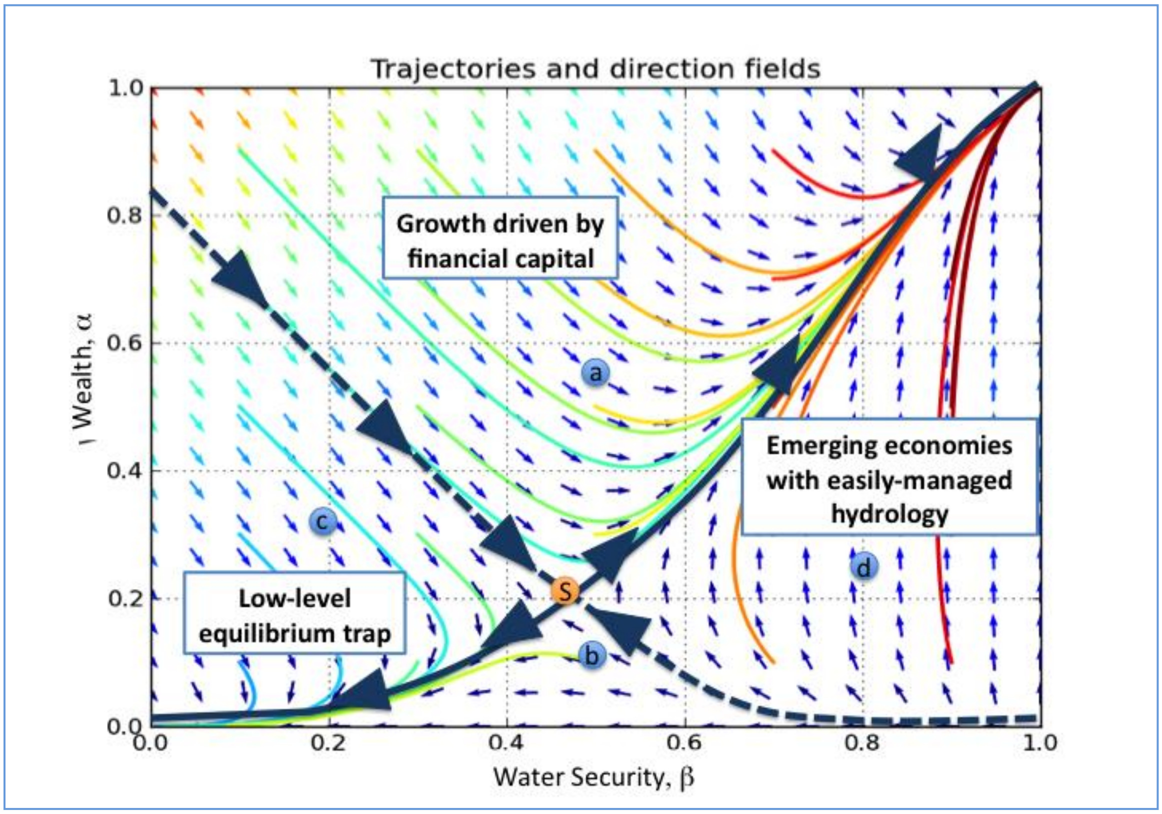


W_0 = wealth in the absence of water-related constraints
I_0 = investment required to achieve water security (the point at which the next $ invested goes elsewhere)

Hereafter, consider α = wealth as a fraction of W_0
And β = investment in water security to date relative to I_0

Dadson et al. (2015) then use a simple conceptual model (Figure 2) to show that when low levels of water availability negatively impact a nation's economic growth, and this occurs at a high enough frequency or magnitude, it can result in a poverty trap. The model illustrates that the location of the 'tipping point' (i.e. the point at which pressures will direct an economy either toward growth or toward poverty) will depend on the adequacy and effectiveness of water security-related investments compared to other investments in the wider economy. Based on these results, Dadson et al (2015) conclude that investing in the development, management, and operation of water-related institutions and assets can act to insulate a country from adverse water-related risk. Developing and maintaining critical water security-related assets and institutions shifts a country's growth trajectory away from the tipping point (S) in Figure 2, and reduces the risk that a country's efforts to grow in other sectors of the economy will be damaged by water-related drags on productivity (Dadson et al., 2015).

Figure 2: Trajectories for Water Security and Growth (Dadson et al., 2015)



The diagram in Figure 2 provides a conceptual basis to understand the importance of infrastructure investments such as irrigation in improving the economic trajectory of water insecure nations. This theoretical framework advances a set of hypotheses about the relationship between water investment and growth. Building on this work, this thesis aims to evaluate and refine these concepts by providing empirical evidence of the localised impacts of such investments on crop productivity, rainfall variability, and welfare of the rural poor within an Indian state. For the purpose of this thesis, analysis focuses on irrigation infrastructure as a policy instrument to achieve water security. This chapter further explores literature on the economic gains from improvements in irrigation and the relationship on poverty in developing countries.

Several researchers have examined the linkages between irrigation and welfare (Datt and Ravallion 1997; Rosegrant et al. 1998; Barker et al. 2004; Hussain and Hanjra 2004; Huang et al. 2005). Research by Gebregziabher et al. (2009) in Ethiopia evaluate the impacts of access to small-scale irrigation on farmer household income and poverty status and find that the irrigating households have about 50% higher average income than non-irrigating households. A study by Dillon (2011) finds that households in Northern Mali with access to surface irrigation increased their household consumption by 27-30%. Results of a study by Jin et al. (2012) confirms that irrigation has a strong impact on land productivity, however, they find that productivity impacts tends to vary by the type of irrigation as well as the quality of irrigation. However, not all researchers are in agreement on the positive benefits of irrigation investments. Others argue that irrigation does not always seem to provide the claimed water security benefits to farmers. These differing viewpoints on irrigation outcomes stem partly from the scale at which impacts are examined and partly from the distributional impacts of irrigation, where some benefit and others do not.

Duflo and Pande (2007) have examined linkages between poverty and water sector infrastructure in the context of dams in India. Overall, they estimate that large dam construction in India is a marginally cost-effective investment with significant distributional implications, which in fact has increased poverty (Duflo and Pande, 2007). Berkoff (2003) argues that there have been large irrigation subsidies and that irrigation raises yield potential substantially but only on a one-off basis. Governments struggle to recover Operation and Maintenance (O&M) costs, which for capital-intensive surface irrigation, may be no more than 10-15% of total costs (Berkoff, 2003). Berkoff (2003) points out that if farmers were not required to pay for O&M fees, only then will they actually increase their yields and hence income. If farmers were asked to pay in full, he argues, they would simply be unable to afford it and would either go bankrupt or withdraw from irrigation or, probably, take water illegally (Berkoff, 2003). Clement et al. (2011) argue that interventions aimed at increasing water productivity (i.e. investment in irrigation infrastructure) do not necessarily benefit the poorest members of rural communities – rather these might favour the better-off farmers who have access to a wider range of capital and have the additional resources to make changes in their farming system and practices. A report by the International Water Management Institute (IWMI) points out that in order for irrigation investments to be geared towards poverty reduction, investments cannot only be solely focused on the number of hectares (ha) developed or amount of infrastructure rehabilitated but must also consider how the number of households or farmers are benefited from these investments (Hussain, 2005).

Furthermore, a large body of research has emerged that recognizes the limitations of purely economic or income-based welfare indicators when evaluating the socio-economic and distributional impacts of policy interventions (Lokshin et al., 2006, Carletto and Zezza, 2006; Lokshin and Ravallion, 2005; Dasgupta, 2001). Researchers argue that in some cases subjective welfare analysis can complement existing measures on income and provide information on socio-economic factors that may affect a households' perception of their personal welfare. This approach can be particularly useful when measuring poverty and welfare responses of farming households to investments in irrigation systems. However, commodity determinants of subjective welfare currently do not incorporate the responses of individuals or society to irrigation infrastructure investments (Dasgupta, 1993; Dasgupta, 2001; Dasgupta and Maler, 2001).

In order to further advance the existing array of literature around water security and infrastructure, irrigation and poverty, and incorporate subjective measures of welfare this thesis analyses whether irrigation investments: a) improve district-level crop productivity; b) buffer yields against variability in spatial rainfall; and, c) enhance perceived welfare of poor, rural households following investments. It is especially critical to identify these impacts in India as several states in the country, including Madhya Pradesh, have embarked on decadal, multi-million dollar, donor-funded surface irrigation investment programs.

2.2 India & Irrigation: Brief Contextual History

India is the top-ranked country globally for the number of people exposed to water scarcity; people at risk of flooding; people without adequate water supply and sanitation; and number of undernourished children (Hall and Borgomeo, 2013). India has 16% of the world's people but has only 2.5% of the world's land area and 4% of the Earth's fresh water resources. Despite recent attempts to diversify India's economy, agriculture remains an intrinsic and fundamental part of the economy, society and culture. Indian agriculture contributes nearly 20% to the national GDP, although this economic contribution is showing declining trends. This share of agriculture has declined from 50% of GDP in 1950 (Tripathi and Prasad, 2010). Despite this decline, the sector employs 65% of the total Indian workforce. With two-thirds of India's population living off farming-related activities, rural incomes are a major source of demand for all products and services (Malkani and Shah, 2007). Therefore, these figures illustrate the significant imbalance between the social and the economic importance of agriculture in India.

Agriculture, however, is heavily influenced by climatological patterns of rainfall variability. Rainfall is one of the major factors limiting agricultural productivity in India (Haileslassie et al., 2016). Gadgil and Gadgil (2006) find that despite the decrease in the contribution of the agriculture sector to GDP in India, severe droughts continue to negatively reduce GDP by 2-5% throughout their study period. Thus water and poverty are intimately connected in the context of agriculture in India. India has, therefore, invested in irrigation systems as a core policy to address this challenge.

India's irrigation sector is one of the largest in the world and irrigated area has increased from 20.9 million ha in 1950-51 to 78.4 million ha in 2002-2003 (Narayanamoorthy, 2011). Between 1951 and 1997, Indian public investment in major and medium irrigation projects was approximately USD$ 33 billion (Thakkar, 2000). Within the broad category of types of irrigation there also has been a major shift, canal irrigation accounted for about 42% of the Net Irrigated Area (NIA) during the fifties and sixties, whereas tank and groundwater accounted for about 18 and 29% respectively (Narayanamoorthy, 2011). This changed in 2002–2003 where groundwater alone accounted for about 62% of NIA, and surface irrigation sources such as canals and tanks accounted for about 33% (Narayanamoorthy, 2011). In addition, despite large-scale investment and expansion of irrigation facilities across multiple states in India, about 60% of the total cropped area in India is still dependent on rain-fed agriculture.

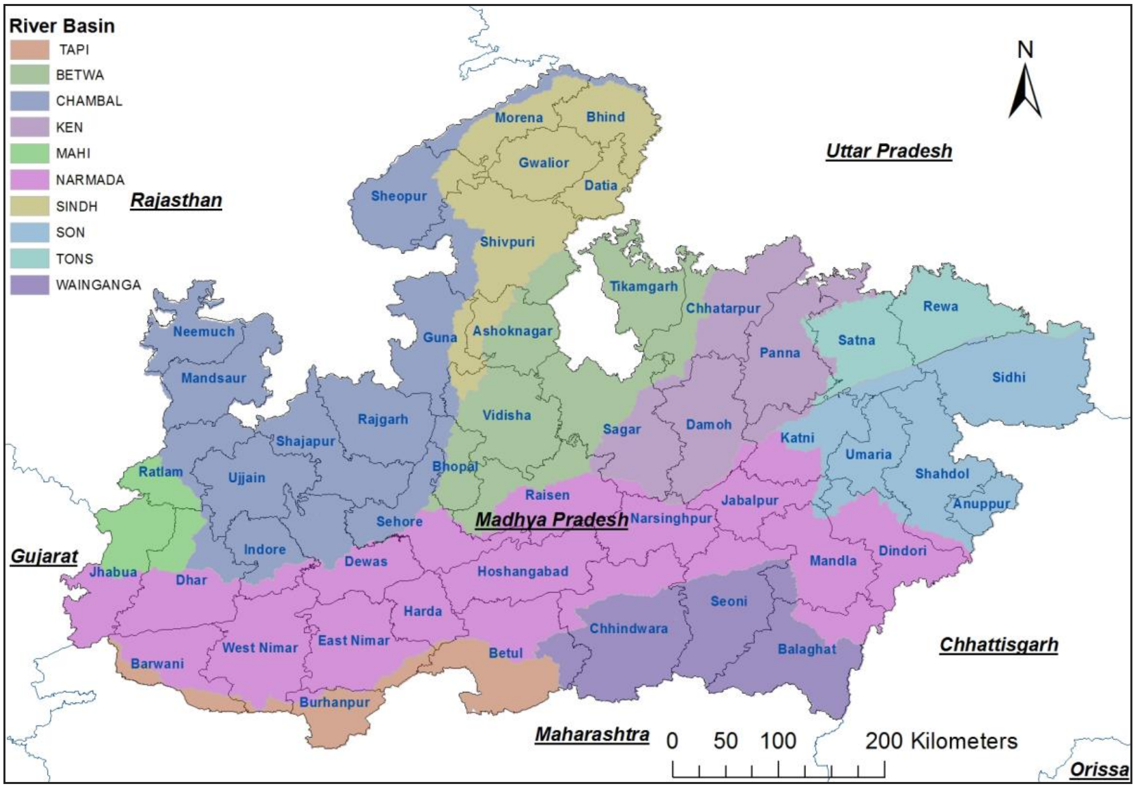
International finance has been critical in expanding irrigated agriculture in India, and thus India has been a significant destination of donor funds. Duflo and Pande (2007) point out that between 1950 and 1993, India was the single largest beneficiary of World Bank lending for irrigation. India has received about 26% of total Bank loans, and irrigation made up 7% of total Bank lending in India (World Bank, 2002). The main incentive for both the Indian government and the World Bank for undertaking irrigation projects are agricultural growth and rural poverty alleviation (World Bank, 2002; Dhawan, 1993). Therefore, the World Bank engaged in a large-scale investment program on irrigation infrastructure and other activities in Madhya Pradesh. As this program began in 2005 and was completed in 2015, it is an ideal location to analyse and test the questions posed in this thesis.

2.3 Water & Agriculture in Madhya Pradesh

The Indian state of MP is situated in the centre of India. The topography of MP is mostly plains from north to south separated by upland areas. The state is endowed with rich natural resources including several river basins, the second highest production of mineral resources in India, and forest areas, which cover 30.7% of the state.

MP has ten river systems (Mahi, Chambal, Sindh, Betwa, Ken, Tons, Son, Narmada, Wainganga and Tapi) (Figure 3). All, except Sindh are part of inter-state river systems. The Sindh and Tons sub-basin systems are a part of the Yamuna. The Sindh River joins the Yamuna in the Indian state of Uttar Pradesh. Chambal, Betwa, Sindh and Tons are tributaries of the Yamuna, which is part of the Ganga Basin. Tons and Son are tributaries of the Ganga. These rivers flow north originating from the central plateau of MP. Wainganaga is a tributary of the Godavari flowing southeast to the Bay of Bengal. Narmada, Mahi and Tapi are west flowing river systems terminating in the Arabian Sea.

Figure 3: River Basins & Districts of Madhya Pradesh (*Source*: *Biswas, S. (2016), Water Resources Department, Government of Madhya Pradesh*)



Madhya Pradesh's economy is predominantly agrarian with agriculture, animal husbandry and fisheries making up the primary sectors in the state. In recent years, the annual growth performance of the agriculture sector in MP has shown large-scale fluctuation with growth rates ranging from -2.4% in 2007–08 to +11.2% in 2010–11 (Sapre, 2014). During this period, per capita income rose by an average of 4% (Government of Madhya Pradesh, 2011). Although the contribution of agriculture in the state's Gross State Domestic Product (GSDP) has gradually declined from about 60% in 1961 down to 20.5% in 2010–11, the percentage of labour employed in the sector continues to be over 70% (Gilmont et al., 2016, Sapre, 2014). Thus, the growth performance of agriculture is critical for the socio-economic welfare of people engaged in this sector.

The net sown area in MP is 15.07 million ha. MP has a total irrigated area of 6.72 million ha. Total irrigable area is the net sown area less the area that is not available for irrigation. As of March 2014, the state had created an irrigation potential of 3.15 million ha through development of surface water projects such as dams, irrigation canals, and diversion channels (Enarth et al., 2016)[1]. Out of the Net Irrigated Area in the state, 68% of the irrigation is received from wells and tube wells, indicating a high dependence on groundwater sources. About 2.1 million ha of cropland are currently irrigated using surface water sources at an average gross cropping intensity of about 80% (Enarth et al., 2016). As of 2006, small and marginal land holdings constituted over 67% of the total land holdings in the state (Enarth et al., 2016). Between 2000 and 2006, the average landholding size reduced from 2.22 ha to 2.02 ha.

As stated in the Madhya Pradesh 2011 state plan, about 59% of the gross cropped area was under food crops and the remaining 41% area was under non-food crops. During 2009-10, the gross cropped area under wheat was 23% and 7.4% was under paddy (Government of Madhya Pradesh, 2011). Wheat and rice contribute about 50.5% of the total food grain production in the state. Pulses collectively contribute about 27% of the total food grain production. Among non-food crops, oilseeds production is dominated by soybean in MP (Government of Madhya Pradesh, 2011).

A study by Sapre (2014) empirically analyses whether agricultural growth performance in MP determines the overall growth trajectory of the state economy. The results of Sapre's study (2014) indicate that long-term trends over nearly three decades show that fluctuations in agricultural growth clearly coincide with fluctuations in GSDP growth and have considerable impact on the state's growth performance (Sapre, 2014). This coincides with the findings of a forthcoming paper by Gilmont et al. (2016) who find that MP exhibits strong coupling between rainfall variability and economic growth throughout the available state-wise data from 1961 to 2011 (Gilmont et al., 2016). The

[1] Irrigation potential is the area which can potentially be irrigated depending on the physical resources 'soil' and 'water', combined with the irrigation water requirements as determined by the cropping patterns and climate. However, environmental and socioeconomic constraints also have to be taken into consideration in order to guarantee a sustainable use of the available physical resources (*Source*: FAO).

methodology for this study calculated the percentage deviation of rainfall from the 1961-2011 average and regressed this against annual economic growth rates for the same period. The paper finds that this relationship persists even after the separation of Chhattisgarh in 2000. Accounting for this change in political boundaries caused the average rainfall within MP to drop from 1073 mm/yr. to 994mm/yr. (Gilmont et al., 2016).

The states' sensitivity to drought also persists despite a significant growth in irrigated area in the state until 2007 (Gilmont et al., 2016). Overall Gilmont et al. (2016) conclude that MP remains coupled in terms of the agricultural economy through to 2012. The results of Gilmont et al. (2016) analysis has built upon earlier work by Singh (1997) who found that the state faces high water insecurity in the form of droughts and floods with strong linkages between state-wide economic growth and variability in its monsoons. In the agricultural sector, Shankar (2005) reviews four decades of agricultural development in the state. He finds that the lack of regional or location-specific policies and unsustainable irrigation practices led to a near-stagnation of agricultural development in early 2000, thereby leading to technological and economic backwardness of many regions in the state.

In recent years, the Government of Madhya Pradesh has taken a renewed approach to overcome these variations in agricultural growth and also to promote water-related infrastructure investment in the state (Sapre, 2014). A number of major, medium and minor irrigation schemes have been developed for surface irrigation through large-scale investments under successive five-year plans. Prior to the start of the World Bank funded program, many of the state's irrigation schemes were old (many over 20 years and some older than 50 years) and required substantial investments to modernize the systems and to improve the productivity of the land and efficiency in water management.

The MP Water Resources Department (WRD) holds the main responsibility for irrigation in the state. It is responsible for estimation, planning and comprehensive utilization of surface and groundwater resources of the state. Based on this context, the

GoMP WRD was able to obtain financing support from the World Bank and implemented a ten-year program of modernization and rehabilitation of irrigation systems in several districts in the state. This program is called the Madhya Pradesh Water Sector Restructuring Project (MPWSRP). The program invested in irrigation systems across six of the ten river basins in MP. Investments consisted of a wide array of engineering repair works on dams and embankments including: a) resolving seepage and drainage issues, b) improving boundary stones, and c) repairing sluice and radial gates on the infrastructure. Extensive details of the MPWSRP are provided in paper one (chapter 4) and paper two (chapter 5) of this thesis.

As this chapter demonstrates, several authors have already identified the need to examine irrigation schemes and the relationships with poverty and welfare in developing countries (Mollinga and Bolding, 2003; Molle and Berkoff, 2007; Meinzen-Dick et al., 2002). This need is particularly important at the local scale – at both the district and household level. Therefore, this thesis advances upon the existing global and regional frameworks on water security and infrastructure. By exploring impacts of investments in irrigation infrastructure on the vulnerability of yields to rainfall fluctuations, on crop yields at a district-scale and on welfare responses of rural households in MP, this thesis further nuances the discourse on water security towards a more granular understanding of localised impacts. This literature review exercise culminated in the development of two distinct yet linked research questions.

Question one which has two parts asks: a) *do investments in irrigation infrastructure lead to higher crop yields compared to districts without investments*?*; and, b) do investments buffer crop yields from fluctuations in rainfall levels at a district-level compared to districts without investments*? These questions are addressed in paper one by examining rainfall data, irrigation investment data from 31 districts and comparing the results of crop yields for three staple crops against the investment and rainfall trends within 31 districts across the six intervention river basins.

The second question that emerged from this exercise is: *do investments in irrigation infrastructure improve perceived welfare of farmers compared to farmers living in districts without investments*? Paper two addresses this question by constructing an empirical model to illustrate the results of a household survey that queries farmers from districts with and without investments on whether they perceive their welfare to be worse-off or better-off after investments.

The design of the research questions and methods for this thesis were conceptualised in close collaboration with the former project manager of the MPWSRP as well as the senior officials from Department of Water Resources in GoMP along with support from the lead irrigation specialist of the World Bank.

CHAPTER 3: RESEARCH DESIGN & METHODOLOGY

This thesis draws on a mixed methods approach to analyse variations in achievements and outcomes as a result of investments made in irrigation infrastructure across different rainfall regimes within several districts in Madhya Pradesh. The research methods combine quantitative and qualitative household survey data with secondary data on inter-annual and intra-annual district-level rainfall, district-level crop yields, and irrigation investment data. The sources of the data that were collected in this research are presented in Appendix A. The research methods used in papers one and two are innovative in that it brings together multiple methodologies in examining the research questions posed in this study to identify implications for water security at the district and household level. The background of the research process, the design of the research questions, and the utilisation of a mixed methods approach form a sound basis to expand the knowledge base and deepen the understanding of the implications of irrigation investments at a micro-level and for water security more broadly.

The next sections briefly outline the ethical considerations; design of the research strategy and methods utilised for each of the papers as well as describe some of the limitations of this approach.

3.1 Ethical Considerations

This research was conceptualised based on prior engagement in the MPWSRP as a member of the World Bank implementation support team from 2010-2014. Upon departure from the World Bank in 2014 and closure of the program in 2015, the main research questions were formulated. The research strategy for this thesis was developed by building on past work experience on irrigation projects as well as technical and background knowledge of the water and irrigation sector in Madhya Pradesh. The design of the research methods were developed in close collaboration with the World Bank senior project management officials as well as senior Government of Madhya Pradesh, WRD officials. The state government provided concrete and invaluable support throughout the process of the development of an independent research tool for secondary data collection and household survey design. Generous financial support for completion of the household survey throughout multiple districts in the state was provided by the MP WRD along with execution of the survey by the MP Water and Land Management Institute (WALMI).

In order to execute the household survey, a strict code of ethics was followed in alignment with University of Oxford Central University Research Ethics Committee (CUREC) requirements. As the survey interviewed adult male and female farmers above the age of 18, the CUREC checklist was filled and approved by the Ethics Committee prior to the commencement of fieldwork in MP. In addition, prior to the start of the household surveys, a one-day enumerator training was conducted in Bhopal in November 2015 in partnership with WALMI and WRD officials.

During the training, the first aspect that was discussed in detail was to respect the ethics code of conduct and to train enumerators on respectful behaviour towards respondents during the execution of the survey. Secondly, it was agreed that enumerators would not require respondents to sign consent forms directly to be sensitive to illiterate participants in the survey as well as understanding the context that when farmers in rural parts of India "sign" forms in official surveys they can often misunderstand the nature of the survey and thus this raises expectations from respondents to receive benefits from government authorities for answered questions. Therefore, oral consent was obtained from each of the farmer respondents prior to the start of the questionnaire. A formal process of obtaining oral permission from respondents for consent to participate in the survey as well as permission for taking direct quotes from participants was initiated during the implementation of the survey. The participant consent form is provided in Appendix D.

Upon publication of the two research papers developed for this thesis, the results will be presented directly to the MP government for validation and triangulation purposes. Furthermore, presentations will be made to relevant technical experts in the

World Bank on the findings of the research papers to advance ongoing work at the World Bank on design and implementation of irrigation sector operational programs in South Asia and other regions.

Lastly, the initial findings presented in this thesis have been further developed into a two-year Doctor of Philosophy (D.Phil.) research project at the School of Geography and the Environment with two additional forthcoming papers. The D.Phil. will build on the questions emerging from the results of paper one and two. Data collection for the two new papers will entail engaging directly with farmer survey participants in the form of Focus Group Discussions during the fieldwork phase of the D.Phil. Efforts will be made to investigate causes and responses of the initial survey results based on direct inputs from respondents. During the Focus Group Discussions, the findings of the first survey and benefits of this thesis research for the farmers themselves will be explained to the respondents as a core part of the ethical considerations of this research.

3.2 Research Strategy & Data Analysis for Paper One

Research paper one addresses the following research question in two parts: a) *do investments in irrigation infrastructure lead to higher crop yields compared to districts without investments*?*; and, b) do investments buffer crop yields from fluctuations in rainfall levels at a district-level compared to districts without investments*? In order to address this question, the first paper explores variations among district-wise yield rates for specific crops (rice, wheat and chickpeas) and compares results among districts that received investments in infrastructure to districts that did not receive irrigation interventions under MPWSRP. It also compares how yields differed among districts with variations in levels of inter-annual and intra-annual rainfall variability.

The research strategy for paper 1 was divided into the following components: a) analysis of the inter-annual and intra-annual rainfall variability across 31 districts, b) analysis of variation in crop yields for three staple crops across districts that received investments and districts that did not; c) analysis of variations in percentage of investments made to irrigated areas in districts that did receive investments; and, d) designing a matrix of analysis to differentiate and compare differing degrees of investment and rainfall variability among the 31 districts. Background data and general characteristics of the districts that were not included in the household survey are presented in Appendix C.

3.2.1 Rainfall Data Analysis Methods

In order to examine inter-annual and intra-annual rainfall variability in MP among the 31 districts, monthly rainfall data from 2005-2014 for all districts was obtained from the GoMP. To analyse inter-annual variability, annual averages were determined for each consecutive year from 2005-2014 for each of the 31 districts by averaging monthly rainfall figures for all available rain gauge stations in each district. Intra-annual rainfall variability was examined across all 31 districts from 2005-2014 by conducting an assessment of month-to-month variability and monthly variability between years (e.g. January 2005 vs. January 2007). In order to understand how each district's monsoon patterns differed compared to other districts and from year to year, standardised anomalies were calculated. The standardised anomaly graphs for each district are presented in Appendix B.

Standardized anomalies generally provide more information about the magnitude of the anomalies because differences in dispersion between datasets have been removed. This comparison showed the monsoon trends for each district and illustrated graphically the number of wet vs. dry years within the study time period and enabled comparisons to be made with crop yield data among districts with and without investments in irrigation. Once the rainfall variability analysis was completed, the districts were divided into three rainfall zones: low, average, and high rainfall. Threshold values for determining the classification of each district as low, average or high are described in detail in the methods section of paper one in Chapter 4.

3.2.2 Agricultural Data Analysis Methods

Three key staple crops were selected for analysis. This included rice, wheat and gram (chickpeas). Data on the yield values for each crop for each district over the time period were collected to analyse trends and patterns between districts with interventions in comparison to districts with no interventions. Data on crop yields were obtained from state government repositories in Bhopal's Irrigation and Agricultural Department. Lastly, a graphical analysis of changing yield trends across differing rainfall zones was developed for each district from 2005-2014.

3.2.3 Irrigation Investment Data Methods

In order to analyse the location and size of the irrigation investments, data were collected on the irrigation investments made in specific locations during the course of the MPWSRP. Districts were then classified as "Rehab" for districts where irrigation investment in rehabilitation of infrastructure was made by the state government and "No Rehab" where infrastructure investments were not made. The Rehab districts were then classified by the percentage of the irrigated area covered by the investments. Thus all 31 districts were assigned to one of the two categories. The classification of the districts into these categories was conducted in consultation with the WRD officials in Bhopal.

3.2.4 Matrix of Analysis

In order to develop a methodological framework to analyse both parts of the research question of paper one, two key variables were identified for data analysis: irrigation investment and rainfall variability. To compare the results from the data analysis of the rainfall and the irrigation investments, a two by three matrix was developed to spatially classify the 31 selected districts across the three rainfall zones and two irrigation investment categories.

Complete details of the research methods, data analysis and results of the matrix for paper one are presented in Chapter 4.

3.3 Research Strategy & Data Analysis for Paper Two

Research paper two addresses the following research question: *do investments in irrigation infrastructure improve perceived welfare of farmers compared to farmers living in districts without investments*? Beyond examining how irrigation investments impact crop yields and how they buffer crops against rainfall variability, paper two attempted to understand how irrigation investments impacted the welfare of farmers.

Paper two investigates the second research question by deliberately going beyond economic measures of poverty (e.g. income) to examine subjective measures of welfare of an individual farmer within a district in MP that participated in the MPWSRP and farmers residing in districts that did not. Dasgupta (2001) describes the benefits of evaluating policy interventions by "valuing states of affairs in terms of the quality of life they sustain" rather than only examining economic outcomes, which tends to overlook the determinants of human welfare. Welfare is measured based on the perception of how an individual farmer perceives his or her quality of life at a point in time with respect to the past (Dasgupta, 2001). To develop this measure of welfare, paper two focuses on 'commodity determinants of welfare', which were based on a farmer's individual reports of land ownership, assets owned, and importantly their perception of the benefits to their welfare from the irrigation intervention. In order to gather the data for paper two, a cross-sectional, household survey was successfully conducted across multiple districts in November 2015. Background data and general characteristic of the survey districts are presented in paper two in Chapter 5.

The purpose of the survey was to generate primary data about crop cultivation, irrigation practices, and welfare trends among a sample of farmer households living within a selection of districts across the 31 study districts in MP. The main survey instrument is structured interviews of farmers based on a pre-defined set of questions. Chapter 5 provides in-depth details of the sampling and survey methodology utilised based on a random stratified sample selection of households. Data were collected about individual farmers in a household on a series of variables at a single point in time based on structured interviews by means of a questionnaire containing specific questions across the following six main areas of interest: a) general information; b) personal details about the respondent; c) socio-economic details about the household; d) land holding details; e) irrigation details; and, f) agriculture details. The survey questionnaires for Rehab and No Rehab farmers are presented in Appendices E and F, respectively. The core strategy of the survey for Rehab farmers was to differentiate the status quo for the farmer WUA member between the current scenario (post rehabilitation works) and their past scenario (prior to rehabilitation works). The strategy for the No Rehab farmers was to differentiate the status quo between the current scenario and the past (in 2005).

Paper two presents initial results of the survey to determine subjective measures of farmer welfare by examining data from three critical responses of the survey: a) rainfall and geographic characteristics; b) socio-economic details; and, c) farm management and agricultural practices. Results of the survey were analysed using Ordinary Least Squares (OLS) regression model. Details of how the subjective measure of welfare was constructed and the limitations associated with subjective measures are provided in paper two in Chapter 5.

3.4 Limitations

There are several limitations with a study of this nature that is attempting to evaluate impacts of irrigation investments across multiple years and multiple districts without concrete baseline data at the start of the MPWSRP.

Paper one analyses the differences in crop yields across districts with different rainfall zones and different irrigation investment categories. However, as this paper utilised secondary data mainly from GoMP sources at the district scale, the results for paper one do not account for variations within districts, within villages and even how farmers were responding to the variations in crop yields. Secondly, although the data is obtained from the MP Department of Agriculture, Water Resources and Land Records Divisions directly from the MP government, there is always a margin of error in the quality of data obtained from public sector sources. Although efforts were made to verify the robustness of the secondary data, there is always some degree of uncertainty associated with the data. Lastly, this thesis focuses mainly on surface irrigation impacts and does not incorporate the role of groundwater in variations in district-level crop yields, which can have a significant contributing factor in determining yields.

Paper two provides a more nuanced analysis into the subjective welfare of farmers building on the secondary analysis of reported statistics on crop and rainfall in paper one. However, the methodology of the survey is based on recall of the present and past situation for each individual farmer in the absence of a baseline survey. Aside from the limitations of focusing on subjective measures of welfare, which are discussed in detail in Chapter 5, farmers can have a tendency to recall a rosier past, which can bias their answers in a more positive manner than in reality. Chapter 5 describes how these limitations were addressed in the econometric approach for paper two. In addition, errors in the data collection phase of the survey were minimised by means of targeted trainings of enumerators and random quality checks during the survey administration and data entry process. Lastly, paper two presents an initial analysis of the data collected during the household surveys. The survey questionnaires included specific questions on the crop production and irrigation methods of farmers, as well as changes in irrigation practices in the study area, farm-level investments in irrigation equipment and choices of cropping patterns. However, *all* of these details have not been incorporated into the econometric models presented in paper two as these results will be analysed in more depth in the forthcoming papers of the proposed D.Phil. project.

Specific limitations that are relevant to the methods for paper one and two are described in detail in Chapters 4 and 5.

CHAPTER 4: PAPER ONE

Exploring links between irrigation infrastructure investments, rainfall variability and crop yields in Madhya Pradesh, India

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Exploring links between irrigation infrastructure investments, rainfall variability and crop yields in Madhya Pradesh, India

Abstract

Investments in irrigation infrastructure are assumed to lead to higher agricultural yields and improved resilience of crops against rainfall variability. To test this assumption, we derive annual and monsoon estimates of rainfall variability to analyse the impact of investments on crop yields, drawing on a decade of irrigation infrastructure interventions in Madhya Pradesh, India. Trends in agricultural yields of three staple crops: gram (chickpeas), paddy (rice), and wheat are examined for 21 districts receiving investment, compared with 10 districts that received little or no funding. Results reveal that crops in the intervention districts do not always show higher yields compared to the non-intervention districts, either overall or during dry periods. Secondly, investments do not always buffer crop yields from monsoon variability compared with non-intervention areas. Where yields are less sensitive to rainfall variability, this buffering occurs for some crops in districts with the lowest investments in irrigation. With predicted increases in the uncertainty of India's future rainfall patterns, the evidence here promotes pre-screening infrastructure investment decisions by climate risks to increase irrigation returns.

Keywords: Irrigation; infrastructure; India; water security; rainfall variability

1. Introduction

Global debates on water security advocate that countries facing challenges of water resources should invest a significant percentage of their national wealth in "productive water-related assets" to prevent water-related risks (Sadoff et al., 2015, Dadson et al., 2015, Grey et al., 2013, and Sadoff, 2007). Investing in water-related infrastructure and the agriculture sector is expected to increase economic growth, especially of water-insecure developing countries against shocks from rainfall variability. For example, one long-standing pillar of the Government of India's policy to reduce variability in water availability in agriculture is to invest in irrigation infrastructure (Dhawan, 1993; World Bank, 2002; Duflo and Pande, 2007). India's public investment in major and medium irrigation projects has been viewed as enhancing its agricultural growth (Thakkar, 2000). Areas with investment in irrigation have seen increasing yields, changing cropping patterns, increasing gross cropped area, and transition from a mono crop regime to double cropping (Planning Commission, 2011).

Despite extensive literature on irrigation in India, there is little empirical evidence on the impact of these irrigation investments on crop yields across districts within a state (Hope, 2007; Mollinga, 2014; Mosse 2006; Wade, 1988a). Specifically, it is unclear a) how rainfall patterns vary at a sub-basin level (e.g., district to district) within a state in India; b) how irrigation investments impact agricultural productivity in terms of crop yields; and c) whether irrigation investments improve resilience of crop yields from district-level rainfall variability? Few studies have examined the relationship between district-level rainfall variability, infrastructure and impacts on crop yields (Thakkar, 2000). In the current study, we explored these impacts using data from interventions made in modernization and rehabilitation of irrigation systems in Madhya Pradesh (MP), India under the Madhya Pradesh Water Sector Restructuring Project (MPWSRP) supported by the World Bank.

The MPWSRP was initiated in 2005 by the Government of Madhya Pradesh, and funded by the World Bank to overcome variations in agricultural growth and promote irrigation investment in the state (Sapre, 2014). Madhya Pradesh's economy is predominantly agrarian with agriculture, animal husbandry, and fisheries as the primary sectors of the state. However, there have been large-scale fluctuations in the agriculture sector's performance in recent years with annual growth rates between -2.44% (2007–08) and +11.18% (2010–11) (Sapre, 2014). Therefore, the key challenges for poverty reduction and economic growth in the state are sustainable management of water and related natural resources, particularly within the agrarian rural sector (Government of Madhya Pradesh, 2011). The MPWSRP aimed at improving productivity of water for sustainable growth, and poverty reduction across 31 districts in selected focus river basins of MP (World Bank, 2005).

The rationale for investments in asset rehabilitation was based on a hydrological basin approach (World Bank, 2004). The MP government aimed to shift the focus of the Water Resources Department (WRD) towards holistic development, with an integrated vision for water sector development (World Bank, 2005). MP has ten river systems (Mahi, Chambal, Sindh, Betwa, Ken, Tons, Son, Narmada, Wainganga and Tapi) (Figure 1). Asset rehabilitation and modernisation was implemented on a hydrological basin-scale in six out of the ten river basins (Chambal, Sindh, Betwa, Ken, Tons, and Wainganga) (Figure 1). The primary justification for selecting six out of the ten basins was to take all major river basins north of the Narmada basin. The Narmada basin is a transboundary basin and thus could not be part of the project due to World Bank regulations (World Bank, 2005). There are seven river basins north of the Narmada (Figure 1). The Mahi river basin was determined to be too small for integration into the project due to the lack of large-scale irrigation systems. Within the six target basins, investments were targeted to engineering needs; systems that were built before 1986, and those that exceeded a certain degradation threshold of designed performance, were selected for rehabilitation (World Bank, 2005).

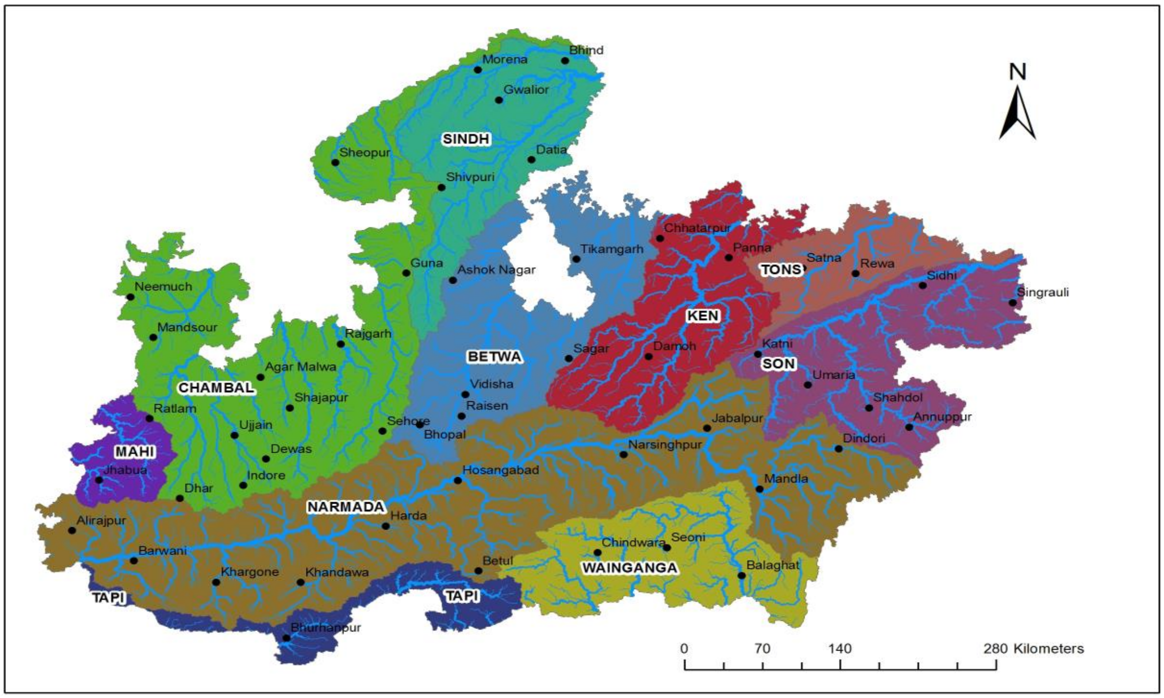

Fig. 1: Map of River Basins of Madhya Pradesh

To analyse the impact of the infrastructure investments made in the MPWSRP, we test two hypotheses:

1. Investments in irrigation infrastructure leads to higher crop yields at a district-level; and,
2. Investment in irrigation infrastructure buffers crop yields from fluctuations in rainfall levels at a district-level.

We examined them by analysing the project's impact across 31 districts, with and without irrigation infrastructure investment. Gram, paddy and wheat yields were assessed to compare variations in yield between intervention and non-intervention districts and differing levels of rainfall variability. Yield is an impact indicator of irrigation investment because amongst the multiple factors of crop yield, access to adequate irrigation is a key determinant of agriculture production. Paddy and wheat were selected because of all the cereal crops grown in MP, 80% of the cultivated land area is dedicated to the production of these crops (Government of Madhya Pradesh Economic Survey, 2014). And, of the pulses, about 60% of the cultivable area is dedicated to gram production (Government of

Madhya Pradesh Economic Survey, 2014). In order to examine fluctuations in rainfall at a district level, we analysed data on rainfall patterns from 2005-2014 of all of the selected districts, and determined standardised anomaly patterns for each district's monsoons over the last ten years.

We found that sub-basin hydro-climatic heterogeneity influences crop yields despite the availability of assured surface irrigation. Yields of all three crops show sensitivity to rainfall, indicating that crop yields are dependent on monsoon rainfall despite investments in surface irrigation systems. With constrained resources and increasing rainfall variability, this paper provides a more granular analysis of the district-wise yield impact of canal irrigation investments across 31 districts of three staple crops in MP.

Section 2 describes the methodology and the analytical framework used to analyse the data on rainfall and crop yields. Section 3 describes the results. Section 4 presents a discussion of the results and limitations, and section 5 concludes.

2. Methodology and Sampling Framework

2.1.1 Characteristics of the study area

MP is the third largest state in India with a total geographical area of about 40 million hectares (ha). The state has a population of 72 million as per the 2011 Census with an estimated 36% rural population living below the poverty line. The economy is dominated by agriculture, which accounts for 26.5% of the Net State Domestic Product (NSDP) (Government of Madhya Pradesh, 2011). The agricultural sector employs 73% of labour (Gilmont et al., 2016, Sapre, 2014).

The Human Development Index of Madhya Pradesh has consistently ranked the state among the bottom four in India over the past few years (Planning Commission, 2011). More than one third of the population is categorized as "socially and economically disadvantaged" consisting of Scheduled Tribes (ST) (20%) and Scheduled Castes (SC) (15%). This figure is one of the highest in India (Government of Madhya Pradesh, 2011).

MP has five regions with 52,143 villages, 23,044 panchayats (village councils) and 323 development blocks in 51 districts. There are 10 agro-climatic zones and five main crops zones in the state (De et al., 2001) (Table 2)[2].

MP has five physiographic regions: a) Northern low-lying plains; b) Malwa and Vindhya plateau; c) Narmada valley; d) Satpura stretch; and, e) Bastar plateau (De et al., 2001). The state has a great deal of diversity with areas ranging from less than 50 metres above mean sea level to more than 1200 metres. Annual rainfall ranges from 800 millimetres (mm) to 1,600 mm from west to east, occurring mainly during the monsoon (June to September) (Government of Madhya Pradesh, 2011). Historical analysis of rainfall variability indicates that the summer monsoon (June to September) in central India has changed significantly between 1950 and 2000 (Sushant, 2013). The frequency of days with heavy rainfall (100 mm/day) increased from 45 to 65 days per year, while the frequency of extreme rainfall events (150 mm/day) has doubled from 9 to 18 days per year during this period (Sushant, 2013). In contrast, the frequency of days with moderate rainfall (e.g. between 5 and 100 mm/day) has decreased. An increased frequency of extreme events and erratic rainfall along with a decline in number of moderate rainfall days indicates that MP is facing high levels of hydro-climatic variability. Overall, 40% of the total sown (cropped) area in the state is served by surface water and 60% of the cropped area in the state is irrigated by groundwater. Therefore, erratic and uneven distribution of the monsoon is one of the main constraints in accelerating and sustaining growth of the agriculture sector.

Our analysis focuses on 31 districts that fall within the six selected river basins. Districts in India are local administrative units that form the tier of local government just below the Indian state. In this study, we collected and analysed data at a district-scale rather than river basin scale, to identify variations in impacts across different districts. Basin level analysis alone tends to mask heterogeneity in patterns among districts within a state.

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[2] The agro-climatic zones are Bastar Plateau Zone, Kymore Plateau and Satpura Hill Zone, Vindhya Plateau Zone, Central Narmada Valley Zone, Grid Zone, Bundelkhand Zone, Satpura Plateau Zone, Malwa Plateau Zone, Nimar Valley Zone and Jhabua Hill Zone (De et al., 2001)

Figures on demographic, agricultural, and socio-economic data for each of these districts based on data available from the Madhya Pradesh Planning Commission are available as supplementary tables[3].

2.1.2 The Madhya Pradesh Water Sector Restructuring Project

The MPWSRP focused on maximizing water productivity in all its uses in 495,000 ha of designed potential irrigation command areas in the six basins, out of which, only half of the area was serviced when the project began (World Bank, 2005). Over half of the 193,000 farms (61%) in the project area are small farms with an average land holding size of less than one hectare. The MPWSRP made a total investment of USD$ 443 million across four components with the following costs and objectives:

Component A: Water Resources Management – Institutions and Instruments (USD$ 7.27 Million) - to support the establishment and operationalization of the proposed planning, allocation and regulatory institutions, and instruments at the state and basin-levels.

Component B: Service Delivery – Irrigation and Drainage Institutions (USD$ 38.35 Million) - to support measures related to delivering reliable irrigation services at rationalized cost by financially viable entities.

Component C: Improving productivity of selected existing irrigation and drainage assets in six basins (USD$ 388.09 Million) - to provide the necessary investments in six

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[3] Data on the general characteristics of each district was obtained from the District Census Handbook for Madhya Pradesh compiled by The Registrar General & Census Commissioner of India as part of the Ministry of Home Affairs, Government of India. Data on characteristics for the percentage of the rural population below the poverty line was compiled from the Madhya Pradesh State Planning Commission district-wise poverty estimates report for 2004-05. The main source of data for this study is the “Consumer Expenditure Surveys” undertaken by the National Sample Survey Organization (NSSO). District-wise per capita income at current prices from 2004-05 to 2012-2013 was obtained from the Madhya Pradesh Economic Survey 2013-2014.

basins (Chambal, Sindh, Betwa, Ken, Tons, and Wainganga) for (i) reliable delivery of water on an appropriate volumetric basis in the irrigation systems of these basins to improve system performance, cost recovery and accountability of the service provider; (ii) an outcome-oriented approach with integrated sustainable agricultural intensification and diversification; and (iii) improved operation and management of the irrigation and drainage schemes.

Component D: Project Management Support (USD$ 5.52 Million) - the project activities would be coordinated by a multi-disciplinary Project Implementation Coordination Unit (PICU).

For the purposes of this paper, analysis will focus on Component C, as this component made investments in modernisation and rehabilitation of irrigation canals and tanks. Although the MPWSRP made other interventions in institutional reform and water management, they were minor compared to the infrastructure investments in terms of overall percentage share of costs of the project. The selection of schemes for the project was based on hydrologic river basins as units (World Bank, 2005). Within the six river basins, the project selected irrigation schemes that were constructed before 1986 (around 20 years old) and those with degraded performance in actual utilisation of irrigation potential due to deferred maintenance.

Upon closure in 2015, the MPWSRP achieved modernization and rehabilitation of 5 major, 21 medium, and 202 minor irrigation schemes. A major irrigation system is a system that provides irrigation to more than 5000 ha of farmland, a medium system is a system that serves 2000–4999 ha, and minor systems can serve 200–1999 ha. A total of 228 investments were made in civil engineering works to rehabilitate and modernise the irrigation systems. This included activities such as repair works on dams and embankment repair, addressing seepage and drainage issues, improving boundary stones, and repairing sluice and radial gates on the infrastructure. In some cases, new structures had to be built, while in others, old structures were repaired. Old canals were lined with concrete to reduce seepage and improve distribution of water. Based on these interventions, the project aimed to improve cropping intensity, improve irrigation efficiency of the surface irrigation canals, and improve crop production for key kharif, or summer, crops (i.e. paddy) and rabi, or winter crops (i.e. wheat and gram) (World Bank, 2005).

2.2 Sampling Framework

The 228 investments were made based on the engineering repair needs of the irrigation systems within the six basins. Thus some districts received more investments than others, and some received no investments. Based on detailed discussions with Government of Madhya Pradesh Water Resources Department officials, we developed a sampling framework to enable us to compare results of crop yields and rainfall levels between intervention and non-intervention districts. We then collected secondary data on the following: a) the size and scale of the irrigation investments made by the MPWSRP within intervention districts, b) inter and intra-annual rainfall data for 31 districts from the period 2005-2014; and, c) crop yield data for the three main crops across 31 districts within the same timeframe.

2.2.1 Irrigation Investment Data

In order to analyse the 228 irrigation schemes rehabilitated, we obtained data on: a) the total command area of the systems; b) the percentage of irrigated area rehabilitated within each district by the project; c) the total amount of investments made by the project in USD$ within each district; and, d) the dollar amount invested per hectare in each district. This information is summarised in Table 1[4].

We divided the 31 districts into two "irrigation investment categories". Districts were classified as **Rehab** (systems that were rehabilitated by MPWSRP) and **No Rehab** (if there were no MPWSRP investments made in that district). Some districts had partial investments in parts of the district and thus fell into both categories (designated with a * in Table 3). Within the **Rehab** category, districts were further divided into three

[4] Data on the number of irrigation projects in each of the selected river basins and districts along with information on the number of hectares rehabilitated was obtained from the MP Irrigation Department officials. This data was compiled to comply with World Bank monitoring and reporting requirements.

investment categories. **Low Rehab** represents districts that had between 0.01 – 10% of their irrigated area rehabilitated**. Medium Rehab** represents districts that had 11-50% of their irrigated area rehabilitated and **High Rehab** is for districts that had more than 50% of their irrigated area rehabilitated (Table 1).

Table 1: Summary of Data on MPWSRP Investments and Categorisation of District-wise Irrigation Investment Categories[5]

No.	District Name	River Basin	MPWSRP Investment (Yes/None/ Partial)	Number of irrigation schemes rehabilitated	Total irrigated area of surface & ground water (ha)	Total command area of systems rehabilitated (ha)	% irrigated area rehabilitated by MPWSRP (AgStat-2014-15)	Irrigation Investment Category	Investments under MPWSRP (million $)	Investments ($/ha)
1	Ashoknagar	Betwa	Yes	17	196,341	14,106	7	Low	3.56	252
2	Balaghat	Wainganga	Yes	1	143,254	43,136	30	Medium	18.57	430
3	Bhopal	Betwa	Partial	8	107,412	3166	3	Low	2.19	692
4	Bhind	Sindh	Yes	1	206,218	84,955	41	Medium	45.22	532
5	Chhatarpur	Ken	Yes	1	279,145	4170	1	Low	2.12	508
6	Damoh	Ken	Yes	6	203,069	5928	3	Low	2.93	494
7	Datia	Sindh	None	N/A	191,034	N/A	0	N/A	N/A	N/A
8	Dewas	Chambal	Yes	15	304,605	1987	1	Low	0.99	498
9	Dhar	Chambal	Yes	3	394,539	161	0	Low	0.1	621
10	Guna	Chambal, Sindh	Yes	5	232,357	1768	1	Low	0.67	379
11	Gwalior	Sindh	Partial	6	139,695	75,035	54	High	37.61	501
12	Indore	Chambal	None	N/A	212,165	N/A	0	N/A	N/A	N/A
13	Katni	Ken	Yes	11	128,700	2399	2	Low	2.91	1213
14	Mandsaur	Chambal	Yes	5	254,982	962	0	Low	0.36	374
15	Morena	Chambal, Sindh	Yes	3	212,561	212,561	100	High	125.86	592
16	Neemuch	Chambal	Partial	2	127,848	4989	4	Low	1	200
17	Panna	Ken	None	N/A	121,814	N/A	0	N/A	N/A	0
18	Raisen	Betwa	Yes	9	431,709	9752	2	Low	3.45	354

[5] Data provided by Government of Madhya Pradesh Water Resources Department

19	Rajgarh	Chambal	Yes	17	343,861	4050	1	Low	1.86	459
20	Ratlam	Mahi	None	N/A	206,692	N/A	0	N/A	N/A	0
21	Rewa	Tons	Yes	8	117,450	11,643	10	Low	3.76	323
22	Sagar	Ken	Yes	6	367,574	24,221	7	Low	9.79	404
23	Satna	Tons	Yes	25	165,729	13,303	8	Low	2.38	179
24	Sehore	Chambal	Yes	8	328,315	4545	1	Low	1.38	304
25	Seoni	Wainganga	None	N/A	202,758	N/A	0	N/A	N/A	0
26	Shajapur	Chambal	Yes	11	196,040	4834	2	Low	1.99	412
27	Sheopur	Chambal, Sindh	Yes	3	142,592	75,825	53	High	45.24	597
28	Shivpuri	Sindh	Yes	1	302,306	2614	1	Low	0.72	275
29	Tikamgarh	Betwa	Yes	23	223,049	2114	1	Low	0.81	383
30	Ujjain	Chambal	Partial	22	347,571	6994	2	Low	2.37	339
31	Vidisha	Betwa	Partial	12	412,572	35,716	9	Low	8.56	240
	Total (average)			228	7,243,957	650,934	11		12.55	398

2.2.2 Inter-annual Rainfall Data

Inter-annual variation in the monsoon cycle is determined by the relative contribution of multiple external and internal air-sea interactions and oscillations, with heavy or less rainfall traditionally resulting in floods or droughts (Ratna et al., 2011; Neena et al., 2011). To analyse inter-annual variability in MP, we divided the 31 districts into three rainfall categories: **low rainfall**, **average rainfall,** and **high rainfall**. This was to determine if there was significant diversity in the inter-annual rainfall patterns among the **Rehab** and **No Rehab** category districts, and to identify how many of the districts among the 31 tend to have low, average, or high rainfall. Annual averages from 2005-2014 were determined by averaging the 12 monthly rainfall values for all available rain gauge stations in each district[6]. Once the monthly average for each year was calculated, we then calculated the ten-year average for that district. The last step was to classify each district according to its corresponding rainfall zone. To classify each district into the three zones, the following formula was applied:

Average rainfall: In order to determine if a district falls into the average rainfall category, we compared each districts' 10-year average against the average of the 10-year rainfall of all of the 31 districts. For instance, for Rajgarh, which is in the **Low Rehab** investment category, the category was determined by comparing the 10-year average rainfall of Rajgarh of 1019 mm/year against the 10-year averages of the other districts. If Rajgarh's 10-year average is within 10% of the 10-year average of the districts, then Rajgarh is classified as having average rainfall. As the boundary classification for average rainfall is between 869 –1062 mm, Rajgarh falls into this category.

Low rainfall: This classification was determined in the same way as average rainfall, except the criteria to fall into low rainfall is when the district has a 10-year average rainfall that is less than 10% of the 10-year average of all the districts. For instance, Dhar

[6] Monthly rainfall data from 2005-2014 for all districts was obtained from the Government of Madhya Pradesh (GoMP) Irrigation Department officials. Data was provided for all districts for each month (Jan – Dec) for the years 2005-2014. For each district, monthly rainfall values in millimetres are available for each of the rain gauge stations within the district. Data obtained was actual observed values for rainfall compiled by the Irrigation Department rather than satellite data.

is a **Low Rehab** district that falls into low rainfall, as the 10-year average rainfall of Dhar is 860 mm. The boundary classification for low rainfall is less than 869 mm.

High rainfall: The criterion for high rainfall is when the district has a 10-year average rainfall that is more than 10% of the 10-year average of the selected districts. For instance, Bhopal is a **Low Rehab** district that falls into the high rainfall category, as the 10-year average of Bhopal is 1119 mm. The boundary classification for high rainfall is greater than 1062 mm.

Table 2 provides the observed average rainfall values for the 31 districts, the number of rainfall gauge stations in each district, their corresponding rainfall categories, investment categories, and the district agro-climatic and crop zones. The distribution of districts into investment and rainfall categories is illustrated in Table 3. Table 3 illustrates that there is heterogeneity in the inter-annual rainfall averages within the **Low, Medium and High Rehab** districts as well as between the **Rehab** and **No Rehab** districts. Not all districts received the same level of investment, and not all districts have the same patterns of rainfall when examined over a ten-year period.

Table 2: District-wise Ten-year Annual Average Rainfall Values, Rainfall Zones, Investment Categorisation, and Agro-climatic Zone

No.	Name of District	Number of Rain Gauge Stations	Average annual rainfall value 2005-2014 (mm)	Rainfall Category (Low, Average, High)	Investment Category	Agro-climatic & crop zone
1	Ashoknagar	4	960	Average	Low Rehab	Grid region (wheat, jowar zone)
2	Balaghat	24	1332	High	Medium Rehab	Chhatisgarh plains (rice zone)
3	Bhopal	2	1119	High	Partial Low Rehab	Vindhya plateau (wheat zone)
4	Bhind	4	685	Low	Medium Rehab	Grid region (wheat, jowar zone)
5	Chhatarpur	10	902	Average	Low Rehab	Bundelkhand (wheat-jowar zone)
6	Damoh	7	1152	High	Low Rehab	Vindhya plateau (wheat zone)
7	Datia	3	742	Low	No Rehab	Bundelkhand (wheat-jowar zone)
8	Dewas	7	919	Averge	Low Rehab	Malwa plateau (cotton, jowar zone)
9	Dhar	13	859	Low	Low Rehab	Malwa plateau (cotton, jowar zone)
10	Guna	5	1024	Average	Low Rehab	Vindhya plateau (wheat zone)
11	Gwalior	8	725	Low	Partial High Rehab	Grid region (wheat, jowar zone)
12	Indore	5	993	Averge	No Rehab	Malwa plateau (cotton, jowar zone)
13	Katni	2	922	Average	Low Rehab	Kymore plateau & Satpura hills (wheat, rice zone)
14	Mandsaur	6	896	Average	Low Rehab	Malwa plateau (cotton, jowar zone)
15	Morena	6	688	Low	High Rehab	Grid region (wheat, jowar zone)
16	Neemuch	3	897	Average	Partial Low Rehab	Malwa plateau (cotton, jowar zone)
17	Panna	5	932	Average	No Rehab	Kymore plateau & Satpura hills (wheat, rice zone)
18	Raisen	8	1111	High	Low Rehab	Vindhya plateau (wheat zone)

19	Rajgarh	6	1019	Average	Low Rehab	Malwa plateau (cotton, jowar zone)
20	Ratlam	8	983	Average	No Rehab	Malwa plateau (cotton, jowar zone)
21	Rewa	7	963	Average	Low Rehab	Kymore plateau & Satpura hills (wheat, rice zone)
22	Sagar	12	1141	High	Low Rehab	Vindhya plateau (wheat zone)
23	Satna	11	942	Average	Low Rehab	Kymore plateau & Satpura hills (wheat, rice zone)
24	Sehore	5	1048	Average	Low Rehab	Vindhya plateau (wheat zone)
25	Seoni	18	1204	High	No Rehab	Kymore plateau & Satpura hills (wheat, rice zone)
26	Shajapur	7	950	Average	Low Rehab	Malwa plateau (cotton, jowar zone)
27	Sheopur	2	706	Low	Medium Rehab	Grid region (wheat, jowar zone)
28	Shivpuri	8	826	Low	Low Rehab	Grid region (wheat, jowar zone)
29	Tikamgarh	7	822	Low	Low Rehab	Bundelkhand (wheat-jowar zone)
30	Ujjain	7	975	Average	Partial Low Rehab	Malwa plateau (cotton, jowar zone)
31	Vidisha	7	1094	High	Partial Low Rehab	Vindhya plateau (wheat zone)
	Total (average)	227	942			

Table 3: Sampling Framework Classification of 31 Districts into Irrigation Investment Categories & Rainfall Zones

		Inter-annual Rainfall Variability Zones		
Irrigation investment category by percentage of irrigated area rehabilitated	**Rehab**	**Average**	**Low**	**High**
	Low Rehab (0.01-10% of irrigated area rehabilitated)	Ashoknagar,Rajgarh, Ujjain*, Guna, Dewas, Mandsaur, Shajapur, Katni, Neemuch*, Chhatarpur, Satna, Rewa, Sehore	Dhar, Shivpuri, Tikamgarh,	Bhopal*, Sagar, Damoh, Raisen, Vidisha*
	Medium Rehab (11-50% of irrigated area rehabilitated)		Bhind	Balaghat
	High Rehab (More than 50% of irrigated area rehabilitated)		Gwalior*, Sheopur, Morena	
	No Rehab	Panna, Indore, Ratlam, Ujjain*, Neemuch*	Gwalior* Datia	Seoni, Vidisha*, Bhopal*

*Districts that have partial areas where systems were rehabilitated and also some areas where systems were not rehabilitated hence fall under both categories

2.3. Intra-annual Rainfall Data

Building on the inter-annual rainfall analysis, we also examined intra-annual variability. This enabled us to examine changes in a district's hydro-climatic pattern from month to month within a district and across districts. This helped us understand the levels of rainfall variability within each of the districts and across districts in Rehab districts, as well as rainfall patterns in No Rehab areas. In order to test the second hypothesis; whether investments in irrigation infrastructure buffered crop yields from fluctuations in rainfall at a district-level, we examined intra-annual rainfall.

In order to conduct this analysis, data were collected for all 12 months for 30 districts from 2005-2014. For Katni district, monthly rainfall values were available from 2005-2013 as 2014 was not available. This was the same dataset as that utilized for the inter-annual rainfall analysis. As monsoon is important for determining agricultural yields and productivity, it was determined that the four monsoon months across all ten years would be utilised to examine intra-annual variability. The results of all the 31 standardised anomaly graphs for each district are available as supplementary materials.

The first step was to determine a monthly value for each district based on a sum of the values of rainfall in mm of all of the rainfall gauge stations in each district. Thus, monthly values were calculated for the four monsoon months across all 31 districts for all available years from 2005-2104. Each district's monthly rainfall value represents a sum of its values from its rain gauge stations, which varies from district to district (Table 2).

The second step was to calculate "monthly climatology", which is the mean value of rainfall for each month over the time period 2005-2014. Therefore, mean values for each of the four months were calculated by taking an average of the monthly value of each month from the 10 years of data. Monthly climatology was determined for all 12 months for all 31 districts. Rainfall anomalies for each district were computed by subtracting observed values of monthly data from the monthly climatology values for all 31 districts.

The third step was to determine if seasonal variations are present within the monsoon months. Standardized anomalies, also referred to as normalized anomalies, are calculated by dividing the “rainfall anomaly” values by the climatological standard deviation. Thus the climatological standard deviation of the rainfall was calculated for each of the monsoon months for all 31 districts. Once standard deviations were determined, the standardized anomaly was determined by dividing the “rainfall anomaly” for the monsoon months from the standard deviation values of each respective month.

This was calculated using the following formula: $P\{|X-\mu|>k\sigma\}\leq 1/k^2$

(where: σ = standard deviation, k = standardized anomaly, μ = mean, X = rainfall (meteorological parameter). Standardised anomalies generally provide more information about the magnitude of the anomalies because influences of dispersion have been removed.

Lastly, we classified each year from 2005-2014 into the three rainfall zones for all 31 districts. The classification was calculated based on an average of the monthly rainfall values of the four monsoon months for each year in comparison to the average annual rainfall of 10 years for that district. Based on the calculation, each year from 2005-2014 was classified as high, average, or low rainfall.

2.4 Crop Yield Data

For the crop yield analysis, secondary data were compiled for each district on yields produced in tonnes per hectare for wheat, paddy, and gram[7]. Inter-annual monsoon

[7] Agriculture yield data was obtained from the Madhya Pradesh Commissioner Land Records Office in Gwalior district. For the wheat and gram crops data was provided for years 2004-05, 2006-07 onwards to 2013-14. However, data for the year 2005-06 was not available. For the paddy crop data was provided for 2004-05 and from 2006-07 to 2013-14. However, as paddy is cultivated in September and October of each year, data from 2004-05 would qualify as data for the year of 2004. Lastly, instead of providing absolute values for each unit, relative values are given for crop yields as illustrated in the graphs in Section 3.

rainfall values for each district were also included in order to compare how yield values changed during average, low or high rainfall years.

3. Results

Based on the distribution of 31 districts into investment categories and rainfall zones, it is evident that districts do not all have the same inter-annual rainfall patterns and differ in the degree of their total irrigated surface area that was rehabilitated by the MPWSRP (Table 3). This distribution forms the basis for comparison between the degrees of investment, rainfall levels, and crop yield outcomes.

3.1 Rainfall Analysis Results

The result of the standardized monsoon anomaly plots indicates that no two districts are alike. Across the ten-year period, each of the 31 districts has a unique anomaly pattern. Secondly, the classification of each year (2005-2014) into low, average or high rainfall years according to the analysis of the intra-annual monsoon values illustrates that there are some years where the weather is consistently wet or dry, and others where the variability between districts dominates (Table 4). Therefore, water availability for the annual cropping season can vary drastically both within a monsoon season from district to district, and from one year to another within a single district.

Table 4: District-wise Classification of Rainfall Zones for Monsoon Months

	District-wise Classification of Monsoon Rainfall Jun-Sep 2005-2014									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Ashoknagar	High	High	Low	High	Low	Low	High	Average	High	Low
Balaghat	High	High	High	High	Low	High	High	High	High	Low
Bhopal	High	High	Average	Low	Average	Low	High	High	High	Low
Bhind	Low	Low	Low	Average	Low	Low	Average	Low	Average	Low
Chhatarpur	High	Low	Low	Average	Low	Average	High	Average	High	Low
Damoh	High	Low	Average	High	Low	High	High	High	High	Low
Datia	Low	Low	Low	High	Low	Low	Low	Average	Average	Low
Dewas	Low	High	High	Low	Low	Low	High	High	High	Low
Dhar	Low	High	High	Low	Low	Low	Low	Low	High	Low
Guna	High	Average	Low	Average	Low	Low	High	Low	High	Average
Gwalior	Low	Low	Low	Low	Low	Average	Low	Average	Average	Low
Indore	Low	High	Average	Low	Low	Average	High	High	High	Low
Katni	Low	Low	High	Low	Low	Average	High	High	High	Data Gap
Mandsaur	Low	High	Average	Low	Low	Low	High	Average	High	Low
Morena	Low	Low	Low	Low	Low	Low	Low	Average	Average	Low
Neemuch	Low	High	Low	Low	Low	Low	High	Low	High	Average
Panna	High	Low	Low	Low	Low	Low	High	High	High	Low
Raisen	High	High	Low	Average	Average	Low	High	High	High	Average
Rajgarh	Low	High	Average	Low	Low	Low	High	Average	High	Average
Ratlam	Low	High	High	Low	Low	Low	High	High	High	Low
Rewa	High	Low	Low	Low	Low	Low	High	High	High	Low
Sagar	High	Average	Low	High	Average	Low	High	Average	High	Low
Satna	High	Low	Low	Low	Low	Low	High	Average	High	Low
Sehore	High	High	Average	Low	Low	Low	High	High	High	Average
Seoni	High	High	Low	Low	Low	High	High	Low	High	Low
Shajapur	Low	High	High	Low	Low	Low	High	Average	High	Low
Sheopur	Low	Low	Low	Low	Low	Low	High	Low	Average	Low
Shivpuri	Low	Low	Low	Low	Low	Average	Average	Average	High	Low
Tikamgarh	Low	Low	Low	High	Low	Low	High	Low	High	Low
Ujjain	Low	Average	Average	Low	Low	Low	Average	Average	Average	Low
Vidisha	High	High	Low	High	Low	Low	High	Average	High	Average
		Key:								
			Average	Low	High	Data Gap				

Data from the MP Meteorology Department indicates that from 2007 and 2010, 37-41 districts experienced severe drought and rainfall deficiency ranging from 26 days to 30 days (Government of Madhya Pradesh, 2011). However, in 2007, even though a majority of districts experienced low rainfall, some districts actually experienced wet monsoons (Table 4). Districts such as Dhar, Ratlam, Shajahapur, and Dewas saw high rainfall levels with an extreme positive anomaly away from the mean. Conversely, from 2011-2013, the trend is of relatively "wetter" monsoons across a majority of districts, but with some districts with deficient rainfall as well.

We conclude that there is evidence of heterogeneity in the hydrological climate among districts in MP, which could be influencing district-level crop yields. Multiple districts within a river basin in MP have varying degrees of rainfall within a single year and within one monsoon season. This can range from extremes of wet monsoons to dry monsoons within one cropping season. Next, we explored whether crop yields in districts with investments are able to better cope against this heterogeneity compared to districts with no investments.

3.2 Crop Yield Analysis Results

3.2.1 Crop Yield Results for Average Rainfall Zone

Figure 2 indicates the average rainfall districts in both the Low Rehab (LR) and No Rehab (NR) categories in mm per year. Yield data is also presented for the three crops in metric tonnes per hectare (t/ha) for districts falling into the Low Rehab investment category (e.g. Ashoknagar, Rajgarh, Ujjain*, Guna, Dewas, Mandsaur, Shajapur, Katni, Neemuch*, Chhatarpur, Satna, Rewa and Sehore) compared to yield results of districts in the No Rehab category (e.g. Panna, Indore, Ratlam, Ujjain*, and Neemuch*) (Table 3).

Yields for wheat and paddy for the Low Rehab districts are higher and increase in 2010 for paddy, and 2011 for wheat compared to districts in the No Rehab category. This coincides with the fact that many of the newly renovated irrigation systems would have completed construction and were operational within the 2010/2011 cropping season. With a minimum investment from the MPWSRP, there is a noticeable rise in paddy yields in 2012 compared to 2005 yields and compared to the No Rehab districts. Therefore, the first hypothesis we presented is accepted in this scenario. However, rainfall levels for both Low Rehab and No Rehab districts rise in 2011 and 2013 to above 1000 mm and 1200 mm respectively. Hence, we also see increase in yields for all three crops in 2010-11 with a spike in 2013.

For the gram crop, yields in the No Rehab districts continue to be higher than the Low Rehab districts, and only seem to be converging in 2014 when rainfall levels are at their lowest for both categories of districts. Gram also seems to be less sensitive to rainfall. From 2008-2010, when rainfall levels in both the Low Rehab and No Rehab districts are low, gram yields continuously rise above that of wheat and paddy yields. We conclude that for gram, the low percentage of irrigated area that was rehabilitated in the Low Rehab districts was not sufficient to improve yields above that of the No Rehab districts.

Lastly, we see a reduction in rainfall from 2013 to 2014, from a high of more than 1200 mm in 2013 to nearly 600 mm in 2014. Simultaneously, we observe a decline in yields for all three crops for districts in the Low Rehab and No Rehab districts. These initial results indicate that crops yields are still sensitive to district-level rainfall variability independent of investments in irrigation.

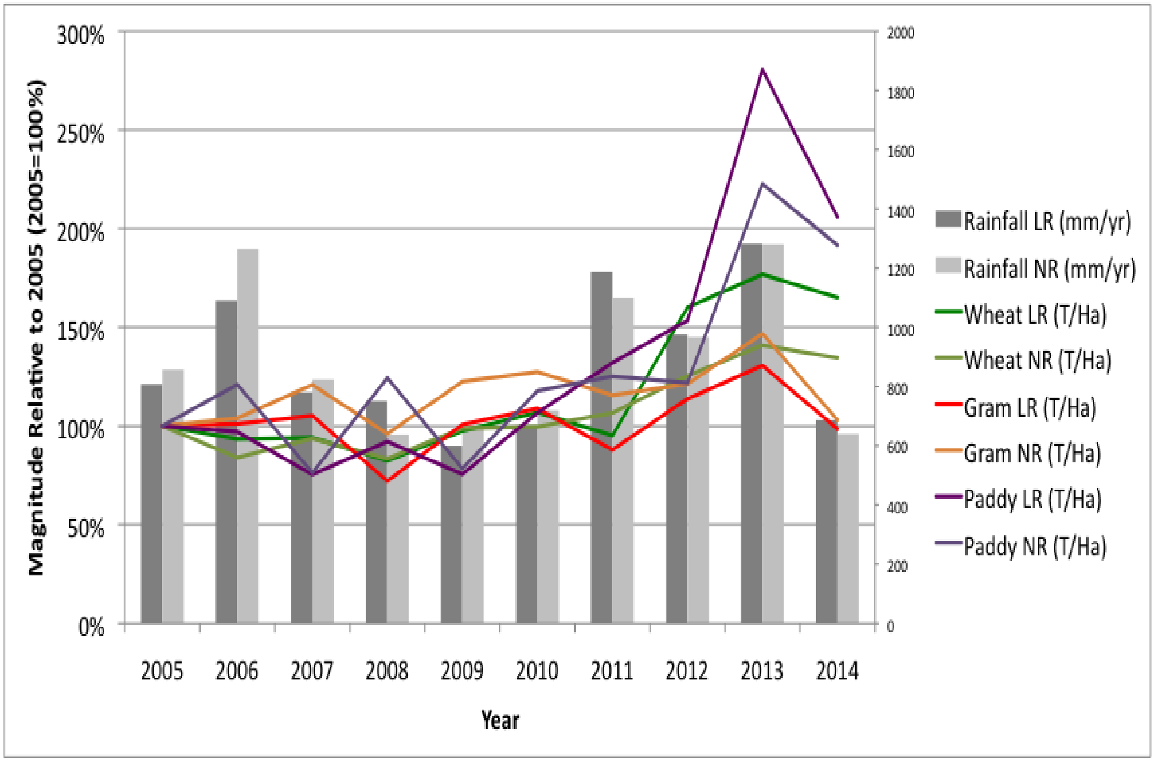

Fig. 2: Results of Crop Yield Analysis for Average Rainfall Zone & Low Rehab (LR) and No Rehab (NR) Districts

3.2.2 Crop Yield Results for Low Rainfall Zone

Figures 3-5 illustrates results of crop yields for low rainfall districts across all investment categories: Low Rehab (Dhar, Shivpuri, Tikamgarh), Medium Rehab (Bhind), and High Rehab (Gwalior*, Sheopur, Morena) in comparison to crop yields for districts in the No Rehab category (Gwalior*, Datia).

Based on the first two hypotheses set out in this paper, we expect yields in the low rainfall zone for all three crops in the Low to High Rehab districts to have higher yields than in the No Rehab districts. Also the availability of assured surface irrigation during periods of deficient rainfall should result in higher yields in the Rehab districts, to indicate that assured surface irrigation is buffering crop yields against reduced rainfall. However, the results do not align with the first two hypotheses across all investment groups and across all crops. Figure 3 represents yield outcomes for the Low Rehab and No Rehab districts for the low rainfall zone.

The first hypothesis for the paddy crop is accepted. Yields in the Low Rehab districts are higher than those in the No Rehab districts from 2010 onwards (Figure 3). In 2013, in the Low Rehab districts, paddy yields rise above 300% from the base yields in 2005 when rainfall levels in these districts are less than 1200 mm (Figure 3). As newly renovated irrigation infrastructure would have been operational by 2013, we can conclude that despite other heterogeneous factors influencing yields, paddy yields in the Low Rehab district yields were higher than the No Rehab districts with some contribution from the irrigation investments. However, the results show that paddy is sensitive to rainfall, as yields rise when there are higher periods of rainfall (2008, 2011, and 2013) and fall in periods of reduced rainfall (2009, 2012 and 2014) for both Low Rehab and No Rehab districts.

Wheat is a rabi (or winter) crop that depends on surface or groundwater irrigation. From 2011-2013, wheat yields in the Low Rehab districts performed better than those of the No Rehab districts (Figure 3). Wheat yields, therefore, align with the first hypothesis. In 2012, wheat yields increased when the Low Rehab districts had lower rainfall than the No Rehab districts. However, wheat has some sensitivity to rainfall levels. With the exception of 2010 and 2012, Low Rehab district wheat yields outperform No Rehab districts when Low Rehab district rainfall levels are higher. As rainfall levels fall drastically in 2014, yields of both the Low Rehab and the No Rehab are converging, indicating that wheat yields in both categories are sensitive to rainfall levels despite the availability of assured surface irrigation.

For gram, both the first two hypotheses are rejected. In 2011, No Rehab districts have higher gram yields than the Low Rehab districts particularly at a time when irrigation systems would be operational and when rainfall in the No Rehab districts is lower (Figure 3). In 2013, gram yields in the Low Rehab districts are only slightly higher than the No Rehab districts but when rainfall levels in the Low Rehab districts are much higher than in the No Rehab districts. These results suggest that gram yields are sensitive to rainfall variability.

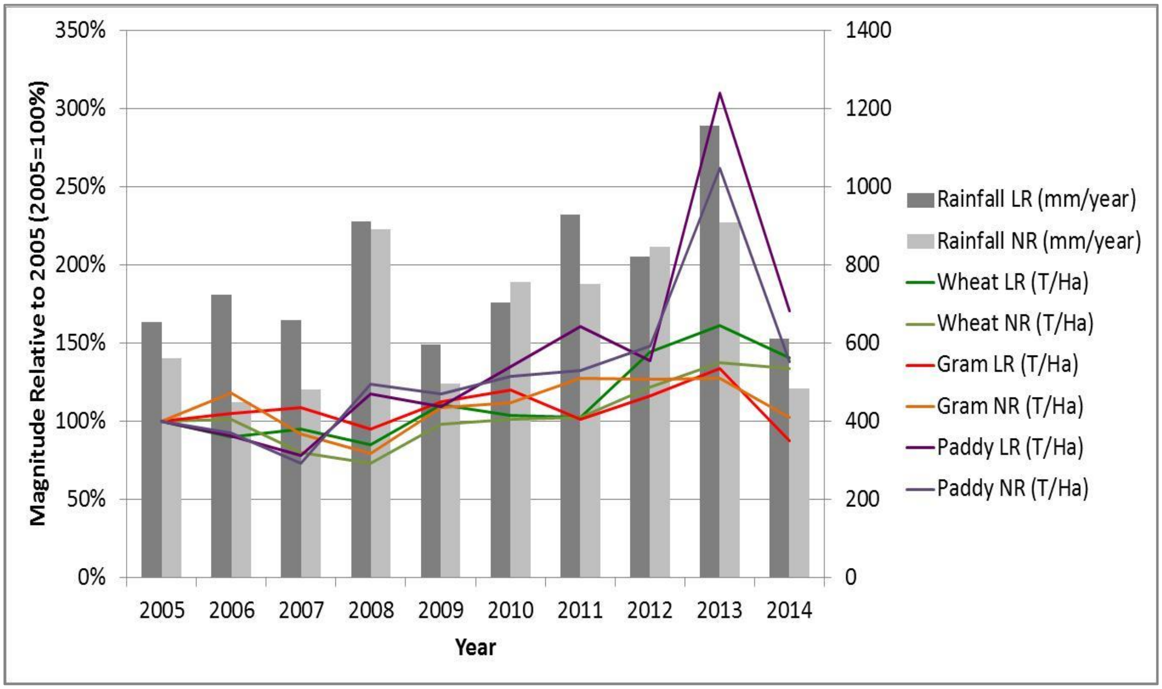

Fig. 3: Results of Crop Yield Analysis for Low Rainfall Zone & Low Rehab (LR) and No Rehab (NR) Districts

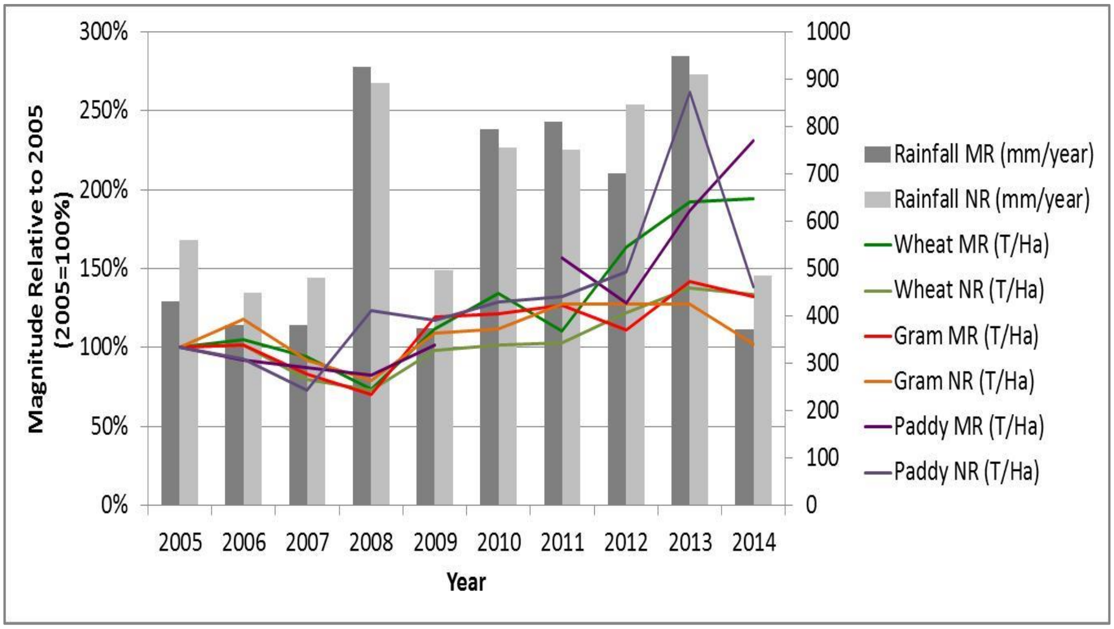

Fig. 4: Results of Crop Yield Analysis for Low Rainfall Zone & Medium Rehab (MR) and No Rehab (NR) Districts

Figure 4 represents yield outcomes for the three crops for low rainfall for the Medium Rehab (MR) districts. Yields of the Medium Rehab district (Bhind) are compared to the yields of districts in the No Rehab districts (Gwalior* and Datia). In this scenario, the hypotheses for crop yields and rainfall sensitivity holds true for wheat, but not for paddy and gram.

In 2011, wheat yields in the Medium Rehab districts increase and continue to rise above 2005 levels. They also continue to rise despite lower rainfall in 2012 and 2014. For paddy, No Rehab districts have lower rainfall in 2008, 2010, 2011, and 2013 than the Medium Rehab districts. However, from 2012 onwards, yields in the No Rehab districts are higher than the Medium Rehab districts. In 2014, paddy yields in the No Rehab districts fall when rainfall levels are lower, indicating the sensitivity of paddy to rainfall. Gram trends show that the Medium Rehab and No Rehab district yields are nearly the same from 2005 – 2008. The Medium Rehab district shows slightly higher yields from 2009-2011. In 2013, although gram yields in the Medium Rehab district are slightly higher, this is coinciding with a period of higher rainfall. Gram is highly sensitive to rainfall, and the larger percentage of newly rehabilitated irrigation area in the Medium Rehab district does not seem to make a large yield difference in the gram crop.

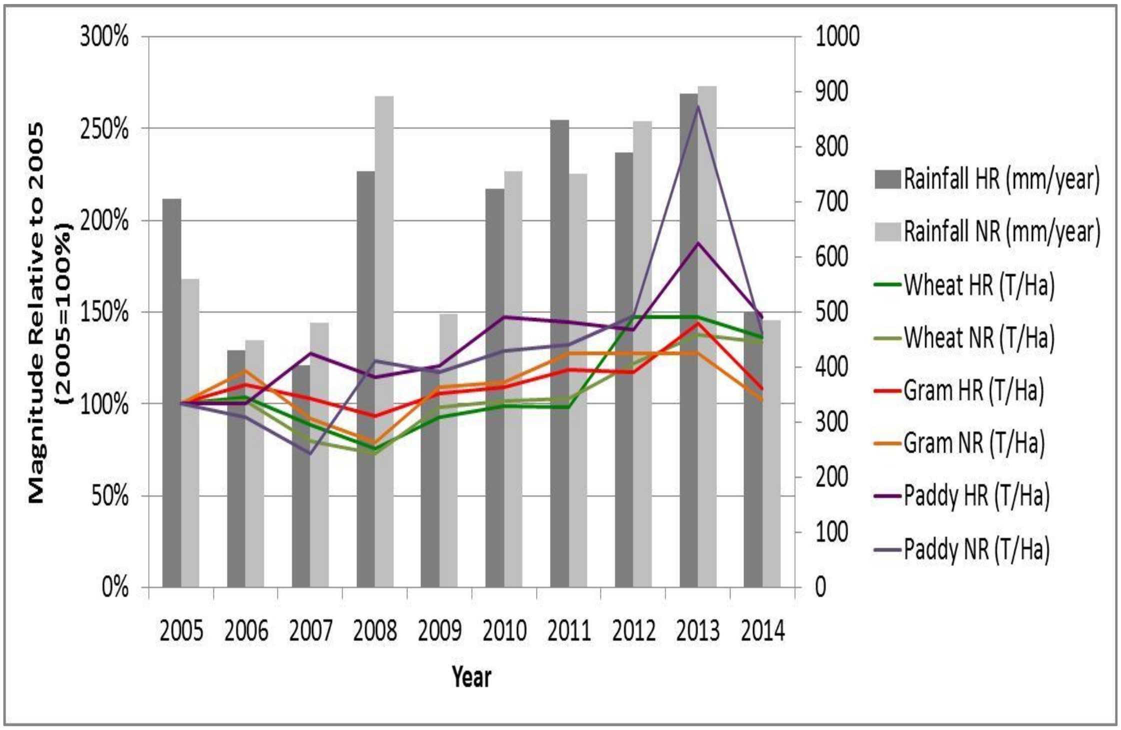

Fig. 5: Results of Crop Yield Analysis for Low Rainfall Zone & High Rehab (HR) and No Rehab (NR) Districts

Figure 5 represents yield outcomes for the districts in the High Rehab (HR) category (e.g. Gwalior*, Sheopur, and Morena) compared to the No Rehab (NR) districts of Gwalior* and Datia. However, despite the increase in the percentage of the district's irrigated area rehabilitated, we observe that crop yield patterns are quite similar to the patterns observed in Figure 4. The hypotheses are rejected for paddy and gram, but holds true for wheat.

3.2.3 Crop Yield Results for High Rainfall Zone

Figures 6 and 7 represent yields for districts in the Low, Medium and No Rehab investment categories with high rainfall. The Low Rehab districts are Bhopal*, Sagar, Damoh, Raisen, and Vidisha*, and the Medium Rehab district is Balaghat. The No Rehab districts are Seoni, Vidisha*, and Bhopal*.

For paddy, both hypotheses are rejected in Figures 6 and 7. Paddy results in Figure 6 show that the Low Rehab districts have only slightly higher yields than the No Rehab districts, and only after 2013 when rainfall in the Low Rehab districts was higher. In Figure 7, the Medium Rehab districts with a higher percentage of irrigated area rehabilitated have lower paddy yields than the No Rehab districts. This occurs, despite the fact that the Medium Rehab districts have consistently higher rainfall levels than in the No Rehab districts (Figure 7).

Wheat follows a similar pattern. From 2011 onwards, wheat yields for the No Rehab districts are higher than the Low Rehab districts (Figure 6). In Figure 7, wheat yields in the Medium Rehab districts are higher until 2012. After 2012, yields fall below yields for the No Rehab districts, when newly renovated irrigation systems would have become operational. There is also evidence of strong sensitivity of crop yields to rainfall, as 2012 coincides with lower rainfall levels in the Medium Rehab districts than the No Rehab districts. Gram yields in the Low and Medium Rehab districts in Figures 6 and 7 are nearly aligned with the yields of the No Rehab districts, showing almost no difference from the additional investment in irrigation despite higher than average rainfall.

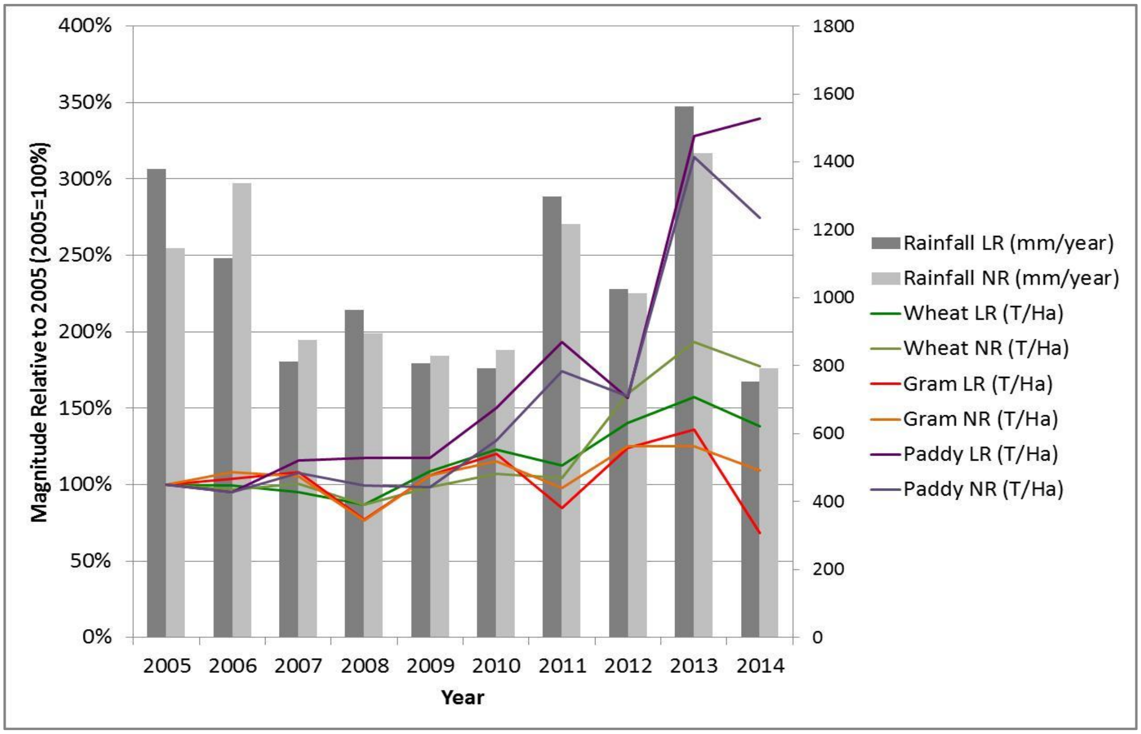

Fig. 6: Results of Crop Yield Analysis for High Rainfall Zone & Low Rehab (LR) and No Rehab (NR) Districts

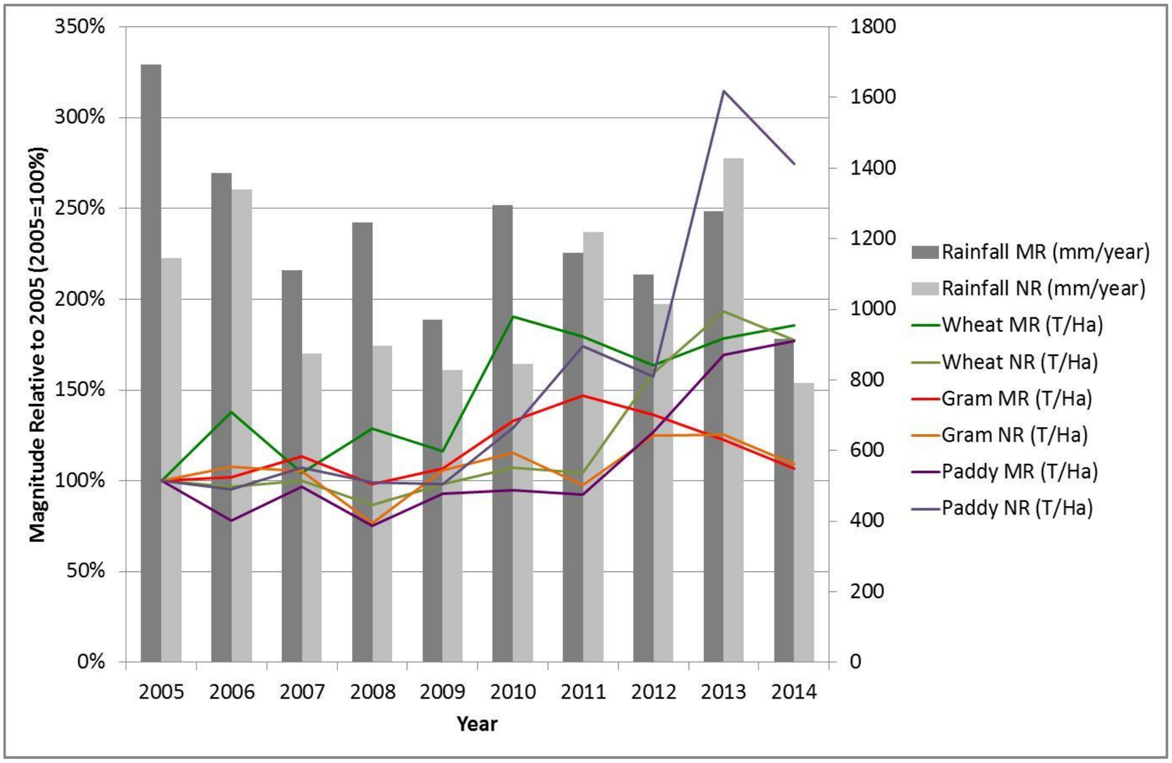

Fig. 7: Results of Crop Yield Analysis for High Rainfall Zone & Medium Rehab (MR) and No Rehab (NR) Districts

4. Discussion and Limitations

4.1 Discussion of Results

4.1.1 **Hypothesis 1**: Investments in irrigation infrastructure leads to higher crop yields

The three crops selected for this analysis are staple crops grown by a majority of farmers across most districts in MP. Although there are a number of factors that contribute to the production of these crops, water availability is a critical component influencing yields. Therefore, the availability of surface irrigation in some districts but not in others can be a determining factor on the yield outcomes of these crops. However, based on the results of our analysis, the first hypothesis was accepted in some circumstances, but rejected in others.

In low rainfall districts growing wheat and paddy, the availability of canal irrigation did not always lead to higher yields. In some circumstances (e.g. paddy and wheat yields in average and low rainfall districts) investments led to higher yields in the Low Rehab districts compared to No Rehab districts. In other cases (e.g. paddy in low rainfall districts and wheat in the high rainfall districts), we observed that yields for paddy in the Medium and High Rehab districts were lower than in the No Rehab districts, and yields for wheat in the Low and Medium Rehab districts were lower than in the No Rehab districts. Therefore, the first hypothesis is rejected.

The results indicate that the availability of assured irrigation alone is not sufficient to show higher yields for all crops under irrigation. Irrigation rehabilitation projects that target investments at a basin-scale and that take into account engineering aspects are important and necessary. But when irrigation investments are not evenly distributed within a basin, inadvertently some districts receive more investments than others. Therefore, we found that investments targeted to hydrological basins and on technical needs of infrastructure are a process-driven approach that solve engineering challenges of deteriorated irrigation systems, but do not always lead to improved yields. We conclude that there are other factors at play at a district, and perhaps at a village or household-level that are influencing yields beyond basin-level infrastructure interventions, resulting in unexpected yield results among irrigated and non-irrigated districts.

4.1.2 **Hypothesis 2**: Investment in irrigation infrastructure buffers crop yields from fluctuations in rainfall levels at a district-level

Based on the results of our analysis, we find that, with a few exceptions, most crops continue to be sensitive to variability in district-level monsoons independent of infrastructure investments. Crops in all investment categories show declining yields in 2014, as rainfall levels also declined across all three zones. This proportionate decline is more relevant than aggregate declines. Conversely, in 2013, when rainfall levels rise to a 10-year high across most of the 3 rainfall zones, yields of most crops, especially paddy, also rise. Therefore, the second hypothesis is rejected.

Our rainfall analysis finds that different districts have different degrees of rainfall variability both for inter-annual rainfall and intra-annual monsoon patterns. However, as the MP water sector project determined investments on an integrated basin and engineering approach, this did not incorporate district-level hydrological factors. As crop yields continue to be sensitive to hydrology, particularly to district-level rainfall variability, infrastructure investments need to be sensitive to this heterogeneity.

Results presented in this paper indicate that investing in irrigation infrastructure in an integrated basin management approach is not a sufficient condition to improve agricultural productivity, particularly when there is significant sub-basin hydrological complexity. Therefore, it is important to match investments to local conditions once there is a critical understanding of how monsoon patterns are behaving within each district, over an extended period of time. This nuanced approach is critical to potentially improving surface irrigation impacts on yields by drilling down below the basin to understand rainfall variations at a district-level.

4.2 Limitations of Study

The results of our analysis have highlighted trends that go against the behavioural hypotheses suggested in the literature; that investments in irrigation lead to higher agricultural yields and improved resilience of crops against rainfall variability. Although we examined yield and rainfall differences, these are not sufficient to explain the agricultural, ecological and socio-economic dynamics at play within districts. There are a number of critical factors that may be causing higher yields in certain crops in districts that did not receive any investments in irrigation.

One major source of complexity is the suite of highly intricate village-level relationships, institutions, and processes in India that has been shown to influence agricultural productivity (Wade 1988b). Variations from one village to another in the way irrigation systems are managed at the community-level also plays a role on variations in agricultural production (Mosse, 2005, 2006; Meizen-Dick et al., 2002; Wade, 1987; Conference Proceedings on Common Property Management, 1986). Our findings suggest that detailed examination of the impact of irrigation investment on household welfare is necessary in order to understand whether the number of rural populations below the poverty line within a district influences yields.

Secondly, we did not examine cropping intensities across districts and dynamics between head and tail farmers within the irrigated command areas. There is evidence that there is heterogeneity in cropping intensity among the districts. The cropping intensity of MP is 135% and varies from 176% in Harda district (highest) to 108% in Bhind district (lowest) (Wani et al., 2010). Factors such as lower cropping intensities can potentially lead to lowered crop yields for certain crops. Linked to this is the need to better understand dynamics of water availability between head- and tail-end farmers within a command area. Others have found that while the water used in the head-reach is quite high, the tail-end regions suffer from a multiplicity of problems such as poor water availability, salinity and lack of drainage (Mahapatra, 2012). The consequences of scarcity of water, unpredictable supply in the tail-end areas of irrigation systems results in lower yields and lower cropping intensity. Other unexplored factors include the actual construction quality of the systems that were rehabilitated, which may also impact crop yield outcomes. The different rules of water delivery and differences between actual and expected deliveries are also worthy of consideration (Wade, 1988a), and might be expected to impact the efficacy of the investments and the quality of crop yields.

5. Conclusion

Our results illustrate two insights: first that no one district is alike when it comes to rainfall variability in its monsoons – each district is facing varying degrees of anomalies of its monsoon rains. As crop yields seem sensitive to rainfall, the greater the district anomaly from the mean rainfall – the more influence this will have on yields. Second, infrastructure investments on a hydrological basis fail to account for rainfall variability, and hence, may be sub-optimal.

Therefore, investing in irrigation infrastructure based on an integrated basin approach alone is not sufficient to improve agricultural productivity, particularly when there is significant sub-basin hydrological complexity. Sub-basin rainfall heterogeneity is playing a role in the outcomes of crop yields despite the availability of assured surface irrigation. Therefore, a basin-wide engineering approach to investments in irrigation infrastructure will address engineering problems of old irrigation systems, but not necessarily lead to improved yields. This paper has attempted to nuance the often all too sweeping analyses of the role of canals for irrigation (Mollinga, 2014).

We conclude that consideration of irrigation investments solely at the basin-scale is insufficient to understand how to plan effective interventions. District-specific rainfall anomaly characteristics should be incorporated into infrastructure decision-making along with engineering specifications and hydrological basin factors. We recommend that donors and state governments examine district-level rainfall patterns before determining the irrigation projects to be executed. This approach may assist stakeholders to maximise impacts of irrigation investments, and lead to stronger results that lower risk for farmers from hydrological variations.

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CHAPTER 5: PAPER TWO

Impact of Irrigation Infrastructure Investments on Farmers' Welfare: Empirical Evidence from Madhya Pradesh, India

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Impact of Irrigation Infrastructure Investments on Farmers' Welfare: Empirical Evidence from Madhya Pradesh, India

Abstract: This study examines farmers' perception of their welfare following USD$ 389 million in investments in upgrading and repairing of irrigation systems in Madhya Pradesh, India between 2005 and 2015. The study is based on a survey of 918 farmers from 10 districts that received investments in irrigation infrastructure and 5 districts that did not. Results indicate that investments in irrigation were associated with increased subjective measures of farmer welfare. Heterogeneous effects were modelled to measure the rehabilitation effect on subjective welfare of different groups across the sample. Regression models show that irrigation investments are a significant determinant of welfare improvements for low-income or vulnerable farmers. Higher perceived welfare is associated with a minority of farmers, who adopted high-value crops and micro-irrigation technologies. We emphasise the need to better understand how complementing infrastructure investments with institutional interventions could support vulnerable farmers in transitioning to more sustainable agriculture practices.

Keywords: Irrigation; infrastructure investments; India; Madhya Pradesh; subjective welfare; OLS; heterogeneity; sustainable agriculture

1. Introduction

Research on the impact of irrigation investment on rural poverty in Asia claims that access to irrigation allows poor people to increase their production and incomes. Investments also enhance their opportunities to diversify their income base, and reduce their vulnerability to the seasonality of agricultural production and external shocks (Hussain and Hanjra, 2004). In Asia, irrigation has played an enabling role in the adoption of green revolution technologies, including modern varieties of rice and wheat, with positive effects on income, employment, prices, food security and overall growth (David and Otsuka, 1994; Freebairn, 1995). In India, analysis of public investments in irrigation reveal that investments offer win–win opportunities for achieving more production growth and greater poverty reduction (Fan et al., 2000 a,b). A number of benefits have been attributed to irrigation investments including: a) higher cropping intensity in irrigated areas than in rain-fed areas, which enables farmers to grow extra crops each year, leading to higher household food security; b) increased land productivity of major crops including rice and wheat in irrigated versus rain-fed areas; and c) higher wage rates per hectare, and labour employment in irrigated areas compared to non-irrigated areas (Kishore, 2002). However, other researchers have shown that perceived irrigation benefits are by far, rosier in theory than in practice (De Silva et al., 2013). Often, the benefits of irrigation investments are not evenly distributed among all members of a community, and existing social, political and institutional barriers limit its impacts and reach to more vulnerable and poorer communities (Mehta, 2001; Mollinga, 2001; Molle, 2004; Shah et al., 2002). Even though irrigation infrastructure is not a silver bullet; investments have continued to be a key policy instrument of the Government of India since the 1950s.

The planned development of the irrigation sector in India started with the First Fiscal Year Plan (1951–56) whereby investments in irrigation projects received 23% of the total plan expenditure (Santos and Stoutjesdijk, 2012). Irrigation infrastructure development in

India continues to have considerable allocation of resources from national and state governments. The Indian government allocated 6.3% and 6% of total plan expenditures in the Tenth (2002-2006) and Eleventh (2007-2012) Fiscal Year Plans (Santos and Stoutjesdijk, 2012). The sector has also received funding from international donors. The World Bank in particular, has been channelling a large part of its Agriculture and Rural Development portfolio in India for investments in irrigation modernization and rehabilitation projects (Santos and Stoutjesdijk, 2012). However, the majority of the empirical evidence on the impact of such irrigation investments on household welfare tended to focus on differences in income outcomes among farmers in command irrigated areas and non-command areas without canal irrigation[8] (Kishore, 2002; Sampath et al., 1983).

Despite the large number of impact assessment studies in the Indian literature, there is still limited understanding of the deeper consequences of irrigation projects (Shah, 2001). Empirical analysis of “before and after” comparisons are rare due to the lack of benchmark studies and reliable secondary data for pre-project years in most of the cases (Kishore, 2002). And even when data is available for longitudinal studies, researchers find it difficult to isolate the impact of irrigation from other factors of change on households (Kishore, 2002). Studies that examine differences in outcomes in neighbouring command areas fail to account for the diversity of agro-climatic, institutional, and hydro-climatic factors among various districts within a state in India, and often do not evaluate how farmers perceive the outcomes of such interventions on their welfare (Wade, 1975). While investing in improvements in irrigation systems and poverty reduction continues to be high priority for national and state governments in India, there is no clear understanding of how poor rural farmers perceive the contribution of investments in irrigation infrastructure to improvements in their welfare across diverse rainfall settings.

[8] Command areas are defined as an area of agricultural land that can be irrigated by an irrigation system and is suitable for cultivation. Non-command areas are areas that are not irrigated by an irrigation system.

A nuanced understanding of how irrigation investments affect farmer perceptions of their welfare when there are variations in rainfall patterns can provide complementary evidence to existing studies that examine income-related differences (Beegle et al., 2012; Ferreira and Lugo, 2012; Fafchamps and Shilipi, 2009; Filmer and Pritchett, 2001). Kahneman and Krueger (2006) argue that subjective measures of welfare enable analysis of welfare in a more direct way than the traditional objective metrics. Subjective measures collect features of individuals' emotional states, how they spend their time, among other aspects. Therefore, they could provide additional dimensions on the impact of projects, and further inform decision-makers on the design of future projects. The Government of Madhya Pradesh (GoMP) gathered information on changes in farmer income for farmers participating in the Madhya Pradesh Water Sector Restructuring Project (MPWSRP), from 2005 (when the project started) to 2015 (when the project closed). However, these income data were not compared with farmers in districts without interventions to see if there were variations within districts that did not participate in the project. Secondly, measures of poverty that only examine income data do not fully capture a holistic measure of welfare (Ravallion, 2012).

Much of the literature around measurements of household poverty currently supports the use of more subjective measures of welfare that assess beyond economic conditions (Alkire, 2015; Stiglitz et al., 2009a, Dasgupta, 1990). The Royal Government of Bhutan has also extended the methodology of their official Gross National Happiness Index to incorporate welfare measurement (Ura et al., 2012). However, as subjective measures of welfare are quite complex, many challenges exist in determining and comparing satisfaction or welfare from one individual to another. Despite the limitations, subjective measures that were designed to understand whether people think they are poor or not, expand the information set traditionally used for assessing welfare and measuring poverty (Ravallion, 2012). In most cases, traditional measurements of income can have multiple issues in terms of the usability and reliability of data. Therefore, utilising subjective measures to determine impacts of irrigation investments could be a useful complement to income measures. The current paper is aimed at understanding impacts of investments in rehabilitation of irrigation systems based on subjective measures of welfare across multiple command areas in several districts of Madhya Pradesh (MP).

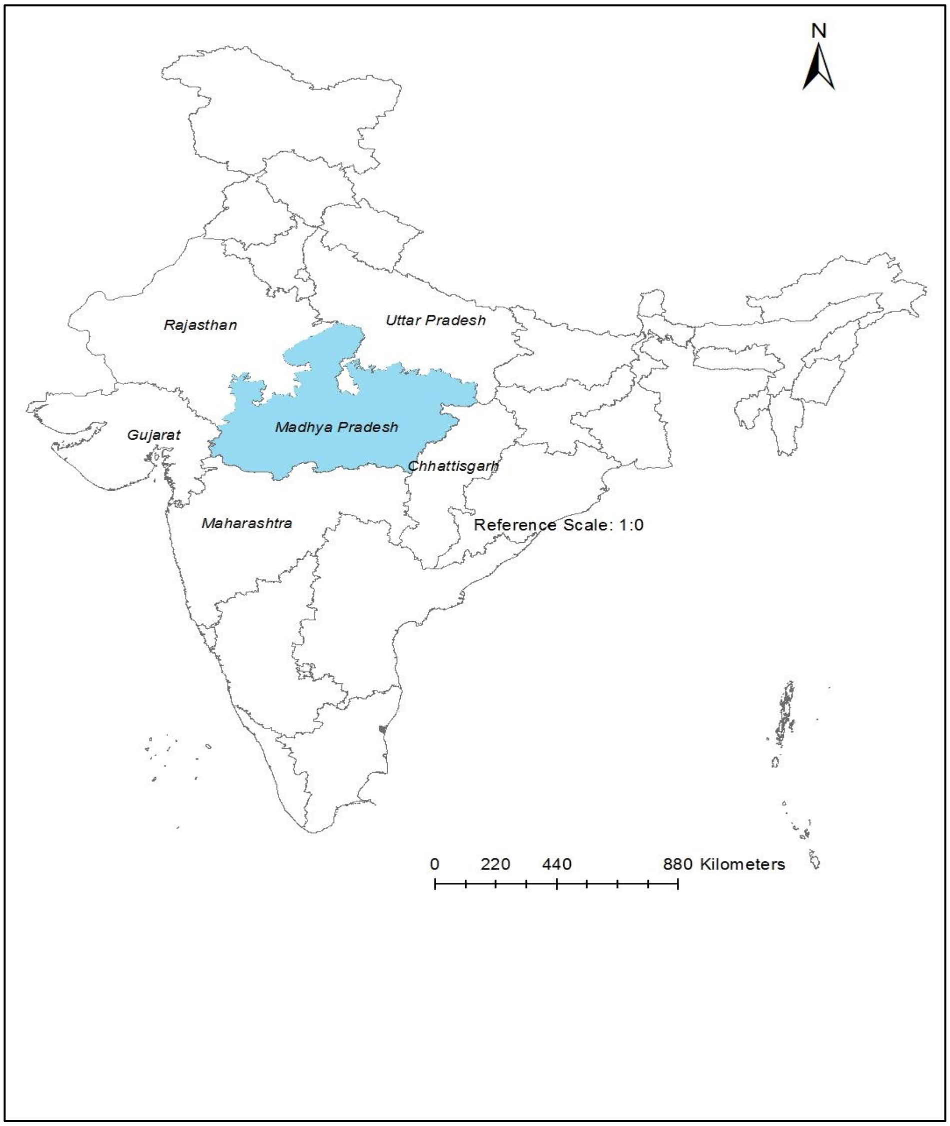
The purpose of this study is to better understand how the availability of surface irrigation in the form of rehabilitated irrigation canals contributes to farmers' perceptions of their welfare compared to farmers without reliable surface irrigation. This study builds on a forthcoming paper that examines the impact of irrigation infrastructure investments on crop yields from the MPWSRP across multiple districts (Sinha et al., 2016). Focusing on crop yield impact, the paper did not examine whether farmers residing within the districts that received irrigation investments perceived their welfare as better or worse-off in comparison to farmers residing in districts without investments. Examining subjective welfare as an additional layer of analysis is essential to develop a holistic understanding of the impacts of the irrigation investments in Madhya Pradesh. Therefore, the main outcome indicators that has been derived from the survey data is whether farmers perceive their welfare to be better or worse-off after investments in rehabilitation of irrigation investments.

Given the existing gaps in the literature, the present study contributes to the literature by using primary data from a household survey of farmers conducted in several districts across diverse rainfall regimes in MP. The household survey posed the following question to farmer respondents: "*Do you perceive your welfare to be better-off, same as, or worse-off, as a result of the irrigation investments*?" The econometric strategy of the paper is based on the Ordinary Least Squares (OLS) regression model to explore associations between investments in irrigation infrastructure and farmer perceptions of welfare. OLS enables us to assess the linear relationship between rehabilitation and welfare. Results were controlled for rainfall zones, district fixed effects, socio-economic indicators, and irrigation and agricultural management practices of farming households. Additional heterogeneity analysis on the differences in welfare across different sub-groups of the sample indicates that some of the poorest groups among the respondents responded positively to the MPWSRP irrigation investments. The current paper is structured as follows: Section 2 provides a description of the study area in MP. Section 3 provides the rationale behind the current methodological design and descriptive statistics. Results and limitations of the study are presented in Section 4, and concluded with wider implications in Section 5.

2. Location & Description of Study Area

MP is the third largest state in India with a total geographical area of about 308,000 square kilometres. The state has a population of 72 million as per the 2011 Census, with an estimated 36% of the rural population living below the poverty line. More than 26% of the Net State Domestic Product (NSDP) is generated from the agriculture sector, which employs 73% of the population (Government of Madhya Pradesh, 2011). The state is land locked (Figure 1). MP consists of five regions with 52,000 villages, 23,000 panchayats and 323 development blocks in 51 districts. These five regions include the Harsi, Malwa, Bundelkhand, Baghelkhand and Mahakaushal regions.

Figure 1: Map of Madhya Pradesh in India[9]



The state is faced with water resource challenges in the forms of droughts and floods with strong linkages between economic growth and rainfall variability in its monsoons (Kundu et al., 2015; Singh 1997). Data on monthly district-wise rainfall indicate that

[9] *Source*: Biswas, S. (2016). Water Resources Department, Government of Madhya Pradesh

rainfall in a majority of districts has been deficient in comparison to long period averages of monthly rainfall for the period 2009-2011. The Madhya Pradesh Water Sector Restructuring Project was conducted from 2005 to 2015, aimed at improving productivity of water resources for sustainable growth, and poverty reduction across 31 districts in six river basins of the state (Chambal, Sindh, Betwa, Ken, Tons, and Wainganga).

The project was focused on maximizing water productivity in all its usage in 495,000 hectares (ha) of designed potential irrigation Culturable Command Areas (CCA)[10] within the six basins. Upon closure, the project was reported to have rehabilitated 202 minor, 21 medium, and 5 major irrigation schemes for a total of 228 projects across 31 districts. The project was claimed to have reached its goal of irrigating 495,000 ha with modernized, developed, and effective irrigation schemes. The project was associated with the creation and training of over 400 Water User Associations (WUAs) in the project area[11]. Out of the 31 districts within the six river basins, 21 districts received investments in rehabilitation of irrigation systems and 10 did not.

For the purposes of the study, 10 districts were selected to survey farming households with investments in irrigation infrastructure and 5 districts that did not receive MPWSRP funding were selected for the survey. Details of these districts in terms of size, population figures and rural poverty numbers are provided in the following Tables 1 & 2. District-specific data is derived from the Government of India Census 2011 unless specified.

[10] Culturable Command Area (CCA): The areas that could be irrigated from an irrigation scheme and are fit for cultivation.
[11] Water User Association (WUA) is a group of water users, such as irrigators, who pool their financial, technical, material, and human resources for the operation and maintenance of a water system.

Table 1: Attributes of Ten Rehab Districts with MPWSRP Investments

District Name	Population (2011) Area (Sq. Km)	Rural population (%) (2011)	Urban population (%) (2011)	Per capita income (USD) (2004-05)	Per capita income (USD) (2011-12)	Average literacy (%) (2011)	Total canal irrigated area (2006-07) (Ha)	Total canal irrigated area (2011-12) (Ha)	Number of total Cultivators (2011) (No. & %)	Number of scheduled caste (2011) (No. & %)	Rural pop. below poverty line (%) (2004-05)
Bhopal*	2,371,061 (2,772)	19.15	80.85	629	1479	80.37	5,700	4637	73,346 (8.46)	357,516 (15.08)	65.43
Gwalior*	2,032,036 (4,560)	37.32	62.69	480	1135	76.65	52,900	64,666	130,586 (19.05)	393,068 (19.34)	9.7
Katni	1,292,042 (4,950)	79.60	20.40	352	788	71.98	8,000	6,193	112,812 (20.74)	155,717 (12.05)	49.5
Neemuch*	826,067 (4,256)	70.32	29.69	397	822	70.80	3,300	10,461	175,602 (41.94)	111,162 (13.46)	0.1
Sagar	2,378,987 (10,252)	70.20	29.80	296	693	76.46	8,200	5,999	203,600 (20.24)	501,630 (21.09)	54.4
Shajapur	1,512,681 (6,195)	80.59	19.41	305	660	69.09	10,200	11,432	287,924 (40.11)	353,914 (23.40)	27.6
Shivpuri	1,726,050 (10,066)	82.88	17.12	254	585	62.55	22,700	46,469	383,340 (50.49)	321,515 (18.63)	43.0
Tikamgarh	1,445,166 (5,048)	82.71	17.29	236	530	61.43	6,700	20,572	305,859 (46.67)	361,604 (25.02)	49.2
Ujjain*	1,986,864 (6,091)	60.78	39.22	439	998	72.34	2,200	8,290	289,013 (32.20)	523,869 (26.37)	27.3
Vidisha*	1,458,875 (7,371)	76.72	23.28	307	668	70.53	39,900	34,674	168,615 (30.63)	292,144 (20.03)	54.1

Table 2: Attributes of Five No Rehab Districts without MPWSRP Irrigation Investments[12][13]

District Name	Population (2011) Area (Sq. Km)	Rural population (%) (2011)	Urban population (%) (2011)	Per capita income (USD) (2004-05)[14]	Per capita income (USD) (2011-12)	Average literacy (%) (2011)	Total canal irrigated area (2006-07) (Ha)	Total canal irrigated area (2011-12) (Ha)	Number of total Cultivators (2011) (No. & %)	Number of scheduled caste (2011) (No. & %)	Rural pop. below poverty line (%) (2004-05)[15]
Bhopal*	2,371,061 (2,772)	19.15	80.85	629	1479	80.37	5,700	4637	73,346 (8.46)	357,516 (15.08)	65.43
Gwalior*	2,032,036 (4,560)	37.32	62.69	480	1135	76.65	52,900	64,666	130,586 (19.05)	393,068 (19.34)	9.7
Neemuch*	826,067 (4,256)	70.32	29.69	397	822	70.80	3,300	10,461	175,602 (41.94)	111,162 (13.46)	0.1
Ujjain*	1,986,864 (6,091)	60.78	39.22	439	998	72.34	2,200	8,290	289,013 (32.20)	523,869 (26.37)	27.3
Vidisha*	1,458,875 (7,371)	76.72	23.28	307	668	70.53	39,900	34,674	168,615 (30.63)	292,144 (20.03)	54.1

*Districts that have BOTH areas that received investment and those that did not.

[12] See https://data.gov.in/catalog/district-wise-capita-income-current-prices#web_catalog_tabs_block_10

[13] Source: Estimates of District Poverty, PMPSU, MP

[14] See https://data.gov.in/catalog/district-wise-capita-income-current-prices#web_catalog_tabs_block_10

[15] Source: Estimates of District Poverty, PMPSU, MP

3. Methodology

3.1 Data Sources and Sampling Procedure

In November 2015, a cross-sectional, household survey was conducted in MP. The objective of the survey was to determine trends among a sample of farmer households living within a selection of districts within the overall population of households across the 31 MPWSRP districts. Table 3 illustrates the division of the selected districts within three rainfall zones and irrigation investment categories.

Table 3. Sampling Framework of Rainfall Zones and Irrigation Investment Categories for Survey Districts

		Inter-annual Rainfall Variability Zones		
Irrigation investment category by percentage of irrigated area rehabilitated	**Rehab**	**Average**	**Low**	**High**
	Low Rehab (0.01-10% of irrigated area rehabilitated)	Ujjain*, Shajapur, Katni, Neemuch*	Shivpuri, Tikamgarh,	Bhopal*, Sagar, Vidisha*
	Medium Rehab (11-50% of irrigated area rehabilitated			
	High Rehab (More than 50% of irrigated area rehabilitated)		Gwalior*,	
	No Rehab	Ujjain*, Neemuch*	Gwalior*	Vidisha*, Bhopal*

*Districts that fall into BOTH Rehab and No Rehab as some systems within these districts were rehabilitated and some irrigations systems were not rehabilitated under MPWSRP

Building on the sampling framework utilised in the forthcoming paper by Sinha et al., (2016), survey districts were divided into two distinct irrigation investment categories: **Rehab** and **No Rehab**. Rehab districts were then further divided into three categories. Within the **Rehab** category, **Low Rehab** represents districts that had between 0.01–10% of their irrigated area rehabilitated. **Medium Rehab** represents districts that had 11-50% of their irrigated area rehabilitated and **High Rehab** is for districts that had more than 50% of their irrigated area rehabilitated. The paper analyses rainfall by looking at district-wise inter-annual rainfall variability and dividing the 31 districts into three rainfall categories: **low rainfall**, **average rainfall**, and **high rainfall** (Sinha et al., 2016). This was to determine if there was significant diversity in the inter-annual rainfall patterns among the Rehab and No Rehab category districts, and to identify how many of the districts tend to have low, average, or high rainfall. Inter-annual rainfall variability was determined by identifying the annual averages from 2005-2014 by averaging the 12 monthly rainfall values for all available rain gauge stations in each district[16].

Table 3 does not cover any districts in the Medium Rehab category for the three rainfall zones, and no districts in the High Rehab category for average and high rainfall zones. These categories are not covered, as the random stratified sampling process utilised for the survey to select sample districts led to a selection of 10 districts in the Rehab category and 5 districts in the No Rehab category that did not fall into these categories. Therefore, results of the survey are relevant for those districts in the Low, High and No Rehab categories only.

3.2. Population & Sample Size

The main survey instrument for this study was structured interviews of farmer members of WUAs based on a pre-defined set of questions. To determine the sample size of the survey, a multistage clustering procedure was utilised, followed by a random, stratified sampling approach from the clustered group (Fowler, 2002). The first cluster was determined by selecting projects where irrigation rehabilitation works were completed at least three years ago and where farmers have had access to rehabilitated irrigation infrastructure for at least three years. This reduced the original population size from 228 projects to 38 projects across 10 districts as illustrated in the table in Appendix A.

[16] Monthly rainfall data from 2005-2014 for all districts was obtained from the Government of Madhya Pradesh (GoMP) Irrigation Department officials. Data was provided for all districts for each month (Jan – Dec) for the years 2005-2014. For each district, monthly rainfall values in millimetres are available for each of the rain gauge stations within the district. Data obtained was actual observed values for rainfall compiled by the Irrigation Department rather than satellite data.

Once the 38 projects were identified, then the stratified sampling of households was determined from this sub-group. As indicated in Appendix A, the cluster of 38 projects comprised of 1 major, 4 medium, and 33 minor irrigation projects. A ratio of 1:4:33; whereby major projects are defined as projects with a CCA of more than 10,000 ha, medium projects have a CCA between 2000 to 10,000 ha, and minor projects have a CCA less than 2000 ha. In order to have representation of all sizes of schemes in the survey sample, a formula of 95% confidence level and 10% confidence interval was used to calculate the sample size. This resulted in a total of 27 projects in which this sample consisted of 1 major, 3 medium and 23 minor projects. The sole major project was an automatic sample, as there was only one data point of its kind. The medium and minor projects were chosen at random. A similar approach was used to calculate the sample size for the No Rehab districts. This resulted in a sample size of 15 projects across 5 districts from the original population size of 10 districts.

The second stage of stratification from the number of projects was the number of WUAs to be surveyed within the selected project sample size. In the Rehab category, there are total of 51 WUAs across the 27 sample projects and there are 14 WUAs across the 15 projects within the No Rehab category. Once again, a formula of 95% confidence level and 10% confidence interval was used to calculate the sample size of WUAs to be surveyed in both categories. The sample size for Rehab districts was 34 WUAs and 12 WUAs for the No Rehab districts.

The third stage stratification was to determine the number of individual farmer members to be surveyed from the sample size of WUAs. To determine a random stratified sample selection of households from the WUA sample size, the sample size formula calculation (95% confidence level and 5% confidence interval) had a proposed sample size of 408 famers, which was increased to 485 farmers to buffer post-survey data cleaning. A similar process was followed for the No Rehab districts, which was stratified from 15 irrigation projects to 14 WUAs and then down to 372 households, with a final sample size of 433 respondents with a similar buffer.

The last stage, the individual farmers selected across the sample of survey respondents for each district included an equal ratio of head, middle and tail farmers in the canal systems. An attempt was also made in the survey to include both male and female respondents, however, the majority of the WUA members in MP are men. Lastly, districts from each of the three rainfall zones were selected to ensure all three rainfall zones are covered as well as districts were selected that are from both the Rehab and No Rehab investment categories (Table 3). Appendices B & C consists of the sample sizes under the stratified sections across Rehab and No Rehab districts.

3.3. Instrumentation & Survey Questionnaire

The household survey elicited data about individual farmer members of WUAs on four individual, household, and farm-level domains after informed consent was verbally provided by each respondent: a) respondent and household demographics; b) welfare and assets including land ownership status; c) farming systems; and, d) irrigation practices.

The difference between Rehab and No Rehab surveys was in the timing of the nature of the questions posed to determine the difference in the impact of the independent variables: investment in rehabilitation of irrigation systems and rainfall variability. In the Rehab category surveys, the main purpose of the questions were to differentiate the status quo for the farmer WUA member between the current scenario (post rehabilitation works) and the past scenario (prior to rehabilitation works). In the No Rehab category surveys, we ask all farmers to differentiate between their perceived welfare conditions at present and in 2005.

3.4 Descriptive Statistics

Descriptive statistics of our sample are presented in Tables 4-6. Estimates are presented by category (Rehab and No Rehab) and under three themes: a) geography and rainfall; b) socio-economic profiles of respondents; and, c) farm management and agricultural practices. The next sub-sections describe each variable in detail.

Rainfall & Geographic Characteristics

Table 4 represents the variations in the sample between Rehab respondents and No Rehab respondents within the three rainfall zones and district-wise division of respondents. Around half of the farmers (56.5%) in the Rehab areas are from predominantly low rainfall zone districts compared to a third of farmers from the No Rehab districts. While a fifth of the respondents are from the Rehab districts that are in the average rainfall zone, over two fifths of the respondents from the No Rehab districts are in the average rainfall zone. The number of respondents from the high rainfall zone districts is similar between the Rehab and No Rehab areas.

As each district received different degrees of investment, or no investment in the case of the No Rehab districts, we included district effects into our regressions. However, it is important to note that Medium Rehab is not represented in the sample. Gwalior, which had the largest percentage of investment in the Rehab category and is a low rainfall zone district, has the largest number of respondents. Gwalior has 27.6% of the farmers from the Rehab category and 33.7% from the No Rehab areas. There are zero No Rehab respondents for the districts of Katni, Sagar, Shajapur, Shivpuri, and Tikamgarh as these districts all received investments under MPWSRP (Table 4).

Socio-economic Characteristics

Rehab and No Rehab respondents are similar in terms of highest educational qualification attained, members of scheduled caste and scheduled tribe castes, ownership of a permanent house, and main income source – which seems to be overwhelmingly agriculture over the entire sample (Table 5). Around one third of the Rehab respondents hold Below the Poverty Line (BPL) cards, while less than one fifth of the No Rehab respondents hold BPL cards[17]. More than three fifths of the Rehab farmers are from the Other Backwards Caste (OBC) category compared to more than one half from the No Rehab category. This signals a poorer socio-economic background of farmers in the Rehab districts. In terms of house ownership,

[17] The Food and Supplies Departments of state governments in India issues “Below Poverty Line” ration cards to individuals who are considered to be 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.

the sample shows that most of the Rehab and No Rehab farmers own their homes. There is also large number of respondents who live in temporary housing (53.7% from Rehab and 67.6% from No Rehab).

With respect to household belongings, to account for the overall household wealth of the farmer respondents, we built a household belongings index. This is constructed as a sum of dummies for whether a farmer possesses specific belongings[18]. This includes items such as: 1) radio, 2) television, 3) personal computer, 4) Internet, 5) landline phone, 6) mobile phone, 7) bicycle, 8) motorcycle, 9) car, 10) thresher, 11) harvester, and 12) tractor. Others have adopted a similar approach to building household wealth indicators (Case et al., 2004; Montgomery et al., 2000; Morris et al., 2000).

Contrary to the poverty predictions suggested by the descriptive statistics for BPL card and caste, farmers in the Rehab districts seem to possess slightly more assets (approximately 2.1 items) than No Rehab farmers (1.8 items). There is a possibility that because there are more BPL farmers in the Rehab areas, state government programs would target more farmers in these areas in order to provide these households with agricultural assets such as threshers, harvesters, or tractors under government sponsored programs for the poor. Also about 33.7% of the farmers in the Rehab areas have a Kisan Credit Card compared to 22.4% of the No Rehab farmers[19]. Possessing a Kisan Credit Card may explain why respondents have higher ownership of assets in the Rehab areas in comparison to the No Rehab areas as more farmers can then purchase items on credit for farming purposes. Lastly, it appears that Rehab respondents own more land (approximately 8.4 acres) than No Rehab respondents (5.6 acres).

[18] Missing values have been treated as zeroes.
[19] 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.

Farm Management & Agricultural Characteristics

There seems to be no substantial difference among farmers in the Rehab and No Rehab groups when it comes to the location of their farms in the head, middle or tail of the canal systems (Table 6). Similarly, both groups seem to own their own plots of land and very few are renting or are working as farm labourers on other farmers' lands. In terms of the type of irrigation methods utilised by farmers in the survey, a majority of the Rehab farmers (approximately 91.5%) and the No Rehab farmers (82.3%) are continuing to flood irrigate their farm fields. Very few Rehab farmers are adopting water-saving, yield-enhancing irrigation technologies such as drip and sprinkler systems (0.2%), while a slightly larger percentage of farmers in the No Rehab areas are adopting such technologies (1.2%).

Lastly, it also seems that there is no significant difference in terms of the index of agriculture technology practices adopted by Rehab and No Rehab farmers, with both adopting about 4.3 and 4.27 practices/items respectively. Similar to the household belongings index in Table 8, the agriculture technology adoption index is built as a sum of dummies for whether farmers adopted the following practices: 1) fertilizers, 2) High Yielding Varieties/hybrid seeds, 3) pesticides, 4) organic manure, 5) micro-irrigation, 6) tractor, 7) thresher, 8) automatic seed drill, and 9) harvester.

Table 4: Descriptive Statistics by Category – Rainfall & Geographic Characteristics[20]

(1)			(2)	
Rehab			**No Rehab**	
	Mean	**SD**	**Mean**	**SD**
Low rainfall	0.565	(0.496)	0.337	(0.473)
Average rainfall	0.202	(0.402)	0.416	(0.493)
High Rainfall	0.233	(0.423)	0.247	(0.432)
Bhopal	0.029	(0.168)	0.166	(0.373)
Gwalior	0.276	(0.448)	0.337	(0.473)
Katni	0.058	(0.233)	0.000	(0.000)
Neemuch	0.029	(0.168)	0.249	(0.433)
Sagar	0.058	(0.233)	0.000	(0.000)
Shajapur	0.029	(0.168)	0.000	(0.000)
Shivpuri	0.058	(0.233)	0.000	(0.000)
Tikamgarh	0.231	(0.422)	0.000	(0.000)
Ujjain	0.087	(0.282)	0.166	(0.373)
Vidisha	0.146	(0.354)	0.081	(0.273)
Observations	**485**		**433**	

[20] Standard Deviation (SD)

Table 5: Descriptive Statistics by Category – Socio-economic Characteristics[21][22]

(1)			(2)	
Rehab			**No Rehab**	
	Mean	**SD**	**Mean**	**SD**
Holds BPL card	0.351	(0.478)	0.162	(0.369)
General caste	0.260	(0.439)	0.397	(0.490)
OBC caste	0.635	(0.482)	0.522	(0.500)
Scheduled caste	0.101	(0.302)	0.074	(0.262)
Scheduled tribe	0.004	(0.064)	0.007	(0.083)
Rented house, past period	0.019	(0.135)	0.058	(0.234)
Other house ownership, past period	0.012	(0.111)	0.079	(0.269)
Owned house, past period	0.969	(0.173)	0.864	(0.343)
Permanent house, past period	0.280	(0.449)	0.315	(0.465)
Semi-permanent house, past period	0.184	(0.388)	0.009	(0.097)
Temporary house, past period	0.537	(0.499)	0.676	(0.469)
HH belongings index, past period	2.107	(1.751)	1.864	(1.460)
Main income source, past period: agriculture	0.992	(0.091)	0.993	(0.083)
Main income source, past period: horticulture	0.039	(0.194)	0.005	(0.068)
Main income source, past period: fisheries	0.010	(0.101)	0.000	(0.000)
Main income source, past period: dairy	0.367	(0.482)	0.303	(0.460)

[21] "Past period" refers to prior to rehabilitation for Rehab district respondents (approximately three years ago) and to 2005 for No Rehab respondents.
[22] Below Poverty Line (BPL), Other Backwards Caste (OBC), household (hh), acres (ac)

Main income source, past period: poultry/meat	0.014	(0.119)	0.000	(0.000)
Main income source, past period: business	0.041	(0.199)	0.012	(0.107)
Main income source, past period: services	0.025	(0.155)	0.016	(0.126)
Main income source, past period: lease agric. tools	0.016	(0.128)	0.018	(0.135)
Main income source, past period: loans	0.006	(0.078)	0.000	(0.000)
Main income source, past period: other	0.068	(0.252)	0.072	(0.258)
Land owned (ac), past period	8.406	(11.280)	5.635	(5.624)
Female	0.027	(0.162)	0.030	(0.171)
Age	45.852	(12.765)	47.744	(11.463)
HH members	7.739	(7.562)	6.767	(3.992)
Holds Kisan Credit Card, past period	0.337	(0.473)	0.224	(0.418)
Observations	**485**		**433**	

Table 6: Descriptive Statistics by Category – Farm Management & Agricultural Characteristics

(1)			(2)	
Rehab			No Rehab	
	Mean	**SD**	**Mean**	**SD**
Farm location: head	0.311	(0.464)	0.332	(0.468)
Farm location: middle	0.348	(0.477)	0.332	(0.472)
Farm location: tail	0.340	(0.474)	0.345	(0.476)
Owned plot	0.990	(0.101)	0.988	(0.108)
Rented plot	0.006	(0.079)	0.007	(0.084)
Farmer Labourer	0.004	(0.064)	0.005	(0.069)
Irrigation method, past period: border strip	0.075	(0.263)	0.145	(0.352)
Irrigation method, past period: check basin	0.002	(0.046)	0.000	(0.000)
Irrigation method, past period: drip/sprinkler	0.002	(0.046)	0.012	(0.110)
Irrigation method, past period: flooding	0.915	(0.279)	0.823	(0.382)
Irrigation method, past period: ridge and furrow	0.006	(0.079)	0.020	(0.139)
Modern agric. technology index, past period	4.305	(1.471)	4.270	(1.501)
Observations	**485**		**433**	

3.5 Empirical Analysis

3.5.1. OLS Regression Analysis

The OLS regression model was used to determine the impact of the irrigation rehabilitation project on a subjective measure of welfare. OLS regression provides the best linear predictor for the dependent variable conditional on a set of covariates. The OLS coefficients therefore represent the best linear approximation of how much a variation in each covariate feeds into changes in the dependent variable, holding all other covariates fixed. Given a household-level outcome *y*, we ran the following OLS regression equation for each farmer's household *h*:

$$y_h = \beta T_h + x_h' \gamma + \sum_{d=1}^{10} \eta_d + \epsilon_h, \quad (1)$$

where *T* is the treatment indicator (it is equal to 1 for households in the Rehab category and 0 for households in the No Rehab category), the $\eta d's$ are district dummies, *x'* is a row vector of household covariates, and ϵ is a random error term. The main coefficient of interest is β, which measures the impact of the rehabilitation programme on farmers' perceived welfare.

The variables included in *x'* are the following:

- Rainfall zones (Low, Average, and High)
- BPL Card ownership
- Caste categories (General Caste, OBC Caste, Scheduled Tribe, Scheduled Caste)
- House ownership (Owned, Rented, Temporary, Permanent, Semi-permanent, Other)
- HH belongings index
- Main source of income
- Land owned (Acres)
- Farm location (Head, Middle, Tail)

- Irrigation method (Border strip, Drip/Sprinkler, Flooding, Ridge & Furrow, Check basin)
- Modern agriculture technology index
- Sex
- Age (linear and square)
- Number of HH members
- Kisan Credit Card ownership

To avoid conditioning on outcomes, we only include beginning of period (2005 or pre-rehabilitation) variables for household wealth indicators, farm management and agricultural practices[23]. Secondly, there were several variables in our survey that had to be excluded from the regression analysis due to low response rates from the farmers. This included variables such as years of education of the household head, the status of irrigation canals in the past, prior to the rehabilitation, the quantity and productivity of horticulture crop cultivation, and livestock holdings by households. These independent variables would have been able to give us a more nuanced picture of the types of farmers reporting improved welfare as a result of the rehabilitation.

3.5.2 Additional Evidence: Heterogeneous Effects

We performed an additional heterogeneity analysis to check whether the impact of the investments in rehabilitation differs across relevant subgroups of the sample population. In particular, we focused on indicators that could identify poor households in order to verify whether the intervention was effective in raising welfare of the most disadvantaged farmers in our sample.

For the heterogeneity analysis, we ran equation (1) above and add an interaction term between the treatment *T*, and an indicator *D* that identifies a relevant subgroup of the population:

[23] The set of variables used for the OLS regression analysis is a sub-set of all of the variables we included in the questionnaire given to farmers. We selected only those variables from the household questionnaire that we determined to be a good predictor of overall farmer welfare and welfare for the purpose of this study. These are categorized as "commodity determinants" that are inputs in the production of welfare and are preferred criteria for determining welfare (Dasgupta and Maler, 2001).

$$y_h = \beta T_h + \delta T_h * D_h + x'_h\gamma + \sum_{d=1}^{10} \eta_d + \epsilon_h, \qquad (2)$$

The main coefficients of interest are therefore β, which measures the impact of the rehabilitation programme on perceived welfare, and δ, which captures the heterogeneous impact of the policy on group *D*.

Specifically, the groups we chose to analyse included: farmers who have a BPL card, farmers in the Scheduled Caste or Scheduled Tribe caste groups, farmers who own a Kisan Credit Card, who own land and reside in temporary houses. Out of the overall variables selected for the regression, we selected these specific sub-groups of the population, as they are the main criteria to indicate income poverty in the household. For instance, when a farmer holds a BPL card or is a member of a marginalised caste group, and resides in temporary housing this is a good indicator of a farmer from a very poor household in India. Therefore, measuring the impact of the rehabilitation on the perceived welfare of these groups indicates whether the interventions had an impact on the lives of some of the poorest members of farming communities in the districts we examined.

4. Results

4.1 Determinants of Farmer Welfare: Does Rehabilitation matter?

OLS results are reported in Table 7. The dependent variable in column (1) is a binary variable taking value 1 if the respondent reports they are better-off as a result of the rehabilitation scheme with respect to the past (as opposed to either being the same or worse-off). The dependent variable in column (2) is a binary variable taking value 1 if the respondent reports they are worse-off as a result of the rehabilitation scheme with respect to the past (as opposed to either being the same or better-off). The dependent variable in column (3) is a sum of the belongings owned by the household.

The OLS analysis shows that farmers with access to rehabilitated irrigation infrastructure were 43.6 percentage points more likely to report feeling better-off with respect to the past (Table 7, column 1). Conversely, column 2 in Table 7 illustrates that farmers in the Rehab category districts are 14.8 percentage points less likely to report that they are worse-off with respect to the past. According to the results presented by the OLS, the model points towards the direction of a significant and positive difference in farmers' perceptions of their welfare as a result of investments in irrigation systems. The fact that respondents exposed to the MPWSRP program had improved feelings of welfare implies that access to assured and reliable irrigation plays an important role in determining farmers' welfare. Results indicate that farmers living in districts in the low rainfall zone are 72.3 percentage points more likely to report an increase in their welfare when compared to the past (column 1). Respondents are also 65.3 percentage points less likely to report feeling worse-off than in the past, despite the fact that on average, the rainfall in the last ten years has been deficient in their area (column 2).

This is an important finding, as most farmers in chronically rain deficient districts in MP and India as a whole, are usually worse-off and more income poor. This result may stem from farmers responding to improved access to surface irrigation water for their crops, which in turn leads to higher incomes and higher standards of living among Rehab farmers. However, it could also be a signal of farmers responding positively to other factors such as increased support from the MP Water Resources Department engineers and participation in training programs for WUAs, which were part of the capacity building interventions under MPWSRP. These factors were not measured in our survey and may need to be explored in further research.

Another finding of note is for the district of Gwalior. Farmers living in Gwalior were 17.9 percentage points less likely to be worse-off than in the past (column 2). Table 3 illustrates that Gwalior is in the low rainfall zone in the High Rehab category (parts of the district had more than 50% of its irrigated area rehabilitated by the MPWSRP). This is another indicator of the positive perceptions of the MPWSRP investments, as farmers living in a low rainfall zone with High Rehab, reported improvements in welfare with respect to the past. On the other hand, farmers living in Tikamgarh district, holding a BPL card, from the general caste category, living in temporary housing, owning land, and having their farm located at the head of a canal system have ceteris paribus, a lower probability of feeling better-off from their past circumstances. As Table 3 indicates, Tikamgarh is in the low rainfall zone and in the Low Rehab category (0.01-10% of irrigated area rehabilitated). Here our results illustrate that even though both districts are within the low rainfall zone and both districts are in the Rehab category, a higher percentage of irrigated area rehabilitated in Gwalior resulted in a larger positive difference in perceptions of welfare than in Tikamgarh (a Low Rehab district).

Our analysis shows that farmers whose farm plots are located at the head of a command system are 5.68 percentage points less likely to report that they are feeling better-off from the past. This is contrary to common literature (Mollinga, 2003). This finding could be attributed to reduction in their ability to access abundant irrigation water through theft (this is often common practice among Indian farmers with plots at the head of a canal system) or reduced ability of head farmers to take as much water as they would like based on a more strict allocation system in place. The investments in irrigation infrastructure are in fact coupled with more responsibility from the MP Irrigation Department (main public sector agency in MP in charge of irrigation water distribution) to distribute water to farmers equitably, coupled with increasing demand from farmers at the middle and tail to demand water in a timely manner and in the right quantity.

Other findings of note include the fact that farmers with BPL cards are 9.650 percentage points less likely to report that they are feeling better-off from the past. In addition, farmers that reside in temporary housing were 8.410 percentage points less likely to report that they are feeling better off while farmers who own their house are 14.50 percentage points more likely to feel better off. This indicates that house ownership status does play a significant role in how farmers perceive their welfare. Surprisingly, farmers in a general caste category are 12 percentage points less likely to report feeling better-off and those farmers who own land are 2.890 percentage points less likely to feel better-off. These results are quite counterintuitive, as farmers who own land and are in a less marginalised caste group might be expected to have better perceptions of their welfare.

Table 7: OLS Regression Analysis Results: Impact of Rehabilitation (see below)[24]

[24] Table 7 indicates that some categoric variables are no longer represented in the results of the analysis. Whenever we had a categoric variable (a variable that is the answer to a multiple choice question) we included in our regression equation a dummy variable for each category. However, the variance-covariance matrix of the regressors is not invertible if a subset of the independent variables are perfectly linearly dependent, which means the OLS estimator is not defined in that case. This is known as the perfect multicollinearity problem, and is automatically solved in Stata (the statisical software used for the analysis) dropping one of the categories from the regression equation. The coefficients of the remaining categories are then to be interpreted as relative to the omitted category.

The impact of the rehabilitation works on the irrigation scheme on household living standards - Full set of regression coefficients

VARIABLES	(1) better-off	(2) worse-off	(3) hh assets index
rehab.	0.436***	-0.148***	-0.0958
	(0.0333)	(0.0341)	(0.101)
low rainfall	0.723***	-0.653***	
	(0.0968)	(0.0991)	
average rainfall	-0.117	0.0456	-1.710***
	(0.0982)	(0.101)	(0.288)
Bhopal	1.183***	-0.964***	0.407
	(0.0948)	(0.0970)	(0.287)
Gwalior	-0.0498	-0.179**	-1.021***
	(0.0769)	(0.0787)	(0.229)
Neemuch	0.661***	-0.714***	1.524***
	(0.0846)	(0.0866)	(0.251)
Shajapur	0.969***	-0.774***	1.382***
	(0.129)	(0.132)	(0.367)
Tikamgarh	-0.638***	0.331***	-0.965***
	(0.0767)	(0.0785)	(0.228)
Ujjain	0.442***	-0.423***	1.063***
	(0.0808)	(0.0828)	(0.241)
Vidisha	-0.0368	-0.682***	0.0750
	(0.0864)	(0.0884)	(0.261)
holds BPL card	-0.0965***	0.0802***	-0.0641
	(0.0295)	(0.0302)	(0.0889)
general caste	-0.120**	0.0250	0.132
	(0.0467)	(0.0478)	(0.142)
OBC caste	0.00385	0.0242	-0.0134
	(0.0426)	(0.0436)	(0.130)
scheduled tribe	0.00539	-0.0196	0.507
	(0.150)	(0.154)	(0.460)
other house ownership, past period	0.0968	0.101	
	(0.0872)	(0.0893)	
owned house, past period	0.145**	0.117*	0.114
	(0.0638)	(0.0653)	(0.197)
semi-permanent house, past period	0.0422	-0.0368	0.0114
	(0.0479)	(0.0490)	(0.143)
temporary house, past period	-0.0841***	0.0271	-0.0181
	(0.0287)	(0.0294)	(0.0870)
hh belongings index, past period	0.00437	0.00697	0.559***
	(0.00818)	(0.00837)	(0.0248)
main income source, past period: agriculture	-0.157	-0.226	-0.475
	(0.189)	(0.193)	(0.579)
main income source, past period: horticulture	0.378***	-0.211***	0.905***
	(0.0765)	(0.0783)	(0.234)
main income source, past period: fisheries	0.278*	-0.183	0.641
	(0.164)	(0.167)	(0.502)
main income source, past period: dairy	0.152***	-0.165***	0.347***
	(0.0287)	(0.0294)	(0.0867)
main income source, past period: poultry/meat	0.0128	-0.222*	-0.124
	(0.126)	(0.129)	(0.385)
main income source, past period: business	0.000265	-0.0571	0.386*
	(0.0732)	(0.0749)	(0.220)
main income source, past period: services	0.0556	-0.0337	0.136
	(0.0775)	(0.0793)	(0.237)
main income source, past period: lease agric. tools	0.0492	0.0664	0.478*
	(0.0910)	(0.0932)	(0.279)
main income source, past period: loans	-0.282	-0.202	0.161
	(0.232)	(0.237)	(0.711)
main income source, past period: other	0.105**	-0.0133	-0.171
	(0.0502)	(0.0514)	(0.154)
land owned (ac), past period	-0.00289**	-0.000201	0.0133***
	(0.00140)	(0.00143)	(0.00403)
farm location: head	-0.0568*	-0.0240	-0.0219
	(0.0292)	(0.0299)	(0.0883)
farm location: tail	-0.0128	0.0177	-0.169**
	(0.0283)	(0.0289)	(0.0854)
owned plot	-0.00402	0.178	0.562
	(0.167)	(0.171)	(0.413)
rented plot	-0.0502	0.194	
	(0.212)	(0.217)	
irrig. method, past period: border strip	-0.0700	-0.0611	-0.105
	(0.327)	(0.334)	(0.464)
irrig. method, past period: drip/sprinker	-0.184	0.260	
	(0.356)	(0.365)	
irrig. method, past period: flooding	-0.167	-0.0340	-0.0487
	(0.324)	(0.332)	(0.458)
irrig. method, past period: ridge and furrow	0.209	-0.207	0.0780
	(0.339)	(0.347)	(0.539)
modern agric. technology index, past period	0.0259**	0.0219*	0.0785**
	(0.0114)	(0.0116)	(0.0347)
female	0.0112	0.0571	-0.585**
	(0.0739)	(0.0757)	(0.227)
age	-0.0109*	-0.00175	0.0303*
	(0.00573)	(0.00587)	(0.0172)
age squared	8.44e-05	1.14e-06	-0.000346**
	(5.88e-05)	(6.02e-05)	(0.000176)
hh members	-0.000388	-0.00243	0.0185**
	(0.00237)	(0.00243)	(0.00719)
holds Kisan Credit Card, past period	0.0154	0.0247	0.248***
	(0.0273)	(0.0280)	(0.0830)
high rainfall			-1.231***
			(0.289)
rented house, past period			0.132
			(0.265)
farmer labourer			1.038
			(0.650)
irrig. method, past period: check basin			-0.726
			(1.093)
Constant	0.162	0.874*	1.465
	(0.446)	(0.456)	(1.012)
Observations	781	781	807
R-squared	0.608	0.397	0.596
Additional controls	YES	YES	YES

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

4.2 Household Asset Ownership

In column 3 of Table 7, we report results for household wealth as a dependent variable. Results in column 3 indicate that in fact, rehabilitation is not a significant factor in whether farmers own more or less household assets. On the other hand, farmers living in the average rainfall zone own on average, 1.7 items less with respect to farmers living in the low rainfall zones. District-wise, farmers are more likely to own more assets in Shajapur, Neemuch and Ujjain and less in Gwalior and Tikamgarh. Yet, Gwalior is a district where farmers report a lower likelihood of feeling worse-off in comparison to the past (column 2, Table 7).

Not surprisingly, the results show that farmers engaged in horticulture and dairy is highly positive and significant predictor for asset ownership, as well as, to a lesser degree, having a business and the leasing of agricultural tools as the main source of income (column 3, Table 7). Farmers that own land are 13.3 percentage points more likely to own assets, while having a farm located at the tail of a canal system results in farmers owning less assets with respect to farmers living in the middle of a canal system. If a farmer is female, she is also less likely than a male farmer to own assets. However, ownership of a Kisan Credit Card seems to result in a positive and significant outcome for asset ownership compared to farmers that do not have a Kisan credit card. This result indicates that the Kisan credit card is indeed an effective means of boosting consumption and the acquisition of household goods for farmer households.

4.3 Heterogeneous Impact Results: Who among the poor farmers are feeling better-off as a result of the rehabilitation?

The results of the heterogeneity analysis are presented in Table 8. The effect of the rehabilitation programme on subjective welfare is particularly strong for farmers who are in the scheduled tribe caste. Farmers from scheduled tribes in rehabilitated areas are on average, 75.9 percentage points more likely to be feeling better-off than in the past. This finding is particularly relevant, as farmers in this caste group are some of the poorest and most vulnerable of the different caste groups in India.

Table 8: OLS Regression Analysis Results: Heterogeneity Analysis

The impact of the rehabilitation works on the irrigation scheme on household living standards - Heterogeneity analysis

Panel A	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	better-off	better-off	better-off	better-off	better-off	better-off
rehab.	0.420***	0.427***	0.432***	0.410***	0.659***	0.469***
	(0.0348)	(0.0340)	(0.0332)	(0.0376)	(0.210)	(0.0479)
rehab.*BPL card	0.0907					
	(0.0599)					
rehab.*scheduled caste		0.118				
		(0.0854)				
rehab.*scheduled tribe			0.759**			
			(0.295)			
rehab.*Kisan credit card				0.0791		
				(0.0538)		
rehab.*owned land					-0.225	
					(0.210)	
rehab.*temporary house						-0.0519
						(0.0546)
Constant	0.160	0.108	0.195	0.00791	-0.137	0.154
	(0.445)	(0.447)	(0.444)	(0.334)	(0.351)	(0.446)
Observations	781	781	781	781	781	781
R-squared	0.609	0.609	0.611	0.609	0.608	0.608
Additional controls	YES	YES	YES	YES	YES	YES

Panel B						
VARIABLES	worse-off	worse-off	worse-off	worse-off	worse-off	worse-off
rehab.	-0.129***	-0.137***	-0.147***	-0.0913**	-0.177	-0.171***
	(0.0356)	(0.0348)	(0.0341)	(0.0383)	(0.216)	(0.0490)
rehab.*BPL card	-0.112*					
	(0.0613)					
rehab.*scheduled caste		-0.137				
		(0.0874)				
rehab.*scheduled tribe			-0.304			
			(0.303)			
rehab.*Kisan credit card				-0.175***		
				(0.0548)		
rehab.*owned land					0.0287	
					(0.215)	
rehab.*temporary house						0.0360
						(0.0560)
Constant	0.877*	0.937**	0.861*	1.070***	1.150***	0.880*
	(0.455)	(0.458)	(0.456)	(0.340)	(0.359)	(0.456)
Observations	781	781	781	781	781	781
R-squared	0.399	0.399	0.397	0.405	0.397	0.397
Additional controls	YES	YES	YES	YES	YES	YES

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

Notes: The outcome variable in Panel A is an indicator for whether the household perceives to be better-off as a result of the rehabilitation scheme. The outcome variable in Panel B is an indicator for whether the household perceives to be worse-off as a result of the rehabilitation scheme. The outcome is regressed on a rehab. dummy, an interaction term capturing heterogenous impacts, rainfall zone (low, average, high) dummies, district of residence, number of household members, age (linear and square), gender, caste of the household head, past house ownership, a (past) asset ownership indicator, household past main source of income, past landholding details, possession of a BPL card and of a Kisan credit card, farm location in the canal system, status of farming, past main method of irrigation, an index for the adoption of modern agriculture technology. In Column (1), the interaction term is between rehab. and possession of a BPL card. In Column (2), the interaction term is between rehab. and scheduled caste. In Column (3), the interaction term is between rehab. and scheduled tribe. In Column (4), the interaction term is between rehab. and possession of a Kisan credit card. In Column (5), the interaction term is between rehab. and ownership of land. In Column (6), the interaction term is between rehab. and temporary housing.

In Panel B, results indicate that those farmers in our sample holding a BPL card (hence, some of the poorest farmers in our sample) are 11.2 percentage points less likely to report feeling worse-off as a result of the rehabilitation than compared to the past. This also holds true for those farmers with Kisan Credit Cards, who are 17.5 percentage points less likely to report feeling worse-off on average than from the past.

The result that the provision of irrigation supply is a significant determinant of subjective welfare improvements for the most vulnerable individuals in society is a positive signal that the MPWSRP achieved success in its targeting of the programme. Beyond this, our results also indicate that availability of surface water is a factor that should be considered as a commodity determinant of welfare as it is a significant factor in the production of welfare for farmers. These results further nuance the work of Dasgupta and Maeler (2001). The additional insights gained from the heterogeneity analysis give us a better sense of "who" among the sample of farmers is feeling better-off or less worse-off. The households that are considered the poorest among Indian society (holders of BPL cards, members of marginalized caste groups) are reporting improvements in welfare. This indicates that the MPWSRP investments were able to improve subjective welfare of the most marginalized farmers and that this did make a positive difference in perceptions among small and marginal farmers residing in districts with farm plots that are between 2 to 5 ha.

4.4 Limitations

The use of subjective measures as an indicator of welfare poses a number of limitations. For example, subjective measures are typically prone to reporting bias. Also, because subjective measures are an ordinal measure, it is difficult to compare between individuals, as subjective measures are individual and unique to each person (see the critique of subjective utilities in Sen, 1979). Nevertheless, we believe that our measure of subjective welfare, by capturing perceived variations in welfare with respect to the past, should be almost immune from this problem. However, there are challenges as the results hinge upon the farmer's ability to recall factors that influenced their welfare in the present and the past. Aside from issues of memory recall, it may well be that a person's different assessment of their own status now and in the past is conditioned by a number of material and psychological conditions that have little to do with the effectiveness of the irrigation programme. One potential approach to address this limitation would be to include a control in the regression for an individual who is more or less optimistic which would control for whether a farmer is more likely to report improved welfare levels. However, the survey questionnaire at this stage does not include questions to assess an individual's optimism levels. This is an additional question that will be added to future iterations of the survey when testing for long-term impacts of the program. Despite this limitation, our results are still consistent due to random assignment of the treatment (farmers in the Rehab districts) which implies that on average there is the same likelihood to find optimistic or pessimistic people in the two groups. Therefore, we are convinced that in practice, our approach is still worth pursuing.

The work of Sitglitz et al., (2009b) points out that results of studies focusing on subjective measures are replicable and help predict people's behaviour. On the other hand, focusing on our subjective measure of welfare allows us to indirectly account for a more comprehensive set of dimensions that affect the life of the farmers exposed to the MPWSRP project than the one provided by income and material goods measures alone. In this sense, the fact that we find no impact of the MPWSRP irrigation investments on household asset ownership, but a strong significant effect on perceived welfare confirms that there is more to life satisfaction and deprivation among rural farmers in India than income and consumption alone.

Lastly, there is also the potential that the OLS regression model would have either underestimated or overestimated the impact of access to irrigation depending on whether the farmers in the Rehab areas are more or less able to realize the potential benefits of irrigation due to omitted variable bias driven by unobservable factors (Zaman et al., 2001). However, given random assignment of the treatment across districts and the inclusion of district dummies in our regression, we are confident that this risk has at least been minimised by the study design, and that our estimates are actually capturing the causal effect of the policy.

5. Conclusion

The results of our analysis revealed that there are significant differences in how farmers perceive their own welfare between areas that received investments under MPWSRP and areas that did not. It appears that access to rehabilitated irrigation is a positive factor in farmers' perceptions of their welfare. After interventions in rehabilitation of canal systems, farmers living in areas with predominantly low rainfall, in low caste groups (e.g. scheduled tribes), holding Below Poverty Line cards, and having Kisan Credit Cards reported feeling better-off in comparison to their own welfare in the past. This is encouraging for the interventions, as these investments were able to target relatively income-poor, disadvantaged members of farming communities from low caste groups in Madhya Pradesh. These findings seem to counter the claims of several studies that indicate that the result of low rates of economic return of irrigation investments may have resulted in diminished poverty reduction impact of irrigation investment projects (Meizen-Dick and Rosegrant 2005; Kikuchi, et al. 2003; Rosegrant and Svendsen 1993).

However, this study also shows that farmers who obtained income mainly from horticulture and dairy reported feeling better-off with respect to the past. It is not surprising that farmers who can diversify away from cereal, low-value crops and invest in more advanced practices, grow horticulture, and obtain income from dairy activities are more likely to perceive higher welfare. This is coupled with those farmers adopting modern agricultural technologies, who are also reporting higher welfare. However, as the results of the descriptive statistics in our sample indicated, a majority of farmers in our sample are not engaging in horticulture production and adoption of micro-irrigation technologies, and are continuing to use flood irrigation methods to cultivate their crops. This implies that most farmers are choosing to maintain their traditional farming practices and grow a traditional set of crops rather than choosing riskier options despite a more assured supply of surface irrigation. Meanwhile, the smaller number of farmers who did choose more risky options saw stronger returns to their welfare. These results raise further questions on what factors led some farmers to adopt high-value agriculture while a majority of farmers chose not to?

Findings from this study also raise a wider policy point on whether large-scale investments in irrigation infrastructure can simultaneously raise agricultural productivity and reduce poverty (both objective and subjective). The distributional impacts from this study suggest that higher capacity and less risk-averse farmers seem to benefit more than those who maintain traditional methods. Further analysis is needed to understand to what extent these conditions or enabling environments are lacking or imperfect within specific districts in Madhya Pradesh, and how these conditions prevented more farmers from switching to horticulture or dairy production. More research is also needed to identify how access to groundwater impacts farm-level use of surface irrigation and how farmer perceptions of welfare can be influenced by groundwater. Secondly, as this study was an initial analysis of the survey results, subsequent analysis of how the rehabilitation influenced crop production and irrigation practices along with farm-level management opportunities of the Rehab farmers needs to be studied. Although these questions were posed in the household survey, they will be analysed in a forthcoming paper on this topic, and have not been included in this study. Lastly, there is the need to explore how the anti-poverty impacts of irrigation can be further intensified or coupled with institutional interventions. It is important to determine the optimal combination of infrastructure and institutional policies that can facilitate enabling environments that could achieve functional inclusion of more vulnerable farmers to shift to high-value market-oriented production and therefore, increase their water-related returns.

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Appendix A: First stage cluster sample of 38 projects for 10 Rehab Districts

No.	Project name	River basin	District	Scheme type
1	Langarpura	Betwa	Bhopal	Minor
2	Ghuwara Tank	Betwa	Sagar	Minor
3	Paniya Tank	Betwa	Sagar	Minor
4	Nanhi Tehri Tank	Betwa	Tikamgarh	Minor
5	Prem Sagar Mabai Tank	Betwa	Tikamgarh	Minor
6	Airora	Betwa	Tikamgarh	Minor
7	Bhitarwar Tank	Betwa	Tikamgarh	Minor
8	Bilwari	Betwa	Tikamgarh	Minor
9	Bund ka Murrah	Betwa	Tikamgarh	Minor
10	Chhutaki Tank	Betwa	Tikamgarh	Minor
11	Gidwasan	Betwa	Tikamgarh	Minor
12	Kandwa	Betwa	Tikamgarh	Minor
13	Kharon	Betwa	Tikamgarh	Minor
14	Kudiyala	Betwa	Tikamgarh	Minor
15	Mamon Tank	Betwa	Tikamgarh	Minor
16	Morpariya	Betwa	Tikamgarh	Minor
17	Para Tank (Badagaon)	Betwa	Tikamgarh	Minor
18	Shahpur	Betwa	Tikamgarh	Minor
19	Kethan Medium Tank	Betwa	Vidisha	Medium
20	Bardha Tank	Betwa	Vidisha	Minor
21	Ghaterapura Tank	Betwa	Vidisha	Minor
22	Jamwar Tank	Betwa	Vidisha	Minor
23	Jajon Minor Tank	Betwa	Vidisha	Minor
24	Morwan Tank	Chambal	Neemuch	Medium
25	Siloda Tank	Chambal	Shajapur	Minor
26	Koyalkhedi Tank	Chambal	Ujjain	Minor
27	Laxmipura Tank	Chambal	Ujjain	Minor
28	Pachola Tank	Chambal	Ujjain	Minor
29	Silarkhedi	Chambal	Ujjain	Minor
30	Narela	Chambal	Ujjain	Minor
31	Bhat Kamaria	Ken	Damoh	Minor
32	Bhartala Tank	Ken	Katni	Minor
33	Pabra Tank	Ken	Katni	Minor
34	Pali Tank	Ken	Katni	Minor
35	Bhonhari Tank	Ken	Sagar	Minor
36	Harsi	Sindh	Gwalior	Major
37	Paronch	Sindh	Shivpuri	Medium
38	Gurma Tank	Tons	Rewa	Medium

Appendix B: Summary of stratified sample size for Rehab districts

Name of project (27)	**Name of District (10)**	**Number of WUAs (34)**	**Number of WUA farmers (485)**
Harsi	Gwalior	9	125
Paronch tank	Shivpuri	2	29
Kethan medium tank	Vidisha	2	29
Bardha tank	Vidisha	1	14
Ghaterapura tank	Vidisha	1	14
Jajon minor tank	Vidisha	1	14
Morwan tank	Neemuch	1	15
Langarpura tank	Bhopal	1	15
Ghuwara tank	Sagar	1	15
Kudiyala tank	Tikamgarh	1	15
Bhitarwar tank	Tikamgarh	1	15
Bilwari tank	Tikamgarh	1	15
Shahpur tank	Tikamgarh	0	Linked to Bilwari tank
Chhutaki tank	Tikamgarh	1	15
Gidwasan tank	Tikamgarh	1	15
Kandwa tank	Tikamgarh	1	15
Kharon tank	Tikamgarh	1	15
Morpariya tank	Tikamgarh	0	Linked to Kharon tank
Para tank (Badagaon)	Tikamgarh	1	14
Siloda tank	Shajapur	1	14
Koyalkhedi tank	Ujjain	1	14
Laxmipura tank	Ujjain	1	14
Silarkhedi tank	Ujjain	1	14
Bhartala tank	Katni	1	14
Pabra tank	Katni	1	14
Pali tank	Katni	0	Linked to Pabra tank
Bhonhari	Katni	1	14

Appendix C: Summary of stratified sample size for No Rehab districts

Name of project (15)	**Name of District (5)**	**Number of WUAs (12)**	**Number of WUA Farmers (433)**
Bahadurpur canal project	Gwalior	1	37
Ramowa canal project	Gwalior	1	36
Himmatgarh tank project	Gwalior	1	36
Sirsa dam project	Gwalior	1	36
Muradpur tank	Vidisha	1	36
Naren tank	Vidisha	0	Linked to other tanks
Bani tank	Neemuch	1	36
Dhangaon tank	Neemuch	1	36
Malgarh and Lasur tanks	Neemuch	1	36
Kervan tank	Bhopal	1	36
Hataikheda tank	Bhopal	1	36
Jastakhedi tank	Ujjain	1	36
Undadasa tank	Ujjain	1	36
Tankaria	Ujjain	0	Linked to other tanks

CHAPTER 6: CONCLUSION

The overall aim of this research was to deepen understanding, and test commonly held assumptions, of the role that investment in irrigation infrastructure plays in improving water security in India at the district and household scale. The majority of irrigation investment research focuses on global, regional and national impacts; in contrast this research thesis examined impacts at a district and household level, beginning to fill a gap in the existing literature.

Although irrigation is not a panacea and does not automatically lead to improved water security, researchers have extensively explored irrigation's potential to reduce water-related risk. They suggest that when poor, agriculture-dependent economies invest in water-related infrastructure (e.g. surface irrigation), this will result in higher crop yields, increased agricultural growth and associated economic growth. However, when one drills down below the national and state level in a country as diverse as India, the picture becomes much more complex. The nature of this complexity determined the key research questions posed by this thesis:

1a) do investments in irrigation infrastructure lead to higher crop yields compared to districts without investments?

1b) do investments buffer crop yields from fluctuations in rainfall levels at a district-level compared to districts without investments?

2) do investments in irrigation infrastructure improve perceived welfare of farmers compared to farmers living in districts without investments?

In answering these questions, this thesis provides an empirical evidence base to understand the local impacts of irrigation infrastructure solutions at the district and household level.

Paper one addressed both parts of question one. The results of this paper suggest that there are inconsistencies within the current paradigm on irrigation investments. The results demonstrate that even when irrigation systems are rehabilitated to a high standard, localised rainfall variability can continue to influence water availability for crops and therefore overall yields, *regardless of the investments*. This research hypothesizes that the basin-wide, engineering approach of the Madhya

Pradesh Water Sector Restructuring Project (MPWSRP) that was utilised to determine where to make investments (i.e. focusing investments on key river basins of the state and on the engineering needs of existing irrigation systems) addressed the infrastructure needs of the systems but did not always result in improved crop yields. The findings of this paper illustrate the complexity associated with localised rainfall patterns and their impacts on crop yields. Irrigation investments can help address these challenges but they must be designed to account for infrastructure engineering needs as well as variability in spatial rainfall.

Importantly, these findings question the prevailing theories on water security. An integrated basin approach for investment decisions may not reduce the vulnerability of crops to variability in district-level monsoon patterns at a district scale, as seems to be the case in MP. This is especially important with ever increasing variability in Indian monsoons due to climate change (Malik et al., 2016). The results of paper one demonstrate the necessity of incorporating analysis of localised rainfall trends into decision-making on the size and location of future irrigation projects within a river basin. Irrigation systems located in command areas facing overall drying trends compared to areas facing excess monsoon trends will need a different scale of investment. This targeted approach will increase the cost effectiveness of irrigation schemes by reducing risk to crops from monsoon variability.

The results of paper one were based on analysis of aggregated district-level statistics. This is a more granular approach that led to new insights into micro-level trends compared to country-level analyses that dominate the water security literature. However, to understand the impact of irrigation investments on farmers, a separate analysis was necessary. The second paper answered question two by analysing results from a large-scale household survey of Water User Association farmers in districts with and without irrigation investments to determine perceived welfare as a result of the investments. Paper two revealed three sets of important findings.

The first finding is that farmers in low rainfall districts, with irrigation investments, perceive their welfare to be improved compared to the past, even when some crop yields were lower compared to districts without irrigation investments. The results of paper two indicate that water security for rural, poor households has additional layers of complexity beyond quantitative economic measures (e.g. crop and household incomes) that should be incorporated into measurements of household water security. Paper two illustrated that the poorest segments of the farming communities (e.g. Below Poverty Line (BPL) and Other Backwards Caste (OBC) farmers), and those living in rainfall-deficient areas, show some of the strongest positive welfare responses to the irrigation investment programme. However, it is within these areas that staple crop yields are not responding as positively to the irrigation rehabilitation compared to the No Rehab areas. The rehabilitation program overall seems to have had other positive impacts on farming households. Farmers could potentially be responding positively to some of the capacity building, farmer training, and community-based institutional reforms that the restructuring project implemented in addition to the infrastructure investments. However, these capacity building measures made up only 10% of the overall project investments in the intervention districts. This finding needs further research to determine which interventions from the project led to improvements in perceived welfare responses.

The second result of paper two is the converse of the first. Subjective welfare analysis rarely includes measures such as availability of rehabilitated irrigation infrastructure. The list of commodity determinants of welfare includes commodity inputs into the production of welfare such as “food, clothing, potable water, shelter, access to knowledge and information, and resources devoted to national security” (Dasgupta, 1993; Dasgupta and Maler, 2001). The findings of paper two reveal that water-related infrastructure has a strong positive relationship in a farmer’s perception of welfare. Therefore, water-related infrastructure, such as irrigation, is a critical commodity that contributes to perceptions of welfare. This also opens further areas of research to examine how differing farming communities respond to a commodity determinant of welfare such as irrigation infrastructure in other regions other than in MP. Incorporating an indicator on subjective welfare in measurements of impacts can provide deeper insight into the responses of communities to specific interventions related to water security.

The third important finding from paper two lends insight into the willingness of farmers to improve their water-related practices. A majority of the farmers we surveyed in MP are growing water intensive, low-value crops such as rice and wheat.

The survey results also suggest that farmers prefer to utilise flood irrigation methods to grow these crops. The findings of the regression models suggest that a small group of farmers in the sample adopted micro-irrigation technologies (e.g. drip and sprinkler systems) and switched to high-value horticulture production. However, those farmers that did switch seemed to have greater improvement in their subjective welfare than farmers who did not. Yet most farmers in the sample preferred to maintain their irrigation and agricultural practices relatively the same compared to past years, despite the availability of assured irrigation supply. Based on these results, there is a need to better understand what factors encouraged some farmers to change their practices towards more sustainable farming, thereby enhancing their long-term water security.

It is important to note that paper one and two are initial results from the secondary and primary data collection conducted for this thesis. The findings of these papers will be enhanced through further analysis of the data. Questions such as why certain farmers adopted new techniques while others did not remain to be explored. Are farmers who are using micro-irrigation technologies reducing their water consumption and/or seeing an increase in crop yields compared to farmers that did not adopt such practices? Broadly, more details of the specific crop and cultivation practices of the farmers that are using flood irrigation in the study area are necessary to understand how irrigation improvements can influence farm-level choices regarding cropping patterns, farm-level investments in irrigation equipment, and farm-level decisions regarding irrigation strategies.

Further research is also needed on how different scales of the irrigation investments (low, medium, high) influenced farm-level access to water and how they impacted farm-level water management opportunities for farmers in the study area. In addition, the analysis in this thesis did not examine household access to groundwater, which is an important source of irrigation for farmers in MP. Questions such as how access to groundwater influenced the need for surface irrigation and related changes in welfare perception for farmers need to be explored.

Based on these crucial topics for future research, the findings of this thesis have been further developed into a two-year D.Phil. project that will explore these questions. The aim of the D.Phil. project is to expand upon the initial findings of this thesis, specifically; the D.Phil. project will produce two additional research papers. Paper three will provide deeper insights into how rehabilitation interventions influenced crop and cultivation practices of farmers across diverse district-level rainfall regimes with more details on the specific surface and groundwater practices of farmers in the study area. Paper four will examine whether the improved welfare results of paper two are stemming from the infrastructure investments or largely due to the impacts of institutional reforms and the community-led farmer empowerment trainings. It is critical to continue the ground-breaking research that was begun in this thesis. In addition to contributions to the study of water security, these results will be important for other agriculture dependent, emerging economies that are embarking on large-scale infrastructure investment programs.

Enhanced water security will require behaviour changes from individual farmers, state governments, national governments, and donor investment programs. When large-scale investments are made, due to a complex but important range of climatological and societal factors, not all crop yields improve and not all farmers automatically have access to the same scale of investment, and consequently not all farmers increase their water-use efficiency. For example, this thesis has shown that the majority of poor and vulnerable farmers continue to use flood irrigation – increasing demands on finite water supplies. This resistance to irrigation behaviour change is fundamentally unsustainable in a water-stressed nation such as India, as it leaves all farmers more water insecure. Therefore, research that understands the contribution of infrastructure and institutional investments to behaviour change is critical to better design and target future projects to achieve a significant reduction in water stress for poor, vulnerable communities.

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APPENDIX A: DATA SOURCES

A. MPWSRP Irrigation Projects

Data on the number of irrigation projects in each of the selected river basins and districts of the state along with information on the number of hectares rehabilitated was obtained directly from the MP Irrigation Department Project Implementation Completion Unit officials. This data was compiled during the period of the MPWSRP by the project officials in Bhopal in order to comply with World Bank monitoring and reporting requirements.

B. General Characteristics of Districts

Data on the general characteristics of each district including total population, rural and urban populations, average literacy rate, number of Scheduled Caste and number of cultivators for the last Census 2011 in India was obtained from the District Census Handbook for Madhya Pradesh compiled by The Registrar General & Census Commissioner of India as part of the Ministry of Home Affairs, Government of India. Data on characteristics for the percentage of the rural population below the poverty line was compiled from the Madhya Pradesh State Planning Commission district-wise poverty estimates report for 2004-05. The main source of data for this study is the "Consumer Expenditure Surveys" undertaken by the National Sample Survey Organization (NSSO).

C. Per Capita Income for Districts

District-wise per capita income at current prices from 2004-05 to 2012-2013 was obtained from the Open Government Data platform that obtains data from the Madhya Pradesh Economic Survey 2013-2014. Per capita income is the mean income of the people in the district. Per capita income is calculated based on a measure of all sources of income in the aggregate (such as GDP or Gross National Income) and then dividing it by the total population of that district.

D. Irrigated Area

Data on the gross and net irrigated area for each district was obtained from the Madhya Pradesh Commissioner Land Records Office in Gwalior district. This data provided gross and net irrigated area by source of irrigation such as: canals, tanks, tube wells, wells, other sources. Total irrigated area in gross and net was also available for each district. Data was provided from 2006-07 to 2013-14. For the purposes of this paper, we used data only on gross canal irrigated area for each of the 31 districts for the year 2006-07 and 2011-12 to coincide with the start of the MPWSRP as well as with the Census 2011 data.

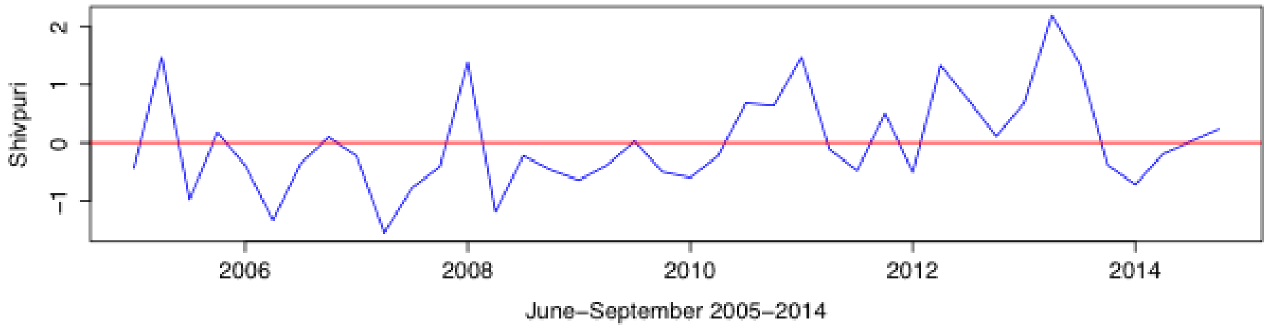
E. Rainfall

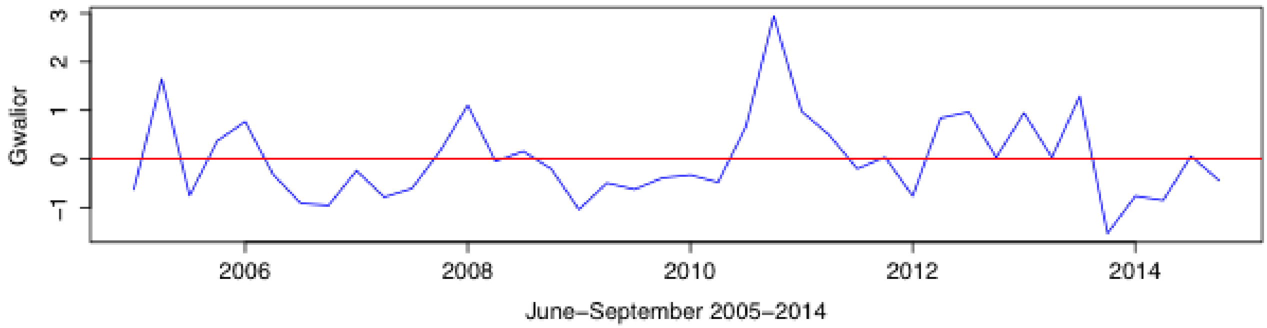
In the first instance, monthly rainfall data from 2005-2014 for all districts was obtained from the Government of Madhya Pradesh Irrigation Department PICU officials. Data was provided for all districts for each month (Jan – Dec) for the years 2005-2014. For each district, monthly rainfall values in millimetres are available for each of the rain gauge stations within the district. It is important to note that the data obtained was actual observed values for rainfall compiled by the Irrigation Department of GoMP rather than satellite data. Based on these raw values for each month, further averages were calculated for each district by summing data from all rain gauge stations and then aggregated for annual values for each year. The district of Katni, however, did not have any monthly rainfall values for 2014, as these were not available with the Department.

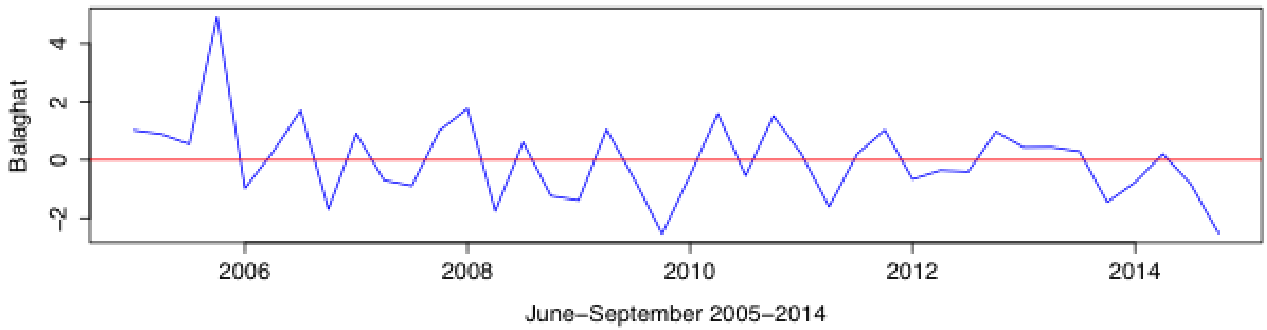
F. Agriculture yields

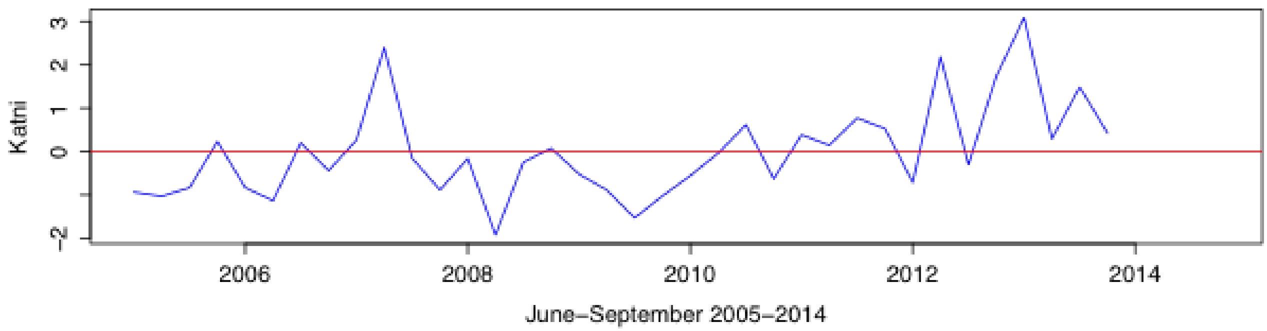
Agriculture yield data was also obtained from the Madhya Pradesh Commissioner Land Records Office in Gwalior district. However, the data was provided for each of the three selected crops (paddy, wheat, and gram) on total area of the crop in the district in thousands of hectares, total production of that crop in each district in thousands of ton units, and total yield was provided in kilograms per hectare. In order to utilize the yield data for the purposes of this thesis, the value for yield was divided by 1000 to obtain values for tons per hectare. For the wheat and gram crops data was provided for years 2004-05, 2006-07 onwards to 2013-14. However, data for the year 2005-06 was not available. For the paddy crop data was provided for 2004-05 and from 2006-07 to 2013-14. However, as paddy is cultivated in September and October of each year, data from 2004-05 would qualify as data for the year of 2004. In order to represent the sum of monthly monsoon values and the crop-wise yield values for each of the crops, absolute values were not utilised in the illustrated graphs for each district. Instead of providing absolute values for each unit, relative values are given as illustrated in the graphs in chapter 4.

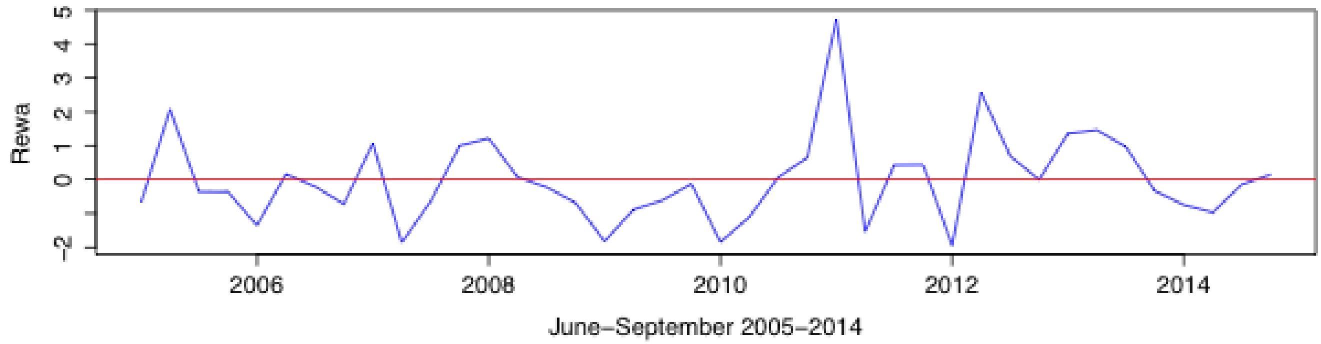
APPENDIX B: DISTRICT-WISE STANDARDISED MONSOON ANOMALY TREND GRAPHS







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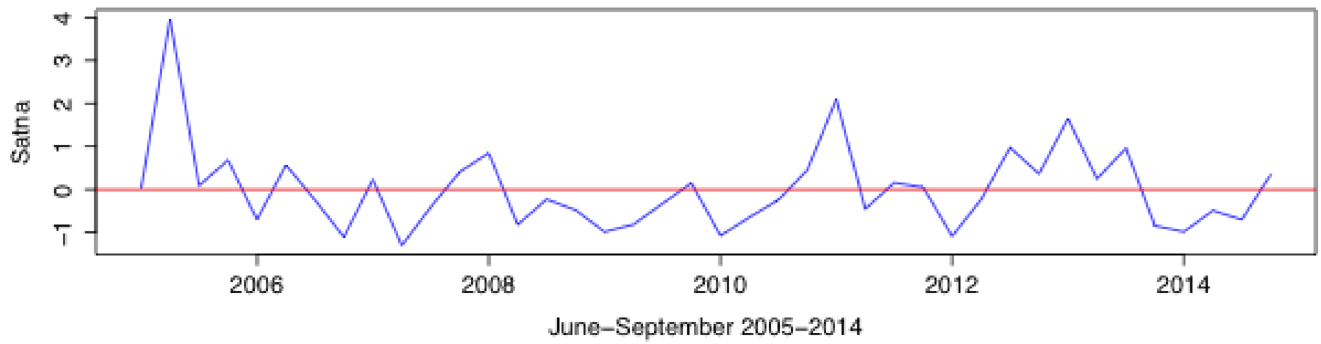
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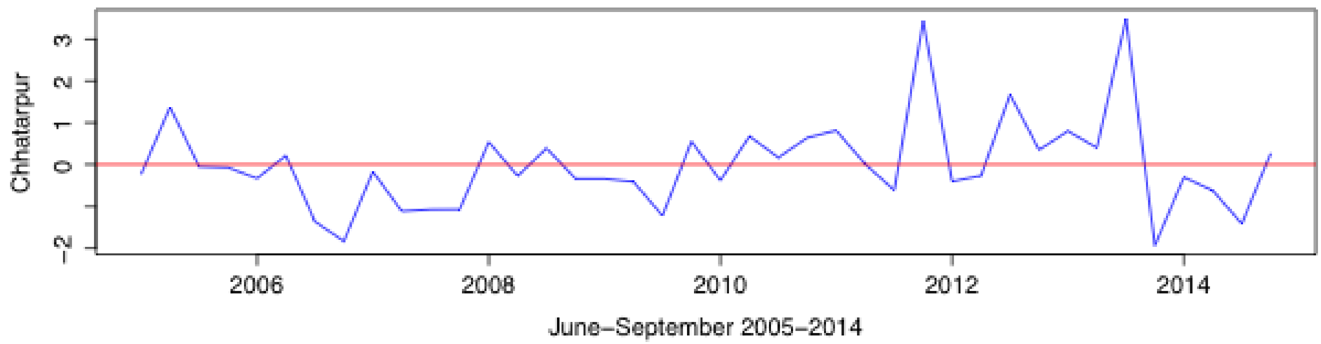
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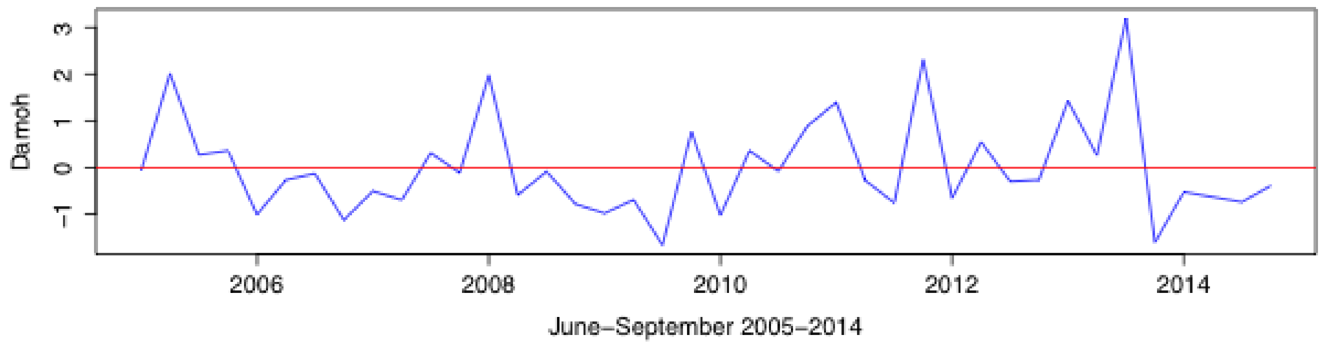
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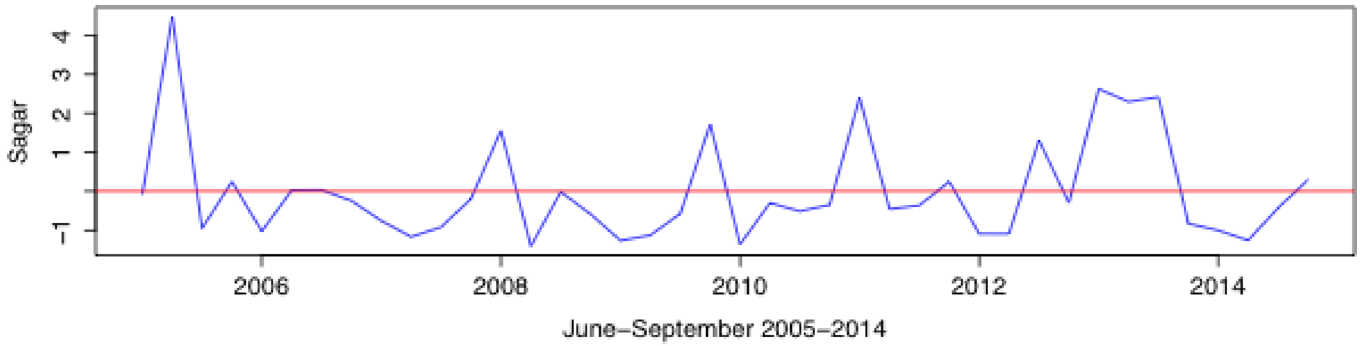
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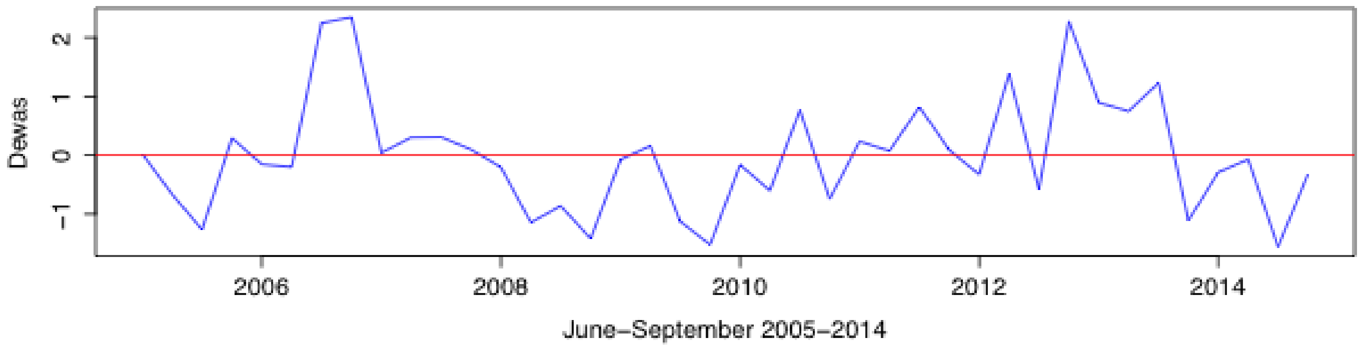
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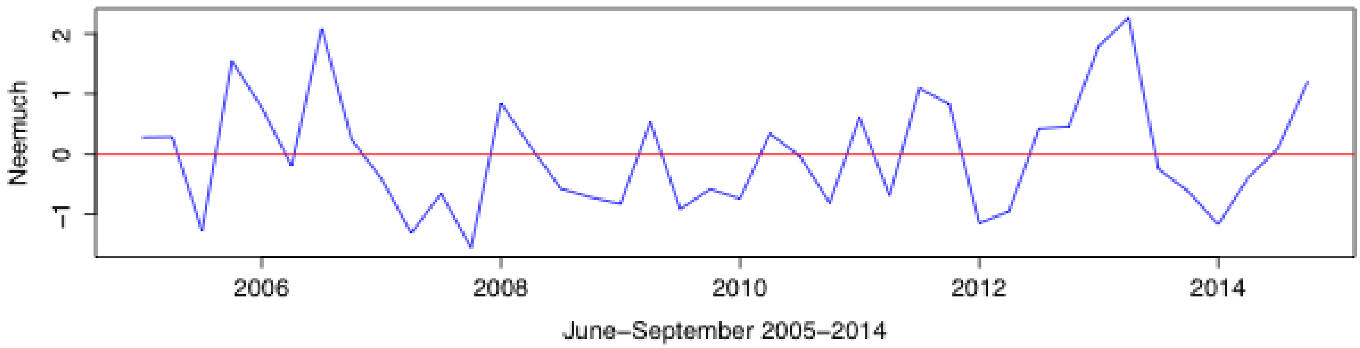
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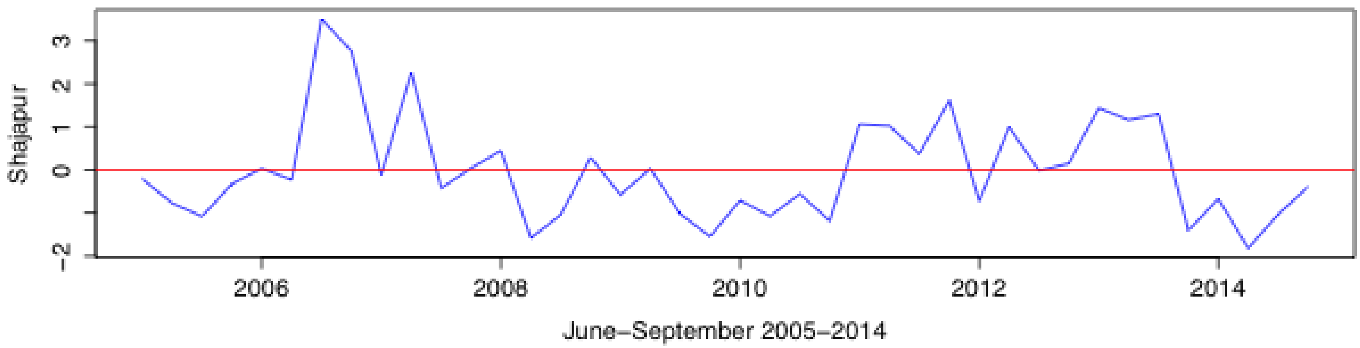
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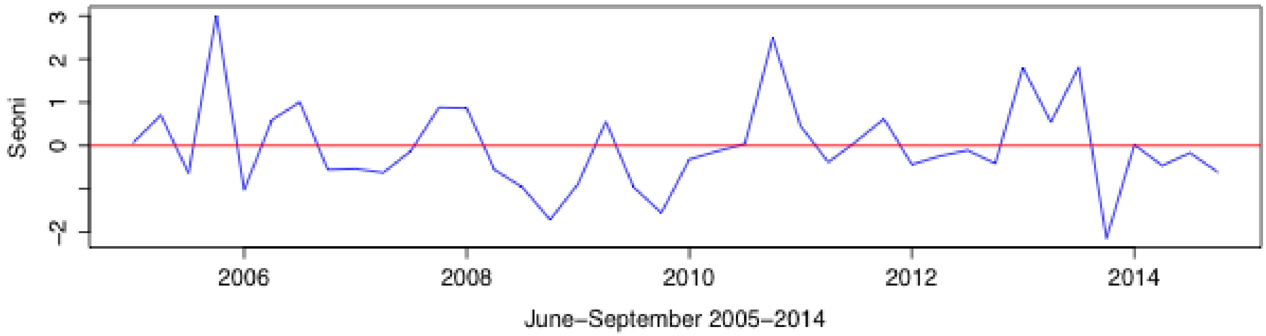
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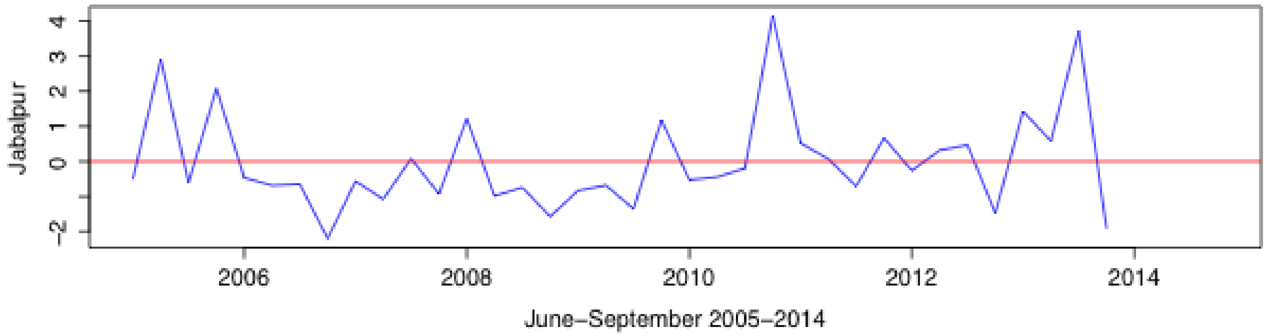
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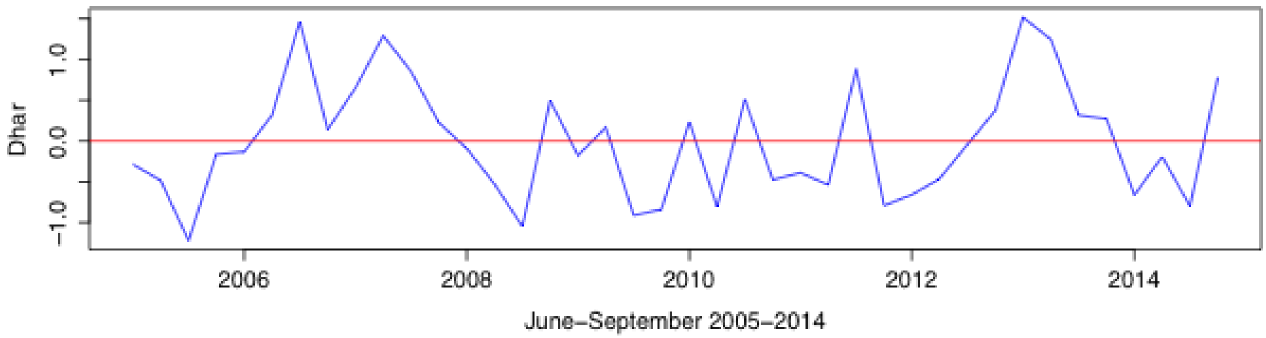
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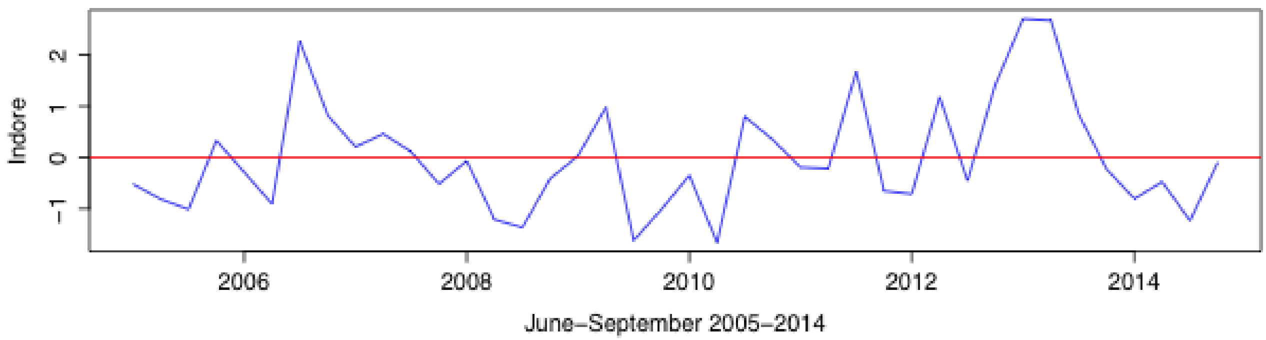
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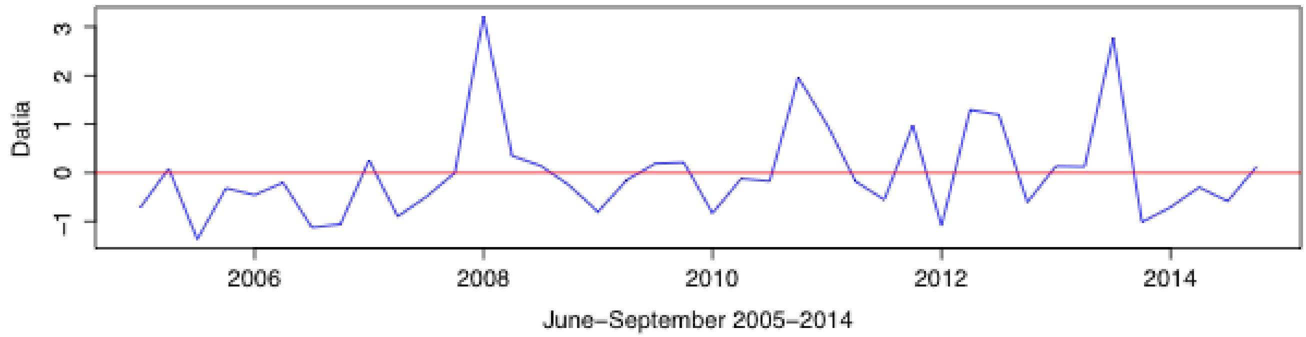
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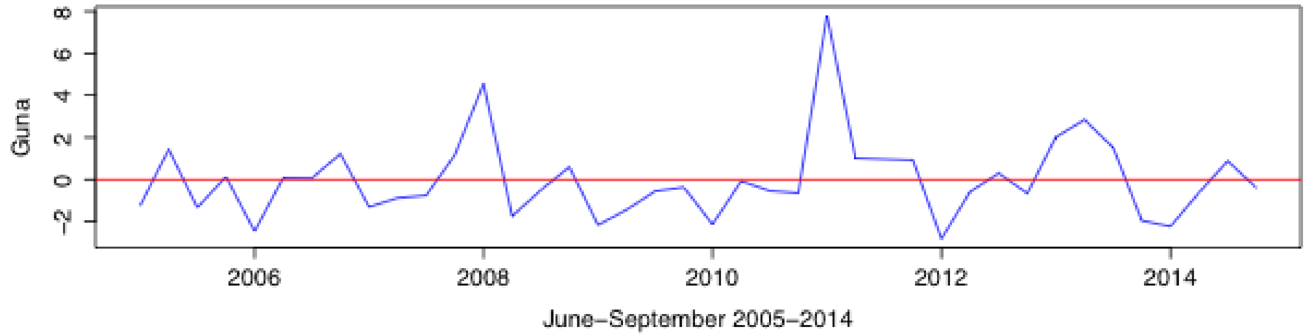
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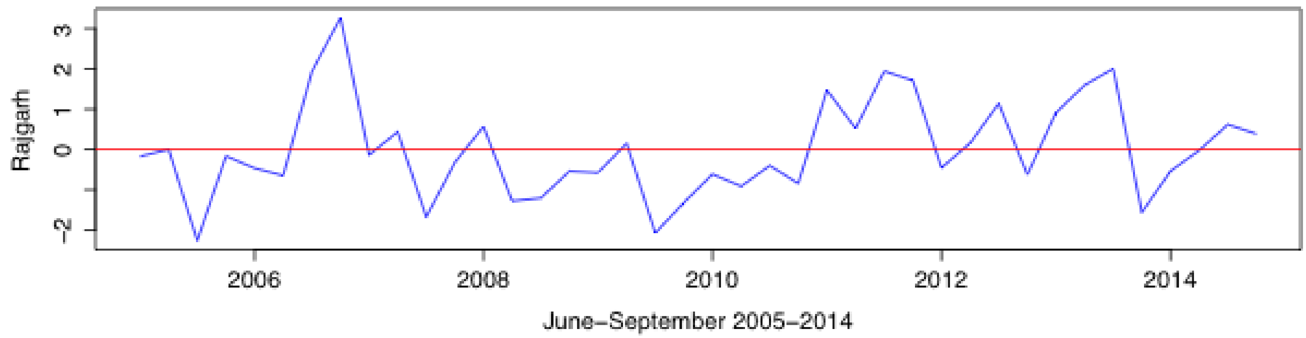
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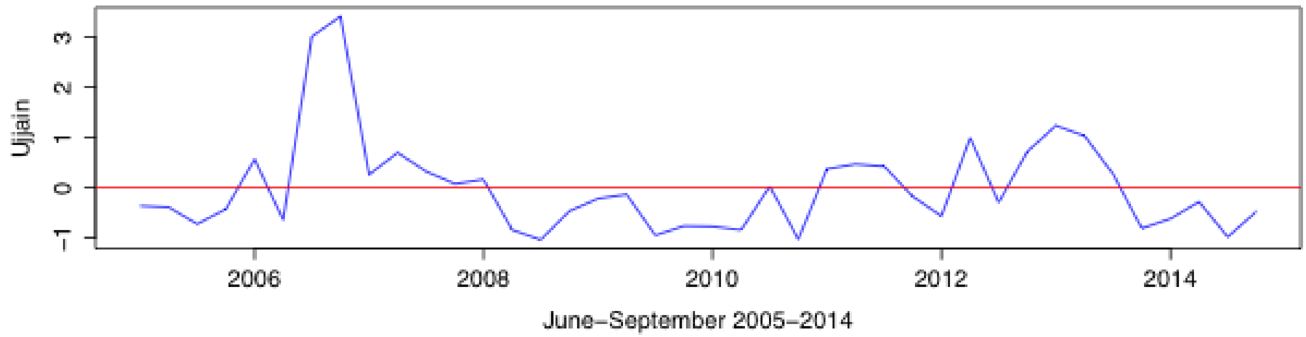
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APPENDIX C: GENERAL CHARACTERISTICS OF NON-SURVEY DISTRICTS

District Name	Population (2011)Area (Sq. Km)	Rural population (%) (2011)	Urban population (%) (2011)	Per capita income (USD) (2004-05)[25]	Per capita income (USD) (2011-12)	Average literacy (%) (2011)	Total canal irrigated area (2006-07) (Ha)	Total canal irrigated area (2011-12) (Ha)	Number of total Cultivators (2011) (No. & %)	Number of scheduled caste (2011) (No. & %)	Rural pop. below poverty line (%) (2004-05)[26]
Ashoknagar	845,071 (4,674)	81.81	18.19	N/A	N/A	66.42	11,100	13,282	116,913 (37.08)	175,764 (20.80)	N/A
Balaghat	1,701,698 (9,229)	85.61	14.39	290	673	77.09	73,600	74,904	257,785 (28.87)	125,426 (7.37)	43.66
Bhind	1,703,005 (4,459)	74.58	25.42	224	542	75.26	18,200	29,355	232,185 (44.39)	374,799 (22.01)	21.82
Chhatarpur	1,762,375 (8,687)	77.36	22.64	265	581	63.74	7,900	13,520	302,228 (40.20)	405,323 (23)	70.60
Damoh	1,264,219 (7,306)	80.18	19.82	297	653	69.73	11,600	12,127	114,611 (19.95)	246,337 (19.49)	59.80
Datia	786,754 (2,902)	76.87	23.13	290	707	72.63	83,600	110,747	152,903 (47.61)	200,270 (25.46)	22.23
Dewas	1,563,715 (7,020)	71.11	28.89	328	750	69.35	5,300	8260	260,222 (35.04)	292,007 (18.67)	32.73
Dhar	2,185,793 (8,153)	81.10	18.90	295	694	59	13,300	20,163	385,522 (37.50)	145,436 (6.65)	39.36

25 See https://data.gov.in/catalog/district-wise-capita-income-current-prices#web_catalog_tabs_block_10

26 Source: Estimates of District Poverty, PMPSU MP

District Name	Population (2011) Area (Sq. Km)	Rural population (%) (2011)	Urban population (%) (2011)	Per capita income (USD) (2004-05)[1]	Per capita income (USD) (2011-12)	Average literacy (%) (2011)	Total canal irrigated area (2006-07) (Ha)	Total canal irrigated area (2011-12) (Ha)	Number of total Cultivators (2011) (No. & %)	Number of scheduled caste (2011) (No. & %)	Rural pop. below poverty line (%) (2004-05)
Guna	1,241,519 (6,390)	74.82	25.18	281	679	63.23	19,900	32,393	213,949 (41.55)	193,115 (15.55)	38.49
Indore	3,276,697 (3,898)	25.91	74.09	767	1813	80.87	17,700	3472	150,907 (11.90)	545,239 (16.64)	12.2
Mandsaur	1,340,411 (5,535)	79.29	20.71	385	826	71.78	1,000	1,827	281,465 (41.41)	249,024 (18.58)	17.8
Morena	1,965,970 (4,989)	76.07	23.93	246	572	71.03	57,800	56,512	304,674 (45.07)	421,519 (21.44)	14.9
Panna	1,016,520 (7,135)	87.67	12.33	252	566	64.79	6,500	9,696	135,445 (32.35)	207,990 (20.46)	47.6
Raisen	1,332,597 (8,466)	77.21	22.79	288	658	72.98	64,200	76,387	138,725 (26.79	225,891 (16.96)	60.4

District Name	Population (2011) Area (Sq. Km)	Rural population (%) (2011)	Urban population (%) (2011)	Per capita income (USD) (2004-05)	Per capita income (USD) (2011-12)	Average literacy (%) (2011)	Total canal irrigated area (2006-07) (Ha)	Total canal irrigated area (2011-12) (Ha)	Number of total Cultivators (2011) (No. & %)	Number of scheduled caste (2011) (No. & %)	Rural pop. below poverty line (%) (2004-05)
Rajgarh	1,545,814 (6,153)	82.12	17.88	283	614	61.21	5,700	4,594	285,095 (38.24)	295,718 (19.13)	12.1
Ratlam	1,455,069 (4,861)	70.10	29.90	401	865	66.78	2,400	4,950	218,692 (32.65)	198,612 (13.65)	29.8
Rewa	2,365,106 (6324)	83.27	16.73	234	516	71.62	12,300	18,814	258,321 (26.04)	383,508 (16.22)	43.6
Satna	2,228,935 (7,502)	78.72	21.28	288	633	72.26	7,100	7,665	227,967 (25.01)	398,569 (17.88)	16.8
Sehore	1,321,332 (6,578)	81.05	18.95	298	651	70.06	41,200	59,903	201,307 (34.35)	271,281 (20.69)	49.1
Seoni	1,379,132 (8,758)	88.12	11.88	257	648	72.12	56,800	62,769	173,665 (25.37)	130,797 (9.48)	61.8
Sheopur	687,861 (6,606)	84.39	15.61	265	585	57.43	60,500	55,564	106,745 (38.47)	108,391 (15.76)	24.5

APPENDIX D: SURVEY PARTICIPANT ORAL CONSENT FORM

Survey Participant Oral Consent Form

Dear Respondent,

Thank you for agreeing to take part in this survey today. The Government of Madhya Pradesh Water Resources Department wishes to conduct a survey of overall farmer satisfaction among Water User Association members within the Madhya Pradesh Water Sector Restructuring project districts and districts that did not participate in the project. This survey is part of an Oxford University study that is helping Madhya Pradesh to understand the impacts of the MPWSRP on farmers. The aim of the survey is to assess satisfaction levels among WUA members with irrigation services as well as better understand the impacts felt by farmers in their agricultural production and welfare due to recent rehabilitation works by WRD under the MPWSRP.

I am here as a representative of the Water and Land Management Institute (WALMI) of Madhya Pradesh and we are helping to facilitate the survey on behalf of the WRD. I would like to ask you some basic questions about your farming and irrigation practices as well as some background on your household situation. The information you provide will be kept confidential and thus will not be revealed to anyone. We will ensure that your responses remain anonymous and will not be used by the Madhya Pradesh government or any other body other than as information for the University study.

Having heard the summary of the survey and its purpose, do you give oral consent to continue with the interview (to be filled by enumerator)?

Yes ☐ No ☐

Section below to be filled by enumerator:

Name of Respondent: ____

Date: ____

Tel: ____

APPENDIX E: SURVEY QUESTIONNAIRE FOR REHAB FARMERS

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. Farm location in canal system (Tick one)

- Head
- Middle
- Tail

g. Are you the main farmer in the household?

- Yes
- No

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

- Owned plot
- Rented plot
- Farm labourer

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. House Ownership Status (Please tick – this is unprompted – don't read from the list)

Before Rehabilitation of scheme

1. Owned
2. Rented
3. Other
4. No response
0. Don't Know

Current Status

1. Owned
2. Rented
3. Other
4. Don't Know
0. No response

d. 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

e. Type of Latrine Facility

Before rehabilitation of scheme

1. Flush/pour flush latrine connected to piped sewer system
2. Flush/pour flush latrine connected to septic tank
3. Flush/pour flush latrine connected to other system
4. Pit latrine With slab/ventilated improved pit
5. Pit latrine Without slab/ open pit
6. Night soil disposed into open drain
7. Service Latrine Night soil removed by human
8. Service Latrine Night soil Service by animal
9. Alternative source due to not having latrine facility within the premises:
    - Public latrine
    - Open

0. Don't know

Current status

1.Flush/pour flush latrine connected to piped sewer system
2.Flush/pour flush latrine connected to septic tank
3.Flush/pour flush latrine connected to other system
4.Pit latrine With slab/ventilated improved pit
5.Pit latrine Without slab/ open pit
6.Night soil disposed into open drain
7.Service Latrine Night soil removed by human
8.Service Latrine Night soil Service by animal
9.Alternative source due to not having latrine facility within the premises:
- Public latrine
- Open

0. Don't know

f. Household drinking water source (Please place one tick under each category)

Before rehabilitation of scheme

1. Main source of drinking water from treated source
2. Main source of drinking water from untreated source
3. Main source of drinking water: covered well
4. Main source of drinking water un-covered well
5. Main source of drinking water handpump
6. Main source of drinking water Tubewell/bore hole
7. Main source of drinking water: spring
8. Main source of drinking water: river/canal
9. Main source of drinking water: pond/lake
10. Other sources (please specify)

0. Don't know

Current status

1. Main source of drinking water from treated source
2. Main source of drinking water from untreated source
3. Main source of drinking water: covered well
4. Main source of drinking water un-covered well
5. Main source of drinking water handpump
6. Main source of drinking water Tubewell/bore hole
7. Main source of drinking water: spring
8. Main source of drinking water: river/canal
9. Main source of drinking water: pond/lake
10. Other sources (please specify)

0. Don't know

g. Type of fuel used for cooking (Please place one tick under each category)

Before rehabilitation of scheme

1. Firewood
2. Crop residue
3. Cowdung cake
4. Coal/lignite/charcoal
5. Kerosene
6. LPG/PNG
7. Electricity
8. Bio-gas
9. Any other (please specify)
10. No cooking

0. Don't know

Current status

1. Firewood
2. Crop residue
3. Cowdung cake
4. Coal/lignite/charcoal
5. Kerosene
6. LPG/PNG
7. Electricity
8. Bio-gas
9. Any other (please specify)
10. No cooking

0. Don't know

h. Belongings Possessed (This question needs to be answered twice (once for the scenario of the farmer prior to rehabilitation works and also again for the present situation). Please tick ALL that apply (for each column – could you tell me now the possessions the household owns and not the household; DHS surveys have; welfare index can be created).

Before rehabilitation of scheme

1. Radio/Transistor
2. Television
3. Computer/laptop
4. Access to Internet (yes/No)
5. Landline Telephone
6. Mobile Telephone
7. Bicycle
8. Scooter/ motor cycle/moped
9. Car/jeep/van
10. Thresher
11. Harvester
12. Tractor
13. Any other (please specify)

0. Don't know

Current status

1. Radio/Transistor
2. Television
3. Computer/laptop
4. Access to Internet (Yes/No)
5. Landline Telephone
6. Mobile Telephone
7. Bicycle
8. Scooter/ motor cycle/moped
9. Car/jeep/van
10. Thresher
11. Harvester
12. Tractor
13. Any other (please specify)

0. Don’t know

i. Major sources of income – (Did you regularly generate income from any of these sources? (break-up between farm and non-farm; rank from 1-3 highest to lowest – of the identified which are the top 3; first tick and then rank) This question is asking from where the farmer made most of his income both at present and also in the past before the canal rehabilitation works were completed. Please tick ALL that apply (for each column)

Before rehabilitation of the scheme

1. Agriculture
2. Horticulture
3. Fisheries
4. Dairy
5. Poultry/meat
6. Business
7. Services
8. Hiring of agricultural implements
9. Loans
10. Hired Labor
11. Others

Current status of the scheme

1. Agriculture
2. Horticulture
3. Fisheries
4. Dairy
5. Poultry/meat
6. Business
7. Services
8. Hiring of agricultural implements
9. Loans
10. Hired Labor
11. Others

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

Current Status

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

b. What was the status of irrigation before modernization works in the canal in each specific season?

Parameters (before rehabilitation of scheme)	**Kharif (Yes/No)**	**Rabi (Yes/No)**
Desired number of irrigations		
At desired time of irrigations		
Quantity of irrigation as desired in each watering		
Don't know		
No response		

Parameters (current status of scheme)	**Kharif (for last Kharif cropping season) (Yes/No)**	**Rabi (for last Rabi cropping season) (Yes/No)**
Desired number of irrigations		
At desired time of irrigations		
Quantity of irrigation as desired in each watering		
Don't know		
No response		

c. 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……				

d. Prior to irrigation season, are you informed about the date of the opening of the canal?

1. Yes
2. No

0. Don't Know

e. If yes, what is the source of the information?

1. WRD
2. WUA
3. Other (specify)

0. Don't know

f. Condition of sluice gate delivering water to WUA since rehabilitation of scheme?

1. Good and functioning
2. Needs minor repairs
3. Needs major repairs
4. No gate at all

0. Don't know

g. Does your household feel better off as a consequence of the rehabilitation works on the irrigation scheme?

1. Better off
2. Same as before
3. Worse off

0. Don't know

h. Irrigation water distribution during last Rabi cropping season (Please provide one tick for each before rehabilitation and current status)

Type of Distribution	**Before rehabilitation of scheme**	**Current Status**
From head to tail		
From tail to head		
No defined sequence of distribution		
As demanded by farmer on individual basis		
Through warabandi		
Any other (specify)		
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
3. Ridge & Furrow
4. Border strip
5. Check basin

Current status (please tick one)

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

j. Irrigation Table

	Irrigation			
Crop	Before rehabilitation of scheme		Current status of last cropping season	
	No. of waterings		**No. of waterings**	
	canal	**groundwater**	**canal**	**groundwater**
Kharif				
Soybean				
Paddy				
....				

Rabi				
Wheat				
Gram				
....				
....				
Summer				
....				
....				

VI. Agriculture Details

a. Adoption of modern agriculture technology by farmers in general for all crops for both Rabi and Kharif seasons

Before rehabilitation of scheme

1. Fertilizer use (Kg/acre/don’t know)
2. HYV/Hybrid (Yes/no/don’t know)
3. Pesticide use (litre/acre/don’t know)
4. Organic manure use (Kg/acre/ don’t know)
5. Micro-irrigation technology (yes/no/don’t know)
6. Tractor (yes/no/don’t know)
7. Thresher (yes/no/don’t know)
8. Automatic seed drill (yes/no/don’t know)
9. Harvester (yes/no/don’t know)
10. Other machinery (please specify)
11. None of the above

Current status

1. Fertilizer use (Kg/acre/don’t know)
2. HYV/Hybrid (Yes/no/don’t know)
3. Pesticide use (litre/acre/don’t know)

4. Organic manure use (Kg/acre/ don't know)
5. Micro-irrigation technology (yes/no/don't know)
6. Tractor (yes/no/don't know)
7. Thresher (yes/no/don't know)
8. Automatic seed drill (yes/no/don't know)
9. Harvester (yes/no/don't know)
10. Other machinery (please specify)
11. None of the above

b. Horticulture crops

	Horticulture crops		Current		Before rehabilitation	
	Crop	**Source of irrigation (Canal/ Groundwater/ Conjunctive use)**	**Area at present (acres)**	**Productivity at present (Q/acres)**	**Area prior to rehab (acres)**	**Productivity prior to rehab (Q/acres)**
1	Vegetables					
2	Fruits					
3	Spices					
4	Medicinal and Aromatic plants					
5	Floriculture					

c. Crop-wise cultivation (before rehabilitation of scheme)

	Crop-wise cost of cultivation	**Before Rehabilitation**				
Crop	Area (in acres)	Productivity (quintals/acre)	Cost of seed (Rs/ acre)	Material cost (Fertilizers, Pesticides, Machinery hire etc) (Rs/ acre)	Labour input (Rs/ acre)	Other costs (Rs/ acre)
Kharif						
Soyabean						
Paddy						
....						

Rabi						
Wheat						
Gram						
....						
....						
Summer						

d. Crop-wise cultivation (current status)

	Crop-wise cost of cultivation	**Current**				
Crop	Area (in acres)	Productivity (quintals/acre)	Cost of seed (Rs/ acre)	Material cost (Fertilizers, Pesticides, Machinery hire etc) (Rs/acre)	Labour input (Rs/ acre)	Other costs (Rs/ acre)
Kharif						
Soyabean						
Paddy						
....						

Rabi						
Wheat						
Gram						
....						
....						
Summer						

e. Livestock Holdings

	Livestock Holdings	(in nos.)	
		Before rehabilitation	Current status
1	Cow		
2	Buffalo		
3	Bullocks		
4	Goat		
5	Sheep		
6	Poultry		

f. What determines when you plant your kharif crop (specify for last cropping season)?

1. Timing of rainfall
2. Quantity of rainfall
3. Labour availability
4. Price information
5. Market dates for selling of crop
6. Other (please specify)

g. Has there been any change in rainfall patterns from last years' Kharif cropping season to this year?

1. Yes
2. No
0. Don't know

h. If yes, please specify reason (please tick all that apply)?

1. Early rains
2. Delayed rains
3. Reduced intensity of rainfall
4. Increased quantity of rainfall
5. Increased duration of dry spells
6. Increased number of days of rainfall
7. Other

i. Have these changes caused any losses to your Kharif crops for last cropping season?

1.Yes
2. No
0. Don't know

j. If yes losses have occurred, have the improvements in rehabilitation works made a difference in mitigating your losses?

1. Significant improvement
2. Moderate improvement
3. No difference
4. Moderate loss
5. Significant loss
0. Don't know

VII. Questions on accuracy and comprehension

a. Do you think the respondents answers were answered accurately?

- Yes in all cases
- Yes but not in all cases

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

- Yes
- In some cases
- No serious doubts

APPENDIX F: SURVEY QUESTIONNAIRE FOR NO REHAB FARMERS

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. Farm location in canal system (Tick one)

- Head
- Middle
- Tail

g. Are you the main farmer in the household?

- Yes
- No

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

- Owned plot
- Rented plot
- Farm labourer

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. House Ownership Status (Please tick – this is unprompted – don't read from the list)

In 2005

1. Owned
2. Rented
3. Other
4. No response
0. Don't Know

Current Status

1. Owned
2. Rented
3. Other
4. Don't Know
0. No response

d. What is the type of house?

In 2005

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

Current Status

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

e. Type of Latrine Facility

In 2005

1. Flush/pour flush latrine connected to piped sewer system
2. Flush/pour flush latrine connected to septic tank
3. Flush/pour flush latrine connected to other system
4. Pit latrine With slab/ventilated improved pit
5. Pit latrine Without slab/ open pit
6. Night soil disposed into open drain
7. Service Latrine Night soil removed by human
8. Service Latrine Night soil Service by animal
9. Alternative source due to not having latrine facility within the premises:
   - Public latrine
   - Open

0. Don't know

Current status

1. Flush/pour flush latrine connected to piped sewer system
2. Flush/pour flush latrine connected to septic tank
3. Flush/pour flush latrine connected to other system
4. Pit latrine With slab/ventilated improved pit
5. Pit latrine Without slab/ open pit
6. Night soil disposed into open drain
7. Service Latrine Night soil removed by human
8. Service Latrine Night soil Service by animal
9. Alternative source due to not having latrine facility within the premises:
    - Public latrine
    - Open

0. Don't know

f. Household drinking water source (Please place one tick under each category)

In 2005

1. Main source of drinking water from treated source
2. Main source of drinking water from untreated source
3. Main source of drinking water: covered well
4. Main source of drinking water un-covered well
5. Main source of drinking water handpump
6. Main source of drinking water Tubewell/bore hole
7. Main source of drinking water: spring
8. Main source of drinking water: river/canal
9. Main source of drinking water: pond/lake
10. Other sources (please specify)

0. Don't know

Current status

1. Main source of drinking water from treated source
2. Main source of drinking water from untreated source
3. Main source of drinking water: covered well
4. Main source of drinking water un-covered well
5. Main source of drinking water handpump
6. Main source of drinking water Tubewell/bore hole
7. Main source of drinking water: spring
8. Main source of drinking water: river/canal
9. Main source of drinking water: pond/lake
10. Other sources (please specify)

0. Don't know

g. Type of fuel used for cooking (Please place one tick under each category)

In 2005

1. Firewood
2. Crop residue
3. Cowdung cake
4. Coal/lignite/charcoal
5. Kerosene
6. LPG/PNG
7. Electricity
8. Bio-gas
9. Any other (please specify)
10. No cooking
0. Don't know

Current status

1. Firewood
2. Crop residue
3. Cowdung cake
4. Coal/lignite/charcoal
5. Kerosene
6. LPG/PNG
7. Electricity
8. Bio-gas
9. Any other (please specify)
10. No cooking
0. Don't know

h. Belongings Possessed (This question needs to be answered twice (once for the scenario of the farmer in 2005 and also again for the present situation). Please tick ALL that apply (for each column – could you tell me now the possessions the household owns and not the household; DHS surveys have; welfare index can be created).

In 2005

1. Radio/Transistor
2. Television
3. Computer/laptop
4. Access to Internet (yes/No)
5. Landline Telephone
6. Mobile Telephone
7. Bicycle
8. Scooter/ motor cycle/moped
9. Car/jeep/van
10. Thresher
11. Harvester
12. Tractor
13. Any other (please specify)
0. Don't know

Current status

1. Radio/Transistor
4. Television
5. Computer/laptop
6. Access to Internet (Yes/No)
7. Landline Telephone
8. Mobile Telephone
9. Bicycle
10. Scooter/ motor cycle/moped
11. Car/jeep/van
12. Thresher
13. Harvester
14. Tractor
15. Any other (please specify)
0. Don't know

i. Major sources of income – (Did you regularly generate income from any of these sources? (break-up between farm and non-farm; rank from 1-3 highest to lowest – of the identified which are the top 3; first tick and then rank) This question is asking from where the farmer made most of his income both at present and also in 2005. Please tick ALL that apply (for each column)

In 2005

1. Agriculture
2. Horticulture
3. Fisheries
4. Dairy
5. Poultry/meat
6. Business
7. Services
8. Hiring of agricultural implements
9. Loans
10. Hired Labor
11. Others

Current status of the scheme

1. Agriculture
2. Horticulture
3. Fisheries
4. Dairy
5. Poultry/meat
6. Business
7. Services
8. Hiring of agricultural implements
9. Loans
10. Hired Labor
11. Others

IV. Land Holding Details

a. Total land owned (acres)
In 2005
Current status

b. Land taken on lease (acres)
In 2005
Current status

c. Land leased out (acres)
In 2005
Current status

V. Irrigation Details

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

In 2005

1. Hand pump
2. Dug well
3. Bore well
4. River
5. Pond
6. Canal

0. Don't Know

Current Status

1. Hand pump
2. Dug well
3. Bore well
4. River
5. Pond
6. Canal

0. Don't Know

b. What was the status of irrigation in 2005 and at present in the canal in each specific season?

Parameters (In 2005)	**Kharif (Yes/No)**	**Rabi (Yes/No)**
Desired number of irrigations		
At desired time of irrigations		
Quantity of irrigation as desired in each watering		
Don't know		
No response		

Parameters (current status of scheme)	**Kharif (for last Kharif cropping season) (Yes/No)**	**Rabi (for last Rabi cropping season) (Yes/No)**
Desired number of irrigations		
At desired time of irrigations		
Quantity of irrigation as desired in each watering		
Don't know		
No response		

c. What is the status of the canal condition at present? (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……				

d. Prior to irrigation season, are you informed about the date of the opening of the canal?

1. Yes
2. No

0. Don't Know

e. If yes, what is the source of the information?

1. WRD
2. WUA
3. Other (specify)

0. Don't know

f. Condition of sluice gate delivering water to WUA at present?

1. Good and functioning
2. Needs minor repairs
3. Needs major repairs
4. No gate at all

0. Don't know

g. Irrigation water distribution during last Rabi cropping season (Please provide one tick for each in 2005 and current status)

Type of Distribution	In 2005	Current Status
From head to tail		
From tail to head		
No defined sequence of distribution		
As demanded by farmer on individual basis		
Through warabandi		
Any other (specify)		
Don't know		

h. Please specify the main method of irrigation for last main Rabi cropping season:

In 2005 (please tick one)
1. Flooding
2. Drip
3. Ridge & Furrow
4. Border strip
5. Check basin

Current status (please tick one)
1. Flooding
2. Drip
3. Ridge & Furrow
4. Border strip
5. Check basin

i. Irrigation Table

	Irrigation			
Crop	In 2005		Current status of last cropping season	
	No. of waterings		**No. of waterings**	
	canal	**groundwater**	**canal**	**groundwater**
Kharif				
Soybean				
Paddy				
....				

Rabi				
Wheat				
Gram				
....				
....				
Summer				
....				
....				

VI. Agriculture Details

a. Adoption of modern agriculture technology by farmers in general for all crops for both Rabi and Kharif seasons

In 2005

1. Fertilizer use (Kg/acre/don't know)
2. HYV/Hybrid (Yes/no/don't know)
3. Pesticide use (litre/acre/don't know)
4. Organic manure use (Kg/acre/ don't know)
5. Micro-irrigation technology (yes/no/don't know)
6. Tractor (yes/no/don't know)
7. Thresher (yes/no/don't know)
8. Automatic seed drill (yes/no/don't know)
9. Harvester (yes/no/don't know)
10. Other machinery (please specify)
11. None of the above

Current status

1. Fertilizer use (Kg/acre/don't know)
2. HYV/Hybrid (Yes/no/don't know)
3. Pesticide use (litre/acre/don't know)
4. Organic manure use (Kg/acre/ don't know)
5. Micro-irrigation technology (yes/no/don't know)
6. Tractor (yes/no/don't know)
7. Thresher (yes/no/don't know)
8. Automatic seed drill (yes/no/don't know)
9. Harvester (yes/no/don't know)
10. Other machinery (please specify)
11. None of the above

b. Horticulture crops

	Horticulture crops		Current		In 2005	
	Crop	**Source of irrigation (Canal/ Groundwater /Conjunctive use)**	**Area at present (acres)**	**Productivity at present (Q/acres)**	**Area prior in 2005 (acres)**	**Productivity in 2005 (Q/acres)**
1	Vegetables					
2	Fruits					
3	Spices					
4	Medicinal and Aromatic plants					
5	Floriculture					

c. Crop-wise cultivation (In 2005)

	Crop-wise cost of cultivation	**In 2005**				
Crop	Area (in acres)	Productivity (quintals/acre)	Cost of seed (Rs/ acre)	Material cost (Fertilizers, Pesticides, Machinery hire etc) (Rs/ acre)	Labour input (Rs/ acre)	Other costs (Rs/ acre)
Kharif						
Soyabean						
Paddy						
....						

Rabi						
Wheat						
Gram						
....						
....						
Summer						

d. Crop-wise cultivation (current status)

	Crop-wise cost of cultivation	**Current**				
Crop	Area (in acres)	Productivity (quintals/acre)	Cost of seed (Rs/ acre)	Material cost (Fertilizers, Pesticides, Machinery hire etc) (Rs/acre)	Labour input (Rs/ acre)	Other costs (Rs/ acre)
Kharif						
Soyabean						
Paddy						
....						

Rabi						
Wheat						
Gram						
....						
....						
Summer						

e. Livestock Holdings

	Livestock Holdings	(in nos.)	
		In 2005	Current status
1	Cow		
2	Buffalo		
3	Bullocks		
4	Goat		
5	Sheep		
6	Poultry		

f. What determines when you plant your kharif crop (specify for last cropping season)?

1. Timing of rainfall
2. Quantity of rainfall
3. Labour availability
4. Price information
5. Market dates for selling of crop
6. Other (please specify)

g. Has there been any change in rainfall patterns from last years' Kharif cropping season to this year?

1. Yes
2. No
0. Don't know

h. If yes, please specify reason (please tick all that apply)?

1. Early rains
2. Delayed rains
3. Reduced intensity of rainfall
4. Increased quantity of rainfall
5. Increased duration of dry spells
6. Increased number of days of rainfall
7. Other

i. Have these changes caused any losses to your Kharif crops for last cropping season?

1. Yes
2. No
0. Don't know

VII. Questions on accuracy and comprehension

a. Do you think the respondents answers were answered accurately?

- Yes in all cases
- Yes but not in all cases

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

- Yes
- In some cases
- No serious doubts