India Studies in Business and Economics

P.K. Viswanathan
M. Dinesh Kumar
A. Narayanamoorthy *Editors*

Micro Irrigation Systems in India

Emergence, Status and Impacts

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Dedicated to

Prof. B. D. Dhawan, a pioneer in water economics research in India with many seminal and timeless contributions

Foreword

Water crisis is looming large with severe impacts across spatial scale and sectoral context. Consensus and contestation coexist in the debate on the resource crisis and its economic cost. This coexistence is not strange, as its origin can be traced to the two apparently distinct narratives that have emerged over time to characterize the cause of, and the solution for water crisis, particularly in regions so important for global agriculture. The first one captures the telltale symptoms of an increasing water scarcity at the macro level and their devastating effects on productivity and livelihood at the micro level. These effects get magnified by binding physical limits for fresh supplies and constant pressures to move water away from agriculture. The second narrative captures the persisting use inefficiency and low productivity of water and the effects of resultant magnitude of resource and economic loss within and beyond agriculture. This scenario gets complicated further by an increasing loss of available local water supply due to aquifer depletion, pollution, and salinity.

These narratives, though distinct, are neither competitive nor mutually exclusive. They relate respectively to two organically linked layers of a single paradigm. When taken together, these narratives actually capture not only the crux of the water problem but also the clue to its answer. From an analytical and functional perspective, the first has a focus more on the micro effects of macro level and supply side aspects. The second has a focus more on the macro effects of micro level and demand side aspects. From a policy perspective, the first underlines investment, infrastructure, and national and regional institutional structures (laws, policies, and organizations). The second, in contrast, emphasizes agronomy, farm practices, technology, and local institutional setting. While their relative focus and priority differ, the narratives negate neither the diagnosis nor the prescription of the other. When this is understood properly, then, it is easy to recognize how these narratives, as analytical components of a single paradigm, can be the basis for developing a unified strategy for achieving water security at different scales.

Macro level policy options involving infrastructure development and institutional reforms are certainly important. But the economic justification and political pressures for undertaking these long-term options have to be very strong and should come from below, particularly from agriculture itself having a dominant water share. But, agriculture, given its current level of water use efficiency, can never generate the needed level of justification and pressure. With its water use efficiency of less than 40 percent, agriculture, in countries such as India, is actually concealing a huge magnitude of hidden water potential and dormant output potential. If these water and output potentials can be realized through some dramatic rise in use efficiency and productivity, agriculture can certainly enhance farm output even while releasing huge amounts of water for other sectors. In this sense, efficient water use at local level constitutes a key component of a strategy for tackling water scarcity both at the sectoral and national levels. A water-wise efficient and productive agriculture can generate tremendous pressures for performance in other sectors and provide strong justification for more infrastructural investments and institutional initiatives at the national level.

The strategic role of local level efficiency improvements as a means for addressing water problems both at the sectoral and national levels is rather unmistakable. So also is the extent that micro irrigation systems can raise field level water use efficiency. Obviously, micro irrigation systems constitute a key component of any national water strategy. Despite their critical roles, unfortunately, the ability of micro irrigation systems to provide water security both at micro and macro scales is often underestimated partly due to the prevalent narrow view of them as just the introduction of drip and sprinkler irrigation techniques and partly due to the purported physical, agronomic, and technical limits for their expansion. With well-documented empirical analysis and detailed case studies from major Indian states, this volume establishes clearly that micro irrigation systems are much more than just drip and sprinkler technologies by analytically linking as well as empirically evaluating their agronomic, hydrologic, economic, legal, policy, and organizational dimensions. It debunks the misconception about micro irrigation systems by establishing the viability and vast scope for expanding their coverage across crops, irrigation sources, and regions when proper policies and supporting arrangements are in place.

The volume is certainly a very rigorous and credible treatment of micro irrigation systems in India, covering almost all major issues and dimensions. As they are evaluated by eminent scholars with vast experience on the subject with varying disciplinary focus and different methodological approaches, it can both be an insightful source book for policy-makers and a practical handbook for scholars working in this emerging area of research and policy. Considering the limited amount of available empirical literature on micro irrigation systems, this volume will also have an immediate appeal to both the Indian and international audience.

It is really very thoughtful of the editors to dedicate this volume to Prof. B. D. Dhawan, a respected economist and a father figure among water researchers in India, who continues to inspire us to this day with his trail blazing research and influential publications. It is indeed a fitting tribute to him. I congratulate the authors and editors of this volume for their scholarship and contribution. Since I believe this volume as a timely and scholarly contribution to the literature, I am positive of its overwhelming reception among students, researchers, and practitioners interested in the subject both within and outside India.

Chennai R. Maria Saleth

Preface

In India, the enthusiasm to adopt the micro irrigation systems (MIS) has been quite overwhelming in a few states, viz., Andhra Pradesh, Maharashtra, Rajasthan, Karnataka, Gujarat and Tamil Nadu. Nevertheless, despite the financial incentives in the form of capital subsidies, the overall adoption in terms of area is quite low in relation to the potential area identified for MIS in the country. These two facts underscore the role of several physical and socio-economic factors that act as determinants of and constraints to adoption of MIS, as the hydrological, hydro-geological, agro-ecological and socio-economic conditions vary across states in India. This called for more in-depth analysis to assess the real potential and examine how the benefits and impacts of micro irrigation system adoption vary across situations. There is also the intellectual curiosity among scholars and policy makers to know the reasons for large-scale adoption of MIS in some states and no adoption in some others, including agriculturally prosperous ones.

The current volume assumes relevance in this backdrop and it takes a critical look at the trajectory and dynamics of adoption of MIS in India based on detailed empirical assessments involving proven methodologies and rigorous analytical procedures. While providing a snapshot of the trends in adoption of the MIS across the major states, such as Andhra Pradesh, Maharashtra, Karnataka, Gujarat, Rajasthan and Tamil Nadu, the chapters in the volume present a rather dispassionate analysis of the socio-economic dimensions of adoption of this technology and its impacts. They mark a significant departure from the 'run-of-the mill' empirical works on micro irrigation, which mechanistically 'quantify' the water-saving, yield improvement, energy saving and income benefits, without putting much scientific rigour in the methodologies to make them context specific. Many advanced concepts in the field of water use hydrology and environmental economics were used in this volume to develop a nuanced understanding of the impacts of MI on irrigation water use in crop production and real costs and benefits of MI adoption, respectively.

A case study of the technical and economic rationale of solar powered drip irrigation systems as an alternative renewable energy source for well irrigation in the current context, as an important addition to the thin, yet emerging literature on the subject, makes the volume much more engaging. The interesting case studies of MIS adoption across the major states also come out with the imperatives of aligning the institutional and policy regimes in the water and energy sub-sectors, in order to achieve larger scale MI adoption and bigger welfare gains.

Consolidating this volume in the present form was possible due to the help and support we received from various quarters and we take this opportunity to express our deep sense of gratitude to each and every individual and organization which were supportive to our endeavor of bringing out this volume. Yet, we will be failing in our duty, if we do not specifically mention some individuals and institutions for the encouragement and support rendered. We thank the Indian Council of Social Science Research, New Delhi for providing a seed grant to GIDR to develop a research proposal, which enabled us to join hands with the Institute for Resource Analysis and Policy (IRAP) to consolidate the work on the status of adoption and impacts of MIS in a few Indian states. We thank all the faculty and staff members at GIDR and IRAP for their constant encouragement and support during the course of consolidating this work. We thank Prof. R. Maria Saleth, a renowned expert on institutional economics of water and former director of Madras Institute of Development Studies, for his encouragement and for agreeing to write a 'Foreword' for the volume. We also thank the contributors for staying with us during the entire process of the publication, without which, this would not have been possible.

We place on record a very special word of appreciation to the Editorial Team, Springer (India) Pvt Ltd., especially, Ms. Sagarika Ghosh, Ms. Nupoor Singh, and Mr. Gowtham Chakravarthy for their untiring efforts in transforming the manuscript into the present volume. While utmost care has been taken by the publisher in editing the manuscript for readability, we solely are responsible for the errors or omissions, if any, that remain. We sincerely hope that this volume would help trigger some serious discussion and research on the various impacts of micro irrigation technologies and the relevance of policies and institutions in shaping their future in the agricultural sector in India and elsewhere.

Lastly, we are proud that we could dedicate this volume to the internationally renowned irrigation economist, Prof. B.D. Dhawan, whose work had immensely influenced many of the contributors to this present volume.

P.K. Viswanathan
M. Dinesh Kumar
A. Narayanamoorthy

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M. Dinesh Kumar is a Ph.D. in water management and has 25 years of professional experience undertaking research, action research, field implementation, and consulting and training in the field of water resources. He is currently the executive director of Institute for Resource Analysis and Policy (IRAP) in Hyderabad, India. He has nearly 150 publications to his credit, including five books, three edited volumes, and several papers in international journals. His internationally acclaimed works are on virtual water trade, energy–groundwater nexus, agricultural water productivity, economics of water harvesting and artificial groundwater recharge, and water management in river basins and integrated urban water management. He is an associate editor of *Water Policy* and member of the Editorial Board of *International Journal of Water Resources Development*.

A. Narayanamoorthy is presently working as professor and head of Department of Economics and Rural Development, Alagappa University, Tamil Nadu, India.

Earlier, he worked with the Gokhale Institute of Politics and Economics, Pune, Maharashtra, and also with the Madras Institute of Development Studies, Chennai. He specializes in the area of irrigation including micro irrigation and watershed management. He has published six books, three mimeographs, and over 100 research papers in well-recognized international and national journals. He is a recipient of the prestigious Professor Ramesh Chandra Agrawal Award of Excellence for the outstanding contribution in the field of agricultural economics by the Indian Society of Agricultural Economics, Mumbai. The National Bank for Agriculture and Rural Development (NABARD), Mumbai, has also awarded the coveted NABARD Chair Professor position to him, which is one among the five chairs established at the all India level. He also worked as the member of the policy committees constituted by the Government of India, New Delhi.

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Chapter 1
Introduction

M. Dinesh Kumar and P.K. Viswanathan

1.1 Background

Growing water scarcity and increasing cost of labour, fertilizer and irrigation are driving the demand for micro irrigation systems such as sprinklers and drips, globally. The other reasons for the growing preference for micro irrigation systems, especially drip systems among the farmers are the possibility of securing higher yield, better quality produce and advancing of harvesting. Increasing use of precision farming techniques for growing high value fruits—vines, oranges, strawberry, olive—, vegetables (capsicum, broccolis) and flowers (such as orchids), which require good degree of automation, has also increased the demand for micro irrigation systems, particularly the high end systems such as inline drippers, foggers and garden sprinklers, which can apply water in a very controlled fashion.

Globally, the market for drips and sprinklers is growing at an annual CGR (Compounded Growth Rate) of 19 and 17.4 %, respectively. The United States has the largest area under micro irrigation, accounting for 56.6 % of the total irrigated area of 24.7 million hectares. However, the area under drip systems is only 6.5 % of the total irrigated area. This is followed by China, which has a total of 4.59 million hectares under micro irrigation.[1]

India has the largest irrigated area in the world (Alexandratos and Bruinsma 2012). But, water scarcity problems are growing in many semi-arid and arid parts of India (Kumar 2010). Many of the river basins in western, north western, southern

[1]Minutes of the 14th Meeting of the Working Group on On-Farm Irrigation Systems (WG-ON-FARM) Tehran, Iran, 17 October 2011: 13.30–17.00 h.

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and central India are already identified as water stressed. These basins also coincide with some of the most agriculturally productive regions in the country. Water is a serious limiting factor for these regions to expand agricultural production through irrigation intensification (Kumar et al. 2012).

Though only five per cent of the net irrigated area is under micro irrigation (MI) systems in India, the recent past has seen some surge in the adoption of MI systems in the country, partly because of the policy interventions from the national and state governments. During the XI plan period alone, the area under MI systems in the country went up by 1.95 million hectares (Planning Commission 2014). Over the past one decade, the national and state governments in India have made huge investments for promoting micro irrigation systems through various schemes involving direct capital subsidy to farmers, with the aim of expanding irrigated area without putting additional stress on the limited fresh water resources, enhancing crop productivity, or even reducing the current stress on water resources particularly groundwater, which is depleting in many arid and semi-arid areas.

The assumption driving the public investment was that micro irrigation systems would require significantly less water than conventional irrigation systems to raise the crops by avoiding heavy 'losses' that are inherent in conventional irrigation systems. These 'losses' are in the form of seepage from conveyance systems, deep percolation from irrigated fields and evaporation from the soils not covered by canopy in the field. It is commonly argued that irrigation efficiencies, which is often considered as very low in India in the range of 35–40 %, can be increased substantially through the use of efficient water technologies, in spite of the fact that this classical method of estimating irrigation efficiency[2] has long been challenged to be one which underestimates real efficiencies in traditional irrigation systems (Allen et al. 1998; Howell 2001; Perry 2007). Therefore, it is widely believed that with the use of micro irrigation systems, not only the application losses can be reduced, but the ET demand of the crop can also be reduced, in all situations. Such beliefs tend to ignore the following scientific facts about irrigation.

First: the water which is 'lost' in conveyance and seepage is not always lost from the system, it gets recycled and used again in another part of the system, and therefore is only a recoverable, non-consumptive use, unless the underlying formation is saline or is very deep and unsaturated in which case it is treated as 'non-recoverable' (Seckler 1996; Perry 2007). Though many in the irrigation circles recognize this fact about recycling and reuse of water, high cost of energy involved in pumping the water is used as a strong justification for reducing the deep percolation 'losses'. Here, again, the economic returns from the use of pumped water, as against the water supplied through gravity, are conveniently ignored.

Second: how significant is the amount of water lost through soil evaporation under conventional method of irrigation depends on the crop type and the weather

[2]The classical method of estimating irrigation efficiency considers the total crop water use (ET) against the total water applied, thereby under-estimating actual water use efficiencies in irrigated crop production.

conditions during the plant-growing stage and post-harvest period during when the wet soil is exposed to solar radiation. Especially in the case of field crops, this component is very small fraction of the water consumed in crop production, i.e., the consumptive use (CU) (Kumar et al. 2008).[3] However, there is dearth of systematic scientific studies which help quantify the different components of water use (consumptive and non-consumptive, and beneficial and non-beneficial) in the field to support evidence based policy-making. This is not to deny the fact that there are situations and conditions under which proper use of micro irrigation systems could actually result in reduction in consumptive use of water, without affecting the ET and thereby the crop yield.

The lack of ability to obtain sufficient scientific data on actual water use efficiencies in irrigation at the system level, i.e., at the level of irrigation scheme or the basin, and considerations of expanding area served by public irrigation systems, has led to irrigation engineers and policy makers sticking to the classical irrigation efficiency concept. Thus, the entire focus in improving irrigation management has been on maximizing the consumed fraction (CF),[4] i.e., maximizing the proportion of the total water consumed for crop production against the water applied. The negative externalities of maximizing the consumptive fraction (the ratio of consumptive water use and the total irrigation water applied), in the form of reduction in reusable return flows from irrigated field and canals, wherever they were relevant, are largely ignored.

Nevertheless, the water productivity in crop production is only likely to improve and not decline with the proper use of efficient irrigation technologies, whether we consider the productivity of applied water or the consumptive use, with the extent of improvement determined by the environmental considerations—climate, soil and geohydrology—, the crop and the MI technology used (Kumar and van Dam 2013). This is because, even if there is no reduction in the value of denominator, i.e., consumptive water use, evidence world over shows that the yield (numerator of WP parameter) would considerably increase, if proper irrigation scheduling is done and recommended agronomic practices are followed. Hence, if we assume that the farmers do not extend the area under irrigation after the adoption of MI systems, even under the worst scenario, the total amount of water depleted or consumed will not increase. Whereas under the best scenario, good reductions in aggregate water use, and 'real' water saving can be achieved.

While these are practical issues involved in estimating 'real' efficiencies in micro irrigation systems (Perry 2007) and in ascertaining whether real water saving could be possible through their use, there are a whole range of questions on the economic front, which need to be addressed, before large-scale public investments are made, for promoting MI systems across the country. Some of them are: are these systems economically viable for the farmers, without subsidies across crops? This is particularly

[3]Allen et al. (1998) defines Consumptive Use as the sum of beneficial ET + non-beneficial evaporation + non-recoverable, deep percolation/non-consumptive use.

[4]It is the ratio of consumptive use and the total water applied, as defined by Allen et al. (1998).

important because most important benefits often associated with MI system, i.e., water saving and energy saving, do not result in real cost saving for the farmers in most situations, due to inefficient pricing of irrigation water and electricity. Yet, in many regions, including Tamil Nadu and Karnataka where electricity is supplied almost free to the farm sector, there is large-scale adoption of MI systems. In this context, a host of questions arise. Does the incremental (net) income resulting from yield enhancement and improved quality of produce and reduced cost of inputs—labour, fertilizer and pesticides—, exceed the incremental costs? Or else, is it the incremental income from additional area that may be brought under irrigation using the 'saved water', which justifies the investment for MI adoption? If not, are there enough social benefits accrued from these systems, which can justify the heavy subsidies that cut down farmers' costs of installing these systems? and if so, are these benefits uniform across all the regions, i.e., water rich as well as water-scarce regions? What are the methodologies that can be employed to quantify the social costs and benefits of MI systems?

Further, the economic evaluation of MI system adoption is often not straight forward. Adoption is often associated with several changes in the cropping system, with introduction of new high value crops, or expansion in area under high value crops followed by reduction in area under traditional crops (Kumar et al. 2010; Planning Commission 2014), or increase or decrease in cropping intensity (Planning Commission 2014). Many of these newly-introduced crops yield much higher return per ha of land as compared to their traditional cereal counterparts, while remaining high in risk vis-à-vis production and marketing. Therefore, in such situations, the question, which needs to be addressed, is whether the incremental benefits accrued post adoption of MI technology could be attributed to MI technology or the farmers' risk taking ability. If the former is to be believed, does the MI technology help avert the production risks involved in raising these high value crops?

Since introduction of MI technology is also linked to cropping system changes, is individual crop/plot the right unit for analyzing the costs and benefits of MI systems?

Lastly, what are the real incentives for farmers to adopt MI systems? As water-saving and energy-saving do not appear to be major benefits in many situations, including those where neither the scope for expanding area under irrigation does exist, nor the marginal cost of using water and electricity is positive (Kumar et al. 2008), what really drives their adoption? With the fast changing rural labour markets, is the 'labour-cost' increasingly becoming important factor in the farmers' decision framework for choice of irrigation technologies? Obviously, the incentives for saving labour would change from location to location. On the other hand, with increasing migration of youth and the older people being left in villages to look after the farms, is saving in time spent and domestic labour for farming, including irrigation increasingly becoming an important criterion for farmers to switch over to micro irrigation systems?

A key question for policy makers is: 'what is the real potential of micro irrigation systems in India as a water-saving irrigation technology?' In the past, mind-boggling numbers have been floated by the Task Force on Micro irrigation in India, which was mandated to develop ideas to promote micro irrigation schemes in the country, and a few scholars. For instance, the Task Force estimates the ultimate potential of MI systems to be 97 million hectares. Narayanamoorthy (2004) estimated the net potential for drip system for the whole of country to be around 21 m ha. But, Palanisami et al. (2011) estimated a figure of 26.8 million hectares from a total of 10 states, which were considered to have potential for uptake of MI systems. Interestingly, these projections did not match with the current reality in terms of geographical spread of MI. For instance, in the case of Punjab and Haryana, the total potential area under MI system was 5.77 m. ha out of the total irrigated area of 7.87 million hectares. But, currently, MI adoption is almost negligible in these states. One major reason for this flaw is that the factors considered as driving MI adoption, viz., 'groundwater depletion' and 'water scarcity' (Palanisami et al. 2011; Planning Commission 2014) are actually not the real drivers. If it has been so, the extent of adoption of MI should have been the highest in Punjab, and that in Andhra Pradesh should have been one of the lowest, as the former has the highest number of 'over-exploited' blocks in the country and the latter has one of the lowest.

The geographical spread of MI systems in the country shows significant patterns with respect to the environmental conditions, socio-economic settings and institutional and policy environments that are favourable for MIS. A careful examination of this could have helped to gain insights into the conditions that are favourable for adoption of MI systems, or in other words the factors that induce constraints or become opportunities for MI adoption. Yet, there were very few attempts to realistically assess the potential for adoption of MI systems in different regions of the country, considering the environmental conditions, the socio-economic characteristics and the overall institutional and policy settings of these regions, and the conditions that favour adoption. These are the questions which are being investigated in this current work.

That said, the level of adoption of sprinklers and drips, estimated to be 3.9 million hectares as on 2011, is much less than the lowest estimated potential of 26.08 million hectares (Chap. 2, this volume), in spite of the heavy subsidies provided by both provincial and central governments. So, are there additional constraints, which create hindrance among farmers from accessing these technologies, over and above the more structural constraints outlined above? They need to be investigated, particularly if the non-adoption shows certain pattern vis-à-vis the landholding classes and financial resource endowments, as this would pose larger equity concerns of distribution of benefits of public subsidies.

Given the fact that micro irrigation systems are amenable to energised wells because of the availability of pressurizing units, access to irrigation infrastructure could be one important factor determining adoption by individual irrigators. While all the crops amenable to MI systems and irrigated by wells are generally expected to be covered by MIs, this is a far cry from the reality. Millions of farmers, who irrigate their crops from well water, do not own irrigation infrastructure (well) and are essentially water buyers. As analysis presented in Kumar (2007) shows, a small fraction of the marginal farmers (around 3 %) and small farmers (around 10 %) own wells. A much smaller fraction of them own pump sets. Both the state and centrally sponsored MI schemes, as they are designed and implemented currently, do not encourage non-well owning small and marginal farmers to adopt the system, as it requires additional infrastructure for installation. Hence, even if these farmers grow crops that are suitable for MI adoption, they are unlikely to install these systems.

1.2 Scope of the Current Volume

The large scale promotion of micro irrigation systems (MIS) in India has been the result of the efforts from the National Mission on Micro Irrigation (NMMI) and with this, there has been a convergence of various state-level initiatives and policies aimed at the expansion of MIS. To a greater extent, the increased focus on MI systems also originate from the growing scarcity of water as well as the growing concerns of the need to economise water use in agriculture and reallocate the saved water for competing/alternate uses. The underlying assumption is that MI systems help ‘save’ water in crop production, which in turn can be either diverted for other competing uses, or used to expand area under irrigation, and at the aggregate level, its large-scale adoption would lead to reduction in water demand in agriculture, thereby averting an impending water crisis. Even if real saving of water resources is not possible, policy makers are interested in micro irrigation as they believe more agricultural output could be produced with the available irrigation water through the use of these technologies.

Set in this backdrop, the present volume takes stock of this technological intervention in India’s agricultural and water management sectors, happening over the past couple of decades. Based on empirical research from the major agriculturally dynamic states, viz., Gujarat, Rajasthan, Maharashtra, Tamil Nadu, Andhra Pradesh and Karnataka, the volume tries to provide a nuanced understanding and objective assessment of the implementation and adoption of MISs across these states. It addresses, theoretically and also with the aid of empirical research, several of the questions related to adoption and impacts of MI systems in India. On the adoption side, the key question that the volume tries to address is ‘which segment of the farming community adopts MI systems across states?’ The impacts analysed include those on physical, agronomic and economic aspects. While analyzing the physical impacts, it rejects the old paradigm of ‘notional’ water saving, and looks at real/‘wet’ water saving. At the macro level, the question being asked is about ‘the future potential of MI systems’ in terms of saving water from agriculture and making more water available for environment. It also addresses the question of the positive/negative externalities and real ‘social benefits’ from the use of MI systems, a major justification for provision of heavy capital subsidies for its purchase by the farmers. The volume also brings out certain critical concerns pertaining to MI system adoption, which need to be addressed through more empirical research based on longitudinal panel/cross sectional data.

As noted, the volume uses empirical research from six Indian states to explore practical answers to the key ground level issues, while a synthesis of international literature available on the topic, including those based on empirical research, is used to address some questions theoretically. Different location studies cover different aspects of micro irrigation, and therefore, there is no common methodology being followed.

The volume contains ten chapters, including an introduction and conclusion. The second chapter by Dinesh Kumar discusses the most debated topic, i.e., 'whether MI systems can bring about real water savings in terms of reduction in consumptive use of water in crop production?'. This is purely a hydrological research question. The specific question being posed is: 'under what kinds of physical environment, crops and MI technologies that such water savings become a reality?'. That said, we need to examine whether such savings can lead to aggregate reduction in water use in the farm so as to enable reallocation of the water to other sectors, i.e., 'what is the likelihood that the farmers would expand area under irrigation after achieving reduction in consumptive use per unit of land?'. This is a pertinent question in social science research. Some important issues concerning economic evaluation of MI are discussed, based on a synthesis of research carried out on the topic by various scholars. It then takes up an important question confronting the water resource managers in erstwhile Andhra Pradesh, a region which is facing serious water stress and known for farmer suicides, i.e., 'whether MI systems, for which huge investments are made by the state government, can check groundwater depletion and rampant well failures?'.

It then attempts to address the practical question of: 'what would be the future potential for MI systems in India, against the theoretical notion that almost every crop, barring paddy can be irrigated by either sprinklers or drips, and that growing water scarcity would drive adoption of water saving technologies'?. The answer to this question would decide India's choices for addressing future water problems, especially meeting the growing demands for water from various competing sectors. It confronts the question in the following way–under the given infrastructural, environmental, socio-economic, and institutional and policy settings, what is the potential spread of sprinklers and drips in India? A systematic methodology is followed, which takes into account the water endowments of different basins/regions, the crops that are amenable to different MI systems in each region, cropping patterns, fraction of the cropped area under well irrigation and overall infrastructure conditions in rural areas. While doing this, it assumes that the socio-technological systems of irrigation, and institutional and policy regimes that influence MI adoption, cropping patterns, and pricing policies in water and energy sector, would by and large remain the same.

Maharashtra is one state where adoption of drip system has been relatively high, having some of the oldest drip-irrigated orchards in the country. The technology is used mainly for cultivating crops like sugarcane, grapes, banana and cotton. However, not many studies have analysed its overall status. In this regard, in Chap. 3, Narayanamoorthy addresses questions, such as: (a) 'what is the current status of adoption of drip irrigation in the state in relation to other Indian states?'; (b) Is drip irrigation economically viable for farmers in terms of private benefits against the costs?; (c) will it be economically viable without government subsidy?; and (d) what needs to be done to increase the coverage of drips in the state?. The study compares the productivity of crops and income benefits under drip and traditional method of irrigation, and estimates (applied) water saving and energy saving for sugarcane, grapes, banana and cotton, and also evaluates the economic returns from drip irrigation for two different scenarios; one with government subsidy and the other without government subsidy. The study used discounted cash flow analysis (DCFA) to assess the viability of drip investment.

In Karnataka, in order to expand the area under irrigation, farmers have over-exploited the limited groundwater in the hard rock areas with the help of subsidized electricity, and gone for water intensive crops. The Karnataka state water policy and state agricultural policy recognized the problem of fast depleting groundwater resource and suggested among others, the promotion of drip and sprinkler irrigation systems for improving water use efficiency in crop production and reduce groundwater exploitation. Various subsidy schemes to encourage the farmers to adopt micro-irrigation are also in vogue. But, the level of adoption of drip and sprinkler irrigation system remains low. In this respect, the fourth chapter by Elumalai Kannan reviews the status of micro-irrigation in Karnataka, and analyse the potential for and constraints in their adoption by the farmers.

In Chap. 5, Viswanathan, Jharna Pathak and Chandrasekhar Bahinipati provides an overview of the state of development and adoption of Micro Irrigation Systems in Gujarat. Following an analysis of the secondary data on irrigation development and cropping pattern changes, the chapter makes a review of the important studies undertaken on various aspects of adoption and impacts of MIS in the context of Gujarat. While Gujarat state has been a major promoter of micro-irrigation systems since 2009, the state government had implemented a new scheme called the 'pressured irrigation network system (PINS) & micro irrigation system (MIS)' under the aegis of the Gujarat Water Resources Development Corporation (GWRDC). The main objective of the programme is to provide multiple benefits to the well irrigator farmers in terms of: (a) water saving; (b) increase in production; and (c) savings in power consumption along with improvements in their socio-economic status. The programme was conceived as a novel one of installing pressurised MIS on the selected public tube wells located in the water scarce districts of North Gujarat, viz., Banaskantha, Mehsana, Patan, Sabarkantha and Gandhinagar. The chapter presents the results of a rapid assessment of the impacts of the MIS in the Banaskantha district covering a sample of 375 farmers who have adopted the PINS & MIS implemented by the GWRDC. The rapid assessment survey was conducted during December 2013–January 2014.

The broad question raised in the study by Kumar and others (Chap. 6) is whether subsidies are desirable for promoting micro irrigation systems in canal commands. The study was undertaken in Indira Gandhi Nehar Project (IGNP) command area where farmers adopted sprinklers with the help of an intermediate storage system locally known as *diggie*. The objectives of the study were to: (1) analyse the farming systems changes associated with MI adoption; and, (2) evaluate the economic and social costs and benefits of sprinkler and drip adoption in the region.

In Chap. 7, Suresh Kumar examines the social benefits and costs of drip irrigation in the context of Coimbatore district in Tamil Nadu. The study identified two different costs namely private costs and external costs. The private costs include capital cost (investment cost on drip irrigation systems) and maintenance costs. The external costs consist of value of reduction in labour absorption per hectare of traditionally irrigated crop replaced by drip irrigation methods and additional consumption expenditure incurred by the villagers because of increase in price of cereals owing to reduced local production. Similarly, the benefits are classified into private benefits and external benefits. The private benefits include value of labour saved and increase in value of outputs. The external benefits include value of increased water availability for irrigation purposes, reduced power consumption in agriculture, reduction in well deepening costs and reduction in cost of well failure.

Though the benefits of adopting micro-irrigation is widely studied, there is a gap in understanding the causal relationship between seasonality and cropping patterns and various benefits of MIS, especially in the western India context. Hence, Chap. 8 by Bahinipati and Viswanathan tries to address this by exploring two key questions: (i) the influence of subsidy in enhancing adoption rate, particularly in the recent years, and (ii) the effects of seasonality and cropping patterns on accessing the benefits of MIS. For empirical assessment, Banaskantha district was selected as the study area, which is a water scarce region located in the northern Gujarat. The study covered 143 public tube wells and 355 farmers. The results suggest that: (i) subsidy significantly increased adoption of MIS in recent years, and (ii) the benefits of MIS were largely confined to specific cropping patterns adopted by the farmers, and the seasons in which they could be chosen. From a policy perspective, this analysis could help in terms of identifying and promoting specific crops/cropping patterns that show better outcome impacts of investments in micro-irrigation.

While groundwater and energy use in irrigated agriculture has gone up exponentially during the past 2–3 decades, pervasive energy subsidies combined with lack of regulation of groundwater withdrawal is resulting in both groundwater over-exploitation and inefficient and wasteful use of energy. Of late, options such as the use of solar irrigation pumps in conjunction with drip systems are being suggested to address the groundwater energy nexus conundrum. The idea being proposed by some researchers is that farmers could produce electricity using solar PV systems, use it for pumping groundwater and sell the excess electricity to the grid, using ‘net metering’, thereby creating incentive for efficient use of energy and groundwater, while reducing the power subsidy burden on the utilities (see for instance, Shah et al. (2014)). In this regard, Chap. 9 by Nitin Bassi based on empirical analysis, explores whether solar pumps are economically viable under the existing energy and water pricing policies. It also examines the degree of incentive farmers would have to make best use of drip systems for improving water use efficiency, while using solar energy to run their pumps.

Chapter 10 concludes with a discussion on major issues for future research in the area of agricultural water management, with focus on the potential of plant genetics, plant architecture, harvest index, evaporation control and enhancing transpiration coefficient (ration of Transpiration and Evapotranspiration). It discusses the technical challenges in estimating actual consumptive water use in crop production in a way that helps assess real water saving through micro irrigation technologies. The chapter also highlights the need for evolving appropriate institutional and policy regimes in the water, energy and agriculture sectors for not only up scaling MI system adoption but also maximizing the welfare benefits from their use.

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Chapter 2
Water Saving and Yield Enhancing Micro Irrigation Technologies in India: Theory and Practice

M. Dinesh Kumar

2.1 Introduction

Demand management is the key to the overall strategy for managing scarce water resources (Molden et al. 2001). Since agriculture is the major user of diverted water in India (GOI 1999), demand management in agriculture in the water-scarce and water-stressed regions would be central to reducing the aggregate demand for water to match with the available future supplies, thereby reducing the extent of water stress that the country is likely to face (Kumar 2010). Improving water productivity in agriculture is important in the overall framework for managing agricultural water demand, thereby increasing the ability of agencies and other interested parties to transfer the water thus "saved" to economically more efficient or other high priority domestic and industrial use sectors (Barker et al. 2003; Kijne et al. 2003).

There are three dimensions of water productivity namely, physical productivity, expressed in kg per unit of water consumed; combined physical and economic productivity expressed in terms of net return per unit of water consumed, and economic productivity expressed in terms of net income returns from a given amount of water consumed against the opportunity cost of using the same amount of water (Kijne et al. 2003). The discussion in the present paper is largely on the first parameter, i.e., physical productivity. There are two major ways of improving the physical productivity of water used in irrigated agriculture. *First*: the water consumption or depletion for producing a certain quantum of biomass for the same amount of land is reduced. *Second*: the yield generated for a particular crop is enhanced without changing the amount of water consumed or depleted per unit of land. Often these two improvements can occur together with an intervention either on the agronomic or on the water control side (for discussion on other aspects of water productivity, see Kumar and van Dam 2013).

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There are several conceptual issues in defining the term "water saving" and irrigation efficiency. This is because with changing contexts and interests, the "unit of analysis" changes from field to farm to irrigation systems to river basins. With the concepts of "dry" and "wet" "water saving", which capture the phenomena such as "return flows from field" and "depleted water", becoming dominant in irrigation science literature during the last one decade, the old concepts of "water saving" and irrigation efficiencies have become obsolete. The real water saving or the "wet water" saving in irrigated production at the field level can come only from reduction in depleted water and not the water applied (Kumar and van Dam 2013; Molden et al. 2001). But, there are methodological and logical issues involved in estimating the depletion fraction of the water effectively applied to the crop. These are due to the complex considerations, including agronomic, hydrologic, geo-hydrological and geo-chemical, in determining the "depletion" fraction. Nevertheless, for the limited purpose of analysis, throughout this paper "water saving" refers to "wet" water saving (Kumar et al. 2008).

Water productivity is an important driver in projecting future water demands (Amarasinghe et al. 2004; Kijne et al. 2003). Efficient irrigation technologies help establish greater control over water delivery (water control) to the crop roots, reduce the non-beneficial evaporation from field and non-recoverable percolation,[1] and return flows into "sinks" and often increases the beneficial ET, though the first component could be very low for field crops. Water productivity improves with reduction in depleted fraction and yield enhancement. Since at the theoretical level, water productivity improvements in irrigated agriculture can result in saving of water used for crop production, any technological interventions which improve the crop yields are also, in effect, water saving technologies. Hence, water saving technologies in agriculture can be broadly classified into three: water saving crop technologies; water saving and yield enhancing irrigation technologies; and, yield improving crop technologies.

There are several technologies practices for water-saving in irrigation. They include: (1) broad beds or small border irrigation; (2) improved furrow irrigation (surge, cutback, proper management) (3) laser leveling of fields; (4) plastic mulches and tunnels; (5) improved soil moisture retention sub-surface barriers; (6) alternative wetting and drying for rice; (7) system of rice intensification; (8) direct seeding of rice; (9) aerobic rice; (10) on-farm storage; and, (11) allowing better control and timing of surface irrigation (micro-irrigation, sprinklers and their variants) (Kumar et al. 2008). But, only micro irrigation technologies are dealt with in this chapter.

A little less than 5 % of the irrigated area in the country is under micro irrigation systems. There are several constraints to adoption of MI devices. These are physical, socio-economic, financial, institutional–pricing, subsidies, extension service–and policy-related in nature (Narayanamoorthy 1997; Kumar et al. 2008). The only systematic attempt to find out the conditions under which MI systems become a

[1]See Kumar and van Dam (2013) for definitions of non-beneficial evaporation, non-recoverable deep percolation.

best bet technology, and assess the magnitude of reduction in water requirement possible through them was by Kumar et al. (2008). Such efforts are crucial from the point of view of assessing the ability to address future water scarcity problems at the regional and national level. This is an extension of their work.

The chapter aims at determining the potential benefits from the use of MI systems. This includes assessment of (a) the conditions that are suitable or unsuitable for MI systems; (b) the field level and aggregate level impacts of the systems on water use; and (c) the economic benefits due to adoption of MI system. The research also aims at assessing the potential future coverage of MI systems in India, followed by a detailed analysis for Andhra Pradesh.

The chapter proceeds as follows. First, it discusses the present spread of MI systems in India. It deals with the potential physical and economic impacts of MI systems in India. This is based on analysis of: (i) physical, socio-economic and institutional constraints for its adoption in the country; (ii) field level water saving, and impacts on drivers of water demand; (iii) and cost-benefit analysis of MI systems for different crops under different socio-economic conditions, and policy environments. In the subsequent section, a macro level analysis is done to assess the cropped areas that can be brought under water saving MI systems in the basins which would benefit from them in terms of water productivity improvements. The last section assesses the area under irrigated crops that are amenable to water-saving MI systems in erstwhile Andhra Pradesh, and the likely impact of the same on water saving in agriculture in the region.

2.2 Contribution of Micro-irrigation Technologies in Indian Agriculture

2.2.1 Present Spread of Micro-irrigation Technologies in Indian Agriculture

Table 2.1 presents the status of adoption of drip and sprinkler irrigation systems under various programmes, viz., macro management plan; technology mission on horticulture; cotton development programme and oil palm development programme. The total area covered by MI systems is 4.94 million hectares of this, nearly 38 % is under drip systems, and the remaining 62 % is under different types of sprinklers. The major crops for which drip systems are currently adopted are: cotton, sugarcane; banana, orange, grapes, pomegranate, lemon, citrus, mangoes, flowers, coconut, and a wide variety of vegetables such as cauliflower, cabbage, chilly, ladies finger and brinjal.

Sprinkler systems in the country are mainly used for field crops such as wheat, sorghum, pearl millet, groundnut and mustard. But the use of sprinklers is often limited to certain part of the crop season when farmers face severe shortage of water in their wells. Normally, this happens before the onset of monsoon when the farmers have to do sowing of these crops, or when there is a long dry spell during

Table 2.1 Area under Micro Irrigation in Indian States (2010) in ha

Name of state	Area under micro irrigation system		Total area
	Drips	Sprinklers	
Andhra Pradesh	505205	256911	762,116
Arunachal Pradesh	613	0	613
Assam	116	129	245
Bihar	301	436	737
Chhattisgarh	6360	95740	102,100
Goa	793	582	1375
Gujarat	226773	180672	407,445
Haryana	11351	533740	545,091
Himachal Pradesh	116	581	697
Jharkhand	208	742	950
Karnataka	209471	385579	595,050
Kerala	15885	3540	19,425
Madhya Pradesh	51712	143233	194,945
Maharashtra	604440	295382	899,822
Odisha	11046	33015	44,061
Punjab	17925	11414	29,339
Rajasthan	30047	866592	896,639
Tamil Nadu	153437	27834	181,271
Uttar Pradesh	12636	13310	25,946
West Bengal	247	150196	150,443
Others (NE States, Uttaranchal)	38600	45312	83912
Total	1897282	3044940	4,942,222

Source Sankaranarayanan et al. (2011)

the monsoon season. Sprinkler for groundnut is common in Saurashtra in Gujarat; for mustard in Khargaon district of Madhya Pradesh and IGNP command areas in Rajasthan. In the high ranges of Kerala and Tamil Nadu, sprinklers are used for irrigating tea and coffee plantations. However, recently, farmers use micro sprinklers and mini micro sprinklers for potato, groundnut and alfalfa.

2.3 Physical Impact of Micro-irrigation Technologies on Water Demand for Crop Production[2]

Analysis of the potential impact of MI systems on the aggregate demand for water in crop production warrants three important considerations. The first concerns the extent of coverage that can be achieved in MI system adoption at the country level.

[2]This section draws heavily from Kumar et al. (2008), but is also updated with latest research.

The second concerns the extent of real water saving possible with MI system adoption at the field level. The third concerns what farmers do with the water saved through MI systems, and the changes in the cropping systems are closely associated with adoption. But, most of the past research on physical impacts of MI systems had dealt with the issue of changes in irrigation water use, crop growth and crop yield.

There is limited analysis available on the potential coverage of MI systems in India, and the extent of water saving possible at the aggregate level. But, these analyses suffer from severe limitations. *First:* the analyses of potential coverage of MI systems are based on simplistic considerations of the area under crops that are amenable to MI systems, and do not take into account the range of physical, socio-economic and institutional factors that induce severe constraints to adoption of these technologies. *Second*: they do not distinguish between saving in applied water and real water. While the real water saving that can be achieved through MI adoption could be much lower than the saving in applied water. *Third*: there is a latent assumption that area under irrigation remains the same, and therefore the saved water would be available for reallocation. But, in reality, it may not be so. With introduction of MI systems, farmers might change the very cropping system itself, including expansion in irrigated area. Therefore, all these assumptions lead to over-estimation of the potential coverage of MI systems and the extent of possible water-saving with MI adoption. These complex questions are addressed in the subsequent sections of this chapter.

(A) **Physical constraints and opportunities for adoption of MI Systems**

Where potential exists, the coverage that can be attained by MI system adoption requires a systematic identification of the conditions that are favourable including geographical assessment of areas. Such conditions can be physical, socio-economic or institutional. They are discussed below.

If we do not consider the difficult options of shifting to less water intensive crops and crops having higher water productivity, there are two major pre-requisites for reducing the overall demand for water in agriculture in the region. They are: (i) reducing the non-beneficial evapotranspiration from crop land; and (ii) maintaining the area under irrigation. The second issue is not being dealt with here. The time-tested and widely available technology for increasing water productivity is pressurized irrigation systems such as sprinklers and drips (or trickle irrigation). However, their adoption is very much limited in India. This includes even areas where the capital investment for creating irrigation source is very high (For example: Kolar district in Karnataka, Coimbatore district in Tamil Nadu and alluvial north and central Gujarat). While, there are several constraints at the field level, which limit the adoption of this technology by the farmers, some of the very critical ones that are physical in nature are analyzed here.

First of all, MI systems need reliable daily water supply. But, nearly 41.24 % of the net irrigated area in the country gets their supplies from surface sources such as canals and tanks (source: GOI 2002). Drips and sprinklers are not conducive to flow irrigation due to two reasons. First, there is no synchronization between water delivery schedules followed in canal irrigation and that to be followed for MI systems. Normally, in surface command areas in India, farmers get their turn once in 10–15 days at flow rates ranging from 0.5 to 1 cusec. But, for drips and sprinklers to give their best, water should be applied to the crop either daily or once in two days with lower flow rates to match with the evapotranspirative demand. This means, intermediate storage systems are essential for farmers to use water from surface schemes for running MIs. Storage systems are also required as settling tanks for cleaning large amounts of silt contents in the canal water supplies. Second, there is a need for pumps to lift water from the storages and running the MI systems. These two investments would reduce the economic viability of MI.

Therefore adoption of MI would be largely restricted to areas irrigated by wells. However, an increasingly large number of farmers in groundwater irrigated areas manage their supplies from water purchase. This also includes areas where groundwater over-draft is not a concern like in Bihar and western Orissa, and where economic access to water is a problem. It is difficult for these farmers to adopt MI devices.

Need for pressuring devices limits the adoption of MI systems. In groundwater over-exploited areas such as north and central Gujarat, Coimbatore district in Tamil Nadu and Kolar district of Karnataka, ownership of wells mostly is not with individual farmers but with groups. Also, a large number of farmers have to depend on water purchases. They get water through underground pipelines at almost negligible water pressure. In order to use the conventional sprinkler and drip systems, high operating pressure (1.0–1.2 kg/cm^2) is required. Unless the systems are directly connected to the tube well, the required amount of “head” to run the sprinkler and drip system cannot be developed. The need for a booster pump and the high cost of energy required for pressurizing the system to run the sprinklers and drips reduce the economic viability. But, there are new MI technologies, which require very low operating head such as sub-surface irrigation systems and the micro-tube drips. The farmers who are either water buyers or share users of wells can store the water in small tanks, lift it to small heights to generate the required head for running the sub-surface drip system or micro tube systems.

Another important constraint is the poor quality of groundwater. Due to the high TDS level of the pumped groundwater (the TDS levels are as high as 2000 ppm (parts per million) in many parts of India where groundwater is still being used for irrigation), the conventional drippers that are exposed to sunlight get choked up due to salt deposit in the dripper perforations. The saline groundwater areas include south western Punjab, north and central Gujarat, parts of Rajasthan, and many parts of Haryana. This needs regular cleaning using mild acids like the hydrochloric acid. This is a major maintenance work, and farmers are not willing to bear the burden of carrying out this regular maintenance. However, in limited cases, rich farmers in South West Punjab use large surface tanks for storing canal water when it is available, and blend it with brackish groundwater, and use for irrigating *kinnow* (citrus) orchards. These farmers can also use this water for drip irrigation to prevent problems of clogging.

In addition to areas irrigated by groundwater, there are hilly areas of the western and eastern Ghat, north-western Himalayas (Himachal Pradesh, J&K and Uttaranchal) and states in north-eastern hill region, where surface streams in steep slopes could be tapped for irrigating horticulture/plantation crops. Such practices are very common in the upper catchment areas of many river basins of Kerala, which are hilly. Farmers tap the water from the streams using hose pipes and connect them to sprinkler systems. The high pressure required to run the sprinkler system is obtained by virtue of the elevation difference, which is in the order of 30–40 m. Such systems are used to irrigate banana, vegetables and other cash crops such as vanilla. With the creation of an intermediate storage, drips could be run for irrigating crops such as coconut, arecanut and other fruit crops during the months of February to June.

Geological setting has a strong influence on MI adoption in well-irrigated areas. In hard rock areas of Maharashtra, Madhya Pradesh, Tamil Nadu, Karnataka and Andhra Pradesh, farmers will have strong incentive to go for MI systems. The reason is dug wells and bore wells in hard rock areas have very poor yield and well owners leave a part of their land fallow due to shortage of water. In most of these areas, farmers will have to discontinue pumping after 2–3 h for the wells to recuperate. When pressurized irrigation systems are used, the rate at which water will be pumped will reduce. This will also give enough opportunity time for wells to recuperate. Since, pump will eventually run for more number of hours, the same quantity of water could be pumped out, and the command area could be expanded. This factor provides a great economic incentive for farmers to adopt water-saving micro irrigation systems.

(B) **Socio-economic and institutional constraints for MI adoption**

Another major constraint in adoption of conventional MI technologies is the predominant cropping pattern in the water-scarce regions. MI systems are best suited for horticultural crops from an economic point of view (Dhawan 2000). This is because the additional investment for drips has to be offset mainly by the better yield and returns farmers get as the saving in input costs are not very significant (Kumar et al. 2004). But, percentage area under horticultural crops is very low in these regions, except Maharashtra. The total area under horticultural crops and vegetables is only 5.04 % of the net irrigated area in the country in 2001–02. It is highest in Maharashtra, both in percentage (19.04 %) and aggregate terms (0.75 M ha).

Though the low cost drip irrigation systems appear to be attractive, they have low physical efficiency when used for crops in which the plant spacing is small (chilly, vegetables, groundnut and potato). In such situations, they also score low on the economic viability front. The low cost systems can be used for some of the row crops such as castor, cotton and fennel, which are very commonly grown. However, to use the system for these crops, it is very important that the farmers maintain a fixed spacing between different rows and different plants. So far as maintaining the spacing between rows is concerned, farmers pay sufficient attention. But, spacing between plants is not observed. Due to this un-even (un-favourable) field conditions, designing and installing drippers becomes extremely difficult. Therefore, for adoption of these water saving technologies, the farmers' agricultural practices need new approaches.

Further, for crops such as paddy neither drips nor sprinkler irrigation systems are feasible. Paddy is an important crop in many arid and semi-arid regions where water levels are going down. Certain studies of ICAR (Patna) have developed Low-Energy Water Application (LEWA) systems which apply regulated water supplies to paddy and have demonstrated potential to save water. But the technology is still in its infancy and requires large scale testing before field scale adoption. Adopting suitable cropping patterns that would improve the adoptability of water saving technologies is one good strategy. But, as mentioned in the beginning of the section, "crop shift" is a harder option for farmers.

The socio-economic viability of crop shifts increases with the size of the operational holding of farmers. Given the fact that small and marginal farmers account for large percentage of the operational holders in India, the future adoption of horticultural crops by farmers in these regions cannot be expected to be high. This is because these crops need at least 3–4 years to start yielding returns, (except for pomegranate, papaya). It will be extremely difficult for the farmers to block their piece of land for investments that do not give any returns in the immediate future, say after a season or so. Market is another constraint. Large-scale shift to fruit crops can lead to sharp decline in the market price of those fruits. Labour absorption is another major issue when traditional crops such as paddy, which are labour-intensive, get replaced by orchards. Orchards require less seasonal labour and the chances for mechanization are higher.

Plot size also influences farmers' choices. Conventional MI systems will be physically and economically less feasible for smaller plots due to the fixed overhead costs of energy, and the various components of these irrigation systems such as filters, overhead tanks (Kumar 2003).

Poor rural infrastructure and power connections to agro wells along with poor quality of power supply, is yet another major constraint for adoption of MI systems. Difficulty in obtaining power connections for farm wells, and poor quality of power supply forces farmers to use diesel pump sets for irrigating their crops. Use of diesel pump increases the cost of abstraction of well water. Regions such as Bihar, eastern UP and Orissa are examples. Here, many cash-starved farmers do not own wells, and depend on water purchased from well owners for irrigation. Drips and sprinklers are energy intensive systems, and requiring extra capital investments for installing higher capacity pump sets as well as recurring expenses for buying diesel. These factors act as deterrents for adopting MI systems.

The current water pricing and energy pricing policies that exist in most states also reduce the economic incentives for MI adoption. Due to these policies, the water-saving and energy-saving benefits from the use of MI systems do not result in private benefits.

Un-scientific water delivery schedules followed in surface irrigation systems, and power supply restrictions for farm sector also cause constraints for MI adoption. It is common in surface irrigation systems that while plenty of water is released for the crops for some parts of the season, in the last stages of the crop season the crops are subject to moisture stress. Poor reliability of water delivery services or lack of adherence to a standard delivery schedules and poor control over volumetric supplies force farmers to adopt crops that are less sensitive to water stress such as paddy and sugarcane and resort to flood irrigation. Regulated power supply in agriculture is also reducing the economic incentive for adoption of MI systems that are energy-intensive. Many states including Punjab, Madhya Pradesh, Tamil Nadu, Gujarat and Karnataka had consistently reduced the duration of power supply to farm sector, due to growing power crisis. In future, this would emerge as a major impediment for large-scale MI adoption.

Poor extension services provided by concerned agencies pose another important bottle-neck. It is not common for the extension wings of Agricultural Universities to set up demonstration of new technologies in farmers' fields. This is applicable to companies which manufacture and sell MI devices. Because of this, there is very little knowledge about MI technologies among the farmers in water-scarce regions. Many farmers believe that MI systems have severe limitations vis-à-vis crops for which they could be used. Another misconception is that coverage of sprinklers being circular leaves a lot of dry spots in the irrigated fields. This belief has mainly come from the experience of farmers who have used the system, with improper designs.

The administration of subsidies in MI devices also operates against the promotion of MI systems. Since in many states, the governments continue to pay the subsidy directly to the manufacturers, many farmers purchase MI systems just to avail of the subsidy benefits, sans maintenance. The suppliers do not offer any after-sales services to the farmers and hence are not interested in ensuring quality control. The systems being supplied are often of sub-standard quality. Over and above, as the amounts of funds available for subsidies are limited, the smartest of farmers take the benefit. On the other hand, the government officials, who inspect the systems installed, only check the amount of materials supplied, to work out the subsidy that has to be paid to the irrigation company. Since the manufacturers had the hassle of doing the entire documentation for obtaining the subsidy, they keep the price (without subsidy) high enough to recover their interests on capital and transaction costs.

The present institutional framework governing the use of groundwater, which puts no limit on the amount of water farmers can pump from aquifer, does not provide clear economic incentives to use water efficiently. This is particularly so for well owners, who have good sources of water supply. Examples are the Indo-Gangetic alluvium and alluvial areas of Gujarat. Though it is the opportunity cost of using water, which influences farmers' decision, such opportunity costs are not felt clearly. This is in spite of the prevalence of water markets in these regions. The reason is that the demand for water from the water buyers and for one's own irrigation use is much less than the number of hours for which the farmers could run their pumps. In such cases, the direct additional financial returns farmer gets by introducing MI systems are from the increased crop yield. This will not happen unless the farmer adopts new agronomic practices (Kumar and Singh 2001).

Due to this reason, the well owners would rather pump for extra hours to sell water to the needy farmers than trying to use water more efficiently by making substantial capital investments. The reason being that the economic efficiency of water use for the irrigated crops grown in the area even with the current inefficient practices is much higher than the price at which water is traded (Kumar and Singh 2001).

Presence of negative externalities in groundwater pumping restrains those who like to adopt MI systems. Well interference is very common in hard rock areas. Under such conditions, pumping by one farmer will have effect on the prospects of pumping by another farmer. Due to this reason, the efforts to cut down pumping rates by a farmer may not result in increased future availability of groundwater for him/her. The efforts to save water from the system by an individual farmer might mean increased availability of groundwater for pumping by his/her neighbouring farmers. Hence, under such situations, the farmers do not have any incentive to invest in MI systems. The technical externality becomes negative externality for well irrigators in the absence of well-defined water rights in groundwater.

(C) Real Water Saving and Water Productivity Impacts of MI Systems in the Field

The real water saving impact of MI systems at the field level depends on the improvements in water use efficiency. All the available data on the efficiency impact of micro irrigation systems are on application efficiency. The classical definition of irrigation efficiency is the ratio of amount of water consumed by the crop to the amount of water applied. This method does not take into account two factors: (1) in certain situations, water will have to be applied in excess of the ET requirements if the irrigated soils have salts for the purpose of leaching; and (2) the actual field performance in the irrigation systems is not as good as that shown in experiments and demonstrations.

But in estimating water-saving, what matters is the amount of depleted water, rather than the amount of water applied. The depleted water includes moisture evaporation from the exposed soil and non-recoverable deep percolation. It would be less than the applied water so long as the un-consumed water is not lost in natural sinks like saline aquifer or swamps (Allen et al. 1998). This means, the application of the concept of irrigation efficiencies are no longer useful in analyzing the performance of irrigation systems, with greater understanding of agro-hydrology and appreciation of deep percolation from irrigated fields as a component of the available water resources (Keller et al. 1996; Perry 2007), except in situations where the groundwater is saline or deep or the unconsumed water goes into swamps.

Water use efficiency improvements through MI adoption, and therefore the field level water-saving impacts, depend on three major factors: (1) the geo-hydrological environment, (2) the type of crops; (3) climate; and (4) type of MI technology.

In regions where water table is deep and showing declining trends, MI adoption can lead to real water saving at field level. The reason is deep percolation that occurs under traditional method of irrigation, does not reach the groundwater table. This can be explained in the following way. The reason is that the depth of groundwater table is in the range of 20–135 m. The 20–135 m thick vadose zone holds the vertically moving water as hygroscopic water and capillary water. Some of the water from the soil profile within or below the root zone, having higher levels of moisture, also can move up due to differential hydraulic gradients (Ahmad et al. 2004). All this water would eventually get evaporated from the crop land after the harvest if the fallow period is significant depending, on the climate. The depth of soil below the surface from which evaporation could take place can be up to 2–3 m in semi-arid and arid regions (Todd 2003). Some water in the deep vadoze zone would get sucked away by the deep-rooted trees around the farms during the non-rainy season.

Since, under MI system, water is applied daily in small quantities to meet the daily crop water requirements, deep percolation is prevented. Such regions include alluvial tracts of north and central Gujarat, central Punjab, hard rock areas of northern Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, Madhya Pradesh and many parts of Rajasthan. Though deep percolation could be quite significant in paddy irrigation, so far no water-saving irrigation devices are being tried in paddy (Kumar et al. 2008). Though many water saving practices have evolved over time in paddy irrigation, their water saving potential is also questionable (Perry 2007).

Nevertheless, in areas where groundwater levels are still within 20 m below ground level, the saving in applied water achieved through MI devices would mostly result in saving in pumping cost, but no real saving in water from the system. The reason is that a good share of the excess water used in irrigation under the traditional irrigation practices finally goes back to the groundwater system through return flows. It is important to note that the areas having high water table conditions coincide with areas with low level of aridity or mostly sub-humid or humid climate where evaporation losses from soil would be low even in summer months.

The real water saving that can be achieved through MI system would be high under semi- arid and arid climatic conditions. This is because the non-beneficial depletion of moisture from the exposed soil could be high under such situation due to high temperature, wind speed and low humidity. Such losses would be significant during initial stages of crop growth when canopy cover is small (Kumar et al. 2008; Kumar and van Dam 2013).

The real water saving would be more for row crops, including orchards, cotton, fennel, castor, and many vegetables, where the spacing between plants is large. The reason is the area exposed to solar radiation and wind between plants would be large, and as a result the non-beneficial evaporation would be a major component of the total water depleted, under traditional method of irrigation (Kumar et al. 2008).

The water saving impacts will be generally higher for drips than sprinklers. With drip irrigation, water could be directly applied to plants, preventing non-beneficial evaporation. This will not be possible with sprinklers, as they would wet the entire field instead of the plant roots. Hence, the reduction in non-beneficial evaporation from soils and non-recoverable deep percolation, and hence actual water saving through micro irrigation depend on the type of crops and the natural environment (Kumar and van Dam 2013).

(D) Potential aggregate impact of MI systems on water use for crop production

The extent of water saving at system and basin level because of the widespread adoption of MI systems is widely debated. The debate centers around (1) the real water savings at the field level; and, (2) 'what farmers do with the saved water'. We have addressed the first question in the earlier section. As regards the second question, many believe that the aggregate impact of drips on water use would be similar to what it makes on water use in unit area of land. While several others believe that with reduction in water applied per unit area of land, the farmers would divert the saved water for expanding the area under irrigation, subject to favourable conditions with respect to water and equipment availability, and power supplies for pumping water (Kumar 2002), and therefore the net effect of adoption of micro irrigation systems such as drips and sprinklers on water use could be nil or insignificant at the system level. At the same time, there are some others who believe that with adoption of WSTs, there is a greater threat of depletion of water resources, as in the long run, the return flows from irrigated fields would decline, while area under irrigation would increase under WSTs.

These arguments have, however, missed certain critical variables which influence farmers' decision making with regard to area to be brought under irrigated cultivation, and the aggregate water used for irrigation. They are: groundwater availability vis-à-vis power supply availability; crops chosen; and amount of land and finances available for intensifying cultivation. The most important of these factors is the overall availability of groundwater in an area; and the power supply vis-à-vis water availability in the wells.

If power supply restrictions limit pumping of groundwater by farmers, then it is very unlikely that as a result of adoption of conventional WSTs, farmers would expand the area under irrigation. Let us examine how this happens. In the states of Punjab, Gujarat, Karnataka and Madhya Pradesh, power supply to agriculture sector is only for limited hours (GOI 2002). It acts as a constraint in expanding the irrigated area, or increasing irrigation intensity, in those areas where groundwater availability and demand is more than what the restricted power supply can pump.

Since the available power supply is fully utilized during winter and summer seasons, farmers will be able to irrigate only the existing command with MI system. This is because the well discharge would drop when the sprinkler and drip systems connected to the well outlet start running, owing to increase in pressure developed in the system. In other words, the energy required to pump out and deliver a unit volume of groundwater increases with the introduction of MI system. The only way to overcome this is to install a booster pump for running the MI system. As electricity charges are based on connected load, farmers have least incentive to do this. Such outcomes are expected in the alluvial areas of north Gujarat and Punjab. In this area, even in situations of availability of extra land, it won't be possible for farmers to expand the area under irrigated crops due to restrictions of power supply.

The other factor is the lack of availability of extra arable land for cultivation. This is applicable to areas where land use and irrigation intensity is already high.

Example is central Punjab. But, farmer might still adopt water-saving technologies for cash crops to raise yields or for newly introduced high-valued crops to increase their profitability. So, in such situations, adoption results in reduced aggregate water demand.

On the other hand, if the availability of water in wells is less than what the available power supply can extract, the farmers are tempted to expand irrigated area. This is the situation in most of the hard rock areas of peninsular India, central India and Saurashtra. Due to limited groundwater potential and over-exploitation, well water is very scarce in these areas. In such a scenario, the saved water could be used to expand the irrigated area and improve the economics of irrigated farming. In Michael region of central India, for instance, farmers use low cost drips to give pre sowing irrigations to cotton, before monsoon, when there is extreme scarcity of groundwater. This helps them grow cotton in larger area as water availability improves after the monsoon (Verma et al. 2004), and hence there is no water saving at the aquifer level.

The third factor is the crops chosen. Often MI technologies follow a set cropping pattern. All the areas/pockets in the country where adoption of drip irrigation systems has undergone a "scale", orchard crops are the most preferred crops (Dhawan 2000; Narayanamoorthy 2004). Therefore, while farmers adopt MI systems, the crops also change, normally from field crops to fruits.

Farmers bring about significant changes in the cropping systems of farmers with the adoption of drips. When drips are adopted for orchards, farmers are found to permanently abandoning cultivation of traditional crops such as paddy and wheat. An example is Nalgonda district in Andhra. Farmers generally start with small areas under orchards and install drips. After recovering the initial costs, the general tendency of farmers is to bring the entire cultivated land under orchards, and put them under drip irrigation. This is because orchards require special care and attention and putting the entire land under orchards makes farm-management decisions easier. However, the same tendency of area expansion is not seen when MI systems are used for other cash crops such as cotton and sugarcane.

In the case of cotton, it is difficult for farmers to take up any crop that can be irrigated with drips after the harvest towards the close of winter. This is due to the lack of flexibility in the design of the conventional MI systems. Due to the high capital cost, it is best suited to permanent plantings or crops having roughly the same planting space as frequent removal and rolling back can cause damage to online drips. Exceptions are porous pipes used for sub-surface irrigation. In the cotton growing areas, farmers normally roll back the system and cultivate the traditional crops in summer only if water is available. But, early sowing of cotton is found to be common among farmers who have installed drip irrigation, as they are able to manage their pre-sowing irrigation with very little water available from wells (Verma et al. 2004). With improved planting patterns (paired rows, pit system) farmers install almost permanent drip systems for sugarcane.

While for many fruit crops, the gestation period is very large extending from 3 to 10 years (for instance, citrus, orange and mango), for many others like grapes, pomegranate and banana, it is quite short extending from one to two years. Also, farmers can go for intercropping of some vegetables and watermelon, which reduces their financial burden of establishing the orchards. This flexibility enables small and marginal farmers also to adopt MI systems, as found in north Gujarat and Jalgaon and Nasik districts of Maharashtra.

Access to credit and subsidy further increases MI adoption among small and marginal farmers. The irrigation water requirement of the cropping system consisting of field crops such as paddy, wheat, pearl millet/sorghum combinations is much higher than that of fruit crops such as pomegranate, gooseberry, sapota and lemon. Also for other orchard crops such as mango, the irrigation water requirements during the initial years of growth would be much less than that of these field crops. Therefore, even with expansion in cropped area, the aggregate water use would drop. Only in rare situations, the system design for one crop is adaptable for another crop. For example: the micro sprinklers that are used for winter potato, can also be used to irrigate summer ground nut and hence farmers opt for that crop.

A research study was carried out the hydrological and farming system impacts of MI technologies in north Gujarat. The study involved a survey of 114 adopter families and 51 non-adopters, using stratified random sampling, and collection of primary data of their farming systems in detail. In the case of adopters, the survey included both pre and post adoption scenario. The most important and interesting findings of the study was that MI system adoption is associated with cropping pattern shifts. With MI adoption, several of the traditional cereal crops were replaced by cash crops amenable to MI systems. While the irrigation water use rates for individual crops reduced, the aggregate cropped area also reduced. The yield of most crops increased due to MI adoption. There has been substantial increase in water productivity of individual crops, in both physical and economic terms post MI adoption. Further, in spite of all these changes, the groundwater use for irrigation reduced significantly at the farm level by nearly 7527 m^3 per farm (Kumar et al. 2010).

2.4 Economic Impacts of MI Systems

For a given crop, the yield as well as water-saving benefits of MI system could change across different systems, so are the capital costs. Also, it could change along with crops cultivated. But, the research is heavily skewed towards orchard crops, banana, sugarcane and cotton. These crops still occupy a small percentage of the irrigated area in the country. Further, these economic analyses were not contextualized for the socioeconomic and institutional environment for which they were performed. The socio-economic and institutional environments determine the extent to which various physical benefits get translated into private and economic benefits. This is explained it in the subsequent paragraphs.

Normally, it has been found that drip irrigation is economically viable for horticultural crops and orchards such as banana, grapes, orange, coconut, and sugarcane (Dhawan 2000). The reason for this is that the crops are high valued and even a marginal increase in yield results in significant rise in value of crop output. Dhawan (2000) argues that higher value of crop output is realised also from improved price realization due to quality improvements on one hand and early arrival of the drip-irrigated crop in the market on the other. The same need not be true for other cash crops, and field crops.

For instance, the income benefit due to yield improvement depends on the type of crop. For cereals, it cannot be significant. A 10 % rise in yield would result in an incremental gain of 400–500 kg of wheat or Rs. 3000–Rs. 3750 per ha. of irrigated wheat. At the same time, a 10 % rise in yield of pomegranate, whose minimum yield is 60,000 kg per ha. per year, would result in an incremental gain of 6000 kg/ha. or Rs. 90,000 per ha. Besides the incremental value of outputs, an important factor which influences the economic performance of drip system is the cost of installation of the system.

From the point of view of deciding on the investment priorities including the provision of subsidies, it is important to know the social benefits from drip irrigation. As Dhawan (2000) notes, cost-benefit analyses, which do not take into account social costs and benefits, are on weak conceptual footing as the government subsidies in micro irrigation systems are based on the premise that there are positive externalities on the society due to water saving. In areas, where available water in wells is extremely limited, it is logical to take water-saving benefits and convert the same in monetary terms based on market price or in terms of additional area that can be irrigated. Same is the case with energy saving. But the same methodology cannot be applied to areas where access to water is not a limiting factor for enhancing the area under irrigation, or energy is not a scarce resource. But, such analysis are absent in India.

Given the range of variables–physical, socio-economic and financial—, that affect the costs and returns from crops irrigated by MI systems, it is important to carry out comprehensive analysis taking into account all these variables, across situations where at least the physical, socio-economic conditions change. Now, we would examine how the way these variables operate change under different situations.

As regards water saving, in many areas, the well owners are not confronted with the opportunity cost of wasting water. Hence, water saving does not result in any private gains. Where as in some hard rock areas like Kolar district in Karnataka, the amount of water that farmer can pump from the well is limited by the geo-hydrology. The price at which water is sold is also high in such areas (Deepak et al. 2005), and the opportunity cost of using water is high in those areas. Hence, the amount of water saved would mean income saving for the adopters.

Coming to the benefits from energy-saving, it is applicable to certain MI devices, especially low pressure systems and gravity systems such as drip tapes, micro tube drips and easy drips. But, farmers of many water-scarce regions are not confronted with marginal cost of using energy. Hence, for them energy saving does not result in any private gain. But, from a macro-economic perspective, if one wants to examine the economic viability of the system, it is important to consider the full cost of supplying electricity to the farms while evaluating the economics of irrigation using the system. Also, we consider the price at which water is traded in the market for irrigation (ranging from Rs. 1.5/m^3 to Rs. 2.5/m^3 in north Gujarat to Rs. 6/m^3 in Kolar) as the economic value of water then any saving in water resulting from drip use could be treated as an economic gain. The real economic cost of pumping water would range from Rs. 1.5/m^3 in north Gujarat to Rs. 2/m^3 in Kolar district.

The private income benefit due to water saving is applicable to only those who purchase water on hourly basis. Dhawan (2000) cautions that over-assessment of private benefits are possible in certain situations where return flows from conventional irrigation are significant (Dhawan 2000). But in regions where reduction in deep percolation means real water saving, it leads to private benefits. Here, for water buyers, the private income gain from the use of drip or sprinkler system depends on the price at which water is purchased (volumetric) and the reduction in water use achieved. There could be significant social benefits due to water saving in water scarce regions, owing to the reduced stress on precious water resources (Dhawan 2000), resulting from reduced pumping. In situations like north Gujarat, such social benefits could not be over-emphasized.

As regards the cost, the capital costs could vary widely depending on the crop. For widely spaced crops (mango, sapota, orange and gooseberry) the cost could be relatively low due to low density of laterals and drippers. For closely spaced crops such as pomegranate, lemon, papaya, grapes, the cost could go up. For crops such as castor, cotton, fennel and vegetables, the cost would go further up as denser laterals and drippers would be required. Even for low cost micro tube drips, the cost per ha would vary from Rs. 12,000 for sapota and mango to Rs. 28,000 for pomegranate to Rs. 40,000 for castor.

Keeping in view these perspectives and situations, economics of water-saving technologies was simulated for four typical situations for alfalfa in Banaskantha district of north Gujarat based on real time data collected from four demo plots in farmers' fields. Alfalfa is an annual crop used as forage grown in north Gujarat region, including Banaskantha district.

The first level of analysis was limited to private cost-benefits. Yield increase and labour saving are the private gains here. The annual yield benefit was estimated by taking calculated daily yield increase and multiplying by 240, which is the approximate number of days for which the fodder field yields in a year. The labour saving benefit was calculated by taking the irrigation equivalent (in daily terms) of total water saved (total volume of water saved/discharge of pump in 8 h) and multiplying it by the daily wage.

In the second level of analysis, the actual economic cost of using every unit of electricity was considered as a benefit from saving every unit of the energy. In this case, the energy saving and cost saving depend on two factors: the energy required to pump unit volume of groundwater, and the total volume of water saved. Here, it is assumed that no extra energy would be required for using the inline drip system, which is connected to the existing pumping devise. In the third level of analysis, the unit price of water in the market was treated as economic gain from "actual saving" of every unit of water and was added to the cost of electricity to pump unit volume of water. This was multiplied by the total volume of water saved to obtain the total economic gain in excess of the gain from yield increase and labour saving. The fourth level of analysis was for farmers who are irrigating with purchased water. Here in this case, the unit price of water could be considered as a private gain from saving every unit of water. In this case, the cost of construction of a storage tank and a 0.5 HP pump are added to the cost of installation of the system.

An analysis of economics of some water-saving technologies was attempted on the basis of data on crop inputs and outputs, and capital investments collected from primary survey of adopters and non-adopters for Kachchh, Bhavnagar, Rajkot and Banaskantha districts. The analysis was based on the estimates of incremental returns from drip irrigation over the entire life of the system against the additional capital investment for the system. For calculating the present value of an annuity, a discount rate of 6 % was used and the life of the system was considered as 10 years. The incremental returns considered are the average of two consecutive years. This was done to take care of the problems of yield reductions due to crop failure and price fluctuations. While estimating the incremental returns, the effect of differential input costs, and differential return were considered. The benefit cost analysis was carried out for three important crops in all the four districts irrigated by micro irrigation systems.

On the whole it was found that the incremental net returns were generally markedly higher for cash crops viz., ground nut, cotton, castor; and fruits viz., mango and banana than for food crops viz., bajra and wheat (Kumar et al. 2004). This is in conformation with the work of earlier researchers (see Narayanamoorthy 1997). The incremental returns from cash crops, particularly fruits, could, however, fluctuate significantly depending on the price and yield fluctuations. At the same time, it is also equally striking to note that the benefit-cost ratios are good for even cereals given the fact that the capital cost of the system is high and the market value of the produce is not high Perhaps, this could be due to the reason that the farmers, who did not use the system faced significant yield losses due to water stress.

The data available from field research carried out in north Gujarat, involving 114 adopter farmers, was used in working out the benefit-cost analysis of MI-systems for select plots, in which crop shift has not taken place after adoption. The results showed significant variations in B-C ratio across crops from as low as 0.72 to a highest of 5.96. It was found that most farmers simultaneously changed the crop with introduction of MI system. Therefore, the findings emerging from analyses, wherein the crop is expected to remain the same after adoption, have very limited practical and policy relevance (Kumar et al. 2010). In real life situations, MI adoption is associated with selection of high valued crops for which MI systems are the best bet technology (Kumar et al. 2008), and as a result the incremental benefits would far exceed our estimates (Kumar et al. 2010).

2.5 Potential Area Under Different Water Saving MI Technologies in India[3]

For adoption of water saving MI systems, the following conditions need to be satisfied: (1) technical feasibility; and (2) socio-economic viability. The technical feasibility of adoption of MI systems is determined by the following factors (1) the presence of irrigation system which can delivery water to the crop under pressure for running the MI system; (2) the availability of good quality water, or water free from high TDS; (3) scarcity of water for irrigation in the region; and (4) farmers have independent source of water for irrigation.

The three factors which determine the socio-economic viability of MI systems are: (1) presence of crops that are amenable to water saving MI systems; (2) degree of rural electrification; and (3) power supply regime. As regards the first point, Kumar et al. (2008) identified the crops in different regions of India, which are amenable to MI systems. We have refined these estimates by incorporating a few new cash crops, and also taking into account the change in irrigated area under different crops that are amenable to water saving MI systems as on 2010. As regards the second factor, for well owning farmers to adopt MI systems, it is necessary that the wells are electrified. This is because electricity for farming is subsidized, which would bring down the operating costs within affordable limits. Conversely, using diesel engines to pump water and to pressurize the MI system would be prohibitively expensive, as farmers would have to pay for higher capacity engines and sometimes higher fuel consumption.

As regards the third factor, most MI systems are energy intensive, requiring more electricity to pump out a unit volume of water as compared to the traditional method of irrigation. Whereas the biggest benefit from MI is water saving. In rich alluvial areas (such as Punjab, Haryana, Uttar Pradesh, Bihar, Assam and most parts of West Bengal) daily power supply availability is for lesser number of hours than what the energized wells can run. Or in other words, power shortage limits the ability of the well owners to expand the area under irrigation. In such situations, the incentive to go for MI systems will be limited. Whereas in hard rock regions, the power supply is available for more number of hours than what is need to pump out water from the wells, or groundwater scarcity limits farmers ability to expand area under irrigation. Under such situations, the farmers would have strong economic incentive to adopt MI systems, as they would be able to expand the area under irrigation.

In order to estimate the potential area that can be brought under MI system, we followed the following steps: (1) mapped irrigated areas of crops which are amenable to water saving MI systems in major Indian states; (2) deduced areas that are potentially under well irrigation, by multiplying the gross irrigated area under such crops in each state by the ratio of the net groundwater irrigated area and the total

[3]This section is based on a report titled "*Micro Irrigation Business in India: Potential, Challenges and Future Prospects*," prepared by IRAP for Infrastructure Development Finance Company Ltd., Mumbai, July 2012.

(canal, tank and well) net area irrigated; (3) deduced irrigated crop areas which are falling in water-scarce river basins, by eliminating areas that are either falling in water-rich basins (such as the Ganges and Brahmaputra) or have poor rural electrification, or areas that are having rich groundwater but facing severe power shortage.

In order to make an assessment of the extent of energisation of agricultural wells in different states of India, the data on number of pump sets which are used for irrigation and the total annual agricultural power consumption were collected and analyzed. The results vis-à-vis the total number of agricultural pumps and the average energy use by the pumps, show that agricultural power connections is very high in states such as erstwhile AP, Gujarat, Maharashtra, Madhya Pradesh, Punjab, Rajasthan, Karnataka and Tamil Nadu. Though UP had nearly 0.85 million electric pump sets, it is a small percentage of the total no. of agro wells in the state. Though Kerala also has a considerable number of electrified wells, most of the wells are part of the homestead and these wells are also used for domestic purpose. The physical feasibility of using these wells for irrigating crops in the farm will be very poor.

As a coincidence, the states which are falling in water-rich basins also suffer from poor infrastructure conditions such as low level of rural electrification. They are West Bengal, Uttar Pradesh, Bihar and Assam. Majority of the irrigators in these states either depend on diesel engines for pumping groundwater or purchased water from electric or diesel well owners. While demarcating the area under MI systems, the area under irrigated paddy was not considered at all as use of micro irrigation system for paddy has yet not been proved to be beneficial. Further, only field crops were considered for sprinkler irrigation systems, and all row crops were considered for drip irrigation.

Table 2.2 gives the estimated potential area under drip irrigation and sprinkler irrigation for major Indian states, covering a total of 16 states, which are important from the point of view of agricultural production in the country. It gives the total area suitable for MI. It also gives the potential areas for MI adoption where conditions are favourable in terms of power connections, and water scarcity is likely to drive MI system adoption.

However, these figures do not mean that adoption of any type of MI system would lead to water saving even at the plot level. Especially in the case of sprinkler irrigation, which are considered only for field crops here, the extent of water saving is likely to be negligible. This is because soil evaporation (from the soil which is not covered by crop canopy), which is a non-beneficial component of the consumed fraction of irrigation water applied in the field (Perry 2007), is likely to remain same under sprinkler method of irrigation as in the case of traditional method of irrigation. While some reduction in non-recoverable deep percolation, which can be treated as part of the total consumptive use (Allen et al. 1998; Kumar and van Dam 2013), would be possible through sprinkler usage, such benefits would be highly situation specific. One such situation is desert soils with undulating land, where conventional method of irrigation could result in poor distribution uniformity, depression storage and deep percolation of water in the head reaches of the field. Here again, the real impact of sprinklers could be in the form of improved yield resulting from better distribution uniformity, rather than water saving.

Table 2.2 Potential area for water saving micro irrigation systems in India

Name of state	Area suitable for drip system ('000 ha)	Potential area* for drip system ('000)	Area suitable for sprinklers ('000 ha)	Potential area* under sprinklers ('000 ha)
(Erstwhile) Andhra Pradesh	879.66	879.66	385.56	385.56
Bihar	214.59	0.00	1713.27	0.00
Chhattisgarh	20.86	20.86	42.72	42.72
Gujarat	2021.25	2021.25	1422.19	1422.19
Haryana	381.64	381.64	2130.34	2130.34
Jharkhand	42.00	42.00	32.48	32.48
Karnataka	766.85	766.85	644.35	644.35
Kerala	60.00	60.00	0.0	0.0
Madhya Pradesh	413.44	413.44	4228.92	4228.92
Maharashtra	1305.16	1305.16	1312.53	1312.53
Odisha	145.40	145.40	75.8	75.8
Punjab	546.04	546.04	3022.2	3022.2
Rajasthan	677.84	677.84	4471.82	4471.82
Tamil Nadu	646.24	646.24	167.44	167.44
Uttar Pradesh	2222.27	0.00	9269.07	0.0
Uttaranchal	79.73	79.73	165.49	165.49
West Bengal	781.47	0.00	540.36	0.00
Total area MI	11204.0	7986.0	29624.0	18101.0

*Note** While estimating potential areas for micro irrigation, the areas where water saving benefits are likely to be accrued, are only considered. Hence, areas in the states of UP, Bihar, and West Bengal are not considered

Source Authors' own estimates based on secondary data on irrigated area under different crops, in different states (Indiastat.com); IRAP (2012)

Hence, from the point of view of water saving, we can consider 7.98 million hectares as the potential area under MI systems.

2.6 Can Drip Irrigation Solve Water Scarcity Problems in Andhra Pradesh?

Expectations were raised regarding the potential of drip irrigation in erstwhile Andhra Pradesh, with the task force on micro irrigation set up under the Chairmanship of Chandra Babu Naidu, former Chief Minister of erstwhile Andhra Pradesh. But, there has been no scientific assessment of the real potential for drip irrigation in the state, which involved data on the cropping systems that exist in different regions of the state, and due consideration to the conditions under which drip system becomes the best bet technology. Researchers have argued that the drip irrigation systems would become best bet technologies when they are adopted in areas with semi-arid and arid climate with deep water table conditions, for row crops, and under well or lift irrigation. Further, it was argued that the water saving benefit of drip irrigation will be significant under semi-arid and arid climates when used for row crops, and in areas with deep unsaturated zones. The technical feasibility and economic viability of drip irrigation would be higher for well-irrigated crops, with independent pressurizing devices; and also their economic viability better for distantly spaced crops, for which the capital cost of the system would be less.

Unfortunately, none of these issues were given adequate attention while assessing the potential of drip irrigation systems in the state. As cursory look at the irrigation landscape of the state would show that nearly 3.84 million hectares out of the total 6.28 million hectares of the irrigated land is under paddy, i.e., 61 %. One has to exclude this area, while thinking about drip irrigation systems. The crops that are amenable to micro irrigation systems and that are grown extensively in Andhra Pradesh are groundnut, chilly, cotton, sugarcane, cotton and tobacco. They together accounted for a total area of 10.08 lac hectares (Table 2.3). Among these crops, groundnut is actually gives better results under micro sprinklers, and not drips. Nevertheless, it is also considered in view of the water-saving benefit it can give, when irrigated with the use of MI systems. Since some of these crops are also grown in canal command area, MI system adoption will be difficult there. This further reduced the potential of MI systems in the state. The potential area under crops that are conducive to water saving MI technologies, wherein the intended benefits could be derived, in the state was estimated to be only 0.879 million hectares.

Finance is going to be another major impediment for MI adoption. The actual record of MI adoption in the state is a true reflection of these structural constraints facing adoption of drip systems. Under the much-publicized Andhra Pradesh Micro Irrigation project of the government of AP, a total area of 1.66 lac hectares was covered under MI systems over a time period of nearly 30 months. The total subsidy benefit to farmers was to the tune of 209.96 crore rupees, which works out to be Rs. 18,070 per ha. (Kumar and van Dam 2009). The result is that most of the farmers have installed drip systems for fruit crops, for which returns, as noted by Dhawan (2000), would anyway be high even without drips, and sprinklers which

Table 2.3 Area under crops amenable to micro irrigation systems (as on 2008–09)

Name of crop	Area irrigated (‘000 ha)	(%) share
1. Groundnut	294.0	27.1
2. Chilly	169.0	15.6
3. Sugarcane	318.0	29.4
4. Cotton	255.0	23.5
5. Tobacco	47.0	4.3
Total area under crops	1083.0	100.0

Source Based on irrigated cropped area in AP in 2004–05, as cited in Reddy (2007) are low cost but not technically efficient for small farms (Kumar et al. 2008). Crops such as sugarcane, chilly and groundnut would require much higher capital investment for installing drip systems as compared to the fruit crops like sweet lime. By 2010, an area of 0.505 m. ha was under drip irrigation in erstwhile AP. This much needed investment is least likely to come from farmers given the current mode of pricing of electricity and water followed in the farm sector, which does not create any incentive for farmers to save water (Kumar et al. 2008).

While assessing the water saving impact of MI systems, more caution needs to be exercised. Nearly 85 % of the area of erstwhile AP is underlain by hard rock aquifers, comprising crystalline formations and basalt with limited groundwater potential. Wells are the major source of irrigation in these areas. But, due to scarcity of groundwater, only a small percentage of the cultivated area is irrigated in these regions. A major proportion of the area under cash crops, which are amenable to MI systems, is located in these regions. It is quite likely that with the adoption of MI, farmers would expand the area under irrigation in these regions, as increased area under irrigation production is a major economic incentive for adopting MI. Because of this reason, the real economic returns from the use of MI systems can be captured only if we analyze the changes in the farming system of the adopter households.

2.7 Conclusions

The future potential of MIS in improving basin level water productivity is primarily constrained by the physical characteristics of basins vis-à-vis the opportunities they provide for real water-saving at the field level, and area under crops that are conducive to MIS in those basins. Creating appropriate institutions for extension, designing water and electricity pricing policies apart from building proper power supply infrastructure would play a crucial role in facilitating large-scale adoption of different MIS. The real potential for adoption of MI systems in erstwhile AP, for crops wherein real water saving at the field level is possible, appears to be limited. Further limited is the scope for saving water at the farm level, as it is quite likely that farmers would expand the area under irrigation after adoption of MI system.

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Chapter 3
State of Adoption of Drip Irrigation for Crops Cultivation in Maharashtra

A. Narayanamoorthy

3.1 An Overview

Water availability for irrigation is declining rapidly, but the demand for irrigation water is growing at a fast rate in majority of states in India (Saleth 1996; CWC 1996; Seckler et al. 1999). Under such a condition of scarcity, efficient use of irrigation has become important means of increasing the benefits of irrigation. The flood method of irrigation (FMI) practiced extensively in India and elsewhere, leads to inefficient use of water due to enormous losses in evaporation during distribution (INCID 1994, 1998; Rosegrant and Meinzen-Dick 1996; Rosegrant 1997; Postal 1999; Narayanamoorthy 1997, 2004a, b, 2005). Since efficient use of irrigation water is paramount for sustainable agricultural development, different measures have been introduced to conserve water as well as to improve the efficiency in the use of irrigation water. But, the measures introduced for increasing the water-use efficiency under flood method of irrigation have not brought the desired impact (Vaidyanathan 1998).

One of the methods introduced in India to increase the water-use efficiency in irrigation nearly two and a half decades ago is the drip method of irrigation (DMI). In this method, water is supplied continuously or at regular intervals at the root zone of the crops through a network of pipes with the help of emitters. This technology was used primarily for cultivating vegetables and fruits in Israel. Unlike in flood method of irrigation, the efficiency of water-use is extremely high in DMI when it substantially reduces non-beneficial evaporation and losses in conveyance and application (Narayanamoorthy 1996, 1997; Sivanappan 1994), if the same end up in natural sinks such as saline aquifers and swamps (Seckler 1996). Available results in this regard show that the on-farm irrigation efficiency of a properly designed and managed drip irrigation system is about 90 %, whereas it is about 70 % for

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sprinklers and just about 40 % for surface irrigation method (Sivanappan 1994; INCID 1994; Postal et al. 2001). Studies in various parts of India do indicate that DMI increases crop yield significantly and that too with reduced cost of cultivation when compared to FMI (AERT and DSI 1988).

Drip irrigation requires fixed investment, but its fixed investment is not very high if we compare the benefits that can be realised from it. The cost of system varies depending upon the nature of crop, space, water requirement, conditions of terrains, emitter discharge and distance between the source of water and field to be irrigated. Capital cost of drip irrigation is relatively higher for narrow-spaced crops than wide-spaced crops. Despite higher cost of drip systems, estimates based on experimental data indicate that drip irrigation is economically viable for many crops (NCPA 1990; INCID 1994; CBIP 1993). Drip irrigation technology not only increases water-use efficiency in agriculture, but also provides many other economic and social benefits to the society. While increasing the productivity of crops significantly, it also reduces the cost of cultivation substantially, especially in labour-intensive operations. The reduction in water consumption in drip method also reduces the energy use (electricity) that is required to lift the water from irrigation wells (see, Narayanamoorthy 2004a, b). Over the past ten years, a few studies have been carried out focusing on the impact of drip method of irrigation covering various parameters in different crops. These studies, by and large, have focused on the impact of drip method of irrigation on water saving, including water-use efficiency, productivity of crops and cost of cultivation. While some have studied the impact of DMI on electricity saving, others have evaluated its economic viability in different crops, using experimental data.[1] Some studies have attempted to find out whether the investment in drip irrigation is economically viable or not in different crops. While some have estimated benefit-cost ratio including water saving as well as excluding water saving (INCID 1994; Kumar et al. 2004), others have estimated benefit-cost ratio and net present worth under with and without subsidy conditions (Narayanamoorthy 1996, 1997, 2004a, b).

Maharashtra is the first Indian state to introduce specific scheme for promoting the drip irrigation with the aim to ease the intensity of water scarcity during 1986. This chapter focuses on the overall status of drip method of irrigation in the state of Maharashtra, which is one of the water-scarce states in India. What is the current status of drip method of irrigation in the state in relation to other Indian states? How much cost (subsidy) is incurred by the state to promote drip method of irrigation? Is

[1]The BC ratio provided for different crops in INCID (1994) indicates that investment in drip irrigation is economically viable, even after excluding water saving from the calculation. The estimated benefit-cost ratio comes to 13.35 in crops like grapes and 1.41 in the case of coconut. However, it is not clear whether the B-C ratios presented in INCID (1994) have been estimated using discounted cash flow technique or not. Unlike INCID estimates, using discounted cash flow technique and that too utilizing field survey data covering four crops, namely grapes, banana, sugarcane and cotton, Narayanamoorthy (1997, 2003, 2004a, b, 2008) estimated the B-C ratio and net present worth. These studies suggest that the investment in drip method of irrigation is economically viable for farmers, even without availing any subsidy from the government.

the drip method of irrigation economically viable for farmers? Can farmers adopt drip method of irrigation without government subsidy? What needs to be done to increase the coverage of irrigation in the state? This chapter attempts to address these questions using the available information.

3.2 Water Resources Development

Area under irrigation in the state of Maharashtra is only about 17 % of the gross cropped area, which is quite low as compared to many states and to the national level average of about 42 % in 2006–07. Despite severe water scarcity, sugarcane, an important water-intensive crop, is extensively cultivated using surface (flood) method of irrigation in the state. Studies have confirmed that sugarcane not only consumes bulk of the available water but the returns per unit of water are also very low (Rath and Mitra 1989). Given the limited availability of irrigation water, over-exploitation and low percentage of irrigated area, there is an urgent need to increase the efficiency in the existing use of irrigation water in the state. The state government is promoting drip method of irrigation by providing subsidy to the farmers. Due to the concerted efforts taken by the government agencies along with some drip set manufacturers, the area under drip irrigation has increased since 1986–87. The state also has a distinction in accounting for the highest area under drip method of irrigation as on date. More than 20 years have passed now from the date of introduction of state-specific promotional scheme for drip method of irrigation in the Maharashtra State.

Let us briefly discuss the status of water resources of the Maharashtra state before getting into the details of drip method of irrigation, as the availability of irrigation largely determines the adoption of drip method of irrigation in any given region (see, Shreshta and Gopalakrishnan 1993). The irrigation sector of the Maharashtra state is the largest in the country in terms of number of large dams and investment. The gross irrigated area of the state increased to 4.05 million hectares in 2009–10 from the level of 1.22 million hectares in 1960–61, but the progress of it has been very tardy since 1990–91 (see, Table 3.1).

In spite of making increased investment on developing the surface irrigation over the years in the state, the area under surface irrigation has not increased much when one compares with the private irrigation, namely the groundwater. The area under surface irrigation has increased only by about 2.44 times during the time period 1960–61 and 2009–10, whereas groundwater irrigated area has increased by about 3.62 times during this period, suggesting the increased domination of groundwater irrigation in the state. Currently, the area under irrigation by groundwater accounts for over 68 % of the state's total irrigated area. Interestingly, although the Maharashtra state has the distinction of having the largest number of irrigation

Table 3.1 Trends in irrigation development in Maharashtra: 1960–61 to 2009–10

Year	Area irrigated ('000 ha)				No. of irrigation wells ('000)	Net area irrigated per well (ha)	Per cent of GIA to GCA
	Wells	Surface	NIA	GIA			
1960–61	595	477	1072	1220	542	1.10	6.48
1970–71	768	579	1347	1570	694	1.11	8.38
1980–81	1055	780	1835	2415	826	1.28	12.30
1990–91	1162	999	2671	3319	1017	1.64	15.18
2000–01	2262	987	3249	3852	1318	2.47	17.82
2005–06	2077	1070	3147	3810	NA	NA	16.90
2009–10	2156	1162	3321	4050	NA	NA	17.90

Source GoM (2013)

projects in the country,[2] the coverage of irrigation in relation to gross cropped area (GCA) is one of the lowest in the country (see, Deshpande and Narayanamoorthy 2001). While the national coverage of irrigation to cropped area was over 42 % in 2009–10, it was only about 17 % in the state.

The supply and demand position of water in the state is not very encouraging (see, MoWR 1999). As per the estimates provided by the Maharashtra Water and Irrigation Commission (GoM 1999), the annual average availability of water is 148,208 MCM, of which, an amount of 139,227 MCM of water is available for planned use. In 1996, about 39,484 Mm^3 of water was used for different purposes, which accounted for just about 26 % of the total water available for planned use.[3] In the total current use of water, agriculture, which includes irrigation and livestock, accounts for about 81 % and industry and domestic uses account for about 3 and 7 %, respectively, at the state level (Table 3.2). However, the proportion of water used by different sectors is not the same across different basins and sub-basins because of the varying nature of growth of agriculture and other sectors (GoM 1999).

The scenario on demand for water is expected to change drastically in the coming years, because of the increasing demand for water from different sectors. The projections indicate that the total demand for water is likely to grow by about 162 % between 1996 and 2030 at the state level (GoM 2003). That is, the total demand for water is expected to increase from 39,484 MCM in 1996 to 103,705 MCMin 2030. This means that about 70 % of the total available water for planned use will be utilized by different sectors in the year 2030. Water requirement for agriculture (irrigation plus livestock) is expected to grow by about 182 %, from

[2]A total of 4050 large dams were completed in the country as per the latest information available from CWC (2004). Of the total projects completed in the country so far, 1453 dams are in the Maharashtra state alone, which is about 36 % of the total number of large dams in the country. On an average, about 26 projects per year have been completed during the period 1951–2000.

[3]Detailed estimate on demand-supply of water for different sectors across basins is available only for two time points, namely 1996 and 2030. For the purpose of a comparison, the year 1996 has been here referred as the current period.

Table 3.2 Basin-wise water supply and demand in Maharashtra: 1996 and 2030 (million m^3)

Basin	Available water for planned use	Demand for									
		Domestic		Agriculture (irrigation + livestock)		Industry		Others (hydro + thermal power)		Total use	
		1996	2030	1996	2030	1996	2030	1996	2030	1996	2030
Godavari	38,882	874	2066	16,653	40,384	192	678	250	318	17,969	43,446
Tapi	9324	350	731	4126	10,562	35	766	20.20	175	4531	12,234
Narmada	343	3.50	6.46	29.40	245.20	0.00	0.00	0.00	0.00	32.90	251
Krishna	18,356	603	1428	9471	27,438	138	415	3112	3112	13,324	32,393
WFRK	72,322	938	1952	1811	12,030	877	1395	0.90	2.90	3626	15,380
Maharashtra	139,227	2768	6184	32,091	90,660	1241	3254	3394	3617	39,484	103,705

Notes Figures rounded off to the nearest integer; *WFRK* West Flowing Rivers in Konkan
Source GoM (1999)

32,091 Mm^3 in 1996 to 90,660 Mm^3 in 2030. It is very high when compared to the growth of water requirement for domestic and industrial uses, where the water requirement is expected to increase by about 123 and 162 % respectively. Water requirement for different sectors is also expected to increase substantially by 2030 across all basins, with varying rate of increase. Though the projection indicates that there will not be any supply-demand gap for water up to the year 2030 at least at the state level, there is going to be a severe water shortage, particularly in three major basins namely Godavari, Tapi and Krishna—as Tapi and Krishna supply about 26 % of water to Maharashtra. In view of the expected water scarcity, there is an urgent need to increase the adoption of water conserving technologies so as to sustain the growth of agriculture and other sectors in the state.

3.3 Rainfall Pattern

The pattern of rainfall in the state is somewhat different from some of the peninsular states of India. The normal date of onset of monsoon in the state is first week of June. Maharashtra state receives over 90 % of the rainfall between June and September through south-west monsoon, which is the lifeline of state. Though the normal rainfall of the state is 1178 mm, it is not the uniform across regions. For instance, during the year 2004–05, the actual rainfall of the state (excluding Mumbai) was 1065.87 mm, but it was 3000.2 mm in the Konkan division and only 564.42 mm in the Amaravati division. Interestingly, the divisions which receive relatively less rainfall have more rainfed area. Delayed monsoon and uneven distribution of rainfall during different months are the recent phenomena, affecting the normal pattern of crop cultivation. However, as per the data on total rainfall, most of the districts have received either excess or normal rainfall during past nine years from 2004 to 2012 (see, Table 3.3).

Table 3.3 Classification of districts according to rainfall received, Maharashtra state

Percentage of rainfall to normal rainfall	Number of districts during the year								
	2004	2005	2006	2007	2008	2009	2010	2011	2012
120 and above (excess)	3	11	16	6	1	1	17	4	1
81–119 (normal)	15	20	16	26	21	16	16	27	22
41–80 (deficient)	15	2	1	1	11	16	0	2	10
0–40 (scanty)	0	0	0	0	0	0	0	0	0
Total	33	33	33	33	33	33	33	33	33

Source GoM (various years)

3.4 Cropping Pattern

The coverage of irrigation is very less in the state and therefore, it relies heavily on the monsoon for cultivating crops. Delay or failure in monsoon creates many hardships to the farmers in the state. Because of poor coverage of irrigation, the rainfed crops have been dominating in the states' cropping pattern (see, Table 3.4). Rainfed crops such as jowar, bajra, pulses, oilseeds and cotton together accounted for over 73 % of the state's cropped area during 2010–11, which is totally different from rest of India's cropping pattern. Contrary to the experience of other states, crop-wise irrigated area too is not distributed in a desirable manner among different crops in the state. Out of the total irrigated area of 3.55 million hectares available during TE 2000–01, important food grain crops such as paddy, wheat, jowar and bajra together accounted for only 45.89 %, while sugarcane alone accounted for over 18 %. Pulses and oilseeds are the important crops in Maharashtra and accounted for about 28.33 % of GCA in TE 2001, but these two crop groups together accounted for only about 14.50 % of the irrigated area during the same period.

Though net returns per unit of water use generated by sugarcane are estimated to be very low as compared to most of the food grain crops (see, Rath and Mitra 1989), the available estimates show that a major portion of the irrigation water available in the state is still used only for sugarcane, which accounts for less than 3 % of gross cropped area (World Bank 2002). Area under irrigated sugarcane accounted for over 18 % of GIA in the state, which is very high when compared to the national average figure of about 5 %. In spite of severe water scarcity in the state, area under sugarcane has been increasing continuously which currently accounts for close to 5 % of the

Table 3.4 Cropping pattern of the Maharashtra state: 1962–63 to 2010–11

Crop	Percentage to gross cropped area				
	1960–63	1970–73	1980–83	1990–93	2010–11
Paddy	6.96	7.47	7.49	7.50	6.55
Wheat	4.74	4.64	5.16	3.47	5.63
Jowar	32.64	31.98	33.16	27.99	17.52
Bajra	8.80	8.88	8.08	9.13	4.41
Total cereals	55.60	55.21	56.14	50.20	38.78
Total pulses	12.53	12.95	13.58	15.39	13.35
Cotton	13.80	14.53	13.16	12.75	17.00
Sugarcane	0.78	1.12	1.83	2.63	4.16
Total oilseeds	10.11	9.60	8.50	12.18	21.76
Others	7.18	6.59	6.79	6.85	4.91
Total	100 (18,823)	100 (18,737)	100 (19,642)	100 (21,859)	100 (23,175)

Note Figures within the brackets are gross cropped area (in '000 ha) of the state
Source GoM (various years)

cropped area. In view of the increasing demand for irrigation water and drastic decline in the available water for future use, new measures need to be introduced to increase adoption of water conservation technologies, such as drip and sprinkler.

3.5 Trends in Drip Irrigation Development

The Maharashtra state has performed exceptionally well in the adoption of drip method of irrigation when compared to any other states in India. Since DMI is relatively a new irrigation technology, both state and central governments have been implementing separate schemes to promote drip method of irrigation. Maharashtra is one among the few states where both the schemes are currently under operation. The state scheme has been in operation since 1986–87, while central scheme started functioning from 1990–91. Area under DMI increased from a meagre 236 ha in 1986–87 to about 217,447 ha in 2001–02 and further to 604,400 ha in 2009–10 (see, Table 3.5). Maharashtra's share in India's total drip-irrigated area has been over 50 % since 1990–91. Though its share in the total drip irrigated area in the country has declined in the recent years because of high adoption in other states, it still has the largest area under the technology. There are many reasons for the rapid development of drip irrigation in Maharashtra. First, state government is very keen in promoting drip irrigation on a large scale and provides subsidy, and technical and extension services to the farmers.

Table 3.5 State-wise area under drip method of irrigation, 1991–92 and 2009–10

States	Area in '000 ha		Percentage to total area	
	1991–92	2009–10	1991–92	2009–10
Maharashtra	32.92	604.44	44.64	31.86
Karnataka	11.41	209.47	16.17	11.04
Tamil Nadu	5.36	153.44	7.59	8.09
Andhra Pradesh	11.59	505.21	16.41	26.63
Gujarat	3.56	226.77	5.05	11.95
Kerala	3.04	15.89	4.30	0.84
Odisha	0.04	11.05	0.06	0.58
Haryana	0.01	11.31	0.17	0.60
Rajasthan	0.30	30.05	0.43	1.58
Uttar Pradesh	10.11	12.64	0.16	0.67
Punjab	0.02	17.93	0.03	0.95
Other states	2.13	99.08	3.00	5.22
Total	70.59	1897.28	100.00	100.00

Sources AFC (1998), GoI (2004) and personal communication from ICID

Maharashtra government has been providing subsidy since 1986–87 through state schemes. Second, area under irrigation from both surface and groundwater is quite low and hence, many farmers have adopted drip method of irrigation to avoid water scarcity, largely in the divisions like Nashik, Pune, etc. Third, owing to the continuous depletion of groundwater, farmers were not able to cultivate wide-spaced and more lucrative crops like grapes, banana, pomegranate, orange, mango, etc. by using surface method of irrigation in many regions. As a result, farmers had to adopt drip irrigation as these crops are most suitable for this irrigation. Fourth, favourable cropping pattern (horticulture and vegetables) prevailing in the state has also prompted the farmers to adopt DMI. Importantly, the farmers who adopted drip irrigation initially for certain crops have realised its significance in the saving of water and improving productivity of crops. This has further induced many farmers to adopt drip method of irrigation in some of the regions in Maharashtra.

Although the area under DMI has increased appreciably in almost all the regions, the distribution of drip-irrigated area is not uniform across the divisions (see, Table 3.6). The adoption of DMI has been relatively higher in Nashik, Pune and Aurangabad divisions, while it has been lower in other divisions. There are two main reasons for the rapid increase of drip-irrigated area in Nashik and Pune divisions. First, crops that are most suitable for drip irrigation are being extensively cultivated in these regions by using groundwater. Second, these divisions are particularly facing water scarcity due to depletion of groundwater. Since both area under groundwater and wide-spaced crops are less in divisions like Konkan, the growth of drip-irrigated area is not impressive in these two divisions. Although there are variations in the development of drip area across the divisions, the overall development has been very impressive in almost all the regions between 1990–91 and 2009–10.

More than 26 crops were being cultivated using drip irrigation in the state. The important crops were banana, grapes, sugarcane, citrus group of crops and pomegranate. These five crops together had accounted for about 120,335 ha, which was about 75 % of the total area (160,281 ha) under drip irrigation in Maharashtra in

Table 3.6 Division-wise area under drip irrigation: 1990–91 and 2009–10

Division	Area in hectare		Percentage to total area	
	1990–91	2009–10	1990–91	2009–10
Konkan	760	12,783	4.68	2.36
Nashik	3944	210,437	24.29	38.90
Pune	4705	134,385	20.34	24.84
Aurangabad	3622	96,782	10.56	17.89
Amravati	2590	71,017	15.95	13.12
Nagpur	617	15,516	3.80	2.86
Maharashtra state	16,238	540,920	100.00	100

Source Water Resources Department (various years)

1999–2000. In the total area under drip irrigation in Maharashtra, banana accounted for more than one-fifth of the area (22.38 %) followed by grapes (18.15 %), sugarcane (12.68 %), citrus group of crops (11.59 %) and pomegranate (10.27 %). The crop-wise composition of adoption of drip irrigation has not changed much even today. For instance, during 2009–10, crops like banana, grapes, sugarcane, orange, pomegranate, cotton, mango and vegetable crops together accounted for about 90 % of the state's total drip irrigated area. However, the adoption of DMI was not found to be the same for all the districts/divisions. Crops like mango, coconut and sapota are predominantly cultivated with DMI in Konkan division, while crops like banana and grapes accounted for more than three fourth of the total drip irrigated area in Nashik division. Sugarcane, pomegranate and grapes are the important drip irrigated crops in the Pune division.

3.6 Impact of Drip Method of Irrigation

DMI has primarily been introduced to increase water-use efficiency and to cope up with the increasing scarcity of water. However, drip method of irrigation generates many other benefits such as reduced cost of cultivation, saving in electrical energy and increased productivity and income. In this section, using the author's own empirical studies[4] on four different crops (sugarcane, grapes, banana and cotton) carried out in the Maharashtra state, a brief analysis has been presented on the impact of drip method of irrigation on different parameters. First, let us understand the impact of drip technology on the consumption of water. Table 3.7 presents the beneficial impact of drip method of irrigation on different parameters for four crops along with per hectare consumption of water in terms of HP hours.[5]

It is clear from Table 3.7 that the amount of water applied to crop was significantly less under drip method of irrigation than flood method of irrigation (FMI). While saving in applied water in sugarcane was about 44 %, it is about 37 % in grapes, about 29 % in banana and about 45 % in the cotton. Unlike flood method of irrigation, under DMI, water is supplied only at the root zone of the crops and that too in the required quantity. Hence, water losses through evaporation and distribution are completely absent. This helps the DMI-adopters to save water

[4]The studies on four different crops were carried out at different reference periods and at different locations in Maharashtra. The detailed methodology adopted for these studies and the analysis on various issues of drip method of irrigation can be seen from Narayanamoorthy (1997, 2003, 2004a, b, 2008).

[5]Most studies based on research station data have measured water consumption in terms of centimeter (cm) in drip irrigation. But, in practice, measuring water in terms of cm is not an easy task at the field level as HP of the pump sets and water level of the well changes considerably across the farms. Because of these difficulties, one is compelled to measure the water consumption in terms of horse power (HP) hours of irrigation, which is computed by multiplying HP of the pump-set with hours of water used.

Table 3.7 Benefits of drip method of irrigation

Parameters	Crops	DMI	FMI	Gains over FMI (%)
1. Water application (HP hours/ha)	Sugarcane	1767	3179	44.40
	Grapes	3310	5278	37.30
	Banana	7885	11,130	29.15
	Cotton	563	1025	45.00
2. Electricity consumption (kWh/ha)	Sugarcane	1325	2385	44.40
	Grapes	2483	3959	37.30
	Banana	5914	8348	29.15
	Cotton	423	769	45.00
3. Productivity (quintal/ha)	Sugarcane	1384	1124	23.00
	Grapes	243	204	19.00
	Banana	679	526	29.00
	Cotton	45	21	114.70
4. Cost of cultivation (Rs./ha)[a]	Sugarcane[b]	41,993	48,539	−13.50
	Grapes	134,506	147,915	−9.00
	Banana	51,437	52,739	−2.50
	Cotton	42,989	42,467	1.00

Notes
[a]Refers to cost A2, except cotton crop, which is cost A2 + FL
[b]Costs of harvesting, transport and marketing have not been included as sugar factories incur it
Sources Reconstructed from Narayanamoorthy (1997, 2003, 2004a, b)

enormously as compared to the non-adopters of DMI. The requirement of water varies for each crop, depending upon the soil quality and other factors and therefore, the saving of water due to DMI varied among the four crops discussed here.

Drip irrigation also helps to save substantial amount of electricity used for lifting water from wells. It is obvious that along with the number of working hours of pump set, the consumption of electricity also reduces in DMI. It is observed above that HP hours of water used per hectare of crop are significantly less under DMI than FMI. Therefore, it simply follows that the consumption of electricity also reduces significantly under DMI.[6] The estimated consumption of electricity (in kWh) clearly depicted that farmers using DMI use less amount of electricity as compared to FMI farmers in all the four crops. Farmers who cultivated sugarcane under DMI could save about 1059 kWh of electricity per hectare as compared to

[6]In order to know the impact of drip method of irrigation on electricity saving, the consumption of electricity is estimated based on the hours of pump set operation for both drip adopters and non-adopters groups. Further, for estimating the quantum of electricity saved, we have assumed that for every hour of operation of pump-set, 0.750 kWh of power is used per HP. Since all the farmers in both the groups have used only electrical pump sets, we have simply multiplied HP hours of water with assumed power consumption of 0.75/kWh/HP to arrive at the per hectare electricity consumption.

those farmers who cultivated sugarcane under FMI. Similarly, cultivation of grapes and banana could save electricity by about 1476 and 2434 kWh/ha, respectively over the farmers who cultivated these crops under FMI with similar agro-climatic background.

Reduced cost of cultivation is another advantage of drip irrigation, but none of the experimental data based studies seems to have compared the productivity of crops with the cost of cultivation. There is a possibility that productivity of crops under DMI may be higher due to higher use of yield-increasing inputs. Studies carried out using experimental data in different crops indicate that the DMI reduces the cost of cultivation, especially in labour-intensive operations like weeding, irrigation, ploughing, etc. (see, INCID 1994; Dhawan 2002). When labour cost reduces, the total cost of cultivation also reduces as labour cost constitutes a considerable portion in the total cost of cultivation. It is clear from Table 3.7 that drip irrigation reduced the total cost of cultivation in sugarcane crop by about Rs. 6550/ha (nearly 13 %) for the adopters as compared with DMI non-adopters. Similarly, farmers who cultivated grapes, banana and cotton under DMI have also incurred a lower cost of cultivation. Among different operations, cost saving is very high in the cost of irrigation. Second highest saving is noticed in ploughing operation, because DMI does not warrant much ploughing. Cost saving in weeding operation is also high because DMI does not allow weed to come up in the non-crop space by not supplying water beyond the root zone of the crop. It should be noted that the cost of cultivation also varies with situational factors like soil quality, condition of the terrain and farmers' approach.

Productivity gain is one of the important advantages of DMI. Most of the times, yield is affected because of moisture stress faced by crops. It is difficult to maintain the water supply constantly for crops by surface method of irrigation due to various reasons. The problem of moisture stress is considerably reduced by DMI as it supplies water at the root zone of the crops at the required frequency and quantity. As a result, the yield of crops cultivated under DMI is much higher than these cultivated under surface irrigation. As expected, productivity was significantly higher for DMI-adopters than non-adopters in all the four crops. The yield difference between DMI-adopters and non-adopters was found to be about 23 % in sugarcane, 19 % in grapes and 29 % in banana crop. The yield of drip-irrigated cotton was 114 % higher than the FMI counterpart. The important point to be underlined here is that despite incurring higher cost on yield increasing inputs, productivity of crops cultivated under FMI was significantly lower than that of DMI. There are three main reasons for higher yield in drip-irrigated crops. First, because of less moisture stress, the growth of crops cultivated under DMI was good which ultimately helped to increase the productivity. Second, unlike surface method of irrigation, drip does not encourage any growth of weed, especially in the non-crop zone. Weeds consume considerable amount of yield-increasing inputs and reduce the yield of crops in surface method of irrigation. Third, unlike surface method of irrigation, fertilizer losses occurring through evaporation and leaching through water are less under drip method of irrigation, as it supplies water only to crop and not to the land.

3.7 Economic Viability of Investment in Drip Irrigation

Drip irrigation involves fixed investment by farmers. Therefore, its economic viability needs to be studied thoroughly using proper methodology for framing proper policy. Only a few studies have analysed the impact of drip method of irrigation on different parameters. Past studies (e.g., INCID 1994; Sivanappan 1994; AFC 1998) on the subject have either conducted benefit-cost analysis without a proper methodology or relied heavily on the experience of one or few farmers adopting DMI. Therefore, there is a need for a study to empirically evaluate the economic viability of DMI within a relatively more systematic methodological framework. Specifically, we must address the issues of (i) how the factors like fixed investment influence economic viability of DMI, and (ii) how government subsidies and farmers' time preference (i.e., the differential discount rates) influence the economic viability of DMI in different crops. We have computed the benefit-cost ratio (BCR) by utilizing the discounted cash flow technique to evaluate the economic viability of drip investment in the context of four crops.[7] Generally, if the BCR is more than one, then, the investment on that project can be considered as economically viable (for details see Gittinger 1984). The BCR can be defined as follows:

$$\mathrm{BCR} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}}$$

where,

B_t Benefit in the year t

C_t Cost in the year t

t Period (1,2,3, … ,n)

n Project life in years, and

i Rate of interest (or the assumed opportunity cost of the investment)

[7]The drip method of irrigation involves fixed capital and therefore, it is necessary to take into account the income stream for the whole life-span of drip investment. Since it is difficult to generate the cash flows for the entire life-span of drip investment in the absence of observed temporal information on benefits and costs, we had to make few realistic assumptions so as to estimate both the cash inflows and cash outflows for drip investment. These assumptions followed for estimating BCR were: (a) The life-period of the drip-set was considered as five years for sugarcane and banana, and 10 years for grapes and cotton, as followed by the INCID study (1994) as well as the experience gathered from the field, (b) The cost of cultivation and income generated using drip method of irrigation was assumed constant during the entire life-period of drip-set in all the four crops, (c) Differential rates of discount (interest rates) were considered to undertake the sensitivity of investment to the change in capital cost. These were assumed at 10 and 15 % as alternatives representing various opportunity costs of capital, and (d) The crop cultivation technology was assumed constant for all the four crops during the entire life-period of drip-set.

Let us briefly discuss the cost of production, profit without discount, capital cost (without and with subsidy) before studying the benefit-cost ratio of DMI so as to understand the relative profit levels of four crops for the adopters and non-adopters of DMI. Table 3.8 presents the details of production, gross income, etc. for four crops namely, sugarcane, grapes, banana and cotton. While calculating profit, the total cost was calculated by considering only the variable costs but not the fixed cost components like interest rate and depreciation. To calculate per hectare profit, we subtracted the total cost of cultivation from the total income for the groups of adopters and non-adopters. The gross income (in Rs) was calculated by multiplying the total yield with price received by the farmers for their crop output.

The estimate shows that per hectare profit[8] of the adopters in sugarcane was Rs. 27,424 higher than that of the non-adopters. In terms of percentage, profit of the drip adopters was higher by about 74 % over that of non-drip farmers. This is not surprising because on the one hand drip irrigation reduced the cost of cultivation of sugarcane and on the other hand, it increased its yield. The average profit was significantly higher among drip-adopters than non-drip adopters in the case of grapes, banana and cotton (Table 3.8). While the profit differential is substantial for drip-irrigated crops, it cannot be taken as a conclusive indicator of the comparative advantages of the new irrigation technique as our profit calculation was based only on the variable cost, but ignored the fixed cost components like depreciation and interest accrued on the fixed capital while calculating the net profit. The life-period of drip-set is one of the important variables which determine the per hectare profit. Since it is a capital-intensive technique, the initial investment needed for installing drip systems commonly believed to be the main deterrent for the widespread adoption of DMI. Is this true? How important is the government subsidy in influencing the economic viability of drip investment?

Though the farmers (adopters) in the Maharashtra state have received subsidy for installing drip technology for all the four crops through government schemes, the BCR has been estimated separately by including and excluding subsidy in the total fixed capital cost of a drip-set. It was done to assess the potential role that subsidy plays in the adoption of DMI. The BCR is sensitive to discount rate and the degree of such sensitivity depends on the pattern of cash flows and therefore, it is interesting to observe the sensitivity of the BCR when there is simultaneous change in both subsidy and discount factor. Table 3.9 presents the estimates of B-C ratio for all the four crops computed under different scenarios. As expected, the BCR of the investment with subsidy was marginally higher than that under 'no subsidy' option in all the four crops taken for analysis.

In sugarcane, under without subsidy condition, the BCR was 1.909 at 15 % discount, but it was 2.098 under subsidy condition. Similarly, the BCR without subsidy for banana was about 2.253 at 10 % discount rate, but it increased to 2.361 with subsidy. The BCR also increased considerably for both grapes and cotton

[8]This profit was calculated by deducting gross income from cost A2, which can be appropriately called as farm business income.

Table 3.8 Relative economics of drip and non-drip irrigated crops (Rs./ha)

Parameters	Crops	DMI	FMI	Gains over FMI (%)
1. Cost of cultivation[a]	Sugarcane[b]	41,993	48,539	−13.50
	Grapes	134,507	147,915	−9.00
	Banana	51,437	52,739	−2.50
	Cotton	42,989	42,467	1.00
2. Gross income	Sugarcane	106,366	85,488	24.00
	Grapes	247,817	211,038	17.00
	Banana	134,044	102,635	30.20
	Cotton	95,558	44,151	116.00
3. Farm business income	Sugarcane	64,373	36,948	74.00
	Grapes	113,311	63,123	44.00
	Banana	82,607	50,196	64.50
	Cotton	52,569	1684	3021.00
4. Capital cost—without subsidy	Sugarcane	52,811	–	–
	Grapes	32,721	–	–
	Banana	33,595	–	–
	Cotton	52,496	–	–
5. Capital cost—with subsidy	Sugarcane	33,548	–	–
	Grapes	20,101	–	–
	Banana	22,236	–	–
	Cotton	26,537	–	–

Notes
[a]Refers to cost A2, except cotton crop, which is cost A2 + FL
[b]Costs of harvesting, transport and marketing were not included as sugar factories incurred it
Sources Reconstructed using Narayanamoorthy (1996, 1997, 2004a, 2008)

under subsidy condition as compared to the estimates under the condition of without subsidy. This suggests the positive role that subsidy plays in improving the economic viability of DMI for all the four sample crops.

An important policy issue in the context of drip adoption is the number of years needed to recover the capital costs of drip system. Our year-wise computation of net present worth (NPW) for sugarcane, banana, grapes and cotton suggested that farmers could recover the entire capital cost of the drip-set from their net profit in the first year itself. This finding contradicts the general belief that the capital cost recovery for drip investment takes a long time. More importantly, when farmers can recover the capital costs within a year, the role of discount rate as a device to capture the time preference of farmer seems to be of considerably less importance than one might think. However, in order to have more definite answers to the economic and social viability of DMI, one must carry out a social rather than the private cost-benefit analysis, as attempted here. It is possible to carry out a

Table 3.9 Benefit-cost (B-C) ratio of drip irrigated crops under different scenarios

Crop	Subsidy category	Life period (years)	Discount rate (%)	B-C ratio
Sugarcane	With subsidy	5	15	2.098
		5	10	2.289
	Without subsidy	5	15	1.909
		5	10	2.095
Grapes	With subsidy	10	15	1.795
		10	10	1.802
	Without subsidy	10	15	1.767
		10	10	1.778
Banana	With subsidy	5	15	2.343
		5	10	2.361
	Without subsidy	5	15	2.288
		5	10	2.253
Cotton	With subsidy	10	15	1.956
		10	10	1.983
	Without subsidy	10	15	1.789
		10	10	1.835

Sources Reconstructed using Narayanamoorthy (1996, 1997, 2004a, 2008)

comprehensive evaluation by incorporating both the social benefits in the form of water saving, additional irrigation, lower soil degradation and retention of soil fertility as well as the social costs in terms of the negative food and fodder in the crop pattern shift and labour displacement.

3.8 Pointers for Future Research

The analysis presented in the chapter shows that DMI has made significant impact on water saving, electricity consumption, cost of cultivation and productivity of crops. The investment in DMI has been proved to be economically viable and that too without taking government subsidy, in all the four crops, namely sugarcane, grapes, banana and cotton. In spite of having many advantages over conventional method of irrigation, the area under drip-irrigation presently occupies only a very negligible percentage of the potential area. In our assessment, the total potential area suitable for DMI roughly comes to about 1.95 million hectares, which accounted for about 60 % in NIA in 2006–07. Studies relating to Maharashtra state have shown that slow growth of DMI was not mainly due to economic reasons but due to less awareness among the farmers about the real economic and revenue-related benefits of drip technology (see, Narayanamoorthy 1997, 2003, 2004a, b, 2008). This means that apart from the provision of capital subsidy, there is also an urgent need for effective extension work, including aggressive field demonstrations. We present below a few pointers which may be useful for expanding the adoption of drip method of irrigation both at the national level and in the specific context of Maharashtra state:

A major reason for the slow growth of micro-irrigation in India is the high initial investment. In spite of availability of subsidy from state agencies, a majority of the farmers are reluctant to invest in micro-irrigation system even in horticultural crops, which are highly amenable to drip irrigation. Therefore, as suggested by the Task Force on Micro-irrigation (GoI 2004), there is a need to look into the technological options of which crop geometry modification is the most important one. Instead of adopting traditional spacing, adoption of paired row planting has been found to reduce the cost of the system by 40 % in many crops including tomato, brinjal, okra, etc. Therefore, micro-irrigation system should be tailor made, i.e., planned and designed based on location-specific parameters. Standard procedure provided under subsidy scheme may not always help to reduce the cost of the system.

The rate of subsidy provided through government schemes is fixed uniformly for both water-intensive and less water-intensive crops. This needs to be restructured. Special subsidy programme may be introduced for water-intensive crops like sugarcane, banana, vegetables, etc. Differential subsidy rates can be fixed based on the types of crops and the rate of consumption of water. Uniform level of subsidy schemes currently followed for water-scarce and water-abundant areas need to be changed. Higher subsidy should be provided for those regions where the scarcity of water is acute and exploitation of groundwater is very high.

Drip irrigation is mainly used in well irrigated areas. Unlike other countries, drip irrigation is not used in areas fed by gravity systems. Since water-use efficiency under gravity irrigation is very low, farmers should be encouraged to use water from surface sources for DMI. This can be done by allocating certain proportion of water from each irrigation projects only for the use under micro irrigation.One of the important reasons for the low spread of this technology even in the water-scarce area is the availability of highly subsidized canal water as well as electricity for irrigation pump sets. Efficient pricing of water and energy would encourage the farmers to adopt this technology. In addition, as noted by Kumar et al. (2008), for farmers to use drip irrigation systems in canal irrigated areas, intermediate storage systems would also be required, given the mismatch between water delivery schedules in canal systems and the irrigation schedules which need to be followed for crops under drip irrigation.

Though micro irrigation has been in use in different states since mid-1980s, state-wise potential area has not been estimated yet. Therefore, it is essential to prepare state-wise and crop-wise potential area for DMI. It would be useful in fixing and formulating schemes for promoting micro irrigation.

Only Maharashtra and Gujarat have separate state-sponsored schemes for promoting micro irrigation as of today. Most states have been operating schemes mainly with the support of central government, known as centrally-sponsored schemes that started in 1990–91. Considering the water shortage in different states, it is essential to have separate state-sponsored schemes in each state by following the experience of the Maharashtra state.

Although quite a few studies that are carried out in different locations in India have proved that drip method of irrigation generates many economic and environmental benefits, most studies have been carried out on the wide spaced fruit and high value commercial crops. DMI is suitable over 80 crops including some cereal crops that are cultivated in India. Studies based on sample survey data particularly focusing on crops like vegetables and condiments, etc. are very scanty. Besides, most studies on financial viability of drip irrigation have also not followed the discounted cash flow technique for estimating the NPW and BCR which is necessary to exactly measure the viability of drip investment. Studies also need to be carried out in water scarce and water rich regions to know the adoption behavior of the farmers in different locations.

It is understood from field studies that capital cost required to install drip irrigation is high. Several farmers have expressed that they are unable to adopt this technology for low-value crops. If drip system is made available at low cost, area under drip irrigation can be increased at a faster rate. Therefore, following measures can primarily be taken to reduce the fixed cost of drip irrigation by promoting R&D activities. By recognizing drip industry as an infrastructure industry as well as announcing tax holiday for it for a specific time period, competition can be increased which will ultimately bring down the cost of the system. Some companies have come out with a low-cost drip irrigation system which can be adopted even by the farmers having less than one acre of land. Studies need to be carried out to find out the feasibility of low-cost drip materials, including its environment feasibility using field data.

Maharashtra state's experience indicates that farmers have to wait for at least for six months to receive the subsidy from the concerned department. This increases farmers' debt burden, as majority of them use bank loan for procuring drip systems. In order to encourage the adoption of drip technology, adequate arrangements should be made to distribute the subsidy within one or two months.

Sugar industries always try to increase the area under sugarcane to increase their capacity utilisation in almost all the states, including Maharashtra. They are least bothered about the method of cultivation of sugarcane. Since sugar industries have close contact with sugarcane cultivators, some kind of target may be fixed for each sugar industry to bring cultivation of sugarcane under drip system. In hot and arid climates, this would save water. Apart from that, this would also help achieve sustainable sugarcane cultivation. Despite shortage of irrigation water in many states, not only does the area under sugarcane continue to grow at a relatively faster pace, but the method of irrigation of this crop also continues to be inefficient. This puts additional pressure on our limited fresh water resources. To avoid huge demand-supply gap in irrigation water in future, a new set of guidelines should be formulated to bring at least 50 % of sugarcane areas under drip method of irrigation.

Asymmetry in information about the operation, maintenance as well as usefulness of drip irrigation is one of the main reasons for its uneven spread across regions in India. Even the DMI-adopters do not know fully how much subsidy is available per hectare for different crops. Many farmers do not know that drip irrigation can be used efficiently and economically for crops like sugarcane, cotton, vegetables, etc. Strengthening of the existing extension services can remove these problems. The extension network being operated mainly by the government agencies does not seem to be making significant impact on the off-take of this technology. There is a need to involve the drip system manufactures in extension service in order to improve its quality.

Drip system manufacturers should be involved in setting up demonstrations at farmers' field and providing advice on agronomic packages to the farmers so as to aggressively promote the technology. This will help in developing confidence among the farmers about the usefulness of this new technology. For a speedy growth of micro irrigation in potential areas, a special package scheme may be introduced where priority should be given in providing bank loan for digging wells and obtaining electricity connection (pump-set) to those farmers who are ready to adopt the system.

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Chapter 4
Micro-irrigation in Karnataka: Potential and Constraints for Adoption

Elumalai Kannan

4.1 Background

Groundwater irrigation plays an important role in the development of India's agricultural sector. The Green Revolution technology introduced during the 1960s in the form of improved seeds and fertilisers spread faster in the areas where the irrigation water resources were available adequately. It has been estimated that irrigation contributed significantly to total factor productivity growth in Indian agriculture (Fan et al. 1999; Chand et al. 2011; Kannan 2011). In fact, massive investment in irrigation infrastructure helped to achieve India's long term food security. There was considerable increase in the net irrigated area from 24.7 million hectare in 1960–61 to 63.6 million hectare in 2010–11. The surface and groundwater constituted important sources of irrigation even though their relative share has changed over time. While the share of surface irrigation declined from 70.4 to 38.6 % of net irrigated area between 1960–61 and 2010–11, the share of groundwater has almost doubled from 29.6 to 61.4 % (Government of India 2013). The expansion of well irrigation can be attributed to increased adoption of tube wells resulting from easy access to deep drilling technology, electric pump sets and rural electrification in Indian states (Gandhi and Namboodiri 2009; Kumar 2007).

The southern peninsular India including the state of Karnataka is characterised by the hard rock areas, which have widespread weathered zones flexible for water extraction through dug, dug cum bore, shallow bore and deep bore wells (Rao 1993; Nagaraj and Chandrakanth 1997). However, beyond certain depths of groundwater level, diesel pump sets will not be useful and only electric pumps can be used for the extraction of water. The dug wells were the predominant groundwater irrigation structures till 1980s, but thereafter the number of bore wells had

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increased tremendously due to fall in groundwater level as a consequence of its increased demand for irrigation. The increased demand for irrigation water has actually resulted from the intensive cultivation of high water requiring crops like paddy and sugarcane in Karnataka. The state government had provided subsidies for drilling wells and laying power lines to connect irrigation wells with electricity. The electricity tariff rates were also reduced to utilize the tube well technology. With virtually free access to captive groundwater in the hard rock areas and subsidized farm power, farmers did not have any incentive to conserve it for future use and hence they started competitive drilling of bore wells leading to decline in water table (World Bank 2010).

Based on the stage of ground water development, which is estimated as the ratio of net draft to net availability, the ground water scenario of the assessment (hydrological) units is classified as safe (<70 %), semi-critical (70–90 %), critical (90–100 %) and over-exploited (>100 %). According to CGWB (2011), Karnataka has Net Annual Groundwater Availability of 14.81 billion cubic metre (BCM) and the Annual Ground Water Draft of 10.01 BCM. So, the stage of groundwater development is estimated at 68 %, at the aggregate level. Out of the 270 hydrological units assessed, 71 was categorized as over-exploited, 11 as critical, 34 as semi critical and 154 are safe. There is widespread overexploitation of groundwater particularly in the southern districts of Karnataka leading to increased disturbance in the balance between recharge and extraction rates.

Since June 1992, the government of Karnataka has been following a differentiated tariff regime for electricity supplied for agricultural purposes. In fact, electricity supply to the agricultural sector was metered till 1991 and thereafter it has been provided free of charge up to 10 HP irrigation pump sets. For using more than 10 HP pump sets, farmers have to pay Rs. 30/HP/month as fixed charge and additionally pay Rs. 1.40 paisa/kWh as per the usage. Nevertheless, the free electricity supply has led to over draft of groundwater leading to depletion and wastage of energy. Such policy has benefited only the capitalist farmers, while resource poor peasants are left in a disadvantageous position (World Bank 2010, 56; Sarkar 2011). Further, energy subsidies in the farm sector pose serious environmental, social and economic problems, by causing groundwater over-exploitation (World Bank 2010).

Since agriculture is the major consumer of water, demand side management of water assumes great importance not only in the water scarce regions, but also in relatively water abundant regions to avoid possible impending water crisis. Demand side management can be effected through adoption of suitable agronomic practices like bund cultivation, shift in cropping pattern, direct seeding and alternate wet-dry irrigation, and also through adoption of micro-irrigation technologies. The demand management interventions have the potential to save considerable amount of water by reducing net consumptive requirement of water used for irrigation. Among these interventions, micro-irrigation technologies comprising drip irrigation and sprinkler irrigation methods are considered to be superior to conventional method of irrigation as they help to save water, reduce weeds, energy use, enhance crop productivity and improve the water use efficiency considerably (Narayanamoorthy 2003, 2008; Palanisami et al. 2011). In terms of techno-economic feasibility, drip irrigation suits better to well irrigation than gravity irrigation (Chandrakanth et al. 2012). Notwithstanding, sprinkler irrigation method has also been used for crops like ground nut and cabbage in Karnataka. In this chapter, we review the status of adoption micro-irrigation in Karnataka and analyses its potential and constraints.

4.2 Changes in Cropping Pattern and Irrigated Area

Food grain crops dominate the cropping pattern accounting for about two-third of total gross cropped area (GCA) in Karnataka (Table 4.1). Among food grains, coarse cereals such as jowar, maize, ragi and bajra occupy a prominent place in the cropping pattern. But, proportion of area under food grains has declined from 71.9 % in triennium ending 1962–63 to 61.7 % in triennium ending 2010–11.

Table 4.1 Changes in cropping pattern in Karnataka (% of GCA)

Crop	TE 1962–63	TE 1972–73	TE 1982–83	TE 1992–93	TE 2000–01	TE 2010–11
Rice	9.9	10.7	10.3	10.3	11.9	11.9
Jowar	28.0	21.8	19.2	18.0	15.4	10.4
Bajra	4.8	4.6	5.4	3.3	2.6	2.3
Maize	0.1	0.7	1.4	2.3	4.9	9.4
Ragi	9.6	9.8	9.8	8.8	8.1	6.3
Wheat	2.9	2.9	3.0	1.7	2.2	2.1
Small Millets	4.2	4.1	3.2	1.1	0.6	0.2
Cereals	59.7	55.4	52.4	45.5	46.6	42.5
Arhar	2.7	2.5	3.3	3.9	4.3	5.5
Gram	2.5	1.4	1.3	1.7	2.8	6.9
Pulses	11.9	11.0	13.2	13.8	15.8	19.2
Foodgrains	71.9	68.3	66.6	59.4	62.4	61.7
Groundnut	8.4	9.2	7.6	10.5	9.3	6.6
Sunflower	–	–	1.0	8.6	4.9	5.8
Total Oilseeds	9.7	11.0	12.2	22.7	17.3	15.2
Cotton	9.3	10.2	9.0	5.0	4.7	3.7
Sugarcane	0.7	1.0	1.6	2.2	3.1	2.7
Coconut	–	–	1.6	2.0	2.8	3.8
Arecanut	–	0.4	0.5	0.5	0.9	1.5
Fruits and vegetables	–	–	–	2.1	5.4	6.1
Others[a]	8.4	9.1	8.5	6.0	3.5	5.3
GCA	100.0	100.0	100.0	100.0	100.0	100.0

Note [a]Include tobacco, coffee and other plantation crops
Source Government of Karnataka (various issues)

The decline in area under food grains is offset by increase in area under oilseeds and other crops (which include coconut, arecanut, chillies and coffee). The share of area under fruits and vegetables in GCA has considerably increased to 6.1 % in 2010–11 from 2.1 % in 1992–93.

In 2010–11, jowar and rice accounted for a significant proportion of the total cropped area followed by sunflower and maize. Despite occupying relatively high share, area under jowar had declined drastically since early sixties. Similar pattern could be noticed with respect to other coarse cereals such as bajra, ragi and small millets. However, crops like maize, pigeon pea and gram have gained in their relative area during the study period. Maize occupied only 0.1 % of GCA in 1962–63, which had increased steadily to reach 1.4 % in 1982–83 and then to 9.4 % in 2010–11. Similarly, per cent area under pigeon pea in total cropped area had increased from 2.5 % in 1972–73 to 5.5 % in 2010–11. Share of area under gram decelerated during seventies and early eighties, but started picking up since nineties because of better price.

Groundnut is one of the traditional crops grown in Karnataka. It is cultivated both under irrigated and rainfed conditions. The per cent area under this crop has declined sharply since 2000 due to persistent drought like conditions in most parts of the State. However, share of area under sunflower has registered a sharp increase from 1.0 % in 1982–83 to 5.8 % in 2010–11. Among cash crops, area under cotton has declined drastically over time. However, sugarcane area has increased considerably from 1960s to 2000s, but has showed declining trend since 2001–02. It emerges from the analysis that there was a marked shift in area from cereals to pulses, oilseeds and high value crops like vegetables and plantation crops.

Among the sources of irrigation, tanks were predominant source of supply of irrigation water during 1960s (Table 4.2). Overtime, canal and tube wells have

Table 4.2 Sources of irrigation

Particulars	TE 1962–63	TE 1972–73	TE 1982–83	TE 1992–93	TE 2000–01	TE 2009–10
Gross irrigation (lakh ha)	10.0	15.0	18.6	27.4	31.8	39.4
Percentage of GIA to GCA	9.3	14.0	16.9	22.6	26.0	31.0
Net irrig. area (lakh ha)	9.1	12.2	15.1	22.1	25.6	32.5
Sources of irrigation (% of net irrigated area)						
Canal	28.3	35.9	40.5	40.5	37.9	32.4
Tanks	39.5	30.1	21.0	12.0	9.9	6.3
Tube wells	–	0.3	0.5	9.6	19.1	39.6
Wells	16.1	25.5	26.7	24.1	18.7	13.0
Other sources	16.1	8.2	11.3	13.8	14.4	11.5

Source Government of Karnataka (various issues)

emerged as the major sources of irrigation. As percentage to net irrigated area, the share of canal irrigated area has increased from 28.3 % in 1962–63 to 40.5 % in 1982–83. Though canal water as source of irrigation remained almost constant during nineties, it showed decelerating trend during 2000s.

The area irrigated through tanks declined drastically from 3.6 lakh hectare in triennium ending 1962–63 to 3.2 lakh hectare in 1982–83 and then to 2.0 lakh hectare in 2009–10. In terms of percentage to net irrigated area, it was 39.5 % in 1962–63, 21.0 % in 1982–83 and 6.3 % in 2009–10. Although tanks are found to be one of the best strategies for conservation of rain water at low investment with short gestation period, poor maintenance, encroachment of tank bed and change in land use pattern led to decline in tank irrigation (Govindaiah 1994; Palanisami et al. 2010; Thippaiah 2006). Interestingly, area irrigated through tube wells increased remarkably from 0.3 % in 1972–73 to 39.6 % in 2010–11. In fact, drying up of tanks and vagaries of rainfall had forced the farmers to resort to bore wells. Open wells were another important source of irrigation till early 1990s constituting about 25 % of net irrigated area. Its share declined to 13 % in 2010–11. Wells are the third important source of irrigation after tube wells.

As discussed above, only less than one-third of total cropped area is irrigated in Karnataka. The coverage of irrigation to principal crops is also very limited. The per cent irrigated area under food grains crops rose marginally from 10.1 % in 1962–63 to 15.5 % in 1982–83 (Table 4.3). Surprisingly, the irrigation coverage remained more or less constant at around 20 % during 1990s and 2000s. Among individual crops, irrigated area under rice was little over 60 % during 1962–63 to 1992–93 and then rose to 74.2 % in 2006–07.

Table 4.3 Area under irrigation of principal crops (%)

Crop	TE 1962–63	TE 1972–73	TE 1982–83	TE 1992–93	TE 2000–01	TE 2006–07
Rice	59.5	65.1	61.7	63.2	71.3	74.2
Jowar	2.2	5.2	4.5	7.2	7.9	8.8
Maize	84.2	79.2	81.1	69.5	50.3	39.0
Ragi	5.4	10.3	8.4	8.1	5.6	5.0
Wheat	3.3	10.8	19.4	37.2	42.0	52.0
Cereals	12.0	18.3	19.3	24.4	29.7	32.2
Arhar	0.6	0.2	0.3	1.9	1.1	3.3
Gram	0.6	1.2	7.8	12.9	10.4	15.7
Pulses	0.7	0.5	1.6	3.7	3.6	5.6
Foodgrains	10.1	14.9	15.5	19.5	23.1	24.7
Groundnut	–	6.8	13.4	21.8	21.2	20.2
Sunflower	–	–	8.6	18.8	19.9	18.9
Cotton	1.9	5.0	8.4	25.5	16.1	14.7
Sugarcane	96.6	98.4	99.8	99.7	99.9	99.9

Source Government of Karnataka (various issues)

The area under irrigated maize was 84.2 % in 1962–63. It has declined to 69.5 % in 1992–93 and then to 39.0 % in 2006–07. Decline in area irrigated under maize might be due to availability of varieties which can be grown in rainfed conditions. However, area under irrigated wheat has increased considerably from 3.3 % in 1962–63 to 52.0 % in 2006–07. In case of ragi and jowar, less than of 10 % of their respective cropped area is irrigated. Pulses are generally cultivated under rainfed conditions. Similarly, cotton and oilseeds are predominantly grown under rainfed conditions. It emerges from the above analysis that development of irrigation facilities assumes utmost importance in the dry tracts of the state to improve agricultural growth and productivity. Concerted efforts should be made to bring more area under micro-irrigation through water harvesting, storage, and watershed development programmes.

4.3 Policy Initiatives on Micro-irrigation in Karnataka

Karnataka State Water Policy launched in 2002 recognized the fast depleting groundwater resource and hence the need for proper development and management of available resource. The rainfall pattern is erratic both in time and space. As a result there is uneven exploitation of groundwater in the state with a higher level in drier areas of North and South interior Karnataka as compared to malnad, coastal and canal command areas. The state water policy emphasised a proper management of water and land resources for achieving water use efficiency and land productivity. Promotion of appropriate cropping pattern, conjunctive use of water and adoption of drip and sprinkler irrigation hold the key in achieving the goal.

Agricultural Policy of Karnataka 2006 also highlighted the alarming status of groundwater in the state and predicament of farmers' investment in drilling bore wells. Agricultural Policy encourages the adoption of micro-irrigation technologies for saving water, increasing yield, adoption of new technological package and addressing labour shortages. It suggested that the scheme of subsidies for drip and sprinkler irrigations should be provided to all types of farmers and all regions in the state.

Government of Karnataka is one of the earliest states to introduce subsidy scheme to promote micro-irrigation for horticultural crops. The Department of Horticulture had taken lead in promoting drip irrigation system for horticultural crops since 1991–92. Even though micro-irrigation was initially adopted for wide spaced perennial crops, later it was recommended for close spaced annual crops due to availability of technology and demand from the farmers. Under the Centrally Sponsored Scheme of Micro-irrigation implemented from 2006–07 , subsidy has been provided for drip and sprinkler irrigation systems. In case of horticultural crops (except coffee, tea, rubber and oil palm), for drip irrigation system, financial assistance is available for a maximum area of 5 ha per beneficiary household with 80 % subsidy for the first 2 ha and 50 % for the remaining 3 ha. For sprinkler irrigation, subsidy is fixed at 80 % (Government of Karnataka 2013). For field crops, drip and sprinkler are provided at 75 % subsidy to the general farmers and 90 % subsidy to Scheduled Caste/Tribes farmers.

Under the National Horticulture Mission, transfer of subsidy to farmers has been streamlined to avoid the problem of intermediaries and delay in release of subsidy. Under this arrangement, subsidy will be directly transferred to the beneficiary farmers' bank account after the necessary clearance for demonstration of equipment/machinery by the empanelled firms in the farmers' field and subsequent submission of preference for such equipment by the farmers. Due considerations have also been given in guidelines to make available subsidy to marginal and small farmers.

However, field evidences show that there are problems in accessing the subsidy on various inputs including micro-irrigation equipments by the farmers. The average amount of input subsidy received by farmers in the last five years preceding date of survey (2009–10) in Karnataka is presented in Table 4.4. Among the farm size groups, the large farmers received the highest amount of Rs. 20,456 per household followed by marginal, small and medium farmers.

Large farmers appropriate more benefits from the subsidy schemes due to their high economic status and familiarity with the government officials for whom generally the large farmers remain as contact farmers in the village. There are differences in the access to different subsidy items across the farm groups. Although the medium and large farmers appropriated high amount of subsidy on seeds and irrigation equipments, the marginal and small farmers also received subsidy on these items. The average amount of subsidy received on irrigation equipments varied between Rs. 817 per household among small farmers and Rs. 25,400 per household for large farmers. The subsidy on farm machinery like tractor and tractor mounted plough was availed by the large farmers only.

Table 4.4 Average amount of subsidy received by farm size groups in Karnataka (Rs./farm household)

Items	Marginal	Small	Medium	Large
Seeds/planting Materials	590.0	757.5	992.2	1697.5
Plant protection chemicals	–	180.0	900.0	950.0
Irrigation equipments	3000.0	816.7	8837.5	25,400.0
Farm machinery	–	–	–	86,666.7
Land improvements	1140.0	80.0	–	500.0
Construction of farm pond	–	–	–	–
Drilling of wells	45,000.0	60,000.0	–	–
Bio fertilizers	–	–	–	–
Micro nutrients	–	2000.0	–	–
Others[a]	–	–	6155.0	–
Overall	15,995.0	5182.0	3907.6	20,456.3

Note [a]Includes subsidy on cow
Source Kannan et al. (2012)

Table 4.5 Difficulties in receiving direct subsidies in Karnataka (percent farmers reported)

Problems	Marginal	Small	Medium	Large	Overall
Information about subsidy is not available	58.6	61.9	55.0	38.9	54.5
Procedural complexities (e.g. documentation, paper work)	65.5	45.0	66.7	50.0	58.0
Recommendation letter from elected representative	50.0	35.3	55.6	44.4	46.7
Government officials are not co-operative	50.0	52.4	61.1	50.0	53.0
Bribing government officials	10.5	30.0	13.3	20.0	18.8
Sub-standard quality of items supplied	30.0	26.3	20.0	21.4	25.0
Lack of money to meet the remaining cost	5.3	11.8	26.7	20.0	15.2
Favoured towards select farmers	61.5	47.6	42.1	56.3	52.4
Subsidy dispersal agency is located far away from the village	11.8	13.3	7.1	30.8	15.3

Source Kannan et al. (2012)

In addition, there are several constraints that farmers face in availing the benefit of direct input subsidies provided by the government. Among various constraints, lack of information about the subsidy schemes was major problem (Table 4.5). Nearly 33 % of the farmers expressed procedural complexities as another important constraint in getting direct agricultural subsidies. A high percentage of farmers also reported the problems related to getting recommendation letter from elected representative and non-cooperation of government officials. Favouritism towards select farmers and bribing of government officials also seem to be major problems in administering the direct input subsidies to farmers. Therefore, it implies that even after introducing governance reforms for proper administering subsidy programmes, problems of accessibility particularly for marginal and small farmers continue to exist.

4.4 Status of Micro Irrigation in Karnataka

Agriculture is one of the largest users of water and its efficient use will have implications for adequate availability of water for industrial and household purposes. Groundwater is becoming scarce in different parts of the Karnataka state. An important means to overcome the irrigation water scarcity is through effectively managing the consumptive requirement for agriculture and improve efficiency in the application of water. Micro-irrigation has proven to improve the water use efficiency in irrigated region and provide solution to many problems in dry land region (Shashidhara et al. 2007). Despite its known benefits, the spread of micro-irrigation still remains low. According to Palanisami et al. (2011), Karnataka has potential area of about 7.45 lakh hectare, but only 23.8 % (1.77 lakh hectare) has been brought under drip irrigation. In terms of potential area, Karnataka stands at the fifth place at the all India level and as percentage of area coverage to potential area it occupies the fourth place after Andhra Pradesh, Maharashtra and Tamil Nadu. For sprinkler irrigation, potential area has been estimated at 6.97 lakh hectare and actual area at 2.29 lakh hectare with the coverage of 32.8 % only. There exists huge scope to expand the area under micro-irrigation, which will be a boon to the vast stretch of dry tracts in Karnataka.

A few studies have estimated economic benefits of adoption of micro-irrigation as compared to conventional irrigation for different crops in Karnataka. According to Chandrakanth et al. (2012), net return per acre inch of water from mulberry, grapes and tomato was higher for drip irrigated farms than that for conventional irrigation farms by 62, 84 and 61 %, respectively in Karnataka. A high level of return per acre inch of water was a crucial factor influencing the adoption of drip irrigation by the farmers. Further, adoption was also found to be relatively high among farms with high probability of failure of wells. A study conducted in Dharward district showed that drip irrigation saved about 45 % of applied water in fruit crops as compared to the surface method of irrigation (Meti 2013).

Productivity of crops was higher with drip irrigation than conventional method of irrigation. In Karnataka, productivity of banana increased by 25 % with drip irrigation and also fetched a premium price of 5–10 % due to better quality of fruits (Chandrakanth 2009). Similarly, Shashidhara et al. (2007) found that drip irrigation helped to increase the yield in arecanut and banana by 5.9 and 3.5 %, respectively as compared to the traditional irrigation. Drip irrigation was also found to have saved water and labour cost to a large extent.

Even after realisation of perceptible benefits from micro-irrigation, its actual area has not expanded rapidly. Some of the constraints reported for low adoption include high initial capital cost, non-availability of quality spare parts, lack of technical knowledge in operation and maintenance, lack of appropriate design to suit topography, delay in release of subsidy and small land holding (Shashidhara et al. 2007; Narayanamoorthy 2008; Palanisami et al. 2011).

4.5 Conclusions

Irrigation plays an important role for improving agricultural productivity and maintaining food security in the country. Since water is becoming highly scarce due to increase in demand for consumptive use sector and dwindling supplies from the natural system, agricultural production would suffer. Water saving technologies like micro-irrigation system is found to be beneficial to farmers and improve the water use efficiency considerably. With the changes in cropping pattern and technology, farmers tend to adopt the drip irrigation method even for close spaced crops like vegetables. But, area irrigated through drip and sprinkler irrigation systems remains low as compared to their potential area due to various constraints like initial capital cost, lack of technical knowledge for operation and maintenance, unsuitability to different topography and soil conditions. A proper mechanism to address the governance problems with respect to operation of subsidy schemes to make available the subsidy amount timely and also regular revision of subsidy rate to compensate the rise in the cost of equipment components need to be undertaken.

Regular interactions with stakeholders like farmers, micro-irrigation equipment companies, dealers and government officials should be held to get continuous feedback for designing and modification of equipment parts suitable to different soil conditions and farmer groups. Local educated youths should be trained through special programmes to provide repairing and maintenance service to the farmers. This will help to save time and resources that the farmers have to spend to locate the technical persons far away from the villages.

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Chapter 5
State of Development and Adoption of Micro Irrigation Systems in Gujarat

P.K. Viswanathan, Jharna Pathak and Chandra Sekhar Bahinipati

5.1 Introduction

Based on hydro-climatic features, the state of Gujarat (geographical area: 196,136 km^2) has been divided into four physiographic regions, viz., (a) the semi-arid north Gujarat (NG); (b) humid south Gujarat (SG); (c) sub-humid Saurashtra Peninsula (SP); and (d) the arid Kachchh Peninsula (KP). In general, the state shows a north to south contrast in the status of groundwater extraction due to the different water-yielding capacity of the soils (Panda et al. 2012). For instance, the north Gujarat alluvial aquifer, with a net cropped area of 49,914 km^2 (i.e. 47 % of the total cropped area of Gujarat), is identified as one of the over-exploited regions of India based on the classification of the Central Ground Water Board (CGWB 2006), as groundwater abstraction has far exceeded the net availability in several administrative blocks of the region. Similarly, the arid Kachchh Peninsula aquifer is highly water stressed, as 86 % of the annual recharge of 0.63 km^3 is extracted to meet anthropogenic demands. Reportedly, the pronounced groundwater-level decline in Gujarat has been a major cause of social divide, as only wealthy farmers were able to meet the increased groundwater drilling and pumping costs (Dubash 2002). Though water saving technological interventions in the form of micro irrigation systems (MIS) was reckoned as a long-term strategy to mitigate the problems of groundwater scarcity (in the absence of surface irrigation sources), the wide-scale promotion of the same met with setbacks initially, as micro irrigation technologies were capital intensive in nature and hence, unaffordable for smallholders. Nevertheless, the scenario had undergone significant change since, with micro irrigation systems becoming less sophisticated and less capital intensive (Polak et al. 1997; Namara et al. 2007) and thus turning into a technology with more inclusive features.

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Apparently, a frontier technology such as the MIS has been receiving wider promotion nation-wide with strong support policies also benefiting the small and marginal farmers to adopt the same in order to overcome water scarcity problems and achieve water use efficiency at the farm level. As agriculture uses the largest share of water (88–90 %), the significance of demand side management of water in agriculture by using water conservation technologies like micro irrigation systems (MIS) is pertinent for improving the yield of crops and reducing the consumptive use of water. These strategies are built on the premises that water saving technologies like sprinklers and drips enhance the yield and improve efficient use of scarce water resources. The net utilization of irrigation water in the drip system is 90 % and in the sprinkler system, it is 82 %. Though the potential benefits generated by the MIS are apparent, the adoption of such systems is yet to receive pick up on a wider scale across regions, states and elsewhere. It is found that the most ideal policy environment for promotion of micro irrigation technologies in the well-irrigated areas would be pro-rata pricing of electricity, which would create direct incentive for efficient water use (Kumar 2005). Adoption of micro irrigation systems is likely to pick up fast in the arid and semi-arid, well-irrigated areas, where farmers have independent irrigation sources, and where groundwater is scarce. Evidences show that many researchers have attempted to study the impact of micro irrigation, especially, drip irrigation (Narayanamoorthy 2005; Namara et al. 2005; Verma et al. 2004) and found that drip irrigation produces the desired positive impacts. It is reported that the drip irrigation technology is technically feasible, particularly when the farmers depend on groundwater sources (Dhawan 2000). Kumar et al. (2008) argues that real water saving is possible in North Gujarat using drip irrigation in crops grown in rows and also for water efficient crops that give greater returns per unit of land and water.

While Gujarat state continues to be one of the major promoters of micro irrigation systems, since 2009, the state government had implemented a new scheme called the ‘pressured irrigation network system (PINS) and micro irrigation system (MIS)’ under the aegis of the Gujarat Water Resources Development Corporation (GWRDC). The GWRDC, which is a special purpose vehicle (SPV) has been involved in implementing the PINS and MIS on public tubewells located in the water scarce districts of North Gujarat, viz., Banaskantha, Mehsana, Patan, Sabarkantha and Gandhinagar. The main objective of the programme is to provide multiple benefits in terms of: (a) water saving; (b) increase in production; (c) savings in power consumption along with improvements in the socio-economic status of the farmers in the state.

Given this background, the broad objective of this chapter is to present an overview of the status of adoption of MIS and its socio-economic impacts on agriculture as well as water sector in the state of Gujarat. A major concern that the paper puts forth is ‘whether and (if so) how far the water saving technological interventions in the form of micro irrigation systems, such as sprinklers and drips would create positive outcomes in terms of reducing the overdraft of groundwater sources for agriculture purposes in the state?’. It may be observed that such concerns are important as groundwater depletion adversely affects the poor farmers more. The chapter then presents the results of a rapid assessment of the impacts of the MIS in the Banaskantha district covering a sample of 375 farmers who have adopted the PINS and MIS implemented by the GWRDC. The rapid assessment survey was conducted during December 2013–January 2014 so as to identify the key research issues to be addressed in a larger study on the MIS covering six states, viz., Gujarat, Maharashtra, Rajasthan, Andhra Pradesh, Tamil Nadu and Karnataka.

5.2 Water Resources Development in Gujarat

The ultimate irrigation potential through surface and ground water sources in Gujarat is estimated to be 64.88 lakh hectares. Of this, the surface water potential is 39.40 lakh hectares (61 %) while potential for groundwater is estimated at about 25.48 lakh hectares (39 %) (GoG, Gandhinagar, 2011).

Table 5.1 presents the region-wise status of water resources potential (both surface and groundwater) as well as the relative share of each region in the total water resources and the land area. It may be seen from the table that the South and Central Gujarat regions occupying only one fourth of the land area has the dominant share (69 %) of the total water resources, comprising both surface and groundwater. In sharp contrast, the Kachchh and North Gujarat regions are facing acute shortage of water resources while commanding a larger size in land area.

The gross irrigated area of the state increased to 56.14 million ha in 2007–08 from the level of 7.3 million ha in 1960–61, though the progress of it has been slow since 1990–91 (Table 5.2) with marginal improvement in the year 2005–06 after which it gradually slowed down. From the table, it can be seen that a major part of the growth in net as well as gross irrigated area expansion in Gujarat was contributed by the growth in area under tubewells (CAGR being 6.91 %) and other wells (CAGR being 2.90), while the growth in canal irrigated area was 3.25 %.

Table 5.1 Region-wise water resources in Gujarat (million cubic meters)

Region	Total water resources (mm^3)			Storage capacity of existing reservoirs (except SSP) (mm^3)	(%) of water resources	(%) of geographical area of state
	Total	Surface	Groundwater			
1. South and Central	38,105	31,750	6355	10,400	69	25
2. Saurashtra	9723	3600	6123	2250	17	33
3. North Gujarat	6342	2100	4242	2100	11	20
4. Kachchh	1438	650	788	250	3	22
Total	55,608	38,100	17,508	15,000	100	100

Source Narmada water resources, water supply and Kalpasar Department (http://guj-nwrws.gujarat.gov.in/)

Table 5.2 Trends in source-wise net irrigated area in Gujarat ('000 ha): 1960-61-2007-08

Year	Canal sources[a]	Tanks	Tube wells	Other wells	Other sources	Net irrigated area (NIA)	Gross irrigated area (GIA)	GIA/GCA (%)	Share of tubewells and other wells in GIA
1960–61	652	128	0	5677	366	6829	7338	7.51	77.4
1970–71	2364	372	948	9883	141	13,708	14,939	14.24	72.5
1980–81	3668	409	2517	13,367	65	20,026	23,344	21.83	68.0
1990–91	4694	314	4934	14,367	67	24,376	29,105	27.37	66.3
2000–01	3942	182	NA	NA	95	28,060	33,421	32.01	NA
2005–06	7782	422	10,779	19,463	628	39,074	47,642	41.45	63.5
2006–07	7892	398	11,333	21,737	1016	42,376	52,787	44.71	62.6
2007–08	7710	454	11,222	21,805	1142	42,333	56,141	45.97	58.8
CAGR (1960–2008) (%)	3.25[b]	2.73	6.91[b]	2.90	2.45	3.96	4.42	NA	NA

Note CAGR compounded annual growth rate; and *NA* not available
[a]Includes government canals, Panchayat canals, private canals and other canal sources
[b]CAGR for the period 1970–71 to 2007–08
Source Viswanathan and Pathak (2014)

The period since 2005–06 witnessed a spurt in other sources of irrigation, which could be reckoned as an outcome of the construction and operation of 332 km long Sujalam Sufalam Spreading canal (SSSC) crossing seven districts of Gujarat and the artificial groundwater recharge programmes initiated by the state government through various schemes, such as watershed development, de-siltation and renovation of tanks, creation of farm ponds, etc. Under SSSC, water is being made available through Sardar Sarovar dam and other reservoirs and is expected to irrigate 1.2 lakh hectares through lift and groundwater recharge. Currently, the area under irrigation by groundwater sources, including tube wells and open wells accounts for over 59 % of the state's gross irrigated area. While it is important to note the initiatives of the Government of Gujarat in building rain water harvesting structures, the extent of groundwater development is 76 % (CGWA as cited by Parthasarathy 2010).

The supply and demand position of water in the state is not very encouraging. The surface water potential and the gross annual recharge to the groundwater provide the estimate of the total fresh water availability which is 54,593 MCM per year. North Gujarat accounts for 11.2 % of the total renewable freshwater of the state which is lowest after Kachchh. Given the high inter annual variability in rainfall particularly in the low rainfall regions, there were several years when the precipitation has been lower. High evaporation rates reveal that most of the streams and rivers in North Gujarat do not yield adequate water for irrigation. Out of the 185 river basins supplying major part of surface water, North, South and Central Gujarat accounts for 17 river basins with having 89 % share in the total surface water (Parthasarathy 2010).

Shah and Pattnaik (2014) observe that area under bajra, jowar and tobacco have been changed to cotton and wheat. Both these crops have shown drastic increase in irrigated area since 2004 (Table 5.3). The extension of the tubewell technology especially since mid-1970s has been the main trigger for agricultural transformation in the state[1] (Dubash 2000). The intensity of tubewell technology diffusion in Gujarat has been such that almost 60–70 % of the irrigated area under the major crops has been made possible through tube well irrigation (Viswanathan and Pathak 2014). Alongside, it was also observed that the changes in cropping pattern and production in the regions of North Gujarat, Saurashtra and Kachchh can be attributed to construction of SSSC, while the boost in agricultural production in South Gujarat, Central Gujarat and part of North Gujarat and Saurashtra can be attributed to the canal network of SSP (IRAP 2012).

Thus, it is clear that the state has increased area under irrigation by managing supply of water resources, mostly through deepening of the groundwater aquifers, along with artificial water recharging programmes as well as enhancement of canal

[1]The 1970 s and Tube wells brought a qualitative transformation in agriculture practices: fertilizer consumption grew rapidly; the use of HYV seeds increased, and cropping pattern shifted more heavily towards non-food crops and food cash crops (Dubash 2000: 116).

Table 5.3 Changes in area under major crops in Gujarat, 1980-2007-08 (000 ha)

Crop	1980–81	1990–91	2000–01	2004–05	2005–06	2006–07	2007–08	CAGR*
Rice	2001	3108	3756	4211	4270	4880	4941	3.40
Wheat	4741	4823	3295	6762	8115	9578	11,379	3.30
Jowar	335	347	105	193	84	266	300	−0.41
Bajra	1408	1730	1855	1592	1841	2116	2111	1.51
All food crops	12,656	16,272	16,914	23,090	25,842	28,015	30,574	3.32
Cotton	4435	3250	6619	9400	10,465	12,999	14,203	4.41
Groundnut	1853	1498	1127	1250	1601	2060	2291	0.80
Total oil seeds	N.A.	6923	6598	6647	7854	8365	8304	1.08
Tobacco	798	955	879	1162	1075	897	888	0.40
All non-food crops	10,688	12,833	16,507	19,705	21,800	24,772	25,567	3.28
GIA	23,344	29,105	33,421	42,795	47,642	52,787	56,141	3.30

Note * - Compounded annual growth rate for the period 1980–81 to 2007–08
Source GoG (2011). Directorate of agriculture, Gujarat State, Gandhinagar

irrigation supplies in the order of importance.[2] It is important to remember that during the recent decades, most parts of North Gujarat, Saurashtra and Kachchh, have sustained their agriculture production by depleting the aquifers (Kumar et al. 2010). The overexploitation of groundwater in terms of magnitude and intensity not only depletes water tables along with increases in the cost of pumping water but also results in deterioration of the water quality. And this has been occurring mainly in the alluvial areas of North and Central Gujarat especially in Banaskantha, Mehsana, Patan, Ahmedabad and Gandhinagar (Parthasarathy 2010).

Table 5.4 presents that the level of groundwater development in North Gujarat, Kachchh and Saurashtra regions is high compared to South Gujarat. It may be noted that the number of districts falling in over exploited category with more than 100 % groundwater development had increased from one in 1991 to four in 2004 and all these districts are from the North Gujarat.

Available estimates indicate that water use efficiency under flood method of irrigation is only about 35–40 % because of huge conveyance and distribution losses (Rosegrant 1997; INCID 1994). Within Gujarat, North Gujarat, which is the water scarce region ranks the second in terms of per capita water used for irrigation (GoG 1996).

[2]It also emerges that in a state like Gujarat, which has been facing the critical issue of groundwater over exploitation, the river basins are also closed especially in the North Gujarat. This signifies that supply side approaches to deal with groundwater depletion problems may not be a feasible solution (Kumar 2010; Singh 2013:294).

Table 5.4 Status of groundwater development across districts of Gujarat, 1991 and 2009

Region	Districts	Stage of GW development (%)		(%) change 1991–2009
		1991	2009	
North Gujarat	Ahmedabad	87.0	102.0	17.2
	Banaskantha	89.8	137.0	52.6
	Gandhinagar	83.3	165.0	98.1
	Mehsana	193.6	148.0	−23.6
	Sabarkantha	71.0	79.0	11.3
	North Gujarat	*104.2*	*125.7*	*20.6*
North West Arid	Kachchh	55.2	91.0	64.9
	North West Arid	*55.2*	*91.0*	*64.9*
Middle Gujarat	Kheda	53.3	63.0	18.2
	Panchmahals	45.5	50.0	9.9
	Vadodara	52.3	60.0	14.7
	Middle Gujarat	*51.0*	*63.4*	*24.3*
North Saurashtra	Amreli	50.8	68.0	33.9
	Bhavnagar	43.2	65.0	50.5
	Jamnagar	42.6	66.0	54.9
	Rajkot	50.8	70.0	37.8
	Surendranagar	54.6	64.0	17.2
	North Saurashtra	*48.4*	*66.6*	*37.6*
South Saurashtra	Junagadh	62.8	70.0	11.5
	South Saurashtra	*62.8*	*70.0*	*11.5*
Southern Gujarat	Bharuch	39.3	56.0	42.5
	Surat	21.7	40.0	84.3
	Southern Gujarat	*30.5*	*48.0*	*57.4*
Southern Hills	Dang	0.3	16.0	5233.3
	Valsad	30.8	40.0	29.9
	Southern Hills	*27.0*	*44.3*	*64.1*

Source Compiled from Central Groundwater Board Data

On the other hand, status of groundwater irrigation in the state as explained above presents an alarming scenario that necessitates the imperative of demand management by way of technological interventions for reducing and saving of water. Though the state has been in the forefront of adopting water saving technologies (WSTs) ever since the 1990s, a serious effort towards promotion of WSTs in the form of micro irrigation systems (MIS) has taken place only since the last decade. Empirical studies show that up to 40–80 % of water can be saved and water use efficiency can be enhanced up to 100 % in properly designed and managed MI systems compared to 30–40 % under conventional practice (INCID 1994; Sivanappan 1994 cited in Suresh Kumar 2008).

5.3 Overview of Status of Adoption and Impacts of Micro Irrigation Systems in Gujarat

Several studies prove that that drip and sprinkler methods of irrigation helps save water and improves water use efficiency (INCID 1994, 1998). While reducing water consumption, it also reduces substantial amount of electricity required for irrigation purpose, by reducing working hours of irrigation pumpsets (Narayanamoorthy 1996, 2004). Considering the importance of drip method of irrigation in the sustainable use of irrigation water, efforts are being made to propagate the adoption of drip irrigation from 1970 onwards in India (INCID 1994). Special subsidy schemes were introduced during the eighties by the central and state governments for promoting this technology since MIS is considered to be a relatively capital-intensive technology.

As per the latest available data on the status of micro irrigation adoption, the total area covered under MIS in India was about 4.94 million hectares during 2010, of which, Gujarat accounted for the sixth position with a relative share of 8 % in the total reported area under the MIS, comprising drip and sprinkler systems. The five states ahead of Gujarat in MIS adoption are Maharashtra (18.2 %), Rajasthan (18.1 %), and Andhra Pradesh (15.4 %), Karnataka (12 %) and Haryana (11 %). The total area reported under the MIS in Gujarat was 407,445 ha, comprising drip irrigated area of 226,773 ha and sprinkler irrigated area of 180,672 ha. Gujarat has a larger share of area under drip irrigation (56 %) compared to the national level (38 %).

Studies on MIS adoption in the context of Gujarat are few and far between. A recent study by Singh (2013) examines the interventions made under the North Gujarat Initiative (NGI) under the aegis of the SOFILWM supported by the IWMI. It reports that a total of 1200 farmers have adopted the MIS in the North Gujarat under the NGI with a total area of 2450 ha brought under the same over the past 7–8 years. Of this, almost 55 % of the farmers have adopted the drip system and the rest chosen the sprinkler system.

Table 5.5 presents an interesting aspect of the performance of MIS in terms of water savings compared to the traditional method of irrigation. It shows that an

Table 5.5 Savings in irrigation water use due to adoption of MIS in North Gujarat

Season	Irrigation water use (m^3/ha)			Net water saving (m^3/ha)	Water use by	
	Traditional method	Micro irrigation system	Reduction in water use (%)		Drips (%)	Sprinklers (%)
1. Kharif	43,952	40,905	−6.9	3047	52.6	47.4
2. Rabi	23,902	25,701	7.5	−1799	36.7	63.3
3. Summer	54,307	19,418	−64.2	34,888	25.9	74.1
Overall	122,161	86,025	−29.6	36,136	41.8	58.2

Source Estimations based on Singh (2013, Table 4, page 300) overall reduction of almost 30 % in the water use is achieved under the MIS and this percentage is more than 64 % during summer when water scarcity is felt the maximum. If viewed on a unit area (per hectare) basis, the MIS provides a net savings of 36,136 m^3/ha in comparison to the traditional irrigation method. As per the reported MIS installations, it may be observed that during kharif, the water consumption has been the highest for drip systems (53 %) and during Rabi and summer seasons, the sprinkler systems consume the largest chunk of water (63 and 74 % respectively).

Though with variations, the impact of MIS on the yield of crops (quintals per ha) has been reported to be quite significant and ranged from as high as 121 % in case of fodder crop, like fennel during kharif to 80 % in groundnut during summer; to 56 % in case of castor during kharif to 32 % in wheat during rabi season. In terms of area expansion, it was observed that farmers tend to allocate more area to crops that are amenable to MI systems in order to realize more benefits from the adoption of MI systems. The study also reported that the MIS adoption indirectly caused an increase in milk yield by 22 % due to the increased availability of green fodder from alfalfa and other forage crops grown by the farmers. The increase in milk yield in case of crossbred cows was more than 43 % (Singh 2013). An earlier study (Kumar et al. 2004) had also shown the yield impact of MIS on alfalfa in the north Gujarat.

5.3.1 Adoption of Pressure Induced Networks (PINS) and MIS in Gujarat

As mentioned above, the GWRDC had implemented the PINS and MIS systems on about 250 public tube wells in five districts of Gujarat, viz., Banaskantha, Mehsana, Patan, Gandhinagar, and Sabarkantha. It is reported by the GWRDC that it has kept a target of expanding the PINS and MIS to public 1100 tube wells in the state in the next few years. The scheme is being implemented by the GWRDC with the help of the Gujarat Green Revolution Company (GGRC), which acts as the nodal agency for implementation of MIS.

When started in 2009, the farmers were given 50 % subsidy for installation of PINS and MIS and as the response to this scheme was lukewarm, the Government of Gujarat had enhanced the financial subsidy to 75 % and currently, the MIS is provided on full cost subsidy for small and marginal farmers in tribal areas in particular. On an average an aggregate amount of Rs. 4–5 lakhs is being invested for installation of PINS & MIS on a tubewell and a farmer gets an average of about Rs. 50–60,000 for installation of MIS in his/her farms. Large farmers are also encouraged to install MIS with an eligible subsidy of 50 %.

As seen from Table 5.6, PINS and MIS are implemented in about 250 public tube wells covering about 1400 farmers and 1271 ha of area in five districts, viz., Banaskantha, Gandhinagar, Patan, Mehsana and Sabarkantha. Among the five districts, Banaskantha has the largest share (57 %) of tube wells installed with PINS

Table 5.6 Distribution of public tubewells with PINS and MIS in North Gujarat, 2012–13

District	Tubewells (No)	(%) share	Farmers (No)	(%) share	Total area-ha	Avg. no of farmers/tubewell	Area (ha)/tubewell	Avg. farm size (ha)
Banaskantha	143	57.2	650	47.6	642.55	4.55	4.49	1.28
Gandhinagar	24	9.6	131	9.6	122.99	5.46	5.12	1.19
Mehsana	32	12.8	244	17.9	214.43	7.63	6.70	1.11
Patan	42	16.8	285	20.9	204.02	6.79	4.86	0.91
Sabarkantha	9	3.6	55	4.0	87.15	6.11	9.68	1.76
Total	250	100	1365	100.0	1271.14	5.46	5.08	1.20

Source Compiled from GWRDC database

and MIS, followed by Patan (16.8 %) and Mehsana (13 %). Banaskantha also accounts for the highest share in the number of beneficiary farmers (48 %). On an average, a tube well benefits about 5–6 farm households across districts with a relatively smaller number close to 5 farmers in Banaskantha. The average area irrigated by a tube well under the scheme is about 5 ha with an average farm holding size of 1.2 ha across districts. Among the districts, Sabarkantha and Banaskantha districts report a relatively higher size of operational holdings (1.76 ha and 1.28 ha respectively).

5.3.2 Socio-economic Profile of Farmers Adopting PINS/MIS

A rapid assessment was undertaken during December 2013 and January 2014 covering 375 farm households who have adopted the MIS in Banaskantha district under the GWRDC scheme. The survey was undertaken primarily to understand the status of adoption and the impacts of the MIS as realised by the beneficiary farmers as well as to identify the issues and challenges that factor in the process of adoption and the successful implementation of the PINS and MIS in the specific context of Gujarat.

A brief description of the socio-economic profile of the farmers adopting PINS/MIS is made here to understand if the technology has a wider acceptance among all the socio-economic groups. Overall scenario suggests that majority of the farmers belong to semi-medium (37 %) and medium (41 %) size land categories (Table 5.7).

The very low proportion of marginal and small farmers (their combined share being 13 %) depending on the tube wells and thereby benefiting from the PINS/MIS is an important point emerging from the table.[3] This could imply that marginal and small farmers are not accessing the PINS/MIS either due to the lack of knowledge about the scheme or they get excluded from accessing the benefits from the scheme due to the interplay of local dynamics. This could also be an outcome of natural exclusion as caused by the location of the holdings around the PINS/MIS installed tube wells under the study. However, this point needs further empirical validation, which is beyond the scope of this review.

Majority of the farmers adopting the PINS/MIS belong to other backward communities (OBC) with a major share of 76 % at the aggregate level, followed by general (12 %) and scheduled caste (SC) community (11.5 %). Apparently, there was no farmer belonging to the ST category and this may have nothing to do with the implementation of the system. Rather, it may be due to the settlement pattern that prevails in the study villages.

[3]This is somewhat unusual given the fact that both marginal and small farmers together constitute almost 63 % of the total farm holdings in Gujarat as per the agricultural census 2005–06.

Table 5.7 Distribution of farmers adopting PINS/MIS across land size classes and caste

Land size classes	Farmers (%) (N = 564)	Caste	Farmers (%) (N = 564)
1. Marginal	3.4	General	12.2
2. Small	9.4	OBC	76.1
3. Semi-medium	37.1	SC	11.5
4. Medium	41.2	ST	0.2
5. Large	8.9	Total	100.0
Total	100.0		

Source Farm household survey in Banaskantha district, December 2013–January 2014

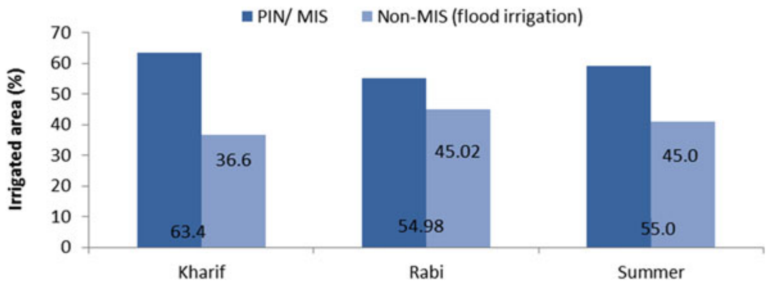

Fig. 5.1 Irrigated area under PINS/MIS versus flood irrigation, season-wise. *Source* Farm household survey in Banaskantha district, December 2013–January 2014

Figure 5.1 suggests that higher proportions of the farmers adopt PINS/MIS during all the three seasons, though the extent of use seems to be relatively higher during the kharif and summer seasons than the Rabi season.

5.3.3 Benefits of Micro Irrigation Systems in Banaskantha, Gujarat

The economic and social benefits of the PINS/MIS were captured through some of the tangible benefits that are accrued to the farmers adopting the new irrigation methods. Table 5.8 shows that majority of the responses are highly appreciative of the overall benefits accrued from the tubewells installed with PINS/MIS.

For instance, almost 88–89 % of the responses indicated that there was notable increase in yield of crops and savings in water use following the adoption of the PINS/MIS. Reductions in over extraction of ground water (61 %) as well as reduction in use of pesticides and fertilizers (55 % each) were reported to be the other major economic and environmental benefits accrued by large number of farmers. Further, majority of responses also indicated that the adoption of the PINS/MIS also resulted in a reduction in the pests and diseases (70 %) as well as savings in weeding costs (70 %).

Table 5.8 Economic, environmental and social benefits of PINS/MIS

Economic, environmental and social benefits	Total responses (no.)	(%) of positive response
A. Economic and environmental benefits		
1. Increase in yield of crops	107	87.7
2. Saving of water use	108	88.5
3. Reduces over-extraction of ground water	74	60.7
4. Reduces use of pesticides	67	54.9
5. Reduction in fertilizer use	67	54.9
6. Reduction in pest and diseases	85	69.7
7. Reduces weeding cost	85	69.7
B. Social benefits		
1. Saving of energy consumption	81	66.4
2. Efficient allocation of water among farmers	114	93.4
3. Reduced water scarcity induced labour migration	43	35.3

Note The figures are multiple responses about the benefits of PINS/MIS, based on first three responses
Source Primary survey (December 2013–January 2014)

In terms of social benefits, majority of the responses reported that the adoption of PINS/MIS has resulted in savings in energy consumption (66 %) and efficient allocation (93 %) of scarce water among the farmers. From a social angle, this has significant importance, as the new irrigation system augurs well in terms of equitable allocation and distribution of water among the farmers. Though smaller in proportion, it was also revealed from the responses that the new system of irrigation has also benefited in terms of reducing the water scarcity induced migration of labour in Banaskantha.

5.3.4 Adoption of MIS During Kharif, Rabi and Summer Seasons

A total of 506.3 ha of land area were cultivated under the tubewell during the kharif season in 2007–08 by sampled households. It has increased to 543.6 ha in 2013–14, a growth rate of 7.4 % (Table 5.9). Out of this, about 48 % of land is under the MIS, and the remaining (52 %) land under flood irrigation during the kharif season.

In the Rabi season, the total cultivated area has increased from 484.8 to 536.9 ha, at 10.8 % growth rate. Out of that, 64 % of land is cultivated under MIS and rest 36 % is cultivated under Non-MIS. The total cultivated land has slightly increased (by 2.8 %) in summer of 2012–13. Thus, among the three seasons, a higher percentage of land is brought under MIS during the summer season (74 %), compared to 64 % during the Rabi and 48 % during the Kharif seasons. Obviously, this is an

Table 5.9 Details about change in cultivation land pattern: Banaskantha District

Season	Total cultivated area (ha)			Irrigation status of total cultivated area (ha)		
	Before MIS	After MIS	(%) change	MIS	Non-MIS	Total
Kharif	506.3	543.6	7.37	259.4 (47.7)	284.2 (52.3)	543.6 (100.0)
Rabi	484.8	536.9	10.75	345.1 (64.3)	191.8 (35.7)	536.9 (100.0)
Summer	318.1	327.0	2.80	240.9 (73.7)	86.0 (26.3)	326.9 (100.0)

Note Before MIS pertains to the year 2007–08 and after MIS pertains to 2013–14. Figures in the parentheses indicate percentage
Source: Primary survey (December 2013–January 2014)

important finding emerging from the study, as there was a significant shift towards MIS adoption across seasons, which would have made significant impacts in terms of reduction in water use during the summer season. The relatively lower usage of MIS during the kharif season may be attributed to the reasonably good rainfall occurred during this season in the study villages of Banaskantha district.

5.3.5 Change in Area Under MIS During Kharif, Rabi and Summer

It may be seen from Tables 5.10, 5.11 and 5.12 that the farmers in Banaskantha grow a variety of crops during the kharif and Rabi seasons depending primarily upon the markets and the availability of irrigation sources.

As may be seen from Table 5.9, there was no significant change in the cropping pattern in the kharif season following the adoption of MIS. A notable change is that area under groundnut has increased from 56.22 ha before MIS (2007–08) to 124.26 ha after MIS (2013–14) and as high as 89 % of the area under groundnut was irrigated through MIS. Another major crop brought under the micro irrigation system was sesame and almost 83 % of the area was irrigated through MIS. Other major kharif crops that were brought under MIS were different vegetables and the MIS irrigated area under these crops was 59 %. In case of other crops, there was a perceptible shift in the use of irrigation sources as a significant proportion of the area under these crops has been brought under MIS, though flood irrigation remained as the dominant mode of irrigation. Cotton is an example, where, a larger proportion of the area (58 %) is still irrigated using flooding method. The relative share of three major rabi crops, viz., mustard, castor and wheat remained more or less the same before and after adoption of MIS (Table 5.11). Potato, reported a more than two fold increase in its area post MIS and almost 89 % of the area under potato was irrigated through MIS.

Table 5.10 Major Kharif crops grown by farmers before and after PINS/MIS

Kharif crops	Total area (ha) before MIS (2007–08)	Total area (in ha) after MIS (2013–14)	Total area (in ha) under MIS (2013–14)	(%) of total area	Total area (in ha) under non-MIS (2013–14)	(%) of total area
1. Bajra	144.74 (15.0)	108.45 (13.1)	38.59	35.6	69.87	64.4
2. Castor	256.24 (26.6)	129.73 (15.7)	43.78	33.7	85.95	66.3
3. Cluster bean	251.15 (26.1)	225.49 (27.3)	83.82	37.2	141.67	62.8
4. Cotton	57.95 (6.0)	69.07 (8.4)	28.78	41.7	40.29	58.3
5. Fodder	106.94 (11.1)	87.85 (10.6)	37.65	42.9	50.2	57.1
6. Groundnut	56.22 (5.8)	124.26 (15.0)	110.44	88.9	13.82	11.1
7. Isabgol	2.31 (0.2)	3.24 (0.4)	0.00	0.0	3.24	100.0
8. Jowar	48.18 (5.0)	46.5 (5.6)	19.78	42.5	26.72	57.5
9. Sesame	17.93 (1.9)	14.57 (1.8)	12.15	83.4	2.43	16.7
10. Others[a]	20.42 (2.1)	17.87 (2.2)	10.58	59.2	7.29	40.8
Total	962.08 (100.0)	827.04 (100.0)	385.57	46.6	441.47	53.4

Note:[a] Barli (Jau), Cauliflower, Cluster Fenugreek (Methi), Groundnut, Jowar, Cabbage, Papaya, Pomegranate, Tobacco, Tomato and Other Vegetables.. Figures in parentheses indicate the row-wise percentages
Source Primary survey (December 2013–January 2014)

Table 5.11 Major Rabi crops grown by farmers before and after PINS/MIS

Rabi crops	Total area (in ha) before MIS (2007–08)	Total area (in ha) after MIS (2012–13)	Total area (in ha) under MIS (2012–13)	(%) of total area	Total area (in ha) under non-MIS (2012–13)	(%) of total area
1. Mustard	296.12 (37.7)	273.06 (32.5)	131.65	48.2	141.41	51.8
2. Castor	239.52 (30.5)	211.96 (25.2)	81.21	38.3	130.75	61.7
3. Wheat	100.6 (12.8)	115.68 (13.8)	60.94	52.7	54.74	47.3
4. Potato	65.47 (8.3)	148.81 (17.7)	133.02	89.4	15.79	10.6
5. Cumin	30.54 (3.9)	22.44 (2.7)	3.24	14.4	19.2	85.6
6. Fodder	13.82 (1.8)	12.8 (1.5)	7.25	56.6	5.55	43.4
7. Rajgaro	10.58 (1.4)	8.99 (1.1)	6.71	74.6	2.28	25.4
8. Cotton	9.09 (1.2)	15.79 (1.9)	10.35	65.5	5.44	34.5
9. Fennel	5.78 (0.7)	3.47 (0.4)	2.31	66.6	1.16	33.4
10. Others[a]	14.75 (1.9)	27.08 (3.2)	24.64	91.0	2.44	9.0
Total	786.27 (100.0)	840.08 (100.0)	461.32	54.9	378.76	45.1

Note:[a]Others include: Barli (Jau), Cauliflower, Cluster Fenugreek (Methi), Groundnut, Jowar, Cabbage, Papaya, Pomegranate, Tobacco, Tomato and Other Vegetables. Figures in parentheses indicate the row-wise percentages
Source Primary survey (December 2013–January 2014)

It is also important to note that unlike the kharif season where the share of cotton area irrigated through MIS was smaller (40 %), during Rabi season there was an increase in absolute area under cotton in the post MIS period and almost 65 % of this area was irrigated through the MIS. In case of other crops, such as fodder crops,

Table 5.12 Major Summer crops grown by farmers before and after PINS/MIS

Summer crops	Total area (in ha) before MIS (2007–08)	Total area (in ha) after MIS (2012–13)	Total area (in ha) under MIS (2012–13)	(%) of total area	Total area (in ha) under non-MIS (2012–13)	(%) of total area
1. Bajra	382.15 (80.5)	371.92 (77.9)	219.04	58.89	152.88	41.11
2. Castor	10.27 (2.2)	8.16 (1.7)	3.47	42.55	4.68	57.45
3. Fodder	63.94 (13.5)	70.91 (14.9)	44.94	63.38	25.97	36.62
4. Groundnut	0.00 (0.0)	1.74 (0.4)	1.74	100.00	0.00	0.00
5. Cluster bean	3.38 (0.7)	6.85 (1.4)	3.85	56.12	3.01	43.88
6. Jowar	7.87 (1.7)	7.40 (1.6)	0.93	12.50	6.48	87.50
7. Papaya	0.00 (0.0)	2.02 (0.4)	2.02	100.00	0.00	0.00
8. Pomegranate	1.16 (0.2)	3.99 (0.8)	3.99	100.00	0.00	0.00
9. Other Veg.	6.25 (1.3)	4.51 (0.9)	4.05	89.74	0.46	10.26
Total	475.01 (100.0)	477.50 (100.0)	284.02	59.48	193.48	40.52

Note Figures in parentheses indicate the row-wise percentages
Source Primary survey (December 2013–January 2014)

fennel and Rajgaro, higher proportion of area was irrigated under the MIS. Only in case of three major rabi crops, viz., cumin, castor and mustard that flood irrigation was used as a dominant method. It also emerges from the table that about 53 % of the area under wheat was brought under the MIS. Unlike other two seasons, the cropping pattern of farmers growing crops in summer before and after MIS remains the same (Table 5.12). However, in case of most crops, the proportion of area irrigated under the MIS was very high (56–100 %), except two crops, viz., Jowar and Castor, in which, the proportion of area irrigated using flood irrigation was 87 and 57 % respectively. In terms of area, two major crops, viz., Bajra and fodder crops have occupied the larger share of area under MIS (80 and 15 % respectively).

5.4 Emerging Issues

From the above analysis, it emerges that the MIS per se has been able to provide several benefits to the farmers who have adopted the same. The benefits by and large included increase in yield of crops, increase in area under high value crops, including fodder and horticultural crops, savings in water, etc.

Nevertheless, it may be observed that there are more indirect social, environmental, ecological as well as hydrological benefits than the mere socio-economic benefits reported by the farmers from the adoption of MIS. It is important to note that these benefits remain to be largely under-reported or less understood and appreciated by the researchers.

Moreover, there are several social, agro-ecological and hydrological challenges facing the wide-scale promotion and adoption of MIS across states in India and these issues and challenges remain to be a grey area under research. Perhaps, understanding these challenges would help us explain better 'why the adoption of micro irrigation systems in India still continues to be abysmally low despite the earnest efforts made by the state governments to promote the MIS through provision of financial subsidies and incentives'?

Water being a scarce commodity with increasing inter-sectoral demand all across the states of India, it is much more important to understand the: (a) larger social impacts of the MIS interventions in terms of 'real water savings' as achieved; and (b) the kind of institutional reforms needed as well as the social, political and cultural regime shifts required to appreciate the real value of water in the fast changing rural environments.

When the poverty reduction impact of micro-irrigation technologies was assessed it was revealed that the largest sections of adopters were farmers that fall into the wealthier categories. In Gujarat, the distribution was somewhat even amongst the middle, rich and the very rich farmers-whereas in Maharashtra, the richest farmers in the sample represented the highest proportion.

The low cost and compatibility of micro-irrigation systems for small cultivators lends itself to targeting the poor, but without specific institutional support and strategies a market for this technology cannot be created, and its uptake will be slow. Hence the most important aspects that influence the adoption of micro-irrigation are the efforts of policy makers and organizations in long-term service provision and training. Policies must have a strong poverty focus that emphasizes the potential to improve incomes and outputs for poor farmers, while building awareness and demonstrating the potential of micro-irrigation technologies in accordance with their priorities and concerns.

Most of the past work which has analyzed the impact of MI considered plot and field as the unit, assuming that the cropping system remains the same and only the irrigation technology changes. While MI adoption is also associated with changes in cropping systems, with the high valued crops replacing traditional cereals and an expansion in the area under crops and irrigation, such an analysis will not provide a holistic assessment of the impact of the technology on overall farm income, food security and agriculture water use. Further, past research has not made a distinction between water saving at the field level and water saving at the farm level, nor between "applied water saving" and real water saving. Therefore, in order to capture the impacts on regional level water use in agriculture, groundwater sustainability and food security, the unit of analysis needs to change from plot and field to the farm.

An alternate scenario is that if large numbers of farmers from a region succeed in adopting new farming systems based on market-oriented crops with the use of micro-irrigation technologies, then this can even motivate them to replace the traditional cereal crops in their farms with the high value cash crops for earning greater income. This was the trend found in the north Gujarat region, where large-scale adoption of micro-irrigation systems along with fruits and vegetables occurred, with some shrinkage in the area under cereals such as wheat and bajra. But, similar trends can cause regional food shortages and food inflation and in fact, this aspect needs further investigation empirically.

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Chapter 6
'Wet' Water Saving and Social Benefits from Micro Irrigation: A Study from IGNP Command Area in Rajasthan

M. Dinesh Kumar

6.1 Introduction

Problems of water scarcity are growing in many arid and semi-arid regions in India. In view of the fact that agriculture consumes lion's share of total water diverted in these regions (GOI 1999; Kumar 2010), micro irrigation is advocated by the government of India (GOI) as a panacea for all problems related to water availability. The task force on micro irrigation constituted by government of India estimated the area that can be brought under micro irrigation systems as 97 m ha. But, little attention has been paid to the constraints facing the farmers in adopting this system such as erratic power supplies; and lack of clear economic incentives for saving water and energy due to their inefficient pricing. The existing cereal centered cropping systems, and the small sized land holdings are other physical constraints (Kumar et al. 2008). Particularly, in canal commands the delivery of water under gravity makes it difficult for farmers to adopt MI systems as they have to go for intermediate storage systems and pressurizing devices, which in turn calls for capital investments in addition to that was required for the MI system making it economically unviable. With the least recognition of these constraints, government employ subsidy as an instrument for promoting adoption.

Another important question which remains unanswered is whether subsidies are really justifiable. Subsidies are desirable when the social benefits exceed the social

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costs, whereas private benefits do not exceed the investment farmers have to make. Water saving and yield enhancement are generally perceived as positive externalities of MI adoption on society. Exchange of farm labour is perceived as a negative externality (Dhawan 2000). However, water saving through efficient irrigation systems can be 'dry' (notional) or 'wet' (i.e., real).[1]

The extent of real or 'wet' water saving from the use of micro irrigation depends on climate, soils, crop type, type of MI technology and geo-hydrological environment (Kumar and van Dam 2013). However, as pointed out by Ward and Pulido-Velazquez (2008), studies that link 'wet' water saving to water conservation measures are rare. The impact of MI adoption on farm labour depends on the socio-economic conditions of the region and the change associated with MI adoption in the farming system. Exchange of farm labour induces negative externalities on employment in regions where labour supply is abundant (Devaraju and Palanisami 2010). However, there is hardly any research available from India to throw light on these issues.

On the other hand, many research studies done in the past seem to suggest that the micro irrigation systems, particularly drip systems are viable for the farmers when the full private costs of the system are compared against the private returns. Hence, subsidies may not be desirable from an equity point of view as it is mostly large farmers having capital who will go for micro irrigation systems.

The general perception is that MI adoption leads to increase in yield (kg/ha), water saving; increase in area under irrigation due to reduction in water requirement per unit area, and advancement in produce harvest, all resulting in social benefits. But, most of these perceptions are based on research on drip irrigated farms of orchards and cash crops. Again, these studies looked at 'applied water' rather than actual crop water use (Kumar et al. 2008) and the distinction between the two is hardly appreciated by policy makers and practitioners (Perry 2007).[2] Also, studies concentrated in agriculturally prosperous regions such as Tamil Nadu, Maharashtra and Gujarat, where labour is in short supply, which motivate the researchers to treat reduction in labour use as a social benefit of MIS. In the absence of rigorous analysis of the physical and socio-economic aspects, the social benefits tend to get over-emphasized, and costs ignored.

A research study on drip irrigated cotton showed a 114 % increase in yield and 45 % reduction in applied water (Narayanamoorthy 2008). The effect of climate, geo-hydrological environment, crop type and type of technology used were never considered in assessing the physical impacts of MI adoption on water and energy use, which determine the real economic and social benefits. The potential negative

[1]Notional or 'dry' water saving in agriculture through efficient irrigation occurs when there is reduction in water applied to crops, whereas real or 'wet' water saving through efficient irrigation occurs when there is reduction in water consumed in crop production. In both the cases, the crop output is expected to be the same as that under traditional method of irrigation or higher (Seckler 1996).

[2]As pointed out by Perry (2007), inability to make this important distinction leads to flawed recommendation on saving water from irrigation systems for other uses such as canal lining, use of efficient irrigation technologies, and improved agricultural practices.

impacts of MI system adoption can have on society (social cost) such as reduced labour absorption in agriculture were generally ignored, and instead the labour saving impact was highlighted as a private benefit. Part of the reason might be the fact that large-scale MI adoption takes place in regions where agriculture is progressive, and labour is in short supply.

The research on the actual physical and economic benefits from sprinkler irrigation is very scanty in India (Kumar et al. 2008).

6.2 Context

One striking example for large-scale and intensive adoption of MI systems is the Indira Gandhi Nahar project–Phase-I located in Bikaner district of Rajasthan. With the growing problems of water logging and salinity in the command area, and inter-state conflict over sharing of water, government motivated farmers to use a local system called *Diggie* to store canal water in order to make water use more efficient. Construction of the diggie enables farmers to use the water for irrigation as and when required. It also enables them use pressurized irrigation techniques like sprinkler irrigation.

While the large scale adoption can be attributed to high returns against the investments, the subsidies being made available to the farmers play an important role in raising the net returns. In Rajasthan case, the government gives a maximum subsidy of Rs. 40,000 for constructing a *Diggie*. This is in addition to the subsidy for MI systems which GOI provides. In Lunkaransar taluka of Bikaner district, farmers had adopted sprinkler irrigation for their existing crops on a large-scale. A properly designed lay-out of a sprinkler system ensures relatively uniform application of water over the field. Sprinkler systems are usually designed to apply water at a lower rate than the soil infiltration rate, so that the amount of water infiltrated at any point depends upon the application rate and time of application. But, it is important to note that the distribution efficiencies would be low in sprinkler irrigated fields, it the fields are small. This is due to high edge effects.

6.3 Physical and Socio-economic Characteristics of the Study Area

As discussed earlier, the physical impacts of use of micro-irrigation technology in a particular region depends on soil, climate, geo-hydrology and crops (Kumar and van Dam 2013). The economic dynamic of micro irrigation depends on the socio-economic factors, including the land-holding pattern, crops, nature of access to irrigation sources etc. (Kumar et al. 2008). Hence, it is important to discuss the physical and socio-economic profile of the region to analyze the physical impacts, and economic and social benefits of sprinkler adoption.

6.3.1 The Location and Its Physical Environment

Bikaner is one of the desert districts situated in the north-west of Rajasthan. It is bound in the north by districts of Sri Gangbanger, on the west by Jaisalmer and Pakistan, Churu in the east and Nagaur and Jodhpur in the south-east. Jaipur, Ganganagar, Amritsar are some of the important cities near to this district. The district is situated between the latitude 27°11′03″–29°03′ north and longitude 71° 54′–74°12′ east comprising a total geographical area of 27,244 km^2.

The district's climate varies from arid in the east to extremely arid in the west. The mean rainfall of the district is 247 mm varying from 300 mm in the east to 180 mm in the west bordering Pakistan with coefficient of variability ranges from 50 to 65 %. The annual potential Evapotranspiration is 1770 mm. The mean maximum temperature ranges from 24.4 to 47.9 °C and mean minimum from 7.3 to (−)1.2 °C. Frequent drought once in 2.5 years is a common phenomenon.

Soils of this district are predominately light textured, weak structured and well drained. Moderately deep to very deep, loamy sands, sandy loams and loam soils occur on the flat aggraded older alluvial plaints and flat interdunal plains. Deep to very deep, fine sandy to fine loamy sand soils occur on the undulating sandy aggraded older alluvial plains and undulating interdunal plains and very deep fine sands on the dunes.

6.3.2 Socio-economic Conditions

The total population of the district is 1,673,562 (1,079,060 rural and 594,502 urban) with a density of 61 persons/km^2 and literacy rate of 46.55 % as per 2001 census. The district has 580 inhabited villages and 67 uninhabited villages. Cultivators account for nearly 45 % of the workforce in the district, and agricultural labourers are only 4.6 %. The other workers account for 49 % of the workforce.

As per 2000–01 land use statistics, the net sown area is 45.43 % of the geographical area; forest constitute 2.68 %; area not available for cultivation, 8.36 %, barren and uncultivable land 1.27 %, permanent pasture and other grazing land 1.27 %, cultivable waste 26.77 %, other fallow lands 8.93 %, current fallow 4.84 %, respectively. The area, which is cropped twice, is only 2.84 %.

Out of the 2.33 lac ha of irrigated area, 84.91 % is served by IGNP canal system and rest is served by wells and tube well. Groundnuts, American cotton, Guar, Kidney beans (Moth), Bajra, Green fodder are the main crops grown in Kharif season. Except bajra all other crops are cash crops. Wheat, mustard, cow-pea, are the main crops in Rabi season. Wheat is grown only for home consumption. Horticulture crops or vegetables are not grown in slightest in the region.

6.3.3 Indira Gandhi Nahar Project

The Indira Gandhi Nahar Project (IGNP) is one of the largest water resources projects in the world, aiming to transform the desert into an agriculturally productive region. The IGNP was conceived and executed to utilize 9393 MCM of the 10,608 MCM of water allocated to Rajasthan from Ravi-Beas in order to convert 1.96 m ha of land in the arid desert. The project aims at drought proofing, providing drinking water, improving environmental conditions, afforestation, employment generation, rehabilitation of project affected people, livestock development and increasing agricultural production in the region. With the advent of the project, the life pattern of the people in the area had dramatically changed.

The problems of vertical drainage of water in IGNP command area are quite well known. This is created by the occurrence of impervious layer between the water table aquifer and deep aquifers. Gypsum-Ferrous layer is present just below the surface layer of soil. It is an impervious layer and it is very thick. As the soil of the area are coarse textures with a significant amount of sand resulting in low water holding capacity. The percolate water is deposited over the Gypsum-ferrous layer and as a result stagnation of water the water table has been increased considerably. The evaporation of this water is possible because of the capillarity action of sand dunes; this is the prime reason of the salinity of the land.

6.3.4 Reasons for Sprinkler Adoption

Three factors have contributed to sprinkler and diggie adoption. They are presence of upland, which cannot be watered by gravity flow from canals; sharp reduction in water availability; and availability of subsidy for purchase of sprinklers and construction of diggie. Since there has been a remarkable reduction in the supply of canal water, the timeliness of water availability reduced, affecting the quality and reliability of irrigation. Here, the *Diggies* act as an intermediate storage system for the water. The diggie and the pumping devise together increase their ability to improve the quality and reliability of irrigation. Although the farmers are not able to irrigate the land adequately, they can now irrigate more land both by virtue of the pressurizing device. Subsidies also act as a motivation for the farmers to adopt the MI system.

6.4 Objectives and Methodology

The objectives of the study are: to analyze the farming systems changes associated with MI adoption adopt micro-irrigation systems in Indira Gandhi Canal command area; and to evaluate the economic and social cost benefits of micro irrigation adoption in the region.

Generally, the variable affecting the economic dynamic of micro irrigation adoption in Bikaner region are: (i) change in crop yield; (ii) change in area under irrigation; (iii) change in cost of crop cultivation; and, (iv) change in value of the produce (Dhawan 2000). But, how these variables get altered depends on the socio-economic conditions of the farmers and the region under consideration, the climate and the geo-hydrological environment (Kumar 2007). In the following section, we would discuss how each one of these variables had been altered due to sprinkler irrigation.

Often in the context of MI, the reduction in water applied due to prevention of deep percolation is counted as a private benefit. But, as Dhawan (2000) cautions, such private benefits can be over-emphasized in situations where the deep percolation appears as return flows to the shallow aquifer and recharge to the well. Nevertheless, such private benefits are applicable in situations where farmers are confronted with marginal cost of using water. Since, the farmers here are not paying for canal water on volumetric basis, changes in volumetric consumption of water due to adoption of micro irrigation system does not lead to cost saving for the farmers.

Whereas, in regions of water shortage, the social benefits due to water saving could be enormous (Devaraju et al. 2010). However, the actual social benefit depends on the extent of real water saving, rather than saving in applied water (Dhawan 2000). Real water saving comes from reduction in non-beneficial evaporation from soil, and non-recoverable deep percolation (see Allen et al. 1998 for details). Real water saving due to MI depends on several physical factors (Kumar et al. 2008; Kumar and van Dam 2013). In regions, with semi-arid and arid climatic conditions and light textured soils and deep water table conditions, the real water saving comes from reduction in non-beneficial evaporation and non-recoverable deep percolation (Kumar et al. 2008; Kumar and van Dam 2013). Again, since return flows create water logging and soil salinity problems, it can be treated as non-beneficial depletion of water. Hence, in the present condition, the applied water saving can be treated as real water saving.

6.4.1 *Sampling Frame, and Method of Data Collection*

The universes of sampling were the villages of Lunkaransar taluka of Bikaner district. Four villages Rozha, Phuldesar, Badadelana and chotadelana were selected. The farmers were selected randomly. A group of thirty farmers who had adopted diggies and use sprinkler irrigation and 30 other farmers who have not adopted diggies and use sprinkler irrigation were chosen for the analysis.

Structured interview using questionnaire were conducted. Based on the questionnaire the data on the cost and benefit components of crop cultivation were collected. The main constituents of cost components are: inputs viz., fertilizers, manure, seeds; labour cost; quantity; transportation; cost of maintenance of MI system; and water charges. The crop returns are: the main product; and the by-product (for wheat, cluster bean and groundnut); and fodder.

6.4.2 Analytical Procedure

The social cost-benefit of micro irrigation adoption was evaluated by taking the ratio of the sum of private benefit and positive externalities associated with MI adoption and the sum of private cost of MI adoption and the negative externalities associated with adoption. On major assumption involved in the evaluation of both positive and negative externalities associated with MI adoption is that the externalities are a linear function of the area irrigated.

The variables to be considered for evaluation of social costs and benefits were decided after preliminary field investigations. These investigations provided insights into the nature of positive and negative externalities associated with sprinkler adoption. Reduction in the amount of water consumed for crop production was identified as a major positive externality. Expansion in the irrigated area and the proportional increase in crop yield were identified as major private benefits of sprinkler adoption. This is contrary to what has been found in most cases due to adoption of MI systems.

The private benefit-cost ratio for sprinkler irrigated crops was evaluated by taking the ratio of the difference between the aggregate net private return from all the sprinkler irrigated crops and the aggregate net private returns from all the flood irrigated crops prior to adoption for the same water supply conditions (as post adoption); and the sum of annualized capital cost and annual operation and maintenance of the systems. Both numerator and denominator were estimated per unit area of the sprinkler system. This can be expressed mathematically as:

$$B - CRatio = \frac{\left[\sum_{i=1}^{m} NR_{SPRINK,i} * ASUM_{SPRINK,i} - RF * \sum_{j=1}^{n} NR_{FMI,j} * ASUM_{FMI,j}\right]}{C_{SPRINK}} \quad (6.1)$$

Here,

$$RF = \frac{\left[\sum_{j=1}^{n} V_j\right]}{\left[\sum_{i=1}^{m} V_i\right]} \quad (6.2)$$

Here, $NR_{SPRINK,i}$ and $NR_{FMI,j}$ are the weighted averages of the net private return for all the farmers growing sprinkler irrigated crop i, and flood-irrigated crop j, respectively. $ASUM_{SPRINK,i}$ is the sum of the area under crop i from all the sprinkler adopter farmers in the sample. $ASUM_{FM,j}$ is the sum of the area under crop j, which is flood-irrigated, from all farmers. Here, V_i and V_j are the volume of water allocated to crop i by all farmers in the sample using sprinkler irrigation, and allocated to crop j by all farmers using flood irrigation, respectively.

Water saving benefit through sprinkler adoption (Δ_{SPRINK}) is the difference between the amount of water that is actually needed to produce the current economic outputs from the farms under traditional method and the actual amount of water used for production currently.

$$\Delta_{SPRINK} = \frac{\left[\sum_{i=1}^{m} NER_{SPRINK,i} ASUM_i\right]}{\left[\sum_{j=1}^{n} \theta_{FMI,j} * V_j / \sum_{j=1}^{n} V_j\right]} - \frac{\left[\sum_{i=1}^{m} NER_{SPRINK,i} ASUM_i\right]}{\left[\sum_{i=1}^{m} \theta_{SRPINK,i} * V_i / \sum_{i=1}^{m} V_i\right]} \tag{6.3}$$

Here, $NER_{SPRINK,i}$ is the net economic return from the sprinkler irrigated crop i. $\theta_{FMI,j}$ is the water productivity for crop j in economic terms under flood method of irrigation. $\theta_{SPRINK,i}$ is the water productivity for crop i in economic terms under sprinklers. Water productivity is estimated using the functional formula, by dividing the net returns from crop production and the volume of water applied.

The positive externality induced by sprinkler use for irrigation through water saving is estimated by multiplying the average volume of water that can be saved from unit area under sprinkler irrigation, and the average net return under flood-irrigated crop from unit volume of water (it is same as the overall net water productivity for flood-irrigated crop). Mathematically, it can be expressed as:

$$\left[\frac{\sum_{j=1}^{n} NR_{FMI,j} ASUM_j}{\sum_{j=1}^{n} V_i}\right] * \frac{\Delta_{SPRINK}}{\sum_{i=1}^{m} ASUM} \tag{6.4}$$

The social benefit-cost ratio is estimated by taking the ratio of the sum of private benefit +positive externality and the sum of private cost and negative externality. This is basically adding up of Eqs. (6.1) and (6.4).

The net water productivity in relation to applied water for different crops under flood method of irrigation were estimated by taking the ratio of net return from crop production and the total volume of irrigation water applied. Similarly for sprinkler irrigated crop, the net water productivity was estimated by taking the net return and the volume of water applied through sprinklers.[3] Here, it is assumed that the rainfall contribution of yield is negligible, and that the entire yield comes from irrigation only.

[3]The volume of water applied through sprinklers for each plot was estimated by multiplying the average number of sprinklers for a unit area of plot, with the discharge of the sprinkler, number of irrigations, the hours of irrigation per watering and the area of the plot.

6.5 Analysis and Results

6.5.1 Changes in Crop Inputs

Comparison of data on crop inputs for flood irrigated crops and their sprinkler irrigation counterparts was made for the four main inputs, viz., seed quantity, irrigation dosage, fertilizer and pesticide. The results are presented in Table 6.1. It did not show any significant change in the level of inputs except for irrigation. Under sprinkler method, farmers increased the frequency of irrigation for all crops. Though the duration of watering also increased with sprinklers for all the crops, this was due to low rate of water delivery through the sprinklers. But, closer analysis using data on discharge rates showed major reduction in water application depth under sprinkler irrigation.

6.5.2 Changes in Crop Yield Due to Sprinkler Adoption

Generally, it is believed that use of micro irrigation systems result in increase in yield due to uniform application of water across the field resulting in more uniform distribution of soil moisture, and uniform growth; frequent application of smaller dosage of water to the crop resulting in lower chances of moisture deficit and water stress, particularly prevention of moisture stress at critical stages of crop growth; optimum dosage of irrigation in each watering, preventing chances of nutrient leaching. But, in the IGNP command area, no trend was found vis-à-vis the crop yield change due to sprinkler adoption.

The major kharif crops that are grown in Lunkaransar taluka are groundnut, cluster bean, bajra and green fodder. The yield figures for these crops before and after adoption of sprinklers are compared and presented in Table 6.2. It shows that there has not been a substantial change in the yield after adoption. In case of groundnut and cluster bean, yield has decreased marginally where as for bajra it had increased marginally. Over all there is no general trend in yield. While the effect of sprinkler irrigation on yield could be both positive and negative, the availability of rains during kharif season can nullify this effect.

The major winter crops that are grown in Lunkaransar taluka are wheat, mustard, pea and green fodder. The crop yields are compared and presented in Table 6.3. It shows that the yield of green fodder has increased substantially where as that of wheat had decreased. There was marginal improvement in the yield of mustard. The yield reduction for wheat can be attributed to the poor distribution uniformity in watering which affect the crop growth adversely. It is to be kept in mind that the input factors that can potentially affect the yield, other than irrigation, had not changed after adoption. What is to be inferred is that the effect of poor distribution uniformity is much higher than that of improved quality and reliability of irrigation.

Table 6.1 Comparison of crop inputs during pre and post adoption of sprinklers

Crop	Crop inputs before adoption of sprinkler					Crop inputs after adoption of sprinkler				
	Seed (kg)	Irrigation		Fertilizer (kg)	Insecticide (Rs.)	Seed (kg)	Irrigation		Fertilizer (kg)	Insecticide (Rs.)
		No.	Hour				No.	Hour		
Kharif										
Cluster bean	14.3	1.0	1.5	0.0	283	13.1	2	5.8	0.0	292.0
Groundnut	87.3	4.5	4.3	DAP-54 U-94.2	0.0	83.2	6.8	7.2	D-53.2 U-92.1	0.0
Cotton	13.5	5.4	4.9	DAP-90 U-180	90	12.4	5.6	7.0	D-82.8 U-165.6	144.0
Green fodder	7.8	1.0	1.2	0.0	0.0	7.8	2.1	4.4	0.0	0.0
Black Gram	15	1.0	1.2	0.0	0.0	15.8	2.6	5.4	0.0	0.0
Winter										
Wheat	74.3	5.8	4.8	DAP-84 U-176	0.0	72	8.4	8.2	D-86 U-172	0.0
Mustard	4.3	3.4	4.4	DAP-54 U-92	0.0	4	5.8	7.2	D-53 U-92	0.0
Cow pea	23	1.3	2.8	34	0.0	23	2.9	6.2	D-31	0.0
Green fodder	8	1.2	1.6	0.0	0.0	7.8	2.3	3.9	0.0	0.0

Source Authors' own analysis based on primary data

Table 6.2 Impact of sprinkler use on yield of kharif crops

Name of crop	Crop yield under		Percentage change in yield (±)
	FMI (qt/ha)	Sprinkler irrigation (qt/ha)	
Groundnut	21.74	21.38	−1.7
Cluster bean	12.76	12.60	−1.3
Cotton	22.20	22.20	0.0
Bajra	15.30	22.20	+45.1

Note + indicates increase after adoption; "−" indicates decrease in yield after adoption
Source Authors' own analysis using primary data

Table 6.3 Impact of sprinkler use on yield of winter crops

Name of crop	Crop yield under		Percentage change in yield (±)
	FMI (qt/ha)	Sprinkler irrigation (qt/ha)	
Wheat	24.43	23.10	−5.4
Mustard	14.53	14.82	2.0
Cow pea	9.39	9.39	0.0
Green fodder	55.44	64.80	16.9

Source Authors' own analysis based on primary data

6.5.3 Changes in Cropping and Irrigation After Sprinkler Adoption

In well irrigation, there are no limits on the amount of water farmers can access, except those imposed by the aquifer characteristics and energy supply. But, here in this case, canal water supply is restricted, and the amount of land, which farmers can irrigate, is constrained by the amount of canal water. In the case of IGNP, the water availability from canals was adequate enough to bring all the operational holdings under flood method of irrigation. But, due to undulating terrain and higher elevation, a significant portion of the land, which cannot be irrigated through gravity flow, had to be left fallow.

But, as farmers in the area experienced drastic reduction in water supply from canals, they had to resort to more efficient method of water application even to maintain the previous levels of irrigation. The availability of subsidies for construction of diggie enabled use of sprinkler irrigation. With the adoption of sprinklers, the farmers could also bring a lot of the undulating land lying in higher elevation, under irrigation. We would examine the changes in area under irrigation for kharif and winter crops.

Table 6.4 shows that the total area under kharif crops experienced a very marginal increase of 1.7 ha. Groundnut and cluster bean area increased slightly, and more importantly, the area under irrigation increased for both the crops. The significant change due to adoption is that more area is put under irrigation. There are

Table 6.4 Impact of sprinkler adoption on area under kharif crop

Name of crop	Area under cultivation (Ha)		Irrigated area before adoption (Ha)	
	Before adoption	After adoption	Before adoption	After adoption
Groundnut	41.39	43.33	41.39	43.33
Cluster bean	136.94	136.12	53.06	60.56
Cotton	6.39	6.39	6.39	6.39
Black Gram	2.78	2.78	0.00	0.00
Bajra	3.05	3.62	2.50	3.06
Green fodder	1.68	1.68	0.00	0.52
Total	192.23	193.92	103.34	113.86

Source Authors' own analysis based on primary data

three major reasons for this increase. First: framers receive remunerative prices for this crop. Second: the agro-climate is very favorable for the cultivation of groundnut. Third: sprinkler is very suitable for irrigating groundnut. The area under irrigated cluster bean saw an increase of 12 %; and the absolute increase in area (7.5 ha) is also quite substantial. This is because cluster bean does not require much water and is mostly rain-fed. Even prior to adoption of sprinkler, the area was quite high.

In the case of cotton, the area under cultivation was also not very large prior to adoption. No change in area under this crop was seen after adoption. It is also to be noted that cotton is not amenable to sprinkler irrigation.

As regards winter crops, as Table 6.5 indicates, there has been some increase in the area under cultivation of these crops, namely wheat, mustard and cow pea. Area under wheat had increased by 0.80 ha. The main reason for this increase is that before adoption of MI system the staple food crop of the area was bajra, but with time wheat has become the staple crop, indicating a general improvement in the welfare of the people. This is in spite of the yield reduction after adoption of sprinklers. Farmers grow it only for domestic consumption. Perhaps the reason is that wheat is a water intensive crop.

The area under mustard has also increased by 2.78 ha (8 %). The main reason for increase in the area for mustard is the high returns. Also, the yield was found to be improving with sprinkler use for this crop. The farmers are able to sell the mustard for attractive price. There was increase in the area under cultivation of cow pea also, but the irrigated area did not increase. The total increase in area under cultivation is 4.3 % and that under irrigation is 3.1 %. In the case of green fodder, the irrigated area decreased by 0.55 ha.

One could argue that change in area under crops in such plots cannot be attributed to sprinkler adoption. But, given the fact that the rainfall is quite low, during droughts these crops also will have to be irrigated. The absence of proper water lifting and irrigation device prevents farmers from taking crops in these plots as the investment for crop inputs would be lost in situations of droughts. But, the

Table 6.5 Impact of sprinkler adoption on area under winter crop

Crop	Area under cultivation (Ha)		Irrigated area (Ha)	
	Before adoption	After adoption	Before adoption	After adoption
Wheat	28.61	29.44	28.61	29.44
Mustard	35.00	37.78	33.891	36.68
Cow Pea	48.33	49.72	32.78	32.78
Green fodder	3.62	3.62	3.33	2.78
Fennel	1.39	1.39	1.39	1.39
Total	116.95	121.95	100.00	103.07

Source Authors' own analysis based on primary data

access to storage system and the sprinkler technology enables the farmers to take crops in plots which otherwise cannot be irrigated under gravity. Hence, this is a positive externality of sprinkler and diggie adoption.

6.5.4 Impact on Livestock Rearing

Livestock forms the organizing feature of the region's farming system. The farmers of the area keep cow, buffalo, goat and camel. The number of livestock per family ranges from two to 20. The livestock holding per family had remained more or less constant over the past many years. When the animals give birth to new ones, the farmers either sell either the calf or the older animals according to the need.

The farmers keep cows and buffalos mainly for dairying. The average production of milk per animal in the area varies from 2 to 5 L per day. The farmers own only the local breed of animals. The amount of feed supplied to the animals varies from 10 to 15 kg per animal each time, with a two-time feeding generally practiced. The fodder is available from within the farm. It includes both green and dry fodder. The residents of the area do not buy milk from the others. They meet their household milk demand from their cows and buffaloes. The excess milk is sold to either the local trader, who makes *mawa* out of it, or to Urmul diary. The price of milk varies from Rs. 10 to Rs. 12 L. The farmers also keep camels for ploughing and transport.

The area used to face severe seasonal fodder shortages in the past. To overcome this, a practice that was prevalent in the area till a few years ago is that during scarcity, one or two persons from the village would collect the cattle from the entire village. These animals would be taken to the neighbouring state of Punjab where plenty of green fodder is available. These animals are taken back to the villages only with the onset of monsoon season when sufficient amount of fodder is available locally. Now-a-days, with the introduction of IGNP waters, farmers produce fodder in their own farms and the shortfall is met through purchase from the local market. Under conditions of water shortage, it is the use of sprinklers which enables the farmers to sustain the area under fodder crops and also those crops which have byproducts that can be used as fodder. This can be treated as a positive externality of sprinkler adoption.

6.5.5 Impact of Sprinkler Irrigation on Crop Water Productivity

Water productivity in crop production can be defined in terms of biomass production for every unit of water used or the net income return per unit of water used. The crop water productivity could be estimated either in relation to the amount of water applied (applied water productivity); or the amount of water consumed by the crop (productivity of consumed water ET) or the total amount of water applied, i.e., irrigation plus the effective rainfall (Kijne et al. 2003). Water productivity in crop production could be manipulated by improving the crop (biomass) output through crop management involving agronomic practices, nutrient management or crop technology management, or by reducing water use through on-farm water management.[4]

Table 6.6 shows that the water productivity for ground nut, cluster bean, mustard and pea are high and for wheat and green fodder is lower under both flood-irrigation and sprinkler irrigation. The reason for high productivity of mustard is that the income per unit of land is high (Rs. 22,000/ha), and is low water-consuming. The reason for low water productivity of wheat is that it is a water intensive crop and takes nearly 2–3 times more water than mustard, while the net returns is more or less same as that of mustard.

Water productivity for cluster bean is also very high. The reason being it requires only 1–2 irrigations. Despite being a water-intensive crop, water productivity for ground nut is high. The reason is that the net return from this crop under both flood and sprinkler irrigation (Rs. 43,700 and 35,500/ha, respectively) is highest among all the crops grown. The slight increase in area under cultivation for mustard from 35 to 37.78 ha (see Table 6.5) is a clear indication that the farmers use their land efficiently so that they can get the maximum returns out of that.

Comparison between sprinkler-irrigated crops and flood-irrigated crops shows that the water productivity values are higher under sprinkler irrigation for all the eight crops. For the remaining crops, since farmers have not irrigated, the estimates of irrigation water productivity are not available. The difference is quite substantial for cluster bean, ground nut and cow pea. The enhancement in water productivity has mainly come from the reduction in applied water in the case of sprinkler irrigated

[4]On farm water management can be through any of the following measures: (i) reducing conveyance losses in irrigation water delivery; (ii) applying optimum dosage of water; (iii) ensuring water application at critical stages of crop growth; and (iv) efficient use of rainwater. First and second measure reduces non-beneficial depletion. The third measure increases the yield response to ET; and the fourth measure reduces the irrigation water requirement and total water depletion.

Table 6.6 Applied water productivity of kharif and winter crops under sprinkler and flood irrigation

Sr. no.	Name of crop	Applied water productivity (Rs./m^3) under Sprinkler	Applied water productivity (Rs./m^3) under flood irrigation
Kharif season			
1	Ground nut	24.24	10.24
2	Cluster bean	34.00	18.27
3	Cotton	13.86	8.31
4	Bajra	10.47	5.55
Winter season			
1	Wheat	8.38	4.19
2	Mustard	20.23	6.69
3	Green fodder	7.74	4.68
4	Cow pea	25.49	8.72

Source Authors' own analysis based on primary data

crop rather than enhancement in net returns. We would see in the subsequent section that the net returns are much higher under flood irrigation for most crops. In the case of cluster bean, cow pea, green fodder and bajra, some farmers were found to be growing the crop under rain-fed conditions. For these crops, those farmers who are irrigating these crops are only considered for water productivity estimates.

6.5.6 Incremental Economic Benefits from Sprinkler Usage

Past research on economics of micro irrigation favoured well irrigators. Two important considerations were involved in the analysis. They are: (i) increase in net crop return from unit area of micro irrigated plot over that irrigated using conventional method; and, (ii) potential return from the additional area that could be brought under irrigation using the water saved through use of micro irrigation. While the first was realistic, the second consideration assumed that physical scarcity of water does not permit the farmers from expanding the area under irrigation prior to adoption. Such analyses were not based on any field evidence of area expansion due to MI adoption. Such considerations are valid for situations where wells are the source of water.

But, here, canal is the only source of irrigation water for the farmers, in which case the amount of water which farmers can access is limited. Under such situations, the criteria for assessing the economic performance should be: increment in aggregate return from all the crops that are irrigated with sprinklers, including the expanded area. Here, the validity of the assumption about area expansion can be tested. Unfortunately, the farmers experienced a major deficit in the volumetric water availability, which prompted them to undertake diggie construction and sprinkler irrigation for their crops. Hence, comparing the net return from sprinkler

Table 6.7 Net return from kharif and winter crops under flood and sprinkler methods of irrigation

Sr. no.	Name of crop	Net return (Rs.) per ha of land under	
		Flood irrigation	Sprinkler irrigation
Kharif crops			
1	Groundnut	43,693.0	35,538.0
2	Cluster bean	23,960.0	16,110.0
3	Cotton	36,586.0	21,959.0
4	Bajra	6644.6	6633.0
Winter crops			
1	Wheat	23,637.0	17,497.0
2	Mustard	22,012.0	24,054.0
3	Green fodder	6165.0	6790.0
4	Cow pea	11,618.0	12,330.0

Note The net return is exclusive of the cost of sprinkler system
Source Authors' own analysis based on primary data

irrigated crop area against the flood-irrigated crop areas does not make sense. The volume reduction should be factored into the area under conventional method of irrigation to make the comparison realistic. Using Eq. (6.2), we have estimated the total amount of water used by the farmers in our sample both prior to and after adoption of sprinkler system. The difference was quite substantial and it corroborated with what farmers reported. While the total water use was 0.638 MCM before adoption of sprinkler, it was reduced to 0.237 MCM, which forced farmers to go for micro irrigation. The reduction factor was estimated to be 0.371.

To begin the economic analysis, the net income return per unit area of land was worked out for all the irrigated crops for both flood method of irrigation and sprinkler method of irrigation. The results are presented in Table 6.7 (Also see Fig. 6.1).

As Table 6.7 indicates, the mean values of net return per ha of the crop is much higher under flood irrigation for four crops, and lower for three crops. Further, the average reduction in net return per unit area for the first set of crops is higher than the average rise in return for the second set of crops. This does not mean that the aggregate returns would be lower under sprinkler irrigation. The reasons are many: (1) every farmer grows more than one crop in each season; (2) the net outcome of sprinkler adoption in terms of change in net return would depend on how much area the farmer allocate to each crop. Nevertheless, it is important to note that comparative income return won't be an important consideration for farmers to go for sprinkler irrigation. The reason is the water supply situation had changed. With heavy rationing of water, the productivity of water would become the most important consideration for farmers rather than returns from unit area of land.

The economic returns from sprinkler irrigation were estimated using the figures of aggregate incremental returns from sprinkler irrigated plots over plots irrigated under conventional method of irrigation (0.371 * 203.37 ha). The incremental return per unit area was deduced from this figure based on the figure of the total

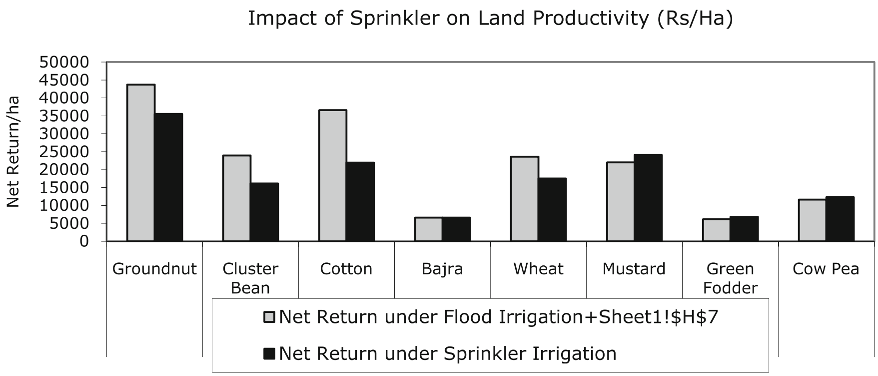

Fig. 6.1 Impact of sprinkler on land productivity (Rs./Ha)

area under sprinkler irrigation (215.57 ha). This was compared against the incremental cost of the sprinkler per unit area covered by the system (Rs. 7519.8/ha). The incremental return was estimated to be Rs. 15,937/ha. Hence, the private cost-benefit ratio for the system is Rs. 2.11. The reason for the high benefit-cost ratio is the unique characteristic of the system itself. The system is movable, and with just with an extra HDPE pipes to be used as main pipe, the same set could be used to irrigate large area, provided sufficient labour is available.

Table 6.8 shows that the net return from sprinkler irrigated crops (Rs. 53.74 lac) row 3, column 3) is slightly higher than that of flood-irrigated crop (Rs. 52.25 lac). The net incremental return per ha is negligible, and is far less than the additional cost which farmers have to incur for sprinklers, which is Rs. 7519.8/ha. But, if we consider the fact that the volume of water available for crop production has been much lower for the post adoption scenario, the effective incremental return from sprinkler-irrigated crops becomes Rs. 15,937/ha. The positive incremental return is mainly due to the effective increase in area (see numerator of Eq. 6.1 in methodology section) from 75.44 to 215.57 ha. Table 6.8 shows that both the private cost benefit ratio and economic benefit cost ratio are more than 1.0. Hence, it can be concluded that farmers would have incentive to adopt the systems even if subsidies are not available.

6.5.7 *Social Benefits from the Use of Sprinklers*

The most significant social benefit in the region due to adoption of sprinkler irrigation is real saving in irrigation water. This is in view of the scarcity value of the resource being acutely felt in this arid region with growing competition from other sectors such as industry and urban drinking, in addition to that from farmers in other parts of IGNP command. The non-adoption of sprinkler irrigation would have

Table 6.8 Private costs and benefits from sprinkler irrigation

Attributes of costs and benefits of sprinkler irrigation	Amount in Rs.	
	Aggregate	Per ha
Net return from crops irrigated by FMI (Rs.)	5,225,368.80	
Net private return from sprinkler irrigated crop (Rs.)	5,374,196.00	
Incremental return after sprinkler adoption	148,827.00	
Annual incremental private/economic returns due to sprinklers (Rs.) (2) − (1) × 0.371	3,435,584.50	15,937.2
Annual incremental private cost (capital and O&M)	1,621,033	7519.8
Annual incremental economic cost (capital and O&M)	1,801,605	8357.4
Private B-C ratio		2.11
Economic B-C ratio		1.90

Note The sprinkler irrigated area is 215.57 ha out of the 314.48 ha under crops; the total cost of sprinklers and diggies is Rs. 43.5 lac without subsidy and Rs. 31.5 lac with subsidy for the entire sprinkler irrigated area. The annualized capital cost (both private and economic) was worked out using a discount rate of 10 % and a life of 10 years for the system. The total annual operation and maintenance cost of the motor, sprinklers and the diggie was estimated to be Rs. 11.32 lac rupees for the entire sprinkler irrigated area

forced the farmers to either tap groundwater to sustain the income from crop production or led to conflicts.

As regards the potential social costs, no major negative externalities were seen to have been induced by sprinkler adoption in the area. The potential negative externalities are: (1) reduced labour absorption in agriculture, mainly coming from replacement of labour-intensive crops by cash crops which depend on mechanized farming, and decline in wage rates due to the reduction in labour demand; and, (2) increase in food prices due to decline in cereal production in the area mainly due to replacement of traditional food crops by high valued cash crops. But, in the case of IGNP, no major change in cropping pattern that could affect cereal production was found. Also, there was no positive or negative impact on either labour demand or wage rate after technology adoption.

Ideally, the aggregate water saving due to adoption depends on the real water saving at the field level per unit area through MI adoption; and what economic value could be generated from the water used as against the pre adoption scenario. We have already estimated the reduction in water use at the aggregate level for the sample farmers through MI adoption to be 0.401 MCM (i.e., 0.638 − 0.237 = 0.401). But, for the purpose of social cost benefit analysis this figure will not make sense. The reason is that the yield and income figures corresponding to pre and post adoption scenarios were different. Hence, it is imperative to know how much water could have been used up by the farmers to generate the return that occurs from the sprinkler-irrigated plots, had they used the conventional method of irrigation.

We had employed Eq. (6.3) to estimate this. This uses net private return from sprinkler irrigated crop, and water productivity (Rs./m^3) estimates for all the crops under the two different methods of irrigation to estimate the hypothetical water

Table 6.9 Social costs and benefits of sprinkler irrigation

No.	Attributes of costs and benefits of sprinkler irrigation	Amount (Rs./ha)
1	Annual incremental economic cost of sprinkler and diggie	8357.00
2	Annual incremental benefit (Rs.) (from Table 6.6)	15,937.2
3	Total water saving in sprinkler-irrigated area due to technology (m^3/ha)	816.00
4	Positive externality due to water saving	7045.00
5	Social cost-benefit ratio (2) + (4)/(1)	2.75

Source Authors' own analysis based on primary data

consumption for generating returns using FMI, and the current water consumption. The net income return from sprinkler irrigated area is estimated by taking the gross returns from all the sprinkler irrigated crops and the total cost of all inputs, including the full cost of sprinkler systems. This was estimated to be Rs. 35.72 lac. The overall net water productivity of all the crops irrigated under flood method of irrigation was estimated to be Rs. 8.63/m^3. The amount of water needed to generate the said income returns from flood irrigated crops is estimated to be 0.413 MCM. Hence, the water saving is 0.163 MCM (i.e., 0.413 − 0.237 = 0.176 MCM).

This means, every hectare of sprinkler irrigated area saves water to the tune of 816 m^3. Had the farmers not used sprinkler irrigation, they would have been forced to depend on tube wells for maintaining the current level of farm returns. Hence, the water saving can be treated as real. If we assume that the farmers allocate the saved water to put additional area under irrigation using flood method, the additional income that can be generated from one cubic metre of water would be Rs. 8.63. Hence, the surplus value product associated with the positive externality induced by sprinkler adoption per ha is Rs. 7045. As Table 6.9 indicates, the social benefit cost ratio is 2.75. This means, subsidies in sprinkler irrigation could be justified.

6.6 Findings

- A major consequence of sprinkler adoption in Bikaner was marginal expansion of irrigated area from 203.33 to 215.57 ha. This is in spite of reduction in volume of irrigation water available to the farmers to an extent of 62.9 %. Hence, the real area expansion benefit due to sprinkler adoption has to be seen from a hypothetical pre-adoption area of 75.44 ha.
- In many regions, MI system adoption was associated with introduction of new high valued fruit and cash crops which replaced traditional food crops or change in cropping pattern towards high valued crops, with impacts on food security, use of animal power for cultivation and labour absorption. But, in Bikaner, no major change in crops or cropping pattern was observed. Hence, there were no major negative externalities.

- With sprinkler adoption, the yield of mustard, bajra and winter green fodder increased, while that of wheat, groundnut and cluster bean decreased marginally. Sprinkler and diggie use could impact on yield both positively and adversely, the former due to improved quality and reliability of irrigation, and the latter due to reduced distribution uniformity. But, the farmers seemed to take advantage of reduced water requirement by allocating more area to those crops which gain in terms of yield through sprinkler use.
- The mean values of net return per ha of land was lower under sprinkler irrigation for four crops, while it was slightly higher for three other crops. But, farmers could manipulate the aggregate returns by allocating more land to such crops which give relatively higher net income per unit of land. Nevertheless, aggregate net return won't be the consideration for farmers to decide in favour of sprinkler irrigation. The reason is the changed water supply situation under which they would try and maximize the return per unit of water.
- The net water productivity was higher under sprinkler irrigation than under flood irrigation for all the crops. The improvement had mainly come from reduction in applied water use achieved through reduction in conveyance loss and deep percolation loss, rather than improvement in net income.
- The private returns from sprinkler-irrigated crops under the scenario of reduced water availability were far higher than the returns that could have accrued if the farmers continued with the traditional method of irrigation under the same scenario of water availability. The net incremental benefit was estimated to be Rs. 15,937/ha. This means, there was no opportunity cost of adoption, but there were only benefits. Hence, adoption of sprinkler with diggie is economically viable for the farmers. The private benefit-cost ratio was 2.11.
- If we consider the actual cost of construction of the diggie and the actual price of sprinklers, the system gave net returns slightly lower than that under flood method of irrigation. The economic benefit-cost ratio was 1.90. This means the farmers adopt the system even without subsidies.
- As regards the positive externality induced by large-scale sprinkler use on society, the main benefit was from water saving. The aggregate income benefit due to sprinkler use for an area of 215.2 ha is equivalent to using an additional 0.176 MCM of water for generating the same economic output from flood-irrigated crops. Hence, the water saving is 0.176 MCM. Another positive externality is on the impact on livestock
- The positive externality of water saving per ha of sprinkler adoption was 816 m^3. This was equivalent to an economic surplus of Rs. 7045/ha if we assume that the farmers use the saved water to grow the same crops with flood irrigation. Hence, the social benefit due to sprinkler adoption is Rs. 22,982/ha. The incremental cost to the society is Rs. 9734.8/ha. The social benefit-cost ratio is 2.75. Hence, the subsidies for diggie and sprinkler system could be justified.

6.7 Conclusion

The analysis in this chapter shows that sprinkler with diggie is economically viable for the farmers even without subsidies. It further shows that the social benefits exceed the social costs. The study showed that incremental income return over pre-adoption scenario will not be the consideration for farmers choose to micro irrigation systems under situations of induced water scarcity. Instead, they would be concerned with enhancement in productivity of water, which also ensures that the income returns are higher than what they would probably secure under conditions of reduced water availability, with flood-irrigated crops. Since the social costs are less than the social benefits, the subsidies are justifiable as it makes the private benefits exceed the private costs. On the social cost benefit front, only the positive externality associated with real (wet) water saving was considered. The study validates the long-held view by some scholars that improved water use efficiency in irrigation, even if leads to 'wet' water saving, may not help save water from agriculture, as farmers could expand the area under irrigation, when extra land is available for expanding cropped area; instead reallocation of water from agriculture would motivate farmers to improve water use efficiency to manage farming with reduced water allocation.

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Chapter 7
Social Benefit Cost Analysis of Drip Irrigation

D. Suresh Kumar

7.1 Introduction

Water is becoming an increasingly scarce resource limiting agricultural development in many developing and developed economies across the world. A study by the International Water Management Institute (IWMI) shows that around 50 % of the increase in demand for water by the year 2025 can be met by increasing the effectiveness of irrigation. Therefore, the capacity of large countries like India to efficiently develop and manage water resources is likely to be a key determinant of global food security in the 21st century (Seckler et al. 1998).

A review of past studies shows that the solution to the problem of growing groundwater scarcity and persistent groundwater resource degradation across regions are two-fold: Firstly, the supply side management practices like watershed development, water resources development through major, medium and minor irrigation projects. The second is through the demand management perspectives. This includes micro irrigation technologies like drip and sprinkler irrigation and other improved water management practices. In India, the economically viable irrigation water potential has already been developed, but the demand for water for different sectors has been growing continuously (Saleth 1996; Vaidyanathan 1999).

A number of demand management strategies (like water pricing, water users association, turnover system) have been introduced since the late seventies to increase the water use efficiency especially in the use of surface irrigation water. However, the net impact of these strategies in increasing water use efficiency was not very impressive (Narayanamoorthy 2003). The water use efficiency in the agricultural sector, which still consumes over 80 % of water, is around 30–40 % in India, indicating that there is considerable scope for improving water use efficiency.

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Evidences show that the water use efficiency can increase up to 100 % in a properly designed and managed drip irrigation system (Indian National Committee on Irrigation and Drainage 1994; Sivanappan 1994). Environmental problems associated with the surface method of irrigation, such as water logging and salinity are generally absent under drip irrigation (Narayanamoorthy 1997a). Drip irrigation increases water use efficiency, decreases tillage requirement, increases crop yields, product quality and fertilizer use efficiency (Qureshi et al. 2001; Sivanappan 2002; Namara et al. 2005).

Many researchers (Narayanamoorhty 1997b, 2003; Magar et al. 1988; Cuykendall et al. 1999; Qureshi et al. 2001; Dhawan 2002; Verma et al. 2004; Namara et al. 2005; Kulecho and Weatherhead 2005) studied the impact of drip irrigation and concluded that drip irrigation technology yielded benefits in terms of resource saving, increased crop yields and reduced costs of cultivation, though their scale of analysis was limited to the plot or field. A major conclusion is that drip irrigation technology is technically feasible particularly when the farmers depend upon groundwater sources (Dhawan 2000). Most previous researchers focused on the private cost and benefits of drip irrigation but the externalities (both positive and negative) associated with drip irrigation were not adequately investigated. Also the information available on the externalities is extremely limited.

In India Rs.1216.75 million were allocated during 2006–07 for the development of drip irrigation (www.Indiastat.com). The projects were implemented by the State and Central governments by providing subsidies to promote micro irrigation through development programmes. It is paramount that micro irrigation generates substantial social benefits. Also many argue that drip irrigation expansion may benefit only the well to do farmers as they can afford system expansion. The relevant questions for policy makers are: (i) what are the positive and negative externalities associated with drip irrigation? and (ii) whether wider adoption of drip irrigation will be socially beneficial? This chapter (i) examines the various positive and negative externalities generated by adoption of drip irrigation; and (ii) evaluates the social cost and benefits associated with drip irrigation technologies.

7.2 Social Benefit-Cost of Drip Irrigation

Social benefit-cost analysis (SBCA) is a process of identifying, measuring and comparing the social benefits and costs of an investment project or program. SBCA is a branch of welfare economics and asks which decision is best when project costs and benefits to the society as a whole are taken into account (Little and Mirrless 1980). SBCA is used to appraise private projects from a social viewpoint as well as to appraise public projects. The need for social benefit-cost analysis arises due to the divergence of market and economic prices associated with externalities.

Externalities arise when certain actions of producers or consumers have unintended external (indirect) effects on other producers or/consumers. Externalities exist when not all costs or benefits are taken into consideration by consumers and producers in their consumption and production activities (Markandya et al. 2002). Positive externalities arise when an action by an individual or a group confers benefits to others which are not compensated. Negative externalities arise when an action by an individual or group of producers creates harmful effects to third parties which are not compensated. In an activity generating positive externalities, social benefit is higher than private benefit and in an activity generating negative externalities, social cost is higher than private cost. For example, a private project may provide employment for the unemployed (positive externality) but generate pollution (negative externality).

The adoption of drip irrigation has significant bearing on society as a whole and generates various positive and negative externalities (Dhawan 2000). The positive externalities include reduction in well failure rate, reduced cost of deepening of existing wells or cost of drilling new wells, and increased availability of irrigation water (Kumar et al. 2008a). In some cases drip irrigation helps in increasing the water level in neighbouring wells or maintaining water level in wells. The adoption of drip irrigation also generates negative externalities such as reduction of employment due to changes in cropping pattern i.e. labour intensive annual cereal crop production to less labour intensive trees (Dhawan 2000).

In order to quantify the various positive and negative externalities caused by the drip irrigation technology, it is essential to enumerate and differentiate between the private and social costs and benefits. Since the social cost is the sum of private cost and external cost and the social benefit is the sum of private benefit and external benefit, it is crucial to estimate these costs and benefits (Markandya et al. 2002). The present study identified two different costs namely private and external costs. The private costs include capital cost (investment cost on drip irrigation systems) and maintenance costs. The external costs consist of value of reduction in labour absorption per hectare of traditionally irrigated crop replaced by drip irrigation methods and additional consumption expenditure incurred by the local villagers because increased local price of cereals due to reduced local production. Similarly, the benefits are classified into private benefits and external benefits. The private benefits include value of labour saved and increase in value of outputs. The external benefits include value of increased water availability for irrigation purposes, reduced power consumption in agriculture, reduction in well deepening costs and reduction in cost of well failure.

7.3 Study Area and Methodology

7.3.1 Study Area

The study area is Coimbatore district of Tamil Nadu state, India. Agriculture depends largely upon minor irrigation such as wells and tanks. The chief source of irrigation in the district is wells. The average well failure rate is 47 % for open wells and 9 % for bore wells (Palanisami et al. 2008). There are six different soil types, viz., red calcareous soil, black soil, red non-calcareous soil, alluvial soil, brown soil and forest soil.

The mean annual rainfall for the 45 years (between 1961 and 2005) was 687.1 mm with a coefficient of variation of 28.21 %. The distribution of rainfall across seasons indicates that the mean rainfall ranged from 16 mm in winter to 348 mm in north-east monsoon. The groundwater potential as on January 2003 indicated that the total groundwater recharge was 880.97 Million Cubic Meter (MCM), net groundwater availability (90 % of total groundwater recharge) was 792.87 MCM, domestic and industrial draft was 40.57 MCM, irrigation draft is 779.13 MCM and the stage of groundwater development was 103 %.

Of the total 19 blocks in the district, the level of groundwater development exceeds 100 % (over exploited blocks) of the utilisable groundwater recharge in eleven blocks, between 90 and 100 % (critical blocks) in four blocks and between 70 and 90 % (semi-critical blocks) in four blocks. The stages of groundwater development in the study blocks in over-exploited regions such as Thondamuthur and Annur blocks is 169 and 173 % respectively indicating the problem of groundwater in the region. While this is 51 and 56 % respectively for Anamalai and Madathukulam blocks in semi-critical region.

Increasing private investment on wells is observed over the years as groundwater irrigation assumes importance. Farmers in this district rely heavily on groundwater for irrigation. There is evidence that surface irrigation particularly the area irrigated by tank sources has been declining over the years. Dependence on groundwater for irrigation is a common phenomenon in both the study blocks. Groundwater accounts for 88.7 and 52 % of the total area irrigated in Thondamuthur and Annur blocks respectively. Similarly, in the semi-critical region, groundwater irrigation accounts for 52.29 % in Annamalai block and 35.85 % in the Madathukulam block.

7.3.2 Methodology

Sampling Framework

In the study district, two blocks in the over-exploited region were selected so as to represent drip adoption and control. Similarly two blocks in the semi-critical region were selected to represent drip adoption and control. From the selected blocks, two revenue villages were selected purposively where the adoption of drip irrigation is widespread. To examine the adoption and impact of drip irrigation on resource use, agricultural production and farm income, 25 farmers adopting drip irrigation were selected in each village and 25 non-drip adopters were selected in control villages. A sample of 100 farmers in each region was studied. Thus a total of 200 farmers were selected for the study. The list of farmers from the Department of Agricultural

Engineering were collected to select the farmers. Also we have enumerated the list of farmers adopting drip irrigation through discussions with the villagers and private firms dealing drip irrigation systems. The data was collected during the period 2007–08.

Data

For the purpose of the study, both secondary and primary information were collected from different sources. The secondary information include trend in rainfall, growth in number of wells, wells functioning, number of wells defunct, cropping pattern, crop yields, occupational structure, area irrigated, socio-economic conditions like migration and employment. The needed information from the respondent groups were gathered personally by administering the interview schedule. The primary information collected from the farm households include details on well investment, groundwater use, extraction, management, crop production including input use and output realised, farm income, adoption of drip irrigation, and investment on drip irrigation. Information on the asset position, education and other socio-economic condtions of the respondents were also collected.

External Benefits

It is apparent that the adoption of drip irrigation generates various positive externalities. They include increased water availability for irrigation purposes, reduced cost of electricity consumption, reduction in cost of well deepening, reduction in cost of drilling new wells/bore wells and reduction in well failure.

The external benefits in the form of increased water availability for irrigation due to the adoption of drip irrigation was computed by

$$W_V = \frac{\sum_{i=1}^{n} \nabla_i A_i}{\sum_{i=1}^{n} A_i} \Omega \tag{7.1}$$

where, W_v is the value of water saved due to adoption of drip irrigation in Rs./ha. ∇_I represents reduction in the applied water due to drip irrigation in M^3, A_i is the area under crop i in hectares, Ω is the economic value of water[1] used in agriculture in the region in Rs./M^3 of water.

The external benefits in the form of reduced consumption of power energy (Rs./ha) was computed as follows.

$$E_V = \frac{\sum_{i=1}^{n} \nabla_i A_i}{\sum_{i=1}^{n} A_i} \Psi \tag{7.2}$$

[1]Gibbons (1987) suggested that the marginal value of water of each M^3 is the marginal physical product times the crop price. Regression analysis was performed with yield as dependent variable and water applied as independent variable. From the estimated production function results, the value of water is determined by multiplying the marginal physical product of water (MPP) with the price of output (Py).

where E_v is the value of energy saved due to adoption of drip irrigation in Rs./ha. ∇_I represents reduction in the energy consumption for irrigation[2] in agriculture due to drip irrigation, A_i is the area under crop i in hectares, and Ψ is the economic cost of energy in Rs./kwh.[3]

The positive externalities due to adoption of drip irrigation, namely, reduced well failure and well deepening were calculated by considering the reduction in well failure and reduction in well deepening cost obtained through comparison with the control villages. The positive externality due to drip irrigation adoption per unit area (Rs./ha) was estimated as (Φ):

$$\Phi = \frac{[(WF_{CD} - WF_{CC}) + (WD_{CD} - WD_{CC})]}{\sum_{i=1}^{n} A_i} \tag{7.3}$$

where WF_{CD} is the cost incurred due to well failure during the last ten years in drip villages and WF_{CC} is the cost incurred due to well failure during last ten years in control villages. WD_{CD} is the cost incurred by the farmers towards well deepening during the last ten years in drip villages and WD_{CC} is the cost incurred by the farmers towards well deepening during the last ten years in control villages.

Social Benefit-Cost Ratio (SBCR) of Drip Irrigation

The various positive and negative externalities generated by the drip irrigation were examined and quantified to compute the social benefit-cost ratio (SBCR). The social benefit cost ratio was computed using the discounted cash flow considering the life of the drip irrigation system and the discount rate. For the purpose, the SBCR with present worth was employed. Thus,

$$SBCR = \frac{\sum_{i=0}^{T} SB_t}{(1+r)^t} \Big/ \frac{\sum_{i=0}^{T} SC_t}{(1+r)^t} \tag{7.4}$$

where:

SBCR	Social benefit cost ratio
SB_t	Social benefit which is defined as $SB_t = (\alpha + \beta)$ in period 't'
SC_t	Social cost which is defined as $SC_t = (\mu + \delta)$ in period 't'
T	Life time of the project period
r	Social rate of discount

[2]The crop-wise electricity consumption was computed as under: A one HP pump run for 1 h consumes 0.746 kwh of power. Accordingly, kwh for each crop = [(HP of pump) × (0.746 kwh) × (Number of hours of irrigation) × (No. of irrigation)].

[3]The economic value of energy is Rs. 3.5/kwh which is the unit cost of supply of electricity in Rs./kwh. The unit cost of supply of electricity represents the cost incurred by the utility to supply electricity to ultimate consumers. This include the cost of fuel, operation and maintenance expenditure, establishment and administration cost, interest payment liability, depreciation and the cost of power purchase (Government of India 2002).

The α is the annual returns from crop production due to adoption of drip irrigation in Rs./ha and β is the annual economic value of all positive externalities generated by the drip irrigation in Rs./ha. The μ is the initial investment on drip equipments, annual operation and maintenance cost of the drip system and cost incurred towards crop production and δ is the annual economic value of all negative externalities induced by drip irrigation.

The life period of drip irrigation set was considered to be 10 years (Palanisami et al. 2004). The life of the drip system is critical in working out the amortized cost of capital. Just as how long equipment lasts before it needs to be replaced obviously depends on the quality of the equipment, how much it is used and how well it is maintained. It is revealed from the discussion with the farmers and drip irrigation firms that the average life is 10 years if it is maintained properly. Two different discount rates namely 2 and 5 % were used to examine the sensitivity of investment to the change in discount rate. They represent different opportunity costs of capital.

7.4 Results and Discussion

7.4.1 Impact of Drip Irrigation on the Farming System

Our aim here is to observe any significant changes in the farming systems particularly the land holdings, cropped area, and irrigated area as a result of introduction of drip irrigation. The drip adopters are compared with control households. The drip adopters generally operate larger farms. The size of holding is 5.41 ha for drip adopters and 2.28 ha in control village in the over-exploited regions while it is 16.54 and 5.06 ha in semi-critical region (Table 7.1).

The average size of holding among the drip adopters is significantly large when compared to non-adopters. Since drip method of irrigation involves large initial investment, large farmers can adopt them widely compared to small and marginal farmers. The longitudinal analysis revealed that the adoption of drip irrigation technology increased the net sown area, net irrigated area, cropping intensity and irrigation intensity. In the drip villages of over-exploited region, the net sown area increased from 4.51 to 5.31 ha whereas the gross cropped area increased from 4.77 to 6.36 ha. Similarly, the net irrigated area and gross irrigated area also increased in drip adopted villages. The percentage of area irrigated by wells to the total cropped area had significantly increased in drip villages. It was evident that the percentage of area irrigated by wells to gross cropped area increased from 82.0 to 98.03 % due to the drip intervention.

Table 7.1 General characteristics of sample households

Particulars	Over-exploited region				Semi-critical region			
	Drip village		Control villages		Drip village		Control villages	
	Before	After	Before	After	Before	After	Before	After
Number of workers in the household (number)	2.7	2.7	1.92	1.92	2.0	2.0	2.52	2.52
Farm size (ha)	5.52	5.41***	2.23	2.28	16.54	16.54***	5.06	5.06
Net sown area (ha)	4.51	5.31***	1.41	1.35	13.27	14.49***	4.66	4.66
Gross cropped area (ha)	4.77	6.36	1.46	1.39	13.71	14.91	4.66	4.66
Cropping intensity (%)[a]	105.57	124.34	103.54	102.96	103.31	102.89	100.00	100.00
Net irrigated area (ha)	3.65	4.97***	1.27	1.22	13.17	14.41***	4.57	4.57
Gross irrigated area (ha)	3.84	6.26***	1.28	1.22	13.67	14.85***	4.57	4.57
Irrigation intensity (%)[b]	104.88	130.16	100.18	100.00	103.79	103.05	100.00	100.00
Percentage of area irrigated by wells to the total cropped area (%)	82.0	98.03	94.65	94.26	99.82	99.74	97.53	97.53
Percentage of area irrigated under drip to gross cropped area (%)	67.14				96.72			
Percentage of area irrigated under drip to gross irrigated area (%)	68.57				96.94			

*** indicate values are significantly different at 1 % levels from the corresponding values of control village
[a]Cropping intensity is defined as the ratio of gross cropped area to net sown area and expressed as percentage
[b]Irrigation intensity is the ratio of gross irrigated area to net irrigated area and expressed as percentage
The details regarding before drip adoption was collected based on the recall basis. For control villages, the reference period for the pre-adoption was considered to be 10 years before i.e. 1995
Source Field survey during 2007–2008

7.4.2 Irrigation Investment and Distribution of Pump Horse Power

Growing groundwater scarcity coupled with cheaper power supply exacerbated the degradation of the groundwater resource in the water scarce regions like Coimbatore resulted in negative externalities such as over pumping, changes in crop pattern towards more water intensive crops, well deepening, increase in well investments, pumping costs, well failure and abandonment and out migration, all of which had increased at a much faster rate (Narayanamoorthy 1997a; Palanisami and Suresh Kumar 2003). This led farmers to adopt various demand side coping strategies, like: adoption of drip irrigation, shifting from agricultural crops to trees, etc. On the supply side, deepening of wells, drilling of new bore wells and construction of intermediate storage structures (farm surface storage tanks) were being widely followed.

The total amortized cost of irrigation investment was worked out as the sum of amortized cost on wells, electric motor and equipments, surface storage tanks and drip irrigation equipments.[4] The total amortized cost of irrigation structures was Rs. 12,759.3/ha of gross cropped area for drip adopters and Rs. 26,595.92/ha in control villages of over-exploited region (Table 7.2). The total investment on wells and other irrigation structures was much lower among the drip adopters than the non-drip adopters in the control villages (52 %). Though the drip adopters incurred on an average Rs. 3935 % on drip equipments, the investment per hectare was high in the control villages. The reason for this high cost per hectare of gross cropped area was less gross cropped area in proportion to fixed investments on wells and other irrigation structures.

Of the total fixed investments, the investment on wells accounted for 51.71 % for drip adopters and 70.79 % for farmers in the control villages in over-exploited region. The per cent share of drip investments varied from 30.84 to 35.67 % implying huge investment on drip irrigation. Growing water scarcity coupled with low discharge rate compels the farmers to construct intermediate water storage structures. These surface storage tanks help the farmers to store water and irrigate when needed. The water is pumped from very deep bore wells and stored in these

[4]The amortization of irrigation structures as follows:
Amortized cost of well = [(Compounded cost of well) * $(1 + i)^{AL} * i] \div [(1 + i)^{AL} - 1]$
where: AL = Average life of wells; Compounded cost of well = (Initial investment on well) * $(1 + i)^{(2008\text{—year of construction})}$.

The discount rate of 5 % is used in amortization reflecting long term sustainable rate. Similarly investment on conveyance, pumpset, electrical installation, and surface storage tanks and drip irrigation structures were amortized. Where AL is average life of wells and it is assumed to be 30 years based on the average life of well life in the study area. Similarly, the average life of borewells is assumed as 20 years, electrical motors 15 years, surface storage tanks 25 years and drip irrigation equipments 10 years.

Table 7.2 Details of well and irrigation investment in the sample farms (Rs./ha of GCA)

Particulars	Over-exploited region		Semi-critical region	
	Drip villages	Control villages	Drip villages	Control villages
Investment on wells	6597.43 (51.71)	18,826.56 (70.79)	3672.75 (39.38)	3324.99 (57.44)
Investment on electric motors	2101.98 (16.47)	7141.18 (26.85)	2271.60 (24.36)	2306.65 (39.85)
Investment on surface storage tanks	124.79 (0.98)	628.18 (2.36)	54.73 (0.59)	157.07 (2.71)
Investment on drip irrigation equipments	3935.09 (30.84)	–	3326.83 (35.67)	–
Total investment on irrigation structures	12,759.30*** (100.00)	26,595.92 (100.00)	9325.91*** (100.00)	5788.71 (100.00)
Distribution of horse power of pump				
HP/pump	6.46	8.61	5.23	6.29
HP/GCA	3.86	10.61	4.45	4.50
HP/GIA	3.94	11.03	4.45	4.65

Note
Figures in parentheses indicate percentage to total
*** indicate values are significantly different at 1 % levels from the corresponding values of control village
Source Field survey during 2007–2008

tanks and then used for irrigation. These storage structures were constructed by both the drip adopters and non-adopters. As the cost of construction of surface storage tank was very low (Rs. 30–42/M^3), it became popular among the farmers. These structures accounted for 1–2.71 % of the total cost.

The power of electric pump is generally dictated by two factors, namely, what horsepower is available and what is needed to draw groundwater to the surface. For instance, marginal and small farmers may be forced to install a larger pump than is economically justified by the area they cultivate, but larger horsepower of pumps is a necessity where water table is too deep. There are significant variations in pump horsepower across different types of farmers and villages. The average size of pump horsepower varied from 6.46 among drip farmers to 8.61 among control farmers in over-exploited region while the same is 5.23–6.29. Though there is no much variation in pump capacity, the horsepower per hectare of gross cropped area and gross irrigated area varies between drip adopters and control farmers.

7.4.3 *Yield of Crops and Productivity Gains*

The drip method of irrigation was followed widely in banana, coconut, grapes and annual crops like maize and turmeric. The yield of banana under drip irrigation is

60.3 ton/ha which is 4.41 % higher than the control villages in over-exploited region. Similarly, an increase in yield of 15.1 % in coconut, 16.9 % in grapes and 22.8 % in turmeric was observed in drip over control villages (Table 7.3).

The findings of our study further confirm that increased productivity could be achieved through drip irrigation supporting the findings in earlier studies (INCID 1994; Narayanamoorthy 2005, 2008). This increased crop productivity under drip method of irrigation can be attributed to high water use efficiency. The drip method of irrigation, unlike flood irrigation method, supplies water continuously at regular intervals and the crops cultivated under the drip method do not face moisture stress, the major factor that can affect crop yield (Sivanappan 1994).

Drip irrigation also contributes to labour saving and reduction in cost of cultivation. In banana cultivation the cost of labour under drip method (Rs. 9761.1/ha) was 69 % less than the control villages (Rs. 31,487.1/ha). In coconut cultivation, the drip method reduces labour cost by 69 %. The cost of cultivation was considerably reduced under drip method registering a reduction of 15.5 %. In grape cultivation, a reduction in cost of cultivation was 15.6 % in drip farms over the control farms was found.

7.4.4 Water and Energy Consumption Under Drip Irrigation

The quantity of water pumped depends on the well yield (discharge rate), frequency of irrigation, and hours of pumping. The drip irrigation method generally requires less pumping hours but, the frequency of irrigation under drip method is higher. For most of the crops, under drip method, farmers tend to irrigate daily or alternate days. The number of irrigations under drip method was 286.4 for banana, 142.8 for coconut, 105.8 for grapes, 15 for maize and 144.3 for turmeric in over-exploited region (Table 7.3).

The frequency of irrigation is very low under flood method of irrigation about once in five to six days. The number of irrigations varies from 34 in turmeric to 67.4 in banana in control villages. Maize is mostly grown as a rainfed crop and farmers usually provide 2–5 irrigations at crucial stage of crop growth.

The crop wise electricity consumption shows that drip farms consume significantly less energy when compared to the flood method of irrigation. For instance in the over-exploited region, the per hectare electricity consumption for banana was 2219.8 kwh/ha which was 73.2 % less when compared to the flood method of irrigation (8294.2 kwh/ha). The difference in consumption of electricity was very high in crops like coconuts and grapes (Table 7.3). The per hectare consumption of electricity was 1554.6 kwh/ha/year in drip adopting farms which was 62.2 % less

Table 7.3 Impact of adoption of drip irrigation on yield of crops, number of irrigation and power consumption

Particulars	Banana	Coconut	Grapes	Maize	Turmeric
1. Yield (ton/ha)					
Over-exploited region					
Drip villages	60.34***	23,155.5***	22.8***	3.15	6.08***
Control villages	57.79	20,118.2	19.5	3.29	4.95
Semi-critical region					
Drip villages	60.56	23,012.8***	–	3.21	5.29
Control villages	59.15	19,213.5	–	3.34	5.03
2. Number of irrigation					
Over-exploited region					
Drip villages	286.4***	142.8***	105.8***	15***	144.3***
Control villages	67.4	61.1	27.4	3.6	34.0
Semi-critical region					
Drip villages	288.6***	136.9***	–	3.3	37.0
Control villages	67.1	65.6	–	3.7	27.5
3. Power consumption by crops (kwh/ha)					
Over-exploited region					
Drip villages	2219.8***	916.9***	549.9***	202.8***	907.5***
Control villages	8294.2	7442.9	3124.5	420.1	3872.6
Semi-critical region					
Drip villages	2670.9***	905.2***	–	416.1	3795.3
Control villages	7313.9	5774.9	–	310.2	3924.1

Notes
Grapes in over-exploited region, the yield, number of irrigation and power consumption are compared with flood method of irrigation in the drip village. For banana in semi critical region, the yield, number of irrigation and power consumption under drip irrigation are compared with flood method of irrigation in the drip village. Coconut yield is in number of nuts per hectare of coconut garden
*** indicate values are significantly different at 1 % levels from the corresponding values of control village
Source Field survey during 2007–2008

than that of farms in control villages (4112.9 kwh/ha/year). In semi-critical region, the per hectare consumption of electricity was 974.9 kwh/ha/year in drip adopting farms which was 77.68 % less than that of farms in control villages (4368.9 kwh/ha/year).

The difference in electricity consumption between the two methods of irrigation was obvious. As the flood method of irrigation requires more hours of pumping, the electricity consumption increases though the horse power of the pump was more or less the same. Extended pumping hours due to low discharge rate is the major reason why the electricity consumption is high under flood method of irrigation.

7.4.5 Impacts of Drip Irrigation on Reduction in Well Failure and Cost of Deepening

In regions where water table is deep and showing declining trends, micro irrigation adoption can lead to real water saving at the field level. The reason is that deep percolation that occurs under traditional method of irrigation, does not reach the groundwater table. Since, under micro irrigation system, water is applied daily in small quantities to meet the daily crop water requirements, deep percolation is prevented and real water saving is achieved. (Kumar et al. 2008b).

We made an analysis on well failure to examine the impact of adoption of drip technologies on reduction in well failure. Being a water scarce region, well failure is a common phenomenon in the study area. Failure of both existing wells and drilling new bore wells is observed in many pockets of the state and elsewhere. The well failure in our study area ranged from 28 % in drip villages to 44 % in control villages.

The cost incurred towards well failure seemed to be much higher in control villages. In over exploited region, it is found that the cost of well failure is Rs. 1563.9 and 1957.8/ha in drip and control villages respectively (Table 7.4).

Table 7.4 Frequency of well failure and cost of deepening of wells in the sample farms (number of farms)

Frequency of well failure/costs incurred	Over-exploited region		Semi critical region	
	Drip villages	Control villages	Drip villages	Control villages
0 well failure	36 (72.0)	28 (56.0)	40 (80.0)	42 (84.0)
1 well failure	8 (16.0)	19 (38.0)	10 (20.0)	7 (14.0)
2 well failure	4 (8.0)	2 (4.0)	–	1 (2.0)
3 well failure	1 (2.0)	1 (2.0)	–	–
4 well failure	1 (2.0)	–	–	–
Total number of farms	50 (100.0)	50 (100.0)	50 (100.0)	50 (100.0)
Cost incurred towards well failure (Rs./ha of GCA)	1563.9***	1957.8	411.6***	1168.9
Well deepening cost (Rs./ha of GCA)	1266.9***	7525.4	626.4***	1554.6

Notes
*** indicate values are significantly different at 1 % levels from the corresponding values of control village
Note Figures in parentheses indicate percentage to total
GCA: Gross cropped area in hectares
Source Field survey during 2007–2008

The difference in cost of well failure between drip village and control villages was Rs. 393.9/ha. The difference is Rs. 757.3/ha in semi-critical region. Though the well failure was higher in control villages than in the drip villages, one may question whether the difference was due to drip adoption or not. However, with similar agro-climatic and hydro-geological conditions, rainfall pattern, pattern of natural and artificial recharge, the difference was observed between the drip and control villages. Hence, the reduction in well failure rate and the costs incurred towards reduction in well failure may be attributed to real water saving due to wider drip adoption.

The other important negative externality as a result of groundwater resource degradation is well deepening. Farmers, as a coping strategy deepen their open wells, and extend their bore wells. Farmers in both the drip and control villages deepened their wells with in last ten years and incurred considerable cost. As deepening of open wells has become costlier due to non-availability of labour for digging wells, farmers preferred drilling new bore wells. Moreover, the cost of drilling bore wells was low (Rs. 35–48/ft) compared to deepening of existing open wells. For instance, the drip adopters spent around Rs. 1266.9/ha of GCA while farmers in the control villages incurred Rs. 7524.4/ha of GCA in over-exploited region. A similar situation was observed in semi-critical region. This was much higher than the drip villages. As the drip irrigation saves water at farm level, it helps in limiting the deepening of existing wells or bore wells.

7.4.6 Social Benefit-Cost Analysis (SBCA) of Drip Irrigation

Governments in both the developing and developed economies introduce various policy interventions to promote economic growth and social equity, reduce poverty, promote environment protection to achieve sustainable development of national and regional economies. To this end various technologies are promoted by the state to enhance agricultural production, resource conservation etc. As part of the promotional activities market based instruments such as taxes and subsidies are introduced. As the State spends considerable amount of funds on subsidies in order to achieve increased agricultural production and water resource conservation, these technologies should be viable and should not only increase private profit but also ensure social benefits. Thus the social benefit-cost analysis of drip adoption is increasingly important.

The private cost includes the cost of investment on drip equipments, establishment of the garden, maintenance of drip system and expenses incurred towards the cultivation. The drip system is widely adopted in crops such as grapes, banana and coconut. In the over-exploited region, the private cost is Rs. 76,824.7/ha without subsidy and Rs. 80,766.3 when the subsidy is included. But, it is Rs. 50,246.4 and Rs. 54,694.8, without subsidy and with subsidies, respectively in semi-critical

Table 7.5 Private and social cost and benefits of drip irrigation (amount (Rs./ha/year))

Particulars	Over-exploited region		Semi critical region	
	Without subsidy	With subsidy[b]	Without subsidy[a]	With subsidy[b]
Private cost and benefits				
Private cost	76,824.7	80,766.3	50,246.4	54,694.8
Private benefit	256,036.9	251,296.9	136,591	132,142.5
External cost and benefits				
External benefits				
Value of water saving (Rs./ha)	149,393.6	149,393.6	76,943.6	76,943.6
Reduced power consumption in agriculture (Rs./ha)	24,997.7	24,997.7	13,844.6	13,844.6
Reduction in well failure and cost of well deepening (Rs./ha)	6652.7	6652.7	1685.5	1685.5
Total external benefits	181,044	181,044	92,473.8	92,473.8
Social costs and benefits				
Social cost (Rs./ha)	76,824.7	80,766.3	50,246.4	54,694.8
Social benefits (Rs./ha)	437,080.9	432,340.9	229,064.8	224,616.4
Social benefit cost ratio (SBCR)				
2 % discount rate	5.19	4.97	4.56	4.33
5 % discount rate	4.94	4.71	4.34	4.01

Notes
Social costs = Private costs + External cost; Social benefits = Private benefits + External benefits
[a]Subsidy component is excluded. Actual cost incurred by the farmers towards drip investment
[b]Subsidy component is included. The total cost of investment on drip system includes both the farmers actually paid cost and subsidy component
Social benefit-cost ratio was worked out incorporating cost and benefit stream for a period of 25 years
Source Field survey during 2007–2008

regions. Investment in drip irrigation system for grapes and banana is higher than the coconut and inclusion of grapes escalates the private cost (Table 7.5).

The potential negative externalities, as evident from a recent study in Nalgonda district of Andhra Pradesh, are: (i) reduced labour absorption in agriculture, mainly coming from replacement of labour-intensive crops by cash crops which depend on mechanized farming, and decline in wage rates due to the reduction in labour demand; and (ii) increase in food prices due to decline in cereal production in the area mainly due to replacement of traditional food crops by high valued cash crops (Kumar et al. 2008a, b). However, in our study area no such phenomenon was observed. Instead, the labour demand increased leading to an increase in the wage rate. We observed that there was a shift in cropping pattern from annual crops to perennial trees particularly coconut, mainly due to labour scarcity. Moreover, discussion with the farmers and government department officials revealed that drip adoption helped farmers to manage their labour scarcity in agriculture. Thus, in the regions where labour and water scarcity is more, the drip adoption does not create any negative externalities. Similarly, with the existence of complete markets, increase in food prices is not significant. As no such major negative externalities are seen in the study area, the social cost is equal to the private cost.

In addition to the private benefits in the form of increased returns from crop cultivation, the drip adoption generates significant positive externalities. The positive externalities are in the form of water saving, reduced electricity power consumption, reduction in well failure and well deepening cost.

Among the different positive externalities, the most significant external benefit in the region is real saving of irrigation water. This is in view of the scarcity value of the resource being acutely felt in the study area with growing competition from other non-agricultural sectors. The non-adoption of drip irrigation would have forced the farmers to over exploit the groundwater to sustain the income from crop production. Hence, it is imperative to know how much water could have been used up by the farmers to generate the return that occurs from the drip irrigated plots, had they used the conventional method of irrigation. In order to do so, we found the difference in water used by the farmers between the drip villages and control villages for different crops and then the value of saved water was determined. Had the farmers not used drip irrigation, they would have been forced to depend on bore wells for maintaining the current level of farm returns. Hence, the water saving can be treated as real. The value of water saving is worked out to Rs. 1,49,393.6/ha in over-exploited regions while it is Rs.76,943.6/ha in semi-critical region.

The drip adoption saves significant amount of electricity in agriculture. Farmers need 30 h of pumping to provide irrigation in one hectare of land under flood method. But, under drip method of irrigation, farmers usually irrigate 1–1.5 ha per time thereby considerable energy saving is achieved. The saved energy was monetized taking into account the economic cost of supply of electricity power. The external benefits due to drip adoption through energy saving is Rs. 24,997.7/ha in over-exploited regions and Rs. 13,844.6 in semi-critical regions. Water scarcity coupled with low discharge rate led the farmers to run their electric motors for longer hours which resulted in high energy consumption. Drip irrigation saves considerable amount of energy. Thus, drip irrigation produced significant external benefits in water scarce regions.

To assess the impact of drip adoption on reduction in well failure and deepening cost, the difference in cost incurred towards well failure and well deepening cost between the drip and control villages was computed and compared. It was evident that the reduction in well failure and well deepening cost was Rs. 6652.7/ha and Rs. 1685.5 respectively in over-exploited and semi-critical regions. The total external benefits due to adoption of drip irrigation was Rs. 181,044/ha in the over-exploited regions and Rs. 92,473.8/ha in semi-critical regions. The social cost in over-exploited region was Rs. 76,824.7/ha under without subsidy and it was Rs. 80,766.3/ha when subsidy included. Similarly, the social benefit was Rs. 437,080.9/ha and Rs. 432,340.9 respectively without and with subsidies. It is clear that the social benefit exceeds the social cost. Having no significant negative externalities in regions characterized by water and labour scarcity, the wider adoption of drip irrigation generates considerable social benefits. Thus, one can conclude that drip irrigation is financially and socially viable and more beneficial in regions where there is more water and labour scarcity.

The social benefit cost ratio (SBCR) was computed using two different discount rates viz., 2 and 5 %. The SBCR in the over-exploited region was 5.19 and 4.94 with a discount rate of 2 and 5 % respectively when subsidy is not included. The SBCR is 4.97 and 4.71 when the subsidy was included. The SBCR was slightly higher when the subsidy component also included. The analysis of social benefit and costs of drip irrigation reveals that the social benefits exceed social cost. This clearly shows that wider adoption of drip irrigation produces sufficient social benefits and huge subsidization (65 % at present in Tamil Nadu) on drip irrigation is justified.

7.5 Conclusion and Policy Suggestions

As found in many earlier studies, the drip irrigation resulted in significant increase in yield over the flood method of irrigation. The analysis of economics of crop cultivation in drip and control villages revealed that the drip method of irrigation has significant impact on resource saving, cost of cultivation, yield of crops and farm profitability. One could conclude that the drip method of irrigation has significant bearing on private costs and benefits and hence profit.

The social benefit-cost analysis revealed that the social benefits exceed the social costs in the water and labour scarce regions. Thus, one can conclude that the drip irrigation is a viable and more beneficial in regions where there is more water scarcity. The SBCR in over-exploited regions is 5.19 and 4.97 respectively without and with subsidy at a discount rate of 2 %, while it is 4.56 and 4.33 in the semi-critical regions. This clearly shows that wider adoption of drip irrigation produces sufficient social benefits and continuing support through subsidies will save water and energy and help achieve sustainable management of groundwater resources. Hence, continuing public support for the wider adoption and promotion of drip irrigation technologies appears warranted.

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Chapter 8
Determinants of Adopting and Accessing Benefits of Water Saving Technologies: A Study of Public Tube Wells with MI Systems in North Gujarat

Chandra Sekhar Bahinipati and P.K. Viswanathan

8.1 Introduction

Water scarce regions in India are highly constrained by high cost of water extraction for agriculture and any other competing uses, including industry, urban water provision, etc. This is mainly due to two important factors: (i) naturally water scarce regions of India have extremely limited surface water resources; and, (ii) among these water-scarce regions, groundwater potential is very low in the hard rock areas of the southern and western India and aquifers are already over-exploited in most parts of alluvial north-western India (Kumar 2014). While the extent of groundwater extraction, for instance, has even far exceeded the net annual groundwater availability in some states of India, like Punjab, Haryana and Rajasthan, the stage of groundwater development (SGWD) is fast approaching the critical limits (SGWD > 65 %) in other states, such as Gujarat, Karnataka, Uttar Pradesh, etc. (Government of India, hereafter GoI 2014). The over exploitation and the resultant depletion of groundwater had caused lowering of water levels, desertification of agricultural lands, increase in cost of construction of wells/bore wells, installation of pumps [mostly, submersible]; and the already declined well yields increasing the cost per unit of water pumped (Kumar 2007).

Gujarat is one of the water scarce regions with unique agro-climatic features, characterised mostly by arid and semi-arid areas that experience acute scarcity of water. Two major factors are identified to be responsible for this. First, the distribution and availability of freshwater across the agro-climatic regions is highly skewed, i.e., almost 70 % of the state's fresh water resources are confined only to 30 % of its geographical area, mostly located in South Gujarat. Second, there is distinct variation in rainfall (rainy days) across regions of the state—from around 40–50 days in South Gujarat to a meager 10–15 days in the Kachchh

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(IRMA/UNICE 2001; Kishore 2013). Further, around 95 % of it occurs during the monsoon season (Mehta 2013). In addition, high variations in temperature and rainfall are observed across the eight agro-climatic regions (Ray et al. 2009; Hiremath and Shiyani 2012; Mehta 2013). Hence, the state experiences frequent droughts (Mall et al. 2006; Kishore 2013). As per the Census 2011, almost half of the rural households of the state depend on agriculture, where intensive agricultural operations are distinctly influenced by the availability of rainwater and groundwater. Considering irrigation as the major insurance against drought, the proportion of irrigated area in the state had increased over the years from 7 % of the gross cropped area (GCA) in 1960–61 to 40 % by 2011–12 (Government of Gujarat, hereafter GoG 2008, 2013); but, around 80–85 % was irrigated through groundwater sources (Kishore 2013; Viswanathan and Pathak 2014).

In fact, the intensification of groundwater use for agriculture had resulted in groundwater overdraft in many parts of the country, including Gujarat. For example, in the six states (Gujarat, Haryana, Maharashtra, Punjab, Rajasthan and Tamil Nadu), around 54 % of the total assessment units were identified as semi-critical, critical or overexploited, compared with a national average of 29 % in the year 2005 (GoI 2007). In Gujarat, the overall level of development of groundwater resources was around 67 % as of 2011, with four districts (Banaskantha, Gandhinagar, Mehsana and Patan) showing over-exploitation (i.e., SGWD > 100 %) and five districts (Ahmadabad, Kutch, Porbandhar, Rajkot and Sabarkantha) falling in grey or semi-critical categories (65–85 %) (GoI 2014). While the groundwater development scenario has been a matter of great concern, it is also critical to consider that the over-exploitation of groundwater resources has been contingent upon energisation and intensive use of pump sets, causing a sharp rise in agricultural power consumption in various states of India, including Gujarat as revealed by several studies (see Viswanathan and Bahinipati 2015 for a latest review).

Hard-pressed by the multifaceted challenges affecting agricultural development, many of the states in India, including Gujarat have been devising strategies and programmes for popularizing the adoption of environmentally benign policies and technologies that help in releasing the pressure of agriculture on water and energy, which got intensified by the unscrupulous agricultural practices promoted during the green revolution (GR) era. Apparently, it may be argued that the technological interventions, like the micro irrigation systems (MIS), currently being promoted at the national and state levels, bear the testimony of environmentally benign means of doing away with the environmental, agro-ecological and hydrological damages caused by the wider adoption of the GR technologies.[1]

[1]The popularization and adoption of Green Revolution technologies in India has been stimulated under the subsidy policy regime (called as 'environmentally damaging subsidies' in the current parlance), by which the national and state governments offered fertilizer, irrigation and power subsidies to the farmers across states. Estimates show that there has been almost threefold increase in the agricultural subsidies provided by the Government of India from US$9700 million during 2000–01 to US$28,500 million during 2008–09. Of this, the three major subsidies, viz., fertilizer,

Thus, the impending water crisis along with potential challenges of adverse environmental and climatic uncertainties in a way motivated many of the Indian states, including Gujarat to adopt prudent strategies and technological interventions for saving the precious water resources from being depleted and degraded further. Since the mid of last decade, the GoI has, therefore, been promoting the MIS under the National Mission on Micro-Irrigation (NMMI); the prime objective is to reduce water footprint and increase yield. In order to enhance the adoption rate, both the GoI and individual state governments provide subsidy that varies with respect to landholding, caste and geographical location (IRAP 2012). Being a water scarce state, the GoG has been taking a special initiative to enhance the wide scale adoption through instituting a special purpose vehicle (SPV), named as Gujarat Green Revolution Company Limited (GGRC), which is the nodal agency for implementing the micro-irrigation (MI) programme in the state. The amount of subsidy given to farmers range from 50–75 % (Indian Rupee (INR) 60,000 to 90,000) depending on the status of beneficiaries with respect to caste, landholding and geographical locations (IRAP 2012).

In the Indian context, the empirical literature on MIS so far looks into two aspects: (i) determinants of adoption (Namara et al. 2007; Palanisami et al. 2011), and (ii) physical and socio-economic benefits of adoption (Palanisami et al. 2002; Kumar et al. 2004; Narayanamoorthy 2004; Kumar 2007; Kumar and Palanisami 2011; Kumar and van Dam 2013). Since MIS adoption rate is much lower, i.e., only 10 % of the total MI potential area in India as of 2010 (Palanisami et al. 2011), a few studies investigated the physical and socio-economic constraints in adopting MIS at the country level (for instance, see Kumar et al. 2008a). However, it is now observed that a large number of farmers adopted MIS during this decade, particularly in the Gujarat state. Such enhanced adoption trend needs to be examined, particularly, to confirm '*whether subsidy has any significant influence on changing the adoption rate in the recent years?*'. This remains a grey area needing further investigations across regions/states. Further, specific studies on the impact of MIS in India as undertaken by various scholars broadly looked at: (a) the physical impact of water-saving technologies (WSTs) on irrigation water use (Narayanamoorthy 2004); (b) the impact of WSTs and water-efficient crops on crop water productivity in physical terms [kg/m^3 of water consumed] (Kumar 2007; Singh 2013; Kumar and van Dam 2013); (c) the benefit-cost analysis of MIS, such as drips and sprinklers (Palanisami et al. 2002; Kumar et al. 2004; Narayanamoorthy 2004); (d) analysis of the economic and social costs and benefits of MIS (Kumar and Palanisami 2011; Kumar et al. 2008b; Suresh Kumar, Chap. 7, this volume). However, none of the studies seems to have looked into *whether seasonal and cropping patterns matter in accessing the various environmental and socio-economic benefits of MIS.*

(Footnote 1 continued)

irrigation and power together accounted for almost 70 % of the total agricultural subsidies (Government of India, Ministry of Agriculture).

In this backdrop, this chapter aims at investigating the role of subsidy in enhancing the adoption rate of MIS and identifying the determinants of accessing the benefits of MIS, which is increasingly reckoned as Water Saving Technology' in reducing the water foot print in agriculture especially in the water scarce regions. For empirical assessment, a farm-household survey was undertaken in the Banaskantha district in North Gujarat [detailed explanation about the survey design is given in data and methods section].

The chapter is organized into five sections, including introduction and conclusions. The second section presents a brief description about the status of MIS across various agro-climatic regions in Gujarat. The third section outlines data and methods. Section four presents the results and discussion, where we discuss about the role of subsidy in enhancing adoption rate among the farmers in recent years; and the socio-economic impacts and the determinants of accessing various benefits of MIS. The fifth section concludes the chapter highlighting the future perspectives on the promotion and scaling up of MIS.

8.2 Status of Development of MIS in Gujarat State

Studies point out that there is a high probability of adopting MIS when water is a scarce resource in a particular region and/or when a large number of farmers depend on groundwater for irrigation purposes (Caswell and Zilberman 1983; Palanisami et al. 2011). Since both the situations coexist in the state of Gujarat, an increasing trend was observed in the number of farmers adopting MIS and area under MIS[2] (see Fig. 8.1). For instance, about 13,000 farmers had adopted MIS in the year 2006–07, which increased more than 10 times by 2013–14 (i.e., 140.1 thousand farmers). Similarly, 25.7 thousand ha land was under MIS during 2006–07, which had gone up by 9 times to 224.95 thousand ha during 2013–14. It is observed that both the number of farmers and the area under MIS have significantly increased since 2009–10, when the programme was launched by the GoG. This could be because of the awareness about MIS systems and the subsidy policy, introduction of extra subsidy for tribal farmers in tribal talukas and farmers in the dark-zone talukas, etc.

Therefore, it is imperative to investigate the role of subsidy in encouraging adoption of MIS in the state. While looking at the number of farmers adopting MIS by land holding categories, it is found that a large number of medium farmers (2–10 ha) adopt it (see Figs. 8.2 and 8.3), while a notable proportion of farmers adopting MIS belong to small (1–2 ha) landholding class, as of 2010–11 (GoG

[2]The information/data presented in this study was collected from GGRC between 2006–07 and 2013–14. But, some farmers could have adopted MIS before GGRC was formed and some may have adopted MIS without the support of GGRC (e.g., farmers under the GWRDC scheme)—Those figures are not included in the analysis presented in this section.

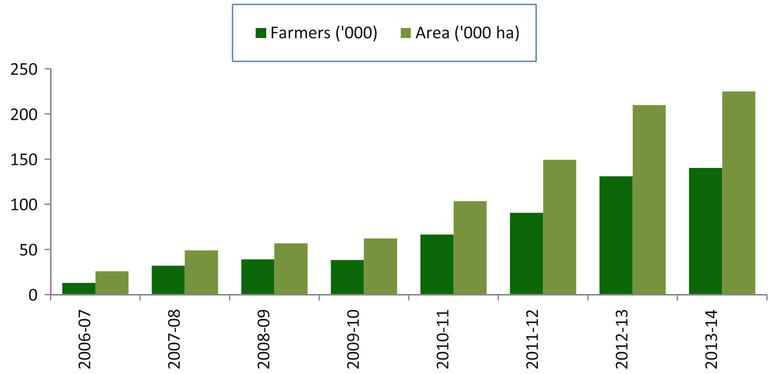

Fig. 8.1 Trends in number of MIS adopted farmers and area under MIS. *Source* Authors' estimates based on data collected from GGRC

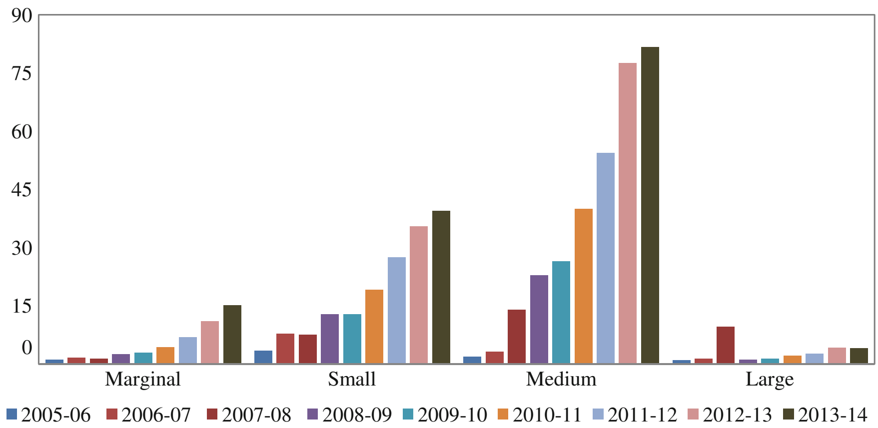

Fig. 8.2 MIS adopted farmers by landholding categories (in '000 nos.). *Source* Authors' estimates based on data collected from GGRC

2011). This reveals that there is still a potential for increasing MIS adoption particularly among the small and marginal farmers in the state.

The agro-climatic region-wise distribution of farmers adopting and area covered under MIS in the state during 2006–07 to 2013–14 is presented in Tables 8.1 and 8.2, respectively. It is observed that both the indicators (i.e., number of farmers adopting MIS and total area under MIS) have seen an increasing trend over the years. There was a notable increase in the number of farmers and area brought under MIS between 2006–07 and 2013–14 in the state across the agro-climatic regions. For instance, the CAGR of number of MIS adopted farmers was 34.7 % (Table 8.1), and it was 31.2 % in the case of area under MIS during the reference period (Table 8.2).

In other words, this signifies that the proactive state policy of providing subsidy in a range of 50–75 % would have motivated a large number of farmers to adopt

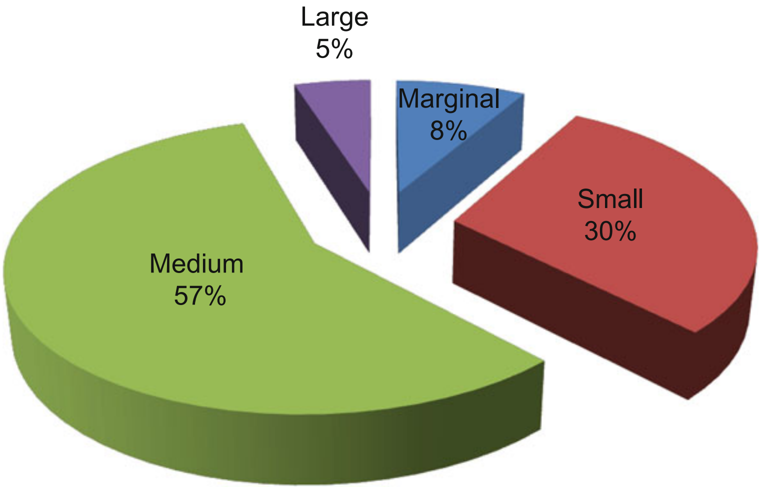

Fig. 8.3 Percentage of MIS adopted farmers by land-holding categories (2005–06 to 2013–14). *Source* Authors' estimates based on data collected from GGRC

MIS over the years, in addition to the perceived physical and socio-economic benefits of adopting MIS. Within the state, a large number of farmers adopted MIS in the three agro-climatic regions, namely, north Gujarat, north Saurashtra and south Saurashtra, as these regions are experiencing severe water scarcity, making it infeasible to grow any crops. Reportedly, the SGWD in these three agro-climatic regions are 102, 63.4 and 67 %, respectively as of 2011 (GoI 2014). These three regions together cover around 74 % of the total number of farmers adopting MIS and 75 % of the total area under MIS in the state. Among them, north Gujarat occupies the first position in terms of number of farmers adopting MIS (i.e., 168.51 thousand farmers which consist of around 31 % of total farmers adopting MIS in the state between 2006–07 and 2013–14) and total area under MIS, i.e., 293.53 thousand ha which is around 33 % of total area under MIS in the state. The lower growth rate was observed in the southern hills, which receive the highest rainfall across all the agro-climatic regions of Gujarat, i.e., 1793 mm per year; the variability of rainfall also less in these regions (Mehta 2013).

8.3 Methodology and Data

The Gujarat Water Resource Development Corporation (GWRDC) has been involved in implementing MIS in the water scarce districts of North Gujarat, viz., Banaskantha, Mehsana, Patan, Sabarkantha and Gandhinagar. So far, GWRDC has implemented MIS in about 250 public tubewells covering about 1365 farmers and 1271 ha of area (see Appendix 8.1); the average number of farmers benefited under

Table 8.1 Farmers adopting MIS in Gujarat, Agro-climatic zone wise: 2006–07 to 2013–14 (in '000)

Agro climatic Region	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	Total	CAGR (%)
North-West Arid	0.59 (4.52)	0.75 (2.36)	0.76 (1.95)	0.81 (2.12)	1.26 (1.89)	0.80 (0.88)	4.84 (3.69)	5.82 (4.16)	15.62 (2.84)	33.27
North Gujarat	2.43 (18.78)	6.6 (20.70)	6.35 (16.33)	13.89 (36.44)	21.46 (32.25)	25.90 (28.57)	44.22 (33.75)	47.65 (34.01)	168.51 (30.63)	45.04
Middle Gujarat	1.05 (8.07)	1.62 (5.08)	2.15 (5.53)	3.32 (8.73)	7.83 (11.76)	15.58 (17.18)	17.08 (13.03)	13.39 (9.56)	62.02 (11.27)	37.55
North Saurashtra	2.73 (21.08)	9.95 (31.20)	18.78 (48.27)	12.22 (32.06)	13.67 (20.54)	27.67 (30.52)	30.96 (23.63)	37.52 (26.78)	153.50 (27.90)	38.75
South Gujarat	1.69 (13.02)	2.11 (6.63)	2.13 (5.48)	1.81 (4.75)	10.62 (15.95)	7.29 (8.04)	10.94 (8.35)	8.00 (5.71)	44.60 (8.11)	21.47
Southern Hills	0.86 (6.65)	0.94 (2.95)	1.17 (3.00)	0 (0)	4.78 (7.19)	3.62 (3.99)	5.53 (4.22)	3.65 (2.60)	20.55 (3.74)	19.75
South Saurashtra	3.61 (27.89)	9.91 (31.08)	7.56 (19.43)	6.06 (15.90)	6.93 (10.42)	9.80 (10.81)	17.46 (13.33)	24.08 (17.18)	85.42 (15.52)	26.75
Gujarat	12.96	31.89	38.90	38.13	66.56	90.65	131.02	140.10	550.21	34.66

Note Figures in parentheses indicate percentage; CAGR—compound annual growth rate
Source Authors' compilation from GGRC

Table 8.2 Area under MIS in Gujarat, agro-climatic zone wise: 2006–07 to 2013–14 (in '000 ha)

Agro climatic region	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	Total	CAGR (%)
North-West Arid	2.11 (8.2)	2.46 (5.0)	2.30 (4.0)	2.40 (3.8)	3.50 (3.4)	2.19 (1.5)	9.68 (4.6)	12.06 (5.4)	36.70 (4.2)	24.37
North Gujarat	5.98 (23.3)	12.78 (26.1)	13.08 (23.0)	24.38 (39.3)	34.08 (32.9)	48.64 (32.6)	75.92 (36.2)	78.68 (35.0)	293.53 (33.3)	38.02
Middle Gujarat	2.27 (8.8)	3.00 (6.1)	3.67 (6.5)	6.04 (9.7)	13.74 (13.3)	24.88 (16.7)	23.55 (11.2)	17.52 (7.8)	94.68 (10.7)	29.09
North Saurashtra	4.62 (17.9)	13.01 (26.6)	22.06 (38.9)	17.16 (27.6)	21.81 (21.1)	43.41 (29.1)	52.21 (24.8)	63.98 (28.4)	238.26 (27.0)	38.91
South Gujarat	3.92 (15.2)	3.49 (7.1)	3.54 (6.2)	3.04 (4.9)	13.73 (13.3)	10.55 (7.1)	15.55 (7.4)	12.27 (5.4)	66.09 (7.5)	15.32
Southern Hills	1.56 (6.1)	1.59 (3.2)	1.81 (3.2)	0 (0)	6.36 (6.1)	5.05 (3.4)	6.62 (3.2)	4.35 (1.9)	27.34 (3.1)	13.64
South Saurashtra	5.25 (20.4)	12.63 (25.8)	10.31 (18.2)	9.04 (14.6)	10.32 (9.9)	14.53 (9.7)	26.34 (12.5)	36.09 (16.0)	124.52 (14.1)	27.26
Gujarat	25.70	48.97	56.76	62.06	103.53	149.26	209.88	224.95	881.11	31.15

Note Figures in parentheses indicate percentage; CAGR—compound annual growth rate
Source Authors' compilation from GGRC

each tubewell is 5 with a range of 1–18 (Viswanathan and Bahinipati 2014, 2015). As is evident, Banaskantha district accounts for almost 60 % of the total number of tubewells on which the MIS has been installed, i.e., 143 tubewells. The district also has the corresponding highest share in the number of beneficiary farmers (i.e., 48 %) (Viswanathan and Bahinipati 2014, 2015; see Appendix 8.1). Patan and Mehsana are the other two districts showing highest number of tubewells and farmers adopting MIS (Viswanathan and Bahinipati 2014, 2015). In view of the larger coverage, we selected the Banaskantha district for the field survey, which is a water scarce region with a groundwater development status of 107 % during 2011 (GoI 2014). Out of the total beneficiary farmers under GWRDC scheme in the Banaskantha district (i.e., 650 households), the study surveyed 5 households under each tubewell, and these households were selected randomly: 355 farmers were interviewed in total. A structured questionnaire was used to gather information from the sample farm households, which included the information on various impacts and benefits of MIS, household characteristics and cropping patterns. The household survey was conducted between December 2013 and February 2014.

A simple descriptive analysis was undertaken to understand the role of subsidy in enhancing the adoption rate of MIS and the socio-economic impacts of it. Further, to analyse the determinants of accessing various benefits of MIS, a discrete choice model was used as the dependent variables are binary in choice. There are two options for this analysis: logit and probit. Logit and probit models can be derived from an underlying latent variable model (Wooldridge 2002):

$$y^* = x\beta + e \quad y = 1[y^* > 0] \tag{8.1}$$

where, y^* is the unobserved latent variable, x denotes the set of explanatory variables, β represents the vector of parameters to be estimated and e is the error term. The main difference between probit and logit models lies in the assumption of the distribution of the error term. While the error term has standard logistic distribution in the context of logit model, it has standard normal distribution in the case of probit model. Understandably, most studies prefer using probit model because of normality assumption (Wooldridge 2002). This study also used a probit model to assess the effects of seasonality and cropping patterns in accessing the benefits of MIS. Further to interpret the effects of explanatory variables on the probabilities, the marginal effects of both continuous and discrete explanatory variables are estimated.

The marginal impact for each continuous explanatory variable on the probability level is given by (Wooldridge 2002):

$$\frac{\partial p(y = 1|x)}{\partial x_k} = g(x\beta)\beta_j \tag{8.2}$$

Further, the marginal effect for a dummy variable, say x_k, is the difference between two derivatives evaluated at the possible values of the dummy, i.e., 1 and 0, thus (Wooldridge 2002):

$$\frac{\partial p(y=1|x)}{\partial x_k} = G(\beta_1 + \beta_2 x_2 + \cdots + \beta_{K-1} x_{K-1} + \beta_k) - G(\beta_1 + \beta_2 x_2 + \cdots + \beta_{K-1} x_{K-1}) \quad (8.3)$$

The cross-section econometric analysis is associated with the problem of multi-collinearity and heteroskedasticity. A variance inflation factor (VIF) for each of the explanatory variable was estimated to check multicollinearity, and a robust standard error was calculated to address the possibility of heteroskedasticity (Wooldridge 2002). The VIF value for all the independent variables is below 10 (i.e., 1.51 with a range of 1.12–4.7; see Appendix 8.2), suggesting no problems of multicollinearity. The descriptive statistics of both dependent and explanatory variables used in the analysis are reported in Appendix 8.3.

8.4 Results and Discussions

8.4.1 Role of Subsidy Policy in Enhancing MIS Adoption Rate

As outlined in the previous section, both national and state governments provide financial incentives (subsidy) to enhance the adoption rate of MIS. In the context of Gujarat, the government gives subsidy of 50 % of the cost of MIS installation or INR 60,000 per ha, whichever is lower, to the farmers (IRAP 2012). Besides, the farmers in the 54 notified dark zone talukas (as per GoG norms) of Gujarat get additional 10 % subsidy for MIS installation on any crop.[3] Whereas, the small and marginal farmers can get a higher amount of subsidy, i.e., 75 % for installation of MIS on the public tubewell, as per the GWRDC MIS scheme launched since 2009 (Viswanathan and Bahinipati 2014). Similarly, the farmers in the tribal talukas are entitled to get a subsidy of 75 % or INR 90,000 per ha, whichever is lower[4].

Since all the farmers are eligible for 50 % subsidy, this section briefly describes the impact of additional 25 % subsidy provided by the GWRDC to marginal and small farmers on the MIS adoption. In this context, Table 8.3 reports MIS adoption status among farmers based on year of adoption and availing extra subsidy. Out of the total 355 sample farmers, almost 75 % of the farmers have adopted MIS since 2009, when it was launched by the GWRDC (Fig. 8.4). The curve showing

[3]http://www.ggrc.co.in/pdf%20files/FAQ%20(13-14).pdf; accessed on 25th August 2014.

[4]See GR No: VKY-2007-345-DSeg date 6/10/2008.

Table 8.3 Status of MIS adoption among farmers, by year of adoption and availing extra subsidy

Year adopted	Extra subsidy[a]		Total
	No	Yes	
2006	9 (100)	0 (0)	9 (2.54)
2008	3 (100)	0 (0)	3 (0.85)
2009	78 (100)	0 (0)	78 (21.97)
2010	22 (23.4)	72 (76.6)	94 (26.48)
2011	18 (16.67)	90 (83.33)	108 (30.42)
2012	10 (22.73)	34 (77.27)	44 (12.39)
2013	4 (21.05)	15 (78.95)	19 (5.35)
Total	144 (40.05)	211 (59.44)	355 (100)

[a]The extra 25 % subsidy is given to the small and marginal farmers in the year 2009 onwards by GWRDC, otherwise all the farmers are eligible to get 50 % subsidy under GGRC
Source Computed from primary data

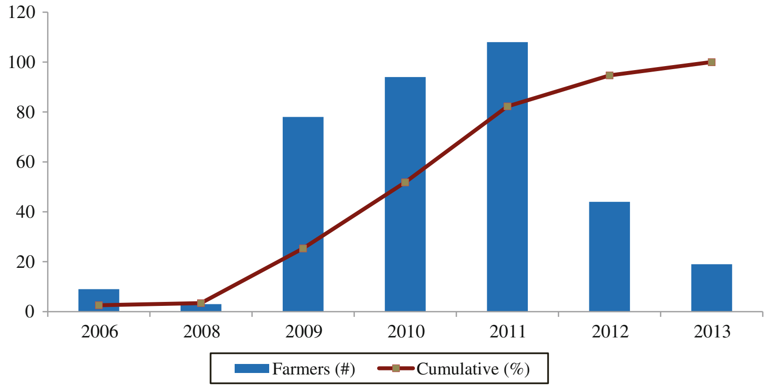

Fig. 8.4 Trend of MIS adopted farmers. *Source* Table 8.3

cumulative percentage of MIS adoption has increased from 25 % during 2009 to 52 % during 2010 and almost 95 % by 2013.

Table 8.3 shows that a large percentage of farmers, who have availed extra subsidy under GWRDC scheme, have undertaken MIS since 2010 (see Fig. 8.4). As regards adoption across landholding categories (Figs. 8.5 and 8.6), larger number of marginal and small farmers have adopted MIS since 2010, as they are entitled to get additional 25 % subsidy. This reveals that the subsidy plays an important role in enhancing adoption rate of MIS in the study area. There are also other confounding factors such as awareness about MIS, learning effect, benefits of MIS, etc. that could have influenced better adoption. The future research should control all these factors to see to what extent subsidy alone influences the MIS adoption rate.

Fig. 8.5 Percentage of MIS adopted farmers, by availing extra subsidy. *Source* Table 8.3

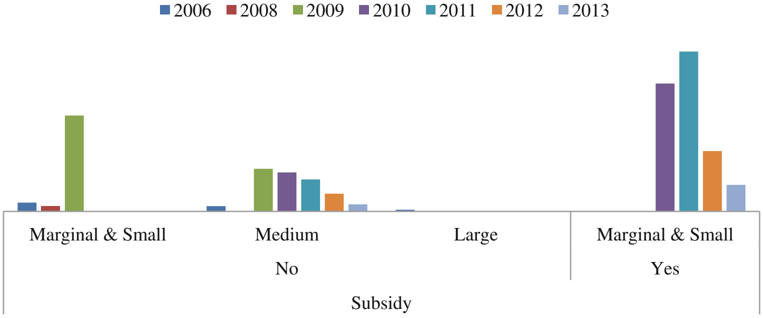

Fig. 8.6 Impact of subsidy policy on adoption behaviour of marginal and small farmers. *Source* Table 8.3

8.4.2 Farmers' Perceptions About Economic and Social Benefits of MIS

An assessment of the economic and social benefits of the MIS is presented here based on the perceptions of farmers as regards some of the visible benefits that emerge from MIS adoption. In this respect, it was found that majority of responses are highly appreciative of the overall benefits accrued from the use of MIS for irrigation. As per the farmers' perception, the major benefits, which are not mutually exclusive, they realise from adopting MIS are: (i) yield increase, (ii) saving water, (iii) saving energy, (iv) reduced labour use, (v) reduced use of fertilizer and pesticides, and (vi) reduced pressure on pump and tubewell. Figure 8.7 shows farmers' perception on benefits of MIS. Among them, two benefits (e.g., yield increase and saving water) were observed by more than 80 % of the farmers. While around 60–70 % of the farmers reported reduction in labour use and energy saving after adopting MIS, around half of the farmers have reported that use of MIS

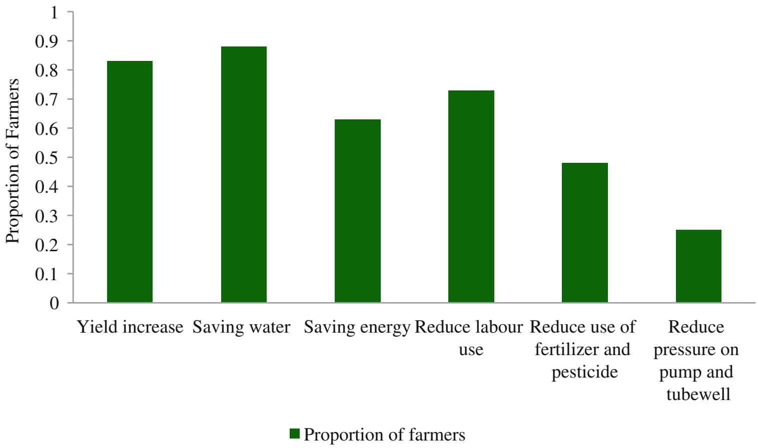

Fig. 8.7 Farmers' perception on benefits of MIS. *Source* Computed from primary data (n = 355)

reduced the use of fertilizer and pesticide. Moreover, about one-fourth of the farmers experienced the positive impact of MIS in reducing pressure on the pump and tubewell.

8.4.3 Determinants of Accessing the Benefits from MIS

Table 8.4 reports the marginal effects of the determinants of accessing benefits of micro-irrigation (MIS). The results show that all the coefficients included in the model had the expected signs. The values of Wald $x^2(15)$ are found as significant in all the models, which indicate that the independent variables taken as a group are quite significant in explaining the farmers' perception on benefits of adopting MIS. Further, it is also found that there are no missing variables in the model as the coefficients of 'Ramsey test' are not significant, and as a result, we can't reject the null hypothesis as there is no missing variable in the model (see Appendix 8.4). In addition, there are no specification errors in all the models. Since the objective of this study is to investigate the effects of seasonality and cropping patterns in accessing the benefits of MIS, this study first discusses about the coefficient of variables undertaken under these two categories.

The variables representing seasonality are area under MIS during kharif, rabi and summer seasons. Among them, it is found that the coefficients of area under MIS during kharif season are positive and significant for the benefits like yield increase, reduced labour use and reduced use of fertilizer and pesticides. For instance, a 1 % increase in area under MIS during kharif season enhances farmers' perception on yield increase by 9.1 %; reduce labour use by 11.5 % and reduce use of fertilizer

Table 8.4 Odds ratio of determinants of benefits of micro-irrigation

	Yield increase	Saving water	Saving energy	Reduce labour use	Reduce use of fertilizer and pesticide	Reduce pressure on pump and tubewell
Age of HH	−0.002 (0.001)	−0.001 (0.001)	−0.002 (0.002)	-0.003* (0.002)	−0.004* (0.002)	−0.002 (0.002)
Years of schooling of HH	0.002 (0.005)	−0.003 (0.004)	−0.007 (0.007)	−0.005 (0.006)	−0.001 (0.006)	−0.003 (0.006)
Ownership of land (in ha)	−0.009 (0.013)	0.006 (0.013)	0.006 (0.023)	−0.008 (0.021)	0.060** (0.026)	−0.009 (0.018)
Share of land under MIS	0.001* (0.001)	0.001 (0.001)	−0.001 (0.001)	0.001 (0.001)	−0.001 (0.001)	−0.002** (0.001)
Area under MIS during kharif	0.091* (0.051)	−0.041 (0.032)	−0.071 (0.061)	0.115** (0.058)	0.185*** (0.062)	0.067 (0.054)
Area under MIS during rabi	0.007 (0.095)	0.054 (0.135)	−0.151 (0.132)	0.103 (0.155)	0.094 (0.158)	0.002 (0.139)
Area under MIS during summer	0.037 (0.048)	0.042 (0.042)	0.079 (0.068)	−0.003 (0.058)	−0.058 (0.071)	0.022 (0.058)
Years completed of MIS adopted	−0.012 (0.017)	−0.029** (0.014)	0.011 (0.024)	−0.032 (0.023)	−0.011 (0.026)	0.043** (0.020)
Number of farmers in a tubewell	0.007 (0.004)	0.008** (0.004)	−0.007 (0.007)	0.011* (0.006)	0.008 (0.006)	−0.006 (0.005)
Ln (depth of tubewell)	0.021 (0.041)	0.042 (0.033)	0.051 (0.060)	0.137*** (0.053)	0.222*** (0.067)	0.081 (0.054)
Deepened in the last five years	0.001 (0.050)	0.093* (0.054)	−0.057 (0.069)	−0.007 (0.063)	0.048 (0.072)	−0.102 (0.069)
Horsepower of pump	−0.004*** (0.001)	−0.004*** (0.001)	−0.003 (0.002)	−0.006*** (0.002)	−0.004* (0.002)	−0.0003 (0.002)
Share of cereals and pulses	0.002** (0.001)	0.0001 (0.001)	0.002 (0.002)	0.0002 (0.001)	0.001 (0.002)	−0.0003 (0.001)
Share of cotton and oil crops	0.005*** (0.001)	0.001 (0.001)	0.004** (0.002)	0.003* (0.002)	0.002 (0.002)	0.001 (0.001)
Share of vegetables	0.004*** (0.001)	0.003** (0.001)	0.005** (0.002)	0.002 (0.002)	−0.002 (0.002)	0.002 (0.002)
Number of observations	355	355	355	355	355	355
Wald $\chi^2(15)$	70.14***	49.60***	24.64**	39.48***	46.69***	27.13**
Pseudo R^2	0.198	0.157	0.052	0.097	0.105	0.063

Note Figures in the parentheses indicate robust standard error; $*p < 0.1$ and $**p < 0.05$ respectively
Source Computed from primary data

and pesticides by 18.5 %. The coefficients of other two variables representing seasonality, such as area under MIS during rabi and summer seasons, are not significant for any of the benefits of MIS. This indicates that farmers perceived various socio-economic benefits while adopting MIS when they realize its potential during periods of water stress, irrespective of the seasons, as some crops overlap across the kharif and rabi seasons. The indicators representing cropping pattern are share of cereals and pulses, share of cotton and oil crops and share of vegetables. The coefficient of share of cereals and pulses is significant in the context of yield increase. Further, the coefficients of share of cotton and oil crops are positive and also significant for benefits like yield increase, saving energy and reduce labour use. The other indicator representing share of vegetables has positive association with three benefits of MIS, such as yield increase, saving water and saving energy.

From the above discussion, it is understood that farmers are accessing various benefits of adopting MIS, if they are cultivating cotton and oil crops as well as vegetables. Therefore, these crops should be promoted in the region where a large number of farmers have already taken up MIS. In sum, it could be said that farmers' perception about various socio-economic benefits of adopting MIS varies with respect to seasonality and cropping patterns.

While the coefficient for share of land under MIS is positive and significant for yield increase, this has negative association with reduced pressure on pump and tubewell. The coefficients for number of farmers in a tubewell command are positive as well as significant for 'yield increase' and 'reduced labour use'. The coefficient for 'deepening of wells in the last five years' is positive and significant for 'water saving'. The coefficients for horsepower (HP) of pump is negative for yield increase, saving water, reduce labour use and reduce use of fertilizer and pesticides.

8.5 Conclusions and Future Perspectives

This chapter presents the results of the techno-economic analysis of the performance of MIS installed public tubewells in the Banaskantha district in Gujarat. Based on an empirical survey of 355 farmers attached to 122 public tubewells, it also brings out the important financial (subsidy), socio-economic as well hydrological factors that significantly contribute towards accessing the benefits of MIS among the farmers. The results of the techno-economic analysis bring forth significant economic and social benefits to the beneficiary farmers in terms of: (a) increase in crop yields during kharif, rabi and summer seasons; (b) considerable savings in energy consumption; (c) reduction in the use of chemical fertilizers and pesticides; (d) reduction in cost of weeding; (e) reduction in groundwater over-extraction; and (f) reduction in water scarcity induced labour migration, etc. to mention a few.

The analysis demonstrates that the farmers who have adopted the MIS under the subsidy programme by the state government have been compensated for the investments they made. By and large, farmers have reported to grow a range of crops especially during the kharif and Rabi seasons and most of these crops have been brought under the MIS. However, while the adoption of MIS by the farmers has been quite impressive during the kharif and Rabi seasons, as some important crops grown by farmers, such as cotton, fennel, and castor spread across kharif and rabi seasons. The results of the study also bring out that the lukewarm adoption of MIS for growing summer crops. This lack of a greater adoption of the MIS during the summer season could be attributed to a host of factors, including the persistent scarcity of ground water in the drier months, which in turn pre-empt the farmers to grow any crops during the summer using MIS. Moreover, there are very few crops grown by farmers during summer that can be benefited under MIS in the present context. This raises an important constraint that comes up in the way of scaling up of the MIS in the specific context of Gujarat, where the farmers are heavily promoted to adopt new agricultural practices, especially such innovative water saving technologies. While the study brings forth the significant positive economic, social and environmental outcomes of the MIS, efforts in terms of extension support and institutional interventions for facilitating wider adoption of the MIS through bringing more crops under the ambit of the scheme. More efforts are needed to rejuvenate the local water harvesting structures through artificial groundwater recharge programmes wherever such potentials exist and this in turn may help increase the adoption of MIS during the summer.

At the same time, the implementation of MIS also creates issues of local conflicts, mostly triggered by the local dynamics in the villages. Our interactions with villagers revealed that in view of the emerging shortage of water, the access to the benefits of MIS is mostly determined by who holds the control over the public tubewell to which the MI systems are installed. This in other words creates more rooms for division of the local village communities on caste or other lines. It was noticed in several places that the water from the bore wells was earlier utilized by larger number farmers (2–15), irrespective of their socio-economic or caste affiliations. But with increased scarcity due to reduction in yield of the wells, the extent of area as well as farmers benefited under such innovative water saving technologies are getting shrunk across villages. Adding more to the water woes, in majority of the cases, the public tubewells or borewells are at least 20–30 years old. In very many of such situations, the benefits of MIS are found to be mostly appropriated by a few family members, who incidentally happen to be the listed beneficiaries at a public tubewell on which MIS has been installed. What type of policies and institutional measures could help resolve such dilemmas is a major issue to be resolved to enhance the social viability and sustenance of the MIS interventions in the specific context of Gujarat.

A much more serious issue is achieving the fuller potentials of the MI technology and taking forward its broad goals of water saving along with inter as well as intra-generational equitable distribution, especially when the rural scenario is fast changing with respect to ageing farming population and the declining interests in farming amongst the younger generations. A study in Pakistan Punjab on the impact of conservation technologies such as zero tillage, laser leveling and use wet seeded rice on water use in irrigated agriculture showed that after adoption, the consumptive water use at the system level increased, though there was significant water saving at the field level (Ahmad et al. 2007). The implication here is that the ultimate long-term impact of a technology, such as MIS in terms of water saving would depend upon how innovative are the farmers in terms of devising new methods of water application, new cropping and agro-management practices and restriction of area under irrigation that could result in 'real water savings'. This essentially requires the enhancement of assimilative capacities and skill levels of the farmers, which can yield better results mostly when the farmers are 'younger enough' to learn and adapt the new water management practices on the field. Given the empirical reality that the average age of a vast majority of the sample farmers is 50 years and above, it may be quite unlikely that the fuller potential of the MIS would be fully realized in the emerging scenario of growing water shortages.

The above facts bring out two major issues of topical relevance, i.e., the need for regulatory systems or institutions for addressing the market prices for crops grown under MIS on the one hand and the regulation of over-extraction of groundwater through appropriate electricity and water pricing and allocation policies to reflect the scarcity value of water. As pointed out by other researchers (Kumar et al. 2008a, 2011), and also emerging from this study, there are no real incentives for the farmers to grow more water efficient and market friendly crops to address these concerns. Moreover, the energy pricing policy of the state has also been least responsive to the serious problem of over-extraction of groundwater using submersible pumpsets installed on the deeper tubewells/borewells all across the state. Given this reality, the adoption or non-adoption of MIS does not contribute much towards conserving the scarce water resources in a water-stressed state like Gujarat.

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Appendix 8.1

Distribution of public tubewells with MIS in Gujarat (up to 2012–13)

District name	Tube wells (No.)	(%) share	Farmers (No.)	(%) share	Total area (ha)	Avg. no of farmers per tubewell	Area (ha) per tubewell	Avg. farm size (ha)
1. Banaskantha	143	57.2	650	47.6	642.55	4.55	4.49	1.28
2. Gandhinagar	24	9.6	131	9.6	122.99	5.46	5.12	1.19
3. Mehsana	32	12.8	244	17.9	214.43	7.63	6.70	1.11
4. Patan	42	16.8	285	20.9	204.02	6.79	4.86	0.91
5. Sabarkantha	9	3.6	55	4.0	87.15	6.11	9.68	1.76
Total	250	100	1365	100.0	1271.14	5.46	5.08	1.20

Source Adopted from Viswanathan and Bahinipati (2015)

Appendix 8.2

Collinearity test for independent variables

Variable	VIF	1/VIF
Age of household head (HH)	1.10	0.91
Years of schooling of HH	1.02	0.98
Ownership of land (in ha)	1.41	0.71
Share of land under MIS	1.42	0.71
Area under MIS during kharif	1.29	0.77
Area under MIS during rabi	1.27	0.79
Area under MIS during summer	1.17	0.86
Years completed of MIS adopted	1.21	0.82
Number of farmers in a tubewell	1.63	0.61
Ln (depth of tubewell)	1.45	0.69
Deepened in the last five years	1.12	0.89
Horsepower of pump	2.09	0.48
Share of cereals and pulses	1.99	0.50
Share of cotton and oil crops	2.54	0.39
Share of vegetables	2.00	0.51
Mean VIF	1.51	

Source Computed from primary data

Appendix 8.3

Descriptive statistics of the variables

S. No.	Variables	Mean	SD	Min	Max	Description
Dependent variables						
1	Yield increase	0.83	0.38	0	1	Binary (Yes, No)
2	Saving water	0.88	0.33	0	1	Binary (Yes, No)
3	Saving energy	0.63	0.48	0	1	Binary (Yes, No)
4	Reduce labour use	0.73	0.44	0	1	Binary (Yes, No)
5	Reduce use of fertilizer and pesticide	0.48	0.50	0	1	Binary (Yes, No)
6	Reduce pressure on pump and tubewell	0.25	0.43	0	1	Binary (Yes, No)
Independent variables						
7	Age of household head (HH)	48.91	13.12	21	85	Numerical
8	Years of schooling of HH	9.03	3.96	1	18	Numerical
9	Ownership of land (in ha)	1.49	1.32	0.2	16.2	Continuous
10	Share of land under MIS	77.99	30.59	6.7	100	Numerical
11	Area under MIS during kharif	0.67	0.47	0	1	Binary (Yes, No)
12	Area under MIS during rabi	0.97	0.18	0	1	Binary (Yes, No)
13	Area under MIS during summer	0.77	0.42	0	1	Binary (Yes, No)
14	Years completed of MIS adopted	3.54	1.15	1	5	Numerical
15	Number of farmers in a tubewell	7.48	5.10	1	27	Numerical
16	Ln (depth of tubewell)	6.29	0.52	4.70	6.91	Numerical
17	Deepened in the last five years	0.83	0.38	0	1	Binary (Yes, No)
18	Horsepower of pump	44.18	17.52	10	85	Numerical
19	Share of cereals and pulses	38.26	22.16	0	100	Numerical
20	Share of cotton and oil crops	32.12	24.10	0	100	Numerical
21	Share of vegetables	17.94	18.39	0	87.5	Numerical

Source Computed from primary data (n = 355)

Appendix 8.4

Test for omitted variable bias and specification error

Dependent variable	Ramsey test for omitted variable bias (H_0: model has no omitted variables)		Specification error test	
	F (3, 336)	Prob. > F	Coefficient of $\hat{Y}^2$	*P* value
Yield increase	1.38	0.248	−0.390 (0.524)	0.456
Saving water	0.66	0.579	−0.625 (0.970)	0.520
Saving energy	0.86	0.464	−0.116 (1.160)	0.921
Reduce labour use	0.23	0.874	−0.058 (0.871)	0.947
Reduce use of fertilizer and pesticide	0.47	0.704	0.457 (0.498)	0.359
Reduce pressure on pump and tubewell	0.10	0.959	0.190 (1.443)	0.895

Source Computed from primary data

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Chapter 9
Managing Groundwater Energy Nexus in India: The Curious Case of Using Solar Irrigation Pumps with Drip Systems

Nitin Bassi

9.1 Introduction

Over the last few decades, there has been an unprecedented growth in groundwater use for irrigation in India. This has been made possible due to growth in large number of private energised wells which transect the country landmass. While the number of electric pumps abstracting groundwater increased from 0.2 million in 1961 to more than 11 million by 2007, diesel pumps increased from 0.16 million to 6.3 million during the same period. Clearly, growth in number of electric pumps was far more than that of diesel pumps. As a result, there has been an exponential increase in electricity use in irrigation, i.e. from 4470 Gigawatt hours (GWh) in 1971 to 160,000 GWh by 2014.

While more dependence on groundwater based irrigation surely aided agricultural growth, pervasive energy subsidies for farm use combined with lack of effective regulation for groundwater withdrawal is resulting in both groundwater over-exploitation and inefficient and wasteful use of energy (Kumar et al. 2011; Bassi 2014). As a result by 2011, in nearly 16 % of the total assessed units, groundwater was overexploited and in many areas of hard rock regions (covers 70 % of the total area of the Country), well failures were found to be very common (Kumar 2007; Bassi et al. 2008). Further, State Electricity Boards (SEB) in larger parts of Peninsular and Western India are making losses due to supply of highly subsidized power to the farm sector, which accounts for a major chunk of the electricity consumption in these areas.

Over-exploitation of groundwater in western India has not only led to groundwater scarcity but has also resulted in wasteful use of energy as farmers are not confronted with marginal cost of abstracting additional groundwater. However in water-rich eastern region, groundwater development is constrained by limited

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availability of arable land. Further, obtaining access to reliable supply of electricity at affordable rates to pump groundwater economically is an issue for many millions of small and marginal farmers, who are forced to depend either on expensive irrigation using diesel pumps or on purchased water from rich well owners (Kumar et al. 2014).

In the water-scarce regions, there is a need to adopt a policy which would restrict groundwater and energy usage, while simultaneously ensuring that the returns from farming are not affected especially for small and marginal farmers. On the contrary, in the water-rich and land scarce regions of eastern India, a policy is needed to promote equity in access to groundwater without costing much to the exchequer. Some of the ideas which are floated in the public policy debate on promoting groundwater irrigation in eastern India include: subsidizing micro diesel pumps; providing free or cheap electricity connections to farmers; and introducing solar pumps, with subsidies. However as recently pointed out by scholars, providing free power connections would not only mean huge draining of public exchequer, but would be counter-productive when it comes to promoting access equity in groundwater (Bassi 2014; Kumar et al. 2013).

Options have also been proposed to address the more complex issue of groundwater energy nexus. Some of the direct and indirect measures include: establishing systems of tradable water rights (Saleth 1994; Kumar 2003; Bassi 2014); pro-rata pricing of electricity for irrigation use (Saleth 1997; Kumar et al. 2011; Bassi 2014); and promotion of solar irrigation pumps with drip systems (SIPDS) (Kishore et al. 2014). In this backdrop, this chapter mainly focuses on the physical and economic feasibility of solar pumps in limiting groundwater and energy use. Analysis was also undertaken to examine the degree of incentives farmers would have to make best use of SIPDS for improving water use efficiency.

9.2 Potential of Solar Power and Its' Uptake in India

The total solar power potential in India is estimated to be about 749 gigawatt peak (GWp) which is the maximum power that can be generated under optimum conditions (no clouds, sun directly overhead 90° to panels and on longest day of the year). State wise potential which is estimated on the basis of proportion of wasteland and urban roof area where solar PV system can be installed and considering a solar PV module efficiency of 15 % is presented in Fig. 9.1. Clearly, the State of Rajasthan in western Indian offers the highest potential (142 GWp) and Goa offers the least (0.9 GWp).

Region wise analysis shows that the highest solar power potential is in Western India, followed by Northern, Southern, Central and North-eastern India and least in Eastern India (Table 9.1). In terms of proportion of contribution to region's solar potential, Madhya Pradesh in Central India; Odisha in East; Jammu & Kashmir in North; Assam in North East; Andhra Pradesh in South; and Rajasthan in West, have the highest shares.

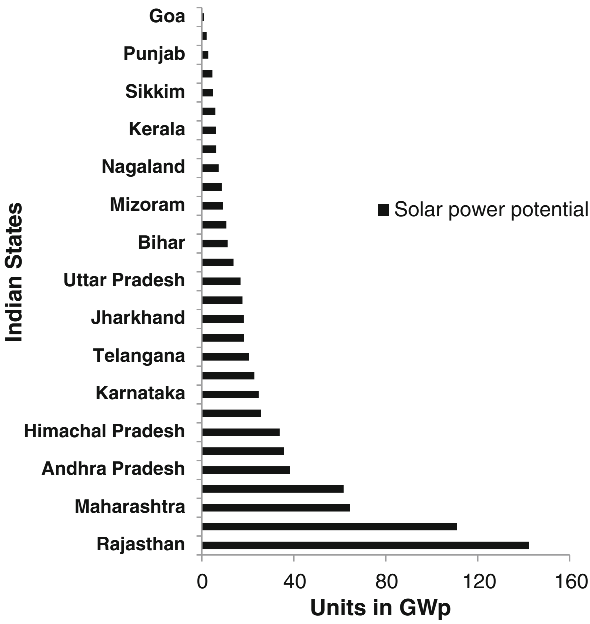

Fig. 9.1 State wise solar power potential in India. *Source* Based on data from National Institute of Solar Energy, Government of India

Table 9.1 Region wise distribution of solar power potential in India

Sl. no	Region	Solar potential (GWp)
1	Central India	80
2	Eastern India	61
3	Northern India	192
4	North eastern India	62
5	Southern India	107
6	Western India	243

Source Author's own analysis using data from National Institute of Solar Energy, Government of India

However, against the potential, India has been able to install only 4 GW of grid connected solar power projects as on 2015. A significant proportion of it was made possible during the last two years with government promoting its adoption by offering heavy subsidies. Still, it contributes only 1.5 % in the total energy mix of the Country (Source: Central Electrical Authority, Government of India). Several reasons have been identified for slow pace of solar PV projects in India. Among others, major ones include: difficulty in making solar projects economically viable mainly due to high initial capital cost; less demand for solar produced electricity which is creating a supply surplus and thus stalling sector growth; time lag between installation of solar PV systems and receipt of government subsidy by installers and buyers which deter new demand; and procedural problems such as the need to secure financing from multiple sources and approval from several government agencies (Sen 2014). Thus even though there is an immense solar power potential in India, its uptake is limited by various constraints which are economic, social and policy related.

9.3 Solar Irrigation Pump: Technical Feasibility and Economic Viability

Carbon foot print in Indian agriculture through the use of diesel pumps is one of the highest in the World and estimated to be around 1.75 million ton (Kumar et al. 2014). In the recent past, with growing environmental concerns about the increase in carbon footprint of agriculture, non-conventional energy, particularly solar energy, has attracted great attention from policy makers. The recent drop in price of solar panels, worldwide, and the diesel price shocks have also prompted practitioners and policy makers to look at solar power as an important source of energy in remote rural areas, otherwise not covered under rural electrification for both domestic and agriculture sector, for lighting, and running water supply and irrigation pumps.

Of late, suggestions have been made by some researchers for large scale adoption of solar pumps to boost groundwater irrigation in eastern India based on their off-take in western India where it is used in conjunction with drip systems (Kishore et al. 2014; Shah et al. 2014). A few researchers have also suggested that farmers can sell the excess electricity using solar PV system to the grid, using 'net metering', thereby creating incentive for efficient use of energy and groundwater, while reducing the power subsidy burden on the utilities (Kishore et al. 2014; Shah et al. 2015). However there are some important concerns related to technical feasibility and economic viability and equity of such approaches, which are overlooked (Bassi 2015). Such concerns cannot be ignored as they could have serious implications for equity in distribution of subsidy benefits and therefore access equity in groundwater and can cause significant financial burden on the public exchequer.

9.3.1 Techno-social Feasibility

To consider solar irrigation pumps for eastern India based on observation that there is a good off take of the technology in western India is unreal. Western region is among the best in the country in terms of solar power generation potential (refer Table 9.1). It is one of the regions with high proportion of solar hotspots, i.e., the regions characterized by an exceptional solar power potential suitable for decentralized commercial exploitation of energy (Ramachandra et al. 2011). The peak sunlight hours (no. of hours of 1 kW per square metre of solar radiation intensity) in most parts of western India varies from 5.5 to 6.5 h a day, whereas in eastern India it is about 4–5 h a day (Fig. 9.2). Thus, the output of solar-powered pumping system in western region will be significantly higher than in eastern India. Further as per the rule, less is the peak sunlight hours available, the more expensive the required solar PV system as more storage is needed to compensate for the limited

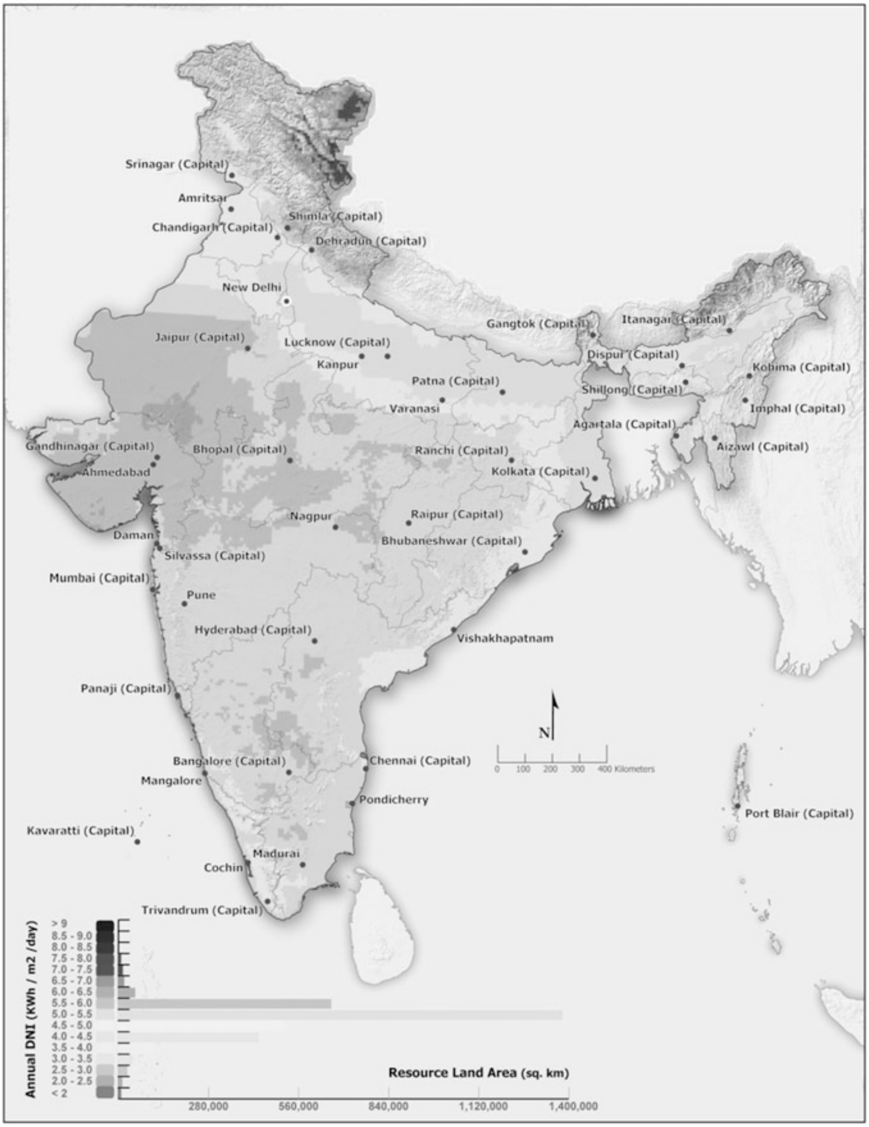

Fig. 9.2 Peak sunlight hours in different regions of India. *Source* National Renewable Energy Laboratory, GoI

exposure of the PV array to peak sunlight hours. Thus the solar generation will also prove to be more costly for the farmers in the eastern region.

Further in most parts of eastern India, groundwater is shallow and majority of farmers depend on rented diesel pumps or cheap Chinese diesel pumps to abstract groundwater. Cost of Chinese pump varies from INR 7000 (INR 1 equals to US$ 0.02) for 3HP to INR 8500 for 5HP (Shah et al. 2009). Contrary to this, cost of solar irrigation pump is INR 400 thousand to INR 450 thousand. Even after getting subsidy of let say 75 %, farmers have to pay around INR 100 thousand to INR 112 thousand per unit. It is almost impossible for small and marginal farmers in eastern India to shell out this money. Even if they borrow from banks or any other financial institutions, it will put huge burden on them to repay the loan as they hardly generate any surplus from their postal stamp-sized holdings. Thus, large scale adoption of solar irrigation pumps becomes distant dream in eastern India. An outcome of such policy would be large and medium farmers availing of the subsidy benefits to replace their old electric and diesel pumps at a huge public cost.

Further, in high solar radiation areas, there are no technological barriers to implementing PV powered irrigation, provided there is enough land available for the PV array (Kelley et al. 2010). However in eastern India, both cropping and irrigation intensity is very high (Kumar et al. 2014) and in States such as West Bengal there is no barren and un-cultivable land which can be used for installing solar array (Ramachandra et al. 2011). Therefore, from technical point of view too, large scale adoption of solar pumps in eastern India looks a remote possibility.

Even in western India which offers a good solar energy potential, there would be a huge technical challenge to keep solar PV system based pump in working condition. The area is frequented by sand storms and dusty winds which can have an adverse impact on the performance of PV cells. It has been found that accumulated dust on the surface of PV solar panel can reduce the system's efficiency by up to 50 %. The reduction in the peak power generated can be up to 18 % (Sulaiman et al. 2011). Further, the system can have a short lifespan if dust is not removed regularly from the surface of solar PV panel. Thus, in such areas, regular maintenance for the upkeep of PV system is required to ensure its optimal performance.

9.3.2 Economic Viability

There is no doubt that solar irrigation pumps will help reduce carbon emissions and have an almost negligible operation and maintenance (O&M) cost but they require very high initial capital investment. Further in rural areas, there is a lack of technically trained personnel and supply chains for components and parts of solar photovoltaic (PV) systems leading to their poor maintenance and delay in repairs (Nathan 2014), which can affect their life and thus economic viability. They are also less efficient than a diesel engine. As highlighted by a manufacturer of solar pumps in India in their product flyer, a solar pump of 3 HP working for 8 h a day using sunlight gives the same water output as a standard 5 HP pump working on grid

Table 9.2 Economics of solar PV water pumps in relation to diesel powered irrigation pumps

Sl. no.	Particulars	Type of irrigation pump	
		Solar	Diesel
1	Pump capacity	3HP	5HP
2	Capital cost (INR)	376,500	25,000
3	Net present maintenance cost (INR)	8514	34,054
4	Net present fuel cost (INR)	0	191,555
5	Net present cost of carbon mitigation (INR)	0	4130
6	Total cost (INR)	385,014	254,739

Source Adapted from Bassi (2015)

power or diesel engine for 2.5 h a day. Presently, a 3HP surface solar pump costs around INR 376.5 thousand and a 5 HP surface operated diesel pump costs about INR 25 thousand (average costs).

In order to test the economic viability of the pumps, the social costs and benefits need to be evaluated. Since the social benefits accrued from irrigation are same for both the technologies, comparative evaluation of the social costs (private cost + negative externality) is needed. For this, the following assumptions are made: (1) a diesel pump will run for 200 days per year and will consume 0.75 litre of fuel per hour of working; (2) maintenance cost will be about INR 4000 per year for diesel pump and INR 1000 per year for solar pump; (3) average fuel price is INR 60 per litre; (4) one litre of diesel consumption will release 2.64 kg of CO_2 and cost of mitigating 1 kg of carbon emission is INR 0.49 (Institute for Resource and Policy 2012). Considering a system life of 20 years and discount rate of 10 %, present value of the cost comes out to be INR 385 thousand for solar and INR 223 thousand for diesel pump (Table 9.2). While the solar pump does not appear to be beneficial to farmers without subsidies, it is economically less viable than the diesel pumps from the point of social costs and benefits. Hence, providing huge subsidies in promoting solar pumps to the tune of 80–85 % is also not justified as the welfare gain is too little (INR 4130).

9.4 Potential of 'Net Metering' with Solar Pumps

There are concerns that adoption of solar powered irrigation pumps may not lead to reduction in groundwater use as the users are not confronted with marginal cost of running their pumps. To address this, suggestions have been made for providing incentives to farmers to adopt solar pumps and to use groundwater sustainably through creating enabling structures (Shah et al. 2014). This incentive structure basically involves investing in the infrastructure to connect farmer's pump sets with the electricity grid and offer an attractive price for the surplus power which they generate on the basis of net metering (Kishore et al. 2014). The idea is that this will create a high opportunity cost of inefficiently using electricity generated through solar power for irrigation and hence would motivate farmers to save energy and water in agriculture. Further, a significant additional income is visualized for farmers from sale of surplus solar power (Shah et al. 2014). To achieve this, a credible power purchase guarantee by the State Electricity Boards is also envisioned. Further, it was suggested that surplus electricity generated from solar pump irrigation in every village should be evacuated at a single point (presumably by establishing a micro- or mini-grid) that the electricity utility can measure and monitor (Shah et al. 2015).

However, such recommendations falter on several accounts. Firstly, it is difficult to connect millions of scattered wells, installed with solar pumps, to the power grid. Secondly, even establishment of village level micro or mini-grids would involve huge financial costs. For instance, the cost of installation of 250 kilowatt (kW) solar powered mini-grid for supplying power to two villages of Indian State of Uttar Pradesh was about INR 61.5 million which is about INR 250 thousand per kilowatt (Siddiqui 2015). There would also be an additional cost of transmission or distribution of surplus electricity from such village level mini-grids. Thirdly, electricity utilities will have no interest in purchasing surplus electricity at a rate which is almost 2-3 times of the heavily subsidised electricity which they supply for farm use. In 2013–2014, energy subsidy to agriculture was almost US$ 11 Billion and the electricity utilities incurred a loss of US$ 5 billion. Under such circumstances it is even difficult to presume that utilities will extend any power purchase guarantee to farmers.

Thus, it appears to be irrational to first of all invest in such an economically unviable technology and then to make additional investments in a costly infrastructure to buy the power generated from this, in the garb of inducing incentive for conservation. Much less investment is required in metering of electricity consumption by agro wells and paving way for charging users of farm wells on pro-rata basis. However, the proposal is resisted by some on the premise that metering will involve a huge transaction cost and the increases in the metered tariff required for elastic demand behaviour are likely to be significantly higher than are acceptable to either farmers or politicians (refer to de Fraiture and Perry 2002; Shah et al. 2007). While the transaction cost of metering can be minimized to a great extent with the use of pre-paid electronic meters which work through scratch cards or use of remotely-sensed meters (Zekri 2009; Kumar et al. 2011), empirical studies have established that the levels of pricing at which the demand for electricity and groundwater becomes elastic to tariff are socio-economically viable (Kumar 2005; Kumar et al. 2011).

9.5 Can SIPDS Lead to Water Use Efficiency Improvement?

Micro-irrigation is being promoted on a large scale in India with the goal of achieving high water use efficiency and water savings through reduction in the total amount of water applied to crops and non-beneficial consumptive use of water in irrigation. However, whether this will result in real water saving depends on several factors. These include: type of micro-irrigation technology used; any existing restriction on volumetric use of water through direct or indirect measures such as metering and pro rata energy pricing; availability of additional arable land that can be brought under irrigation; environmental conditions of the region (soil, climate); crops grown; and also the presence of water markets in the region. Mere adoption of a drip or sprinkler technology may not lead to a water saving at the farm level (refer to Kumar et al. 2008).

It has long been argued by many researchers with the support of empirical evidences that most of the energy subsidy to farm sector is cornered by resource rich farmers (Howes and Murugai 2003; Kumar et al. 2013). Similar findings have also emerged in case of solar pump adoption in western India. For instance, it was found that most of the subsidy on solar irrigation pumps has been availed by medium and large farmers in State of Rajasthan (Kishore et al. 2014). The main reason for this is the criteria set by the State government for availing subsidy. The criteria include the following: (1) the farmer should own 0.5 ha of land; (2) the land should have a farm pond; and, (3) the farmers should have installed a drip irrigation system in the farm. Obviously, the last two conditions will normally be met mostly by medium and large farmers.

One of the arguments in favour of solar pumps appears to be that of reducing groundwater over-draft. But, it still remains to be seen how groundwater overdraft in western India can be controlled by the use of solar pump. For instance, in State of Rajasthan, the technology is used only to distribute water stored in farm ponds, most of which are filled by canal water from Indira Gandhi Nahar Project (IGNP) and used during summer months. Thus there is no way it can address the nexus between groundwater and energy. At best it can only reduce, to an extent, the use of diesel or electricity for transferring water from farm ponds to fields during summers. Again only a very small proportion of farmers can afford to grow crops during summers in western India.

Further, adoption of drip irrigation by the farmers in their fields is placed as a pre-condition for providing subsidies for solar pumps, under the pretext that the solar pump subsidy is to improve water use efficiency. This is a convoluted logic. The reason being that even for the very adoption of drip irrigation, farmers make use of government subsidies. This essentially means that the same farmer who has received government subsidies for purchase of drips is likely to obtain huge subsidies for installing solar pumps. But there is no intervention to restrict water use in volumetric terms. Thus, argument about water use efficiency falls flat as once the farmer switches over to a solar pump he/she has no incentive to use water efficiently.

Another issue is to ascertain that whether areas appropriate for adoption of drip systems are same which offers significant solar power potential. It has been observed that area which offers higher proportion of solar power potential are different from those that provide higher proportion of area suitable for drip adoption (Fig. 9.3). For instance, among Indian States, Rajasthan has the highest proportion of solar power potential (around 19 %), but the proportion of area that is suitable for

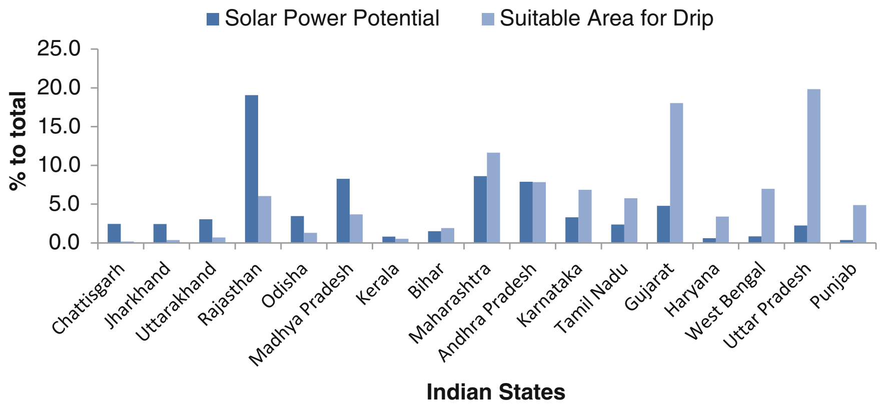

Fig. 9.3 State wise proportion of solar power potential and area suitable for drip adoption. *Source* Based on data from National Institute of Solar Energy, Government of India

installing drips is lesser as compared to other States (only 6 %). Vice-a-versa, Gujarat offers a high proportion of suitable area for drip (18 %), but proportion of total solar power potential offered by the State is low (only 4.8 %). Therefore, even from the bio-physical point of view, simultaneous adoption of solar irrigation pumps along with drip system will be difficult.

It has been found that even in western India which offers significant solar power potential, for instance in State of Rajasthan, introduction and adoption of solar pumps has not reduced demand for new electricity connection and consumption of subsidized electricity for irrigation (Kishore et al. 2014). Further, it has not even resulted in any reduced use of water as the solar pumps are used only to transfer water from farm ponds to fields. It is also quite evident that with the replacement of diesel engines with solar pumps, even the farmers who have installed drip irrigation systems would start applying more water to their crops, owing to the zero marginal cost of using water, unless there are restrictions on the volumetric water delivery to their farms. Then why even a provision of subsidy (even if reduced) should be considered for solar irrigation pumps?. It is clear that farmers have adopted these pumps because of the huge subsidy component, otherwise there is no demand for these even in the best working environment for them. Also, until the farm sector continues to receive free or subsidized electricity, the electric pump owning farmers will have no incentive to switch to other technologies such as solar irrigation pumps.

9.6 Conclusion and Policy Inference

It is clear that because of the huge energy crisis, India will have to look for different sources of energy, both conventional and non-conventional. But, a detailed analysis of the technical feasibility, economic viability and equity aspects need to be carried out before large-scale promotion of such technologies with heavy public subsidies. Ideally, public subsidies for any technology or production system is preferred when the private benefits from the use of the system does not offset the full costs, but the social benefits far exceeds the social costs and with the introduction of the subsidy the private costs to the adopter are lowered. But, this doesn't seem to be the case for solar pumps. Therefore, instead of investing heavily in solar pumps and using them in conjunction with drip irrigation, the government should invest in rural infrastructure such as roads and electrification, and develop good models for administering subsidies for micro diesel engines for marginal farmers of eastern India.

Yet, the Ministry of Non-Conventional Energy of erstwhile government has allocated INR 100 billion in solar irrigation pumps for the 12th five year plan period. This is expected to replace 200 thousand easily replaceable diesel pumps in the country, which at today's market rate would cost only INR 5 billion. The net present worth of the additional cost of maintenance of the 200 thousand solar pumps is estimated to be INR 1.7 billion, against INR 6.8 billion for equal number of diesel pumps. The benefit of carbon emission reduction from this would be a mere INR 826 million accumulated over a period of 20 years, while the total saving in diesel costs would be to the tune of INR 38 billion over a period of 20 years, which is the life of the solar pump. Clearly, there is no gain for the economy, even when one considers the welfare benefit from clean energy, and instead, there is a loss to the tune of INR 51 billion. Its undesirable consequences for groundwater and therefore environment in arid regions also should be taken note of.

The future energy policy of the country should be guided by serious considerations of environmental economics. It is true that the price of solar PV systems has been dropping in the Indian market in the recent. But, if optimistic reactions to this phenomenon take assuming proportions, it would only result in loss to the economy, with no significant gains on the environment front (Bassi 2015). India has an untapped potential of about 100,000 MW of hydropower. Against a carbon emission (CO_2) of 1.04 kg per unit (kWh) of electricity generated in coal based power plants and 0.59 kg per unit (kWh) of electricity generated in diesel based power plants, no carbon is released from electricity generation in hydel projects (Sasi 2015). Thus, hydropower is clean energy and is time tested as source of cheap power. In addition, such projects provide multiple benefits such as water for irrigation and commercial fisheries, domestic and industrial water supplies, and recreational benefits. We need to give serious thought to it, while paying due attention to the concerns of ecological damage, land acquisition and human displacement.

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Chapter 10
Conclusions and Areas for Future Research

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A few decades have passed since micro irrigation systems were first introduced in India in the early 1990s. During the early stage of experimentation, on-farm trials and adoption, the main concern was on water saving and yield enhancement potential of these systems. The focus of the research on micro irrigation systems carried out on experimental fields afterwards was on improvements in conveyance efficiency, changes in irrigation water application rates, and overall change in water use efficiency expressed in terms of (kg/mm) of water for different crops. The estimates of water use efficiency essentially considered the total water applied, rather than the amount of water actually consumed in crop production (Allen et al. 1998; Kumar and van Dam 2013; Perry 2007). Such an approach ignored the relationship between crop transpiration and the yield and that any improvement in yield can only occur through higher transpiration or better dosage of nutrients, if the soil conditions remain the same (Siddique et al. 1990; Schmidhalter and Oertli 1991).

This signifies that any reduction in water application to the field through micro irrigation systems, along with yield enhancement meant that either the 'non-beneficial consumptive use' and 'non-recoverable non-consumptive use' of water or the 'non-consumptive, recoverable percolation' or both might have been much higher under the conventional method of irrigation. This in turn implies that if the entire change in water application under micro irrigation is affected through reduction in the first component of water use, i.e., non-beneficial consumptive use and 'non-recoverable non-consumptive use', then the classical approach of estimating irrigation efficiency and water use efficiency will yield reliable results. But, if the change in water application is affected through the second component, i.e., reduction in non-consumptive recoverable percolation (which is actually beneficial),

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or the first and the second, then the classical approach would end up over-estimating the water saving from micro irrigation systems.

The water engineers and agricultural economists from India who examined the impacts of micro irrigation systems for a long time now ignored the nuances of 'water saving' under MI, and considered the changes in water application to the crop, before and after adoption, or with and without adoption as the basis of quantifying 'water saving'. The complex factors that would determine the extent of reduction in non-beneficial consumptive use, and non-recoverable deep percolation etc., which include, but not limited to, the geo-hydrological environment, climate, crop type and soils, were never considered in the analysis. This resulted in over-estimating water saving benefits of the technology in certain situations. Such methodological weaknesses also severely constrained proper economic evaluation of micro irrigation systems, as the notional 'water saving; was considered as the input for estimating the extent of irrigated area expansion possible with the use of MI system. Such assumptions resulted in inflated benefit cost ratios, and at times counting the social costs as social benefits (see Dhawan 2000). For instance, Dhawan (2000) pointed out that using drip irrigation in canal commands in place of flooding could reduce the return flows from irrigated fields substantially, threatening the sustainability of irrigation from wells, which get replenished by the recharge from such return flows.

Though these methodological issues are yet to be resolved, and application of robust methods yet to be internalized by the engineering and economics professionals and academia working in the water sector, there is significant advancement in the thinking as to what extent, water use efficiencies would be improved through the use of micro irrigation and what are the economic and social benefits.

Chapter 2 discussed the physical and environmental conditions under which real water saving could be obtained through the use of micro irrigation systems. The findings as presented in two chapters (Chaps. 6 and 7) conform to the growing evidence to the effect that increased productivity could be achieved through micro irrigation systems. In Chap. 6, social benefits from micro sprinklers in western Rajasthan were analyzed. Here, the sources of water were large storage tanks in the farmers' fields (*diggies*) fed by canals from IGNP. Chapter 7 analyzed the social benefits from drip irrigation system fed by wells. Among the different positive externalities of MI technologies, the most significant is real saving of irrigation water.

The analysis presented in Chap. 7 on the social benefits and costs revealed that the social benefits exceed the social costs in the water and labour scarce regions. This substantiates the point that drip irrigation is a viable and more beneficial in regions where there is acute water scarcity. Analysis presented in Chap. 6 used a unique methodology to estimate the real water saving from the use of MI, by comparing the water consumed under micro sprinklers with the amount of water that would have actually been consumed to produce the same amount of crop, as under sprinklers, had conventional method of irrigation been practiced to raise those crops. The analysis showed the social benefits (B/C ratio = 2.75) from micro sprinklers higher than private benefits (B/C ratio = 2.11), which was slightly higher than economic benefits (B/C ratio = 1.9).

Analysis presented in Chap. 8 throws important insights on the role of seasonality and subsidies in MI adoption. It is almost certain that technology follows the crops and not vice versa. Before planning large scale adoption of MI systems in a region, it is important to introduce crops that are both amenable to MI technologies and suitable to the agro climates. Analysis presented in Chap. 9 shows that solar pumps would not be economically viable, even after considering the social benefits of carbon emission reduction. Hence, heavy subsidies for its promotion are uncalled for. Further, aggressive promotion of solar pumps with drip irrigation through subsidies would produce undesirable consequences in terms of negative welfare effects, as farmers who use solar pumps would have no incentive to use either groundwater or electricity efficiently.

10.1 Emerging Issues for Research

The foregoing review of the assessment of the status of adoption and performance of MIS across the six major states, viz., Andhra Pradesh, Maharashtra, Karnataka, Gujarat, Rajasthan and Tamil Nadu reveals that by and large, the studies follows a uniform approach of estimating the economic benefits and returns, with a few exceptions. It may be observed that most of the past research on physical impacts of MI systems had dealt with the issue of changes in irrigation water use, crop growth and crop yield. While the economic benefits and returns are critical to be understood as a major factor determining the success of a technology such as the MIS, there are several issues and challenges that are hardly explored/understood by researchers. Some of those issues are discussed below.

First, the limited analyses available on the potential coverage of MI systems in India, which were presented in this volume, take into account factors such as the area under crops that are amenable to MI systems, and the range of physical, socio-economic and institutional factors that induce constraints to adoption of these technologies. However, the issue of millions of farmers not having direct access to wells is not captured in the analysis. This is one issue. *Second*: very few of the research studies done on MI system impacts in India distinguish between saving in applied water and real water saving, while the real water saving that can be achieved through MI adoption could be much lower than the saving in applied water. *Third*: there is an inherent assumption that area under irrigation remains the same, and therefore the saved water would be available for reallocation. But, in reality, it may not be so. With introduction of MI systems, farmers might change the very cropping system, including expansion in irrigated area. Therefore, all these assumptions result in over-estimation of the extent of water-saving possible with MI adoption.

Notwithstanding these issues, it also needs to be examined whether 'the subsidies and incentives provided are efficiently targeted at regions, where MI adoption results in water and energy saving at the aggregate level, so as to maximize the welfare impacts. Ascertaining this is crucial, if subsidies for MI system are to be justified.

A significant concept that is probably least explored in the entire literature in the context of agricultural water management technologies in India (with exception of Kumar and van Dam (2013) is the concept of 'real water saving'. It is important that real water saving is empirically examined in the context of adoption of: (a) water saving crop technologies (seeds/crop varieties); (b) water saving and yield enhancing irrigation technologies; and (c) yield improving crop technologies. An assessment of real water saving would entail understanding the nuances of water use, crop management practices and technology choice of the farmers rather than merely looking at the adoption of a particular type of MIS and the resultant economic impacts per se (Chap. 2, this volume). This way, it can also quantify the actual social benefits through water saving and energy saving if any, through the use of MI systems. Such analysis can help divert the limited financial resources available for offering subsidies to the regions, crops and technologies where it produce the intended social benefits of 'real' water saving.

But, estimating real water saving through different technologies is going to be an enormous task, as this would request instrumentation to measure the consumptive water use by the plants, soil evaporation and deep percolation from the total water applied to the field, using lysimeter installed in the field, separately for different methods of irrigation. An alternative would be to estimate consumptive water use (ET) using field data on crop growth and daily values of hydro-meteorological parameters (solar radiation, wind speed, relative humidity and temperature) and then arrive at different components such as soil evaporation, E and transpiration, T using empirical methods.[1] However, modeling will still be required to estimate the fraction of the deep percolation which is available for reuse through recharge, to arrive at the non-recoverable portion. Such experiments will have to be carried out in different cropping systems and under different geo-hydrological environments and soil conditions. These are complex problems in water use hydrology, and need to be solved if we really want to find out the actual reduction in consumptive water use that can be achieved through micro irrigation systems, rather than applying outdated concepts and methods.

A systematic attempt to find out the conditions under which MI systems become a best bet technology, and assess the magnitude of reduction in water requirement possible through them was by Kumar and others (Kumar et al. 2008). But, the estimates need to be revised, using more realistic figures of water saving under different climates and crops (available from empirical research) and also taking into account the fact that over the past few years, significant shift in cropping pattern is witnessed in the semi-arid and arid regions of India, with diversification towards high value cash crops, fruits and vegetables, with positive implications for 'area'

[1]Penman-Monteith equation can be used for estimating ET. The empirical relationship established by Siddique et al. (1989) can be used for arriving at cumulative bare soil evaporation from estimated ET and leaf area index. Then the actual soil evaporation can then be estimated from the values of bare soil evaporation using light extinction coefficient.

under crops amenable to MI. Such efforts are crucial from the point of view of assessing the ability to address future water scarcity problems at the regional and national levels.

Geo-hydrological setting seems to have a strong influence on MI adoption in well-irrigated areas. In hard rock areas, which are falling in semi-arid tracts, farmers appear to have strong incentive to go for MI systems. This 'link' remains a grey area and needs further exploration across agro-ecological/hydro-geological settings. What needs to be clearly investigated is 'whether this is because of acute scarcity of water in the semi-arid hard rock regions or the strong economic rationale'. As is evident, in these areas, a large proportion of the land remains un-cultivated during the non-monsoon period due to lack of irrigation water—a situation which exists in Gujarat, Karnataka, Andhra Pradesh, Tamil Nadu and Maharashtra—, a factor which motivates MIS adoption, as farmers could extend the area post adoption and enhance their income.

Though many studies have brought out the challenges and constraints facing adoption of MIS, they are more generic in nature. But, the nature of challenges and constraints are very much location-specific. Hence, these studies do not provide specific leads/indicators on the infrastructural improvements, and institutional and policy changes required at the specific provincial/regional contexts to overcome these constraints. While in north Gujarat, lack of independent source of water for irrigators—who are either shareholders of tube wells or water buyers,—is the biggest constraint in further expanding the area under MI system, in Punjab, cropping pattern dominated by rice-wheat system is the major constraint. In this regard, Chap. 3 highlights that crop geometry and information asymmetry still remaining as hindrance to adoption of MI system by farmers even in Maharashtra, a state well-known for large-scale adoption of drip systems.

While there has been impressive growth in adoption of MI systems in many regions of India during the past 7–8 years, the agricultural extension systems in these regions are not equipped to cater to the new requirements of the farmers, particularly in terms of technical knowledge on irrigation scheduling, agronomic practices and operation and maintenance of the system to achieve best results from the use of MI systems. Studies in some pockets of India (for instance in Ahmednagar in Maharashtra) have shown very discouraging results in terms of water use and yield obtained by farmers, with higher dosage of water and lower yields under MI as compared to traditional method (Kumar et al. 2012). If farmers continue to use water inefficiently even after using MI technologies, it is a matter of serious concern. Hence, proper assessment of impacts of MI adoption needs to be carried out through scientifically valid empirical studies in different regions, and factors responsible for such practices need to be identified.

This point leads to an important concern relating to the existing institutional and policy regimes, which influence farmer behaviour with respect to irrigation water use in crop production. The institutional regimes and policies in water and energy sectors should be redesigned in such a way that the farmers' objective of maximizing income from crop production is in alignment with the larger social objectives of reducing the water footprint in agriculture so as to produce maximum welfare benefits. This can be possible only if there are opportunity costs of using water and electricity in irrigated agriculture, the two inputs whose use can be optimized through proper use of the technology, with the result that there would be cost saving for the farmers who use the technology.

Intuitively, the near zero marginal cost of electricity for well irrigators is creating disincentives for farmers to economize on the use of water. Such issues notwithstanding, it is important to know about irrigation schedules for high value cash crops such as cotton, sugarcane and some of the fruit trees, for the farmers to apply water optimally. The reality is that there is too little information currently available from Agricultural Universities and farmers use trial and error method to fix irrigation schedules. Critical to developing irrigation schedules is generating a good understanding of the crop water requirements. In this regard, it is important to mention that crop ET values for many of the horticultural crops are not assessed scientifically, either through field experiments or through empirical methods. For perennial crops such as fruit trees, the ET would change not only across seasons, but also over the years. Future scientific research should focus on these aspects so that farmers get right kind of advice on irrigation schedules.

Given the fact that adoption of MI systems is often associated with shift in cropping pattern towards perennial crops (coconuts, mango, sapota, lemon, gooseberry, pomegranate, citrus, etc.), their overall impact on hydrology and water use under such situations will be different from that of its impact on water use when the crop remains the same. Therefore, the impact needs to be thoroughly studied from a farming system perspective in order to avoid undesirable consequences. Analysis of physical impact of MI system using 'with and without' MI systems is meaningless from a utilitarian perspective. The evapotranspiration outflows from deep-rooted trees can be very high, though this is subject to the leaf area index and tree density (Oliveira et al. 2005). More importantly, trees do survive during the dry seasons in hot tropics, thereby increasing the ET losses during the season. During dry season, the ET losses through trees under natural conditions will be lesser than that of wet season, as in the former case, due to soil drying, which leads to closing of stomata, thus reducing transpiration (Source: www.forestry.gov.uk, Forestry Commission).

The water for meeting ET demand of trees during the dry season can come partly from the moisture in the active root zone, partly from the moisture in the unsaturated zone underlying the soil, and partly also from shallow groundwater in the catchment. While its impact on overall yield of the catchment would be negative, depending on how the increased demand is being met from the hydrological system, the impact will be seen either on runoff or groundwater or both. If the deep soil strata (vadoze zone) along with top soil contribute to evapotranspiration of trees, then the impact will be on both groundwater system and runoff, whereas if shallow groundwater contributes to ET, then the most significant impact will be on base flows and groundwater. Higher the leaf area index, higher will be the transpiration (Hamilton and King 1983; Oliveira et al. 2005). On the other hand, litter cover on the soil increases infiltration rate of precipitation significantly (Hamilton and King 1983). Nevertheless, the large canopy cover will have some effect on the micro climate in terms of increasing the humidity, reducing temperature and solar radiation. While all these factors would reduce ET rates for the vegetation per unit area, the third factor will also have negative impact on the biomass outputs for crops due to the shade created by the tree cover.

Also, research on MI is dominated by the views of economists, hydrologist and water technologists. There is little available by way of understanding and assessing farmer preferences and concerns, which is the other side of the story. In this regard, as discussed in Chap. 4 in the context of Karnataka, some of the reported constraints for low adoption of MI systems were high capital cost, lack of appropriate design of the system for different soil conditions, delay in release of subsidy and small land holding size.

A related concern is the need to evolve appropriate institutional frameworks and policies to overcome the constraints faced by farmers in adopting the MI systems. It is clear that while the government offers financial incentives for promotion of micro irrigation technologies in the form of capital subsidies, the private sector is the sole supplier of the MI systems, and there is no oversight from the government to see who benefits, and who doesn't from such incentive schemes, and examine whether farmers are able to obtain the intended benefits from their adoption. There are no proper checks and balances to ensure ethical business practices with regard to the superiority of the technologies being provided and the availability of post installation services.

Further investigation is needed to find out for what kind of cropping systems, climatic and geo-hydrological conditions, power supply situations (i.e., off-grid or grid connected) and density of power supply network solar powered pumps, and those connected to drip irrigation systems would be economically viable. While it is known that economic viability of drip irrigation system would depend a lot on the agro climate and cropping system, economic viability of solar pumps in an area which is not grid connected would depend on the marginal cost of supplying electricity through grid, or the cost of using alternate sources of energy such as diesel. In a region where farmers already enjoy access to electricity supply from power grid, the cost per unit of solar power should be less than the sum of the cost of supplying power through grid and the negative externality associated with carbon emission from electricity production.

Finally, micro irrigations systems are just one of the many technologies in agriculture to improve productivity of use of water and save the resource. Other ways of improving water productivity and saving water are: improving harvest index of the crops; introduction of crops which have higher genetic yield potential (Siddique et al. 1989, 1990); increasing the transpiration coefficient for the crops (ratio of transpiration and ET) by improving nutrient regimes and controlling salinity (Schmidhalter and Oertli 1991) and changing plant architecture to reduce leaf area index and reduce transpiration (Siddique et al. 1990); and checking barren soil evaporation and conserving the moisture stored in the soil profile from precipitation (Xie et al. 2005). The plant breeders have been working on improving the harvest index (Siddique et al. 1990) and genetic yield potential of crops (Pingali 1999). Worldwide, there is a lot of experimentation on the use of plastic mulching, for reducing bare soil evaporation and conserving the soil moisture available from precipitation, for a variety of crops, including closely spaced crops such as wheat and maize. However, very little adoption of these technologies is happening in India, though farmers have begun to adopt this system along with drip irrigation in many water stressed areas for high value vegetables.

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