Hydrological and Farming System Impacts of Agricultural Water Management Interventions for Sustainable Groundwater Use in North Gujarat

&

Strategies for Improving the Poor Farmers' Access to Groundwater

Draft report of the project carried out by the Institute for Resource Analysis and Policy (in collaboration with Society for Integrated Land and Water Management) under the

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Summary

The report presents the findings of a research study undertaken by Institute for Resource Analysis and Policy (IRAP) in north Gujarat region, which has been undergoing significant changes in its farming systems as a result of several developmental interventions, most important of which is a project initiated by the International Water Management Institute, called north Gujarat Sustainable Groundwater Management Initiative. The project, which is currently managed by the Society for Integrated Land and Water Management (SOFILWM) introduced water-efficient irrigation devices, water-efficient crops and land management practices among farmers in an effort to help them cut down groundwater use in irrigated agriculture without adversely affecting the economic prospects of farming. An estimated area of 73,000 acres of irrigated land is currently under MI systems including drips and sprinklers.

The research study had the following objectives: a] study the water demand management interventions being adopted by different categories of farmers such as small/marginal, medium and large farmers in north Gujarat region; b] analyze the impact of these interventions on the farming system, livelihood patterns, food and nutritional security, poverty and gender division of labour for different categories of farm households; c] design technological innovations that are economically viable for poor small and marginal farmers of north Gujarat, who are dependent on water purchase; and, d] analyze the potential impact of the combinations of water demand management interventions for different scales of implementation on agricultural surpluses and groundwater use, and assess their implications for food security, risk and vulnerability of farming communities, and labour absorption.

The research was based on survey of 114 adopter families and 51 non-adopters, involving collection of primary data of the farming systems in detail. In the case of adopters, the survey included both pre and post adoption scenario. The sample farmers are from a total of 51 villages covering 10 talukas in the project area. These data were analyzed using several analytical tools for evaluating water saving, crop water productivity, benefit-cost, aggregate farm level and regional water use and income impacts of MI adoption. This was followed by discussions with several small & marginal farmers, who are buyers of water or shareholders of tube-well companies.

The most important and interesting findings of the study are with regard to: overall changes in farming system, encompassing the cropping pattern; gross cropped area; investments in water-efficient irrigation technologies; irrigation water use, yield, income and water productivity of individual crops; the overall farm-level income; and groundwater use for irrigation at the farm level. Some of the findings are as follows. MI system adoption is associated with changes in cropping pattern itself. Several of the traditional cereal crops were replaced by cash crops amenable to MI systems. Hence, B-C analysis of MI systems based on input-output data for individual crops has limited practical and policy relevance. While in the immediate term, negative impact of these changes on domestic food security is imminent, in the medium and long term, large-scale MI-adoption will have significant impact on regional food security. 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, and so is the net income from crop production. There has been substantial increase in water productivity of individual crops, in both physical and economic terms. Adoption of MI systems with newly-introduced cash crops and fruits had resulted in remarkable increase in the farm income of adopters. In spite of all these, at the aggregate level, the groundwater use for irrigation reduced significantly.

The researchers designed a system that would enable water buyers to use MI devices for irrigating their crops using purchased groundwater. The system consists of a storage tank, tank lining using HDPE and bricks, a 2-HP electric pump set and drip and micro sprinkler sets covering a total irrigated area of 0.50 ha in two seasons. Economic simulation showed that a water buyer farmer can profitably cultivate five crops, viz., castor, groundnut, fennel, potato and chilli in combination in a net area of 0.40ha (i.e., one acre) and secure a stable extra income of Rs.11800, annually. This also means that the farmers have to show greater risk taking ability, as these crops often pose a lot of risk from the point of view of both production and marketing. These risks need to be covered through proper institutional interventions of agricultural extension and provision of processing and marketing infrastructure.

In spite of the constraints imposed by the denial of power connections in agriculture by the State Electricity Board, a couple of farmers in north Gujarat (one from Mahesana district and the other from Patan district) could be persuaded by SOFILWM to adopt MI system as per the designs prescribed by IRAP on pilot basis, as they were owning low capacity mono-block pump sets prior to the Board's regulations coming into force.

1. Introduction

Numerous research studies in the past on the physical and socio-economic impacts of agricultural water management interventions. They broadly cover the following: physical impacts of water saving technologies on irrigation water use (Narayanamoorthy, 2004); the impacts of water-saving technologies and water efficient crops on crop water productivity in physical terms (kg/m^3) (Kumar, 2007); the benefit cost analysis of micro irrigation systems such as drips and sprinklers (Palanisamy *et al.*, 2002; Kumar *et al.*, 2004; Narayanamoorthy, 2004), and comparative economics of cultivation of water-efficient and high valued crops; limited analysis of economic and social costs and benefits of micro irrigation systems. But, all these analyses are based on individual plot level assessment of physical, economic, environmental or social variables.

But, introduction of micro irrigation systems or agricultural water management technologies can change the dynamic of the entire farming system (Kumar *et al.*, 2008a; Kumar, 2009). For instance, the adoption of micro irrigation system is associated with farmers shifting to crops that are amenable to these systems from the traditional ones. Or else, in certain cases, an expansion in area under crops that are amenable to micro irrigation systems is found after the farmers perceive the benefits of adoption of MI systems for such crops. This means, the water saving impact will be the sum total of the potential improvement in efficiency of use of water for a particular crop resulting from technology adoption, but also from the change in crop water requirement (ET) itself owing to change in crop in the aftermath of technology adoption.

Often, adoption of high valued crops is associated with introduction of skilled labour hired from outside which replaces domestic labour; and mechanization of farms (Kumar *et al.*, 2008b). If the adopter family is not able to divert the saved domestic labour to other production function, system adoption can actually lead to increase in input costs, instead of saving in labour cost, an attribute, often projected as a benefit of MI systems. Shifts in cropping pattern can potentially impact on the livestock holding of farmers, milk production, income from dairying and overall composition of farm economy (Kumar, 2007). For instance, replacement of cereals such as wheat and bajra (pearl millet) by cash crops can create shortage of fodder in composite farming systems (Kumar and Amarasinghe, 2009), thereby forcing farmers to reduce the livestock holding which change the income from dairy production. Hence, individual plot level assessments of physical and socio-economic impacts could be often misleading.

There is a need to understand the overall changes in the farming system resulting from adoption of MI systems and high valued crops. Accordingly, methodologies to evaluate the physical and economic impacts and the changes in socio-economic dynamic could be designed. Equally important is to address the larger research question of how groundwater use in the region changes as a result of adoption of water-saving irrigation technologies, and water-efficient crops, as raised by scholars worldwide. A related concern is of making the MI technology accessible for the small and marginal farmers, particularly those who lack independent source of water supply. In lieu of the fact that groundwater depletion affects the poor farmers more adversely (Dubash, 2000; Kumar, 2007), such concerns are really valid while pursuing the goal of sustainable groundwater management.

2. The North Gujarat Sustainable Groundwater Management Initiative

Groundwater over-exploitation is a phenomenon found in many arid and semi arid regions of the world (Custodio, 2000). With an annual draft of 231 BCM, India stands atop with regard to groundwater withdrawal for agriculture (Kumar, 2007). If one goes by the official estimates of groundwater development, which considers only the hydrological data, only 23.1 M ham out of the 43.2 M ham of renewable groundwater in the country is currently utilized[1]. But, if one goes by the disaggregated data, only 15 per cent (839) of the blocks/talukas/mandals in the country are over-exploited; 4 per cent are critically exploited and 10 per cent (550) are in the semi critical stage (GOI, 2005).

But, a comprehensive understanding of the management alternatives--physical, economic, institutional, policy and legal--, were lacking. Water policy makers are aware of the need for groundwater management, but often not familiar with the range of physical, economic, legal and policy instruments for groundwater management and their potential implications. While "legal and regulatory measures" are common terminology in the groundwater management parlance, the social, equity--both inter and intra-generational--, legal and institutional implications of the same have hardly been analyzed in detail. This "command and control" syndrome has come from the lack of proper understanding of the hydrological, socio-economic and institutional setting under which groundwater use takes place (Kumar, 2007).

Within India, north Gujarat is one of the intensively exploited regions. Groundwater supports irrigated crop production and intensive dairy farming in the region. Well irrigation is critical to the region's rural economy and livelihoods (Kumar, 2007; Singh, 2004). Hence, managing groundwater is crucial for the survival of the rural communities in that region.

Internationally, discussions on approaches to manage groundwater/aquifers include: enforcement of tradable property rights (Rosegrant and Gazmuri, 1996; Tobani, 1997), metering agricultural pump-sets and energy pricing (Kumar, 2007; Saleth, 1997; Zekri, 2008); creating local management regimes with a nested hierarchy of institutions from village to aquifers, along with tradable water rights (Kumar, 2000a; Kumar, 2007); energy rationing (Zekri, 2008); decentralized water harvesting and recharge (Shah *et al.*, 2003); conjunctive management of groundwater using water from large surface reservoirs (Llamas, 2000; Ranade and Kumar, 2004).

IWMI's initiative in north Gujarat in 2002 under IWMI-Tata water policy research program explored at farmer-initiated agricultural water demand management as a strategy to reduce the stress on groundwater resource in the region. The fountainhead of the strategy was improving water productivity in agriculture. This was quite contrary to the popular thinking about the ways to deal with groundwater problems in the region. It was widely propagated by researchers that large-scale water harvesting and local groundwater recharging activities, if undertaken in the region, would help, to a great extent in reducing the rate at which groundwater is depleting in the region (see for instance, Shah *et al.*, 2003). The North Gujarat Initiative, currently being managed by SOFILWM, focused on introducing water-efficient irrigation technologies; water-efficient crops that give high returns per unit of both land and water; and practices that improve the primary productivity of land.

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[1] Source: key note speech by Kirit S. Parikh, member, planning commission, GOI in XII World Water Congress, New Delhi, 22-25 November, 2005.

2.1 The Strategy in North Gujarat Groundwater Initiative

According to some estimates done for the White Paper on Water in Gujarat, the total water used in agriculture is 5372.5 MCM in 1996-97 in the region (IRMA/UNICEF, 2001). On the other hand, while the total renewable water resources of the region is 6105 MCM (as per GOG, 1996 cited in IRMA/UNICEF, 2001), the total water use was estimated to be 6008 MCM as far back as 1996-97(Table 8: IRMA/UNICEF, 2001). The per capita annual water withdrawals in north Gujarat exceeded the renewable water availability by 2000 (Kumar and Singh, 2001).

From these figures and the earlier statement that the basins in north Gujarat are closed, it is clear that supply side approaches to deal with groundwater depletion problems are not going to make any impact on the region's groundwater regime, and the solution only lies in water demand management. Since agriculture takes lion' share of the total water diverted from surface systems and aquifers in the region (nearly 92 per cent), water demand management in agriculture was chosen as the strategy for improving the demand-supply balance in groundwater of the region in order to achieve long term sustainability in its use, through enhancing water productivity in the sector. Three specific interventions were identified to achieve water productivity improvement: 1] use of efficient irrigation technologies for crops which helps improve the crop yields and reduce the consumptive water use (depleted water); 2] introduction of crop that are highly water-efficient in terms of net return per unit of water consumed (Rs/ET); and 3] improving the primary productivity of land through improvement soil nutrient management measures.

Table 1: Per Capita Renewable Freshwater Availability in Gujarat by Region

Name of the Region	Total Freshwater Availability (MCM)
S & C Gujarat	37926
North Gujarat	6105
Saurashtra	9287
Kachchh	1275
Gujarat	54593

Source: IRMA/UNICEF, 2001: White Paper on Water in Gujarat

The theoretical foundations for the strategy were two: 1] use of micro irrigation devices would reduce the actual amount of water depleted in crop production. While this goes by the conventional wisdom, internationally, the concept of using micro irrigation to reduce consumptive use of water for crop production and water saving in agriculture have not been widely recognized. Instead, there are many in the water management circles who believe that use of MI systems would eventually increase the consumptive use of water. They make a distinction between applied water saving and real water saving (Allen *et al.*, 1998; Molle and Turral, 2004). The contention is that while the amount of water applied could be reduced through efficiency improvements, the consumptive use of water remains the same. But, since the farmers are concerned with how much water they pump out and use for irrigation, they would eventually expand the area under irrigation, resulting in increase in consumptive use of water.

But, in the case of north Gujarat's the hydrology of water use is different. The water, which goes into deep percolation under conventional method of irrigation, is "non-recoverable" as eventually part of it gets lost in non-beneficial soil evaporation (after the land becomes fallow) and the remaining part gets held up in the unsaturated zone as hygroscopic water (see Allen *et al*., 1998 for various terminologies). In sum, use of micro irrigation technologies would reduce the consumptive fraction (CF) leading to real water saving. Further, the issue of return flow less relevant for row crops, in which the non-beneficial soil evaporation from the land which is not covered by the crop canopy can be reduced using technologies like drip irrigation. Hence, the real water saving would be more in the case of drip systems used for row crops (Kumar *et al*., 2008a). Second: use of water-efficient crops that give higher returns per unit of land and water would also help towards reducing the depletion of groundwater.

2.2 Major Achievements

The activities undertaken by NGI in the project area to promote agricultural water demand management technologies and practices included: village meetings and awareness programmes; direct farmer contacts in the fields; training and workshops on various topics related to the theme of agricultural water demand management including women; exposure trips; and supply chain management for MI products. The physical achievements made as a result of these various interventions over the past seven years in the region are summarized in Table 2.

Table 2: Key Physical Achievements of North Gujarat Initiative

Sr. No	Type of activity	No. of farmers in the project villages	Total Area in the project villages (ha)	Total No. of farmers outside the project area	Total Area outside the project villages (ha)
1	Drip irrigation	656	1519.0		
2	Sprinkler irrigation	542	1229.0	10,689	21,537.0
3	Plastic mulching	15	62.1		NA
4	Organic farming	801	792.0		NA
5	Horticulture	680	320.0		NA
6	Drum kit	411	411.0		
7	Vegetable kits	1670	1670.0		NA

Source: SOFILWM office records

3. Objectives and Scope of the Study

The objectives of the study undertaken by IRAP are as follows:

- Study the water demand management interventions being adopted by different categories of farmers such as small/marginal, medium and large farmers in north Gujarat region

- Analyze the impact of these interventions on the farming system, livelihood patterns, food and nutritional security, poverty and gender division of labour for different categories of farm households

- Design technological innovations that are economically viable for poor small and marginal farmers of north Gujarat, who are dependent on water purchase.

- Analyze the potential impact of the combinations of water demand management interventions for different scales of implementation on agricultural surpluses and groundwater use, and assess their implications for food security, risk and vulnerability of farming communities, and labour absorption

The study covered 49 villages of eight talukas from two districts of north Gujarat viz., Banaskantha and Mahesana, covering a total of 114 adopter farmers and 51 non-adopter farmers. The sample farmers are picked up from the alluvial areas in the semi arid and arid parts of the region, and hence the findings would be more relevant for such areas. The study analyzes the impacts of various interventions at the plot, field and farm level.

4. Approach, Methods and Tools

The approach used in the study involved comparing the plots, fields and farms of farmers before and after the adoption of new crops and water-saving irrigation technologies. The variable considered for comparison are: the overall cropping pattern, gross cropped area of the farm and area under different crops; livestock composition and size; the water application rate for individual plots of crops; the level of crop inputs and the cost; yield and net return from different crops; and, the inputs and outputs for different types of livestock.

However, since this comparison is across time horizons and that the time factor must have influenced several of the variables considered for analyzing the impacts (like change in crops yields due to new crop technologies, wage rates due to change in labour market conditions, price of produce in the market due to demand-supply situation in the market etc.) that can induce some error in the estimates. Therefore, the post adoption scenario vis-à-vis several of the impact variables is compared with those of the non-adopters wherever required, to revalidate the results emerging from the analyses with regard to the impact of adoption of water saving MI technologies and water-efficient crops on the farming system dynamic. Thus, both longitudinal and cross sectional analysis are involved in the study.

B-C Ratio for MI-irrigated crop i is worked out as:

$$\{NI_{MI-irrigation.i} - NI_{trad-irrigation,i}\} \Big/ C_{MI,i} \quad \ldots\ldots\ldots\ldots (1)$$

Here, NI is the net income from one hectare of the crop grown in the plot, and suffixes $MI - irrigation$ and $trad - irrigation$ stand for crops irrigated by MI system and crops under traditional method of irrigation respectively. $C_{MI,i}$is the annualized capital cost of the system for one hectare, apportioned among all the crops grown during the year with the same system. Obviously, if two crops are grown during the same year (for instance, groundnut in summer followed by potato in winter), the annualized cost of the MI system was apportioned among them.

The net income from the crop i (NI_i) is worked out as:

$$NI_i = GI_i - IC_i \text{.......................................} \quad (2)$$

Here, GI_i and IC_i stand for gross income and input costs per hectare of the crop, respectively for crop i. Nevertheless, while estimating the input costs, the capital cost of the MI system should not be considered. The same is taken into account for estimating the modified net income, and is estimated as:

$$NI^1_{i\ i} = NI_i - C_{MI,i} \text{..........................} \quad (3)$$

The total farm level water saving WS_{FARM} (m^3) owing to adoption of MI systems and water-efficient crops is estimated as:

$$WS_{FARM} = 10000 * \{\sum_{i=1}^{m} A_i * \Delta_i - \sum_{j=1}^{n} A_j * \Delta_j\} \text{..............} \quad (4)$$

Here, A_i stand for the area under crop i in hectares, grown in the farm in the pre MI-adoption case; A_j stand for area under crop j grown in the post MI adoption phase. The suffixes m and n stand for the number of crops grown in the pre adoption phase and post MI adoption phase, respectively. Δ_i and Δ_j are the irrigation water applied for crop i and j, respectively in cubic metres per ha. The area figures are averages estimated for the entire sample of 114 farmers. Hence, the water saving estimated would be for an average farm.

The physical productivity of water in crop production θ_i (kg/m^3) for crop i was estimated as:

$$\theta_i = {Y_i}/{\Delta_i} \text{......................................} \quad (5)$$

Here, Y_i is the yield of crop i (kg/ha); and Δ_i is as explained above.

The economic productivity of water in crop production ∂_i (Rs/m^3) for crop i was estimated as:

$$\partial_i = {NI_i}/{\Delta_i} \text{..} \quad (6)$$

While estimating the economic productivity of water for crops irrigated by MI, the modified net income was considered (see Equation (3)).

The regional level water saving $(WS_{REGIONAL})$ through a combination of agricultural water management interventions is estimated by multiplying the average water saving per individual farm (WS_{FARM}) by the total number of farms under micro irrigation. The second variable is estimated on the basis of the total area under MI systems in north Gujarat region, and the average size of the MI-irrigated plot in the sample farm. Using such a methodology, the error in estimation would be high if the sample farms are not representative of the regional situation in terms of the proportion of the total farm under MI systems.

$$WS_{REGIONAL} = {WS_{FARM} * TAREA_{MI}} / {AREA_{MI,\ FARM}} \ldots\ldots\ldots\ldots (7)$$

Here, $TAREA_{MI}$ and $AREA_{MI,FARM}$ are the area under MI system in north Gujarat region and average area under MI system in the sample farm, respectively.

Change in the overall net return from farming can be estimated as:

$$NI_{FARM} = \{\sum_{j=1}^{n} A_j * NI_j + \sum_{l=1}^{p} N_p * LI_p - \sum_{i=1}^{n} A_i * NI_i - \sum_{k=1}^{o} N_k * LI_k\} \ldots\ldots (8)$$

Here$A_i$is the area under crop i which is not MI irrigated; $A_j$is the area under crop j which is MI-irrigated; m and n are the number of crops grown by farmers before adoption and after adoption, respectively. N_kA and LI_k stand for the total number of livestock belonging to the category k, and the net income per annum from one animal belonging to that category, respectively. The suffixes $o$and p stand for the total number of livestock categories owned by the farmers before and after the adoption of MI system.

Data Sources and Types

The major source of data was primary survey of adopter and non-adopter farmers in north Gujarat region. The types of data included: i] inputs and outputs of all the crops grown and different types of livestock reared by the adopter farmers, including those which are not covered by MI systems; and inputs and outputs of all the crops grown and livestock reared by the non-adopters. The data for adopters included that prior to adoption as well. The data are: i] area under each crop; ii] the inputs such as seed cost; labour (days); iii] cost of fertilizer and pesticide used; iv] number of waterings and hours of irrigations for each watering (hours per irrigation per ha); v] the number of different types of livestock, and average feed and fodder (both dry and green) inputs for various types of livestock (per animal per day; vi] yield of various crops including both main product and byproduct (kg/ha); and, vii] the average milk outputs for different animals (litres per day; the cost of various MI systems (Rs/ha).

Table 3: Sample Size and the Selection showing the Names of Villages and Talukas

Name of the district	Name of the Taluka	WST Adaptor		Non-Adaptor	
		Name of the village	Sample size	Name of the village	Sample size
Banaskantha	Amirgarh	Amirgarh	5	1. Aarasuri	1
		Bantavada	5	2. Laxmipura	1
		Iqbalgadh	1	3. Mahadevia	1
		Jhanjharva kampa	1	4. Ramjiyari	1
		Juni Roh	2	5. Tibafarm	1
		Kali mati	2	6. Tibafarm	1
		Kikotar	1		

		Mahadeviya	3		
		Neechlabandh	2		
		Patel farm	1		
		Ramgadh	1		
		Ramipura	1		
		Zanjarva kampa	1		
	Dantiwada	Bhakhar khedi	1	7. Dhanera	3
		Dangiya	2	8. Ranol	5
		Dantiwada	1		
		Kheda	6	9. Kheda	1
	Deesa	Aakholsa	2	10. Dama	1
		Akholnani	1	11. Kant	1
		Dama	1	12. Kapat	1
		Deesa	6		
		Gugakali	1		
		Kupar	1		
		Mahadeviya	2		
		Malgadh	10	13. Malgadh	3
		Rakapur	1		
		Rampura	7	14. Rampura	2
		Ranpur	2		
		Samserpura	3		
		Sherpura	4		
		Valaval	7	15. Vadavad	2
	Malgadh	Malgadh	1		
	Palanpur	Chadotar	3		
		Ganeshpura	2	16. Ganeshpura	1
		Jodnapura	2	17. Kuskar	2
		Koytapura	1		
		Kumbhasan	2	18. Palanpur	1
		Laxmipura	2	19. Laxmipura	1
		Ramgadh	1	20. Malan	1
		Ratanpur	1	21. Moria	1
		Sadarpur	1		
		Salempura	2	22. Salempura	4
	Vadgam	Bharkavada	1		
		Chapi	1		
		Ghodiyal	6	23. Ghodiyal	4
		Jalotra	1	24. Jalotra	2
		Mahi	1	25. Mahi	4
		Saklana	1	26. Magarvada	1
	Data			27. Aderan	2
Mahesana	Unjha	Vishol	1	28. Vishol	2
Total	8	49	114	28	51

Source: authors' own estimates based on primary data

5. Results and Discussions

5.1 Who are the Adopters?

The average family size and farm holding size of the adopter and non-adopter farmers is given in Tables 4 and Table 5, respectively.

Table 4: Average Family Size of Adopters and Non-Adopters

Particulars	Total family size	Adult male	Adult female	Children	
				Male	Female
WST Adaptor	8.22	2.58	2.61	1.68	1.34
Non-adaptor	6.83	2.40	2.48	1.08	0.90

Source: authors' own estimates based on primary data

From Table 4, it appears that the adopter families are slightly bigger than the non-adopter families in terms of number of members. But, the difference is mainly due to the higher (average) number of children in the adopter families, which was quite significant (one unit). Comparison was also made of the average size of farm holdings of the adopters and non-adopters. It shows that the average holding of adopters is quite larger than that of non-adopters, with the difference to the tune of more than one hectare. In other words, the adopters own nearly 35% more land than the non-adopters. The entire land of the adopters is irrigated, while a small fraction of the holding of non-adopters lies un-irrigated. A marginal difference in the livestock holding is also found between the adopters (5.10 per family) and the non-adopters (5.25 per family, with 1.88 buffalos, 1.21 cross bred cows and 0.07).

Table 5: Average Farm Holdings of Adopters and Non-Adopters

Particulars	Total land holding size	Cultivable land	Cultivated land	Irrigated land
WST Adaptor	3.79	3.76	3.74	3.74
Non-Adaptor	2.76	2.75	2.74	2.68

Source: authors' own estimates based on primary data

5.2 Changes in Individual Components of the Farming System

The individual components of the farming system that are considered for analysis are: cropping pattern; crop yields; different types of water-efficient irrigation systems and their capital costs; irrigation intensity with and without MI system; the area under forage crops; area under orchards; the livestock holding; and the gross and net outputs from crops, and gross return from dairying. They are analyzed separately in the subsequent sections vis-à-vis changes in irrigation water use, changes in crop yield, changes in cropping pattern and livestock composition, changes in net return from the entire farm with structural changes, as well as for individual crops and livestock categories, B-C analysis of different MI technologies and farming system level change in irrigation water use.

5.2.1 Changes in Water Application for Different Crops

As noted by Kumar *et al.* (2008a), the real water saving through the use of micro irrigation systems is a function of the crop grown, the soil type, type of MI technology, the climate and geo-hydrology. Therefore, applied water saving also would be a function of the first three factors. In situations like north Gujarat, the most perceptible impact of adoption of MI system is likely to be applied water saving, as it would be high in semi arid and arid climate, sandy soils, and for row crops. The saving would be more for drip irrigated row crops due to the reduction in non-beneficial soil evaporation (based on Allen *et al.*, 1998; Kumar *et al.*, 2008a).

Table 6: Irrigation Water Use for Different Crops before and after Adoption of MI

Name of the Season	Name of the Crop	Method of Irrigation	Irrigation Water Use (M^3/Ha)
Before Adoption of WST			
Monsoon	Cluster bean	TMI	2549.00
	Castor		7890.10
	Groundnut		5602.80
	Chilli		11500.00
	Brinjal		5966.70
	Green Gram		840.00
	Cotton		7150.60
	Fennel		2455.25
Winter	Mustard		6337.01
	Potato		13964.90
	Rajgaro		3600.00
Summer	Pearl Millet		8368.20
	Millet		11338.60
	Fodder bajra		20850.00
	Vegetable		13750.00
After Adoption of WST			
Monsoon	Cluster bean	Sprinkler	1305.00
	Castor	Drip	7695.00
	Groundnut	Sprinkler	5258.20
	Chilli	Drip	3540.00
	Alfalfa	Sprinkler	12815.10
	Brinjal	Drip	1180.00
	Kola	Drip	540.00
	Pomegranate	Drip	3334.0
	Cotton	Drip	3510.00
	Fennel	Drip	1728.00
Winter	Tomato	Drip	9440.00
	Potato	Sprinkler	12721.40
	Flower	Sprinkler	3540.00
Summer	Pearl Millet	Drip	5030.80
	Millet	Sprinkler	8776.10
	Choli	Sprinkler	5611.50

Source: authors' own estimates based on primary data

Note: TMI=traditional method of irrigation

Table 6 shows that with the adoption of MI system, the total irrigation water application rate had reduced significantly for most of the crops. The reduction is more than 50 per cent in some cases, while insignificant in some others. As we have earlier pointed out, the extent of reduction is function of the technology used for irrigation. This again is determined by the crop. For most vegetables, drip irrigation is used (chilli, tomato and brinjal). For potato, cluster bean and groundnut, micro sprinklers are used. For cotton and castor, drip irrigation is used. For bajra, overhead and mini sprinklers are used. So is the case with cluster bean.

As regards actual impact, in the case of cluster bean, the water application rate dropped from 254.8mm to 130.5mm. In the case of cotton, the extent of reduction is more than 50 per cent from 715mm to 351mm. In the case of chilli, the extent of reduction was nearly 70% (i.e., from 1150mm to 354mm). This is an exceptionally high value. In the case of summer bajra (pearl millet), the water application rate reduced from 836.8mm to 503mm. The total water application rate for pomegranate was estimated to be 333mm. But, this is a crop introduced with MI system, and data on irrigation water use rate without MI system are not available.

For potato, the water application rate was found to be excessively high when compared to the fact that it is a short duration crop (90-100 days) of winter. The main reasons for this could be that the area where the crop is predominantly grown has very light sandy soils with high rate of soil infiltration. So, substantial amount of water is lost in deep percolation even under sprinkler method of irrigation.

5.2.2 Changes in Yield of Different Crops

Analyses of crop yields show some interesting trends. For most crops, the yield was higher under MI system. To cite a few examples are: cluster bean, castor, chilly, cotton, fennel, wheat and groundnut. In the case of castor and fennel, the increase in yield was more than 50%. In the case of chilli, the yield increase was 25%. But, for some crops such as brinjal and summer bajra, the yield was lower under micro irrigation. In the case of summer bajra, this phenomenon of reduced yield with micro irrigation can be explained by the poor distribution uniformity obtained in water application through the overhead sprinklers. While the same problem is applicable to wheat, which is irrigated by overhead sprinklers, the trend was different for this crop. The reason for this could not be explained. Since some of the crops, which were grown by the farmers prior to adoption, were discontinued after adoption, comparison was not possible.

But these unusual findings with regard to yield no way mean that with the adoption of MI systems, the yield for these crops can go down. It only means that under MI technology, the yield could be as low as what was found. In other words, without MI system, these farmers might have ended up securing even lower yields had the poor yield been because of poor agronomic inputs and soil nutrient management. The reason is that the figures presented in the Table are averages for those who grew the crops with MI systems and those who grew without it, and the farmers who showed lower yield under MI systems are not necessarily same as those who showed higher yield without MI, though some farmers might be common. The results lead us to the importance of agronomic practices such as use of nitrogenous fertilizers and provision of adequate irrigation to meet the crop water requirement, in obtaining higher yields, along with using MI systems.

Table 7: Yield of Irrigated Crops with and without MI Systems

Before Adoption of WST			After Adoption of WST		
Name of the Season	Name of the Crops	Average Yield (Qt/Ha)	Name of the Season	Name of the Crops	Average Yield (Qt/Ha)
Kharif	Cluster bean	14.34	Kharif	Cluster bean	15.00
	Castor	21.40		Castor	33.33
	Groundnut	20.80		Groundnut	21.78
	Chilli	600.00		Chilli	750.00
	Alfalfa	NA		Alfalfa	1620.00
	Brinjal	466.67		Brinjal	250.00
	Cotton	32.72		Cotton	39.71
	Fennel	7.17		Fennel	15.84
	Bajra	16.67		Kola	60.00
	Green gram	12.00		Pomegranate	42.03
Winter	Wheat	37.98	Winter	Wheat	50.00
	Potato	337.37		Potato	345.34
	Rajgaro	4.00		Flower	100.00
	Mustard	32.43		Tomato	1200.00
Summer	Bajra	48.97	Summer	Bajra	40.68
	Millet (Jowar)	59.00		Millet (Jowar)	55.18
	Vegetable	50.00		Chick pea	39.93
	Fodder bajra	875.00		Groundnut	45.00
	Groundnut	25.00			

Source: authors' own estimates based on primary data

5.2.3 Changes in Area under Different Crops

Some remarkable changes in area under crops were noticed after the adoption of MI systems. But, these changes seem to affect only select crops. Table 8 shows that both the absolute and percentage area under potato, kharif groundnut, vegetables and alfalfa had increased significantly. Also, tomato appears as a winter crop in the post adoption scenario. But, on the other hand, both the absolute area and percentage under bajra and wheat reduced substantially, while mustard completely disappeared. The reduction in area under wheat, millet, pearl millet and *rajgaro* is quite remarkable. These are crops which are grown mainly for domestic consumption as wheat and bajra are part of the staple food. Particularly, rajgaro cooked in milk is used for feeding children. Hence, reduction in their area will have significant implications for domestic food security in the immediate term, in view of the fact that the prices of cereals have shot up during the past one year.

It should be kept in mind here that potato, groundnut and chilli are amenable to micro irrigation systems, and farmers in the area are extensively irrigating these crops with mini micro sprinklers (potato and groundnut) and drips (chilli). This observation validates our assumption that after realizing the benefits of adoption of MI systems, farmers tend to allocate more area from their farms to the crops that are amenable to MI systems for which they obtained good results with MI systems.

Table 8: Area under Different Crops of Adopters before and After Adoption of MI

Kharif		Winter		Summer	
Name of the crop	Area (Ha)	Name of the crop	Area (Ha)	Name of the crop	Area (Ha)
Before Adoption of WST					
1. Cotton	0.118	1. Potato	1.016	1. Millet (Jowar)	0.146
2. Castor	0.288	2. Wheat	0.148	2. Pearl Millet	0.921
3. Fennel	0.028	3. *Rajgaro*	0.018	3. Vegetable	0.005
4. Groundnut	0.835	4. Mustard	0.177	4. Groundnut	0.007
5. Chilli	0.004			5. Fodder bajra	0.019
6. Brinjal	0.013				
7. Alfalfa	0.117				
8. Cluster bean	0.174				
9. Sesamum	0.026				
10. Pearl Millet	0.011				
11. Green gram	0.004				
Gross Cropped Area					**4.074**
After Adoption of WST					
1. Cotton	0.106	1. Potato	1.469	1. Millet (Jowar)	0.031
2. Castor	0.014	2. Wheat	0.019	2. Pearl Millet	0.172
3. Fennel	0.020	3. Flower	0.004	3. Vegetable	0.039
4. Pomegranate	0.047	4. Tomato	0.011	4. Groundnut	0.007
5. Groundnut	1.109				
6. Chilli	0.011				
7. Brinjal	0.003				
8. Alfalfa	0.122				
9. Cluster bean	0.009				
10. Sesamum	0.014				
11. Kola	0.004				
Gross Cropped Area					**3.211**

Source: authors' own estimates based on primary data

5.2.4 Changes in Inputs and Outputs of Livestock

Table 9 shows that the average number of milch animals (per farmer) belonging to all the three categories of livestock, viz., buffalo, cross bred cow and indigenous cow, belonging to the adopter farmers, had increased in the post adoption scenario, though the increase is not very substantial. More importantly, the average milk yield (in litres per day) has also gone up for all the three categories of livestock, with significant increase in the case of cross bred cows. The price of milk has also gone up over the years. Hence, the gross income from milk production has gone up significantly. But, what is important from the point of view of our analysis is the differential income due to the increase in milk output per animal and increase in holding size rather than the rise in price. This may be attributed to the increase in availability of green fodder from alfalfa and other forage crops grown by the farmers, resulting from expansion in area under those crops and the crops yields owing to MI system adoption.

Table 9: Yield and Gross Income obtained by Farmers from Different Types of Livestock before and after Adoption of MI Systems

Type of animal	Total in-milk Animal	Total milk production (Lt/day)	Milk price (Rs/Lt)	Dry animal	Calves	Gross income (Rs/day)
Before Adoption of WST						
1. Buffalo	2.29	17.06	14.80	1.05	1.65	252.44
2. CB Cow	0.84	8.27	11.05	0.27	0.52	91.43
3. Indigenous Cow	0.08	0.61	10.00	0.01	0.06	6.05
After Adoption of WST						
1. Buffalo	2.38	17.47	18.41	1.07	2.05	321.66
2. CB Cow	1.04	11.86	12.04	0.25	0.81	142.77
3. Indigenous Cow	0.09	0.74	10.80	0.08	0.09	7.96

A close look at the fodder cultivation practices of the adopters and non-adopters illustrate this (see Table 10). In spite of lesser number of farmers growing alfalfa after adoption, the average area per family (worked out on the basis of the total number of adopters, i.e., 114) is still higher (0.122ha against 0.117ha). Also, around 18 farmers are using sprinkler and drip for the crop, and 15 are using sprinklers for fodder bajra. Earlier studies have shown the yield impact of micro irrigation systems on alfalfa in the region (Kumar *et al.*, 2008a). This also might have contributed to increasing the availability of green fodder of the adopter households at the farm level.

Table 10: Average Area under Different Fodder Crops Grown by Farmers before and after Adoption of MI Systems

Name of the green fodder	Area (Ha)	Total number of farmer growing	Season				Method of irrigation		
			Autumn	Winter	Summer	Monsoon	Flood	Drip	Sprinkler
Before Adoption of WST									
Alfalfa	0.117	81	73	9	5	4	81	-	-
Fodder bajra	0.032	81	2	28	51	13	81	-	-
Chikodi	0.015	53	-	28	23	2	53	-	-
Barley	0.008	22	-	22	-	-	22	-	-
Maize	0.003	12	2	4	3	3	12	-	-
Mithi Jowar	0.003	8	-	3	6	1	8	-	-
After Adoption of WST									
Alfalfa	0.122	76	65	9	4	3	58	4	14
Fodder bajra	0.036	73	2	25	46	12	58	-	15
Chikodi	0.014	52	-	28	20	2	41	1	10

Barley	0.008	23	-	19	1	2	19	1	3
Maize	0.004	13	2	5	4	2	12	1	-
Mithi Jowar	0.003	7	-	2	2	2	-	-	1

Source: authors' own estimates based on primary data

5.2.5 Changes in Net Return and Water Productivity of Different Crops

Table 11 gives the mean values of net income, modified net return and water productivity of the crops without MI systems and with MI systems. The modified net returns are obtained by subtracting the annualized cost of the micro irrigation system from the net return for the crops. Therefore, for pre adoption condition, it is same as the net return. As expected, it is seen that the average net returns are higher under MI systems for all the crops, except brinjal and cotton. We have earlier seen that in the case of brinjal, the average yield of this crop for irrigated plots was slightly lower. This might have resulted in lower net income. In the case of cotton, though the yield was higher under MI system, the net income is lower. This is due to the higher input costs under MI irrigated plots.

Table 11: The Net Income, Modified Net Income and Water Productivity in Physical and Economic Terms with and without Adoption of MI Systems

Name of the season	Name of the crop	Type of technology Used for Irrigation	Net Return (Rs/Ha)	Modified Net Return (Rs/Ha)	Water Productivity	
					Physical (Kg/m^3)	Economic (Rs/m^3)
Before adoption of WST						
Monsoon	Cluster bean	TMI	13194.24	13194.24	0.56	7.68
	Castor		21070.10	21070.10	0.27	3.04
	Groundnut		11133.74	11133.74	0.37	4.13
	Chilli		411833.33	411833.33	5.22	34.90
	Brinjal		157533.33	157533.33	7.82	44.91
	Pearl Millet		4663.33	4663.33	0.13	0.76
	Green gram		4450.00	4450.00	1.43	5.30
	Cotton		68876.42	68876.42	0.46	10.30
	Fennel		12333.33	12333.33	0.29	6.30
Winter	Mustard		43994.00	43994.00	0.51	8.00
	Wheat		23195.36	23195.36	0.47	4.58
	Potato		60684.85	60684.85	2.42	7.04
	Rajgaro		4182.00	4182.00	0.11	1.16
Summer	Pearl Millet		19771.10	19771.10	0.27	3.49
	Millet		26797.62	26797.62	0.52	2.15
	Fodder bajra		28583.33	28583.33	4.20	1.56
	Vegetable		16166.67	16166.67	0.36	1.18
After adoption of WST						
Monsoon	Cluster bean	Sprinkler	20575.00	17811.55	1.15	13.65
	Castor	Drip	51150.00	40360.51	0.43	5.43
	Groundnut	Sprinkler	27894.17	24039.10	0.41	7.70
	Chilli	Drip	524250.00	520162.19	21.20	146.90
	Alfalfa	Sprinkler	55349.57	48513.63	12.60	5.67

	Brinjal	Drip	86650.00	82562.19	21.20	119.00
	Kola	Drip	9800.00	6559.74	7.41	12.15
	Pomegranate	Drip	81662.50	67988.34	1.26	37.80
	Cotton	Drip	52822.88	29617.54	1.13	12.44
	Fennel	Drip	23730.29	18034.76	0.92	36.91
Winter	Tomato	Drip	475000.00	469646.10	12.70	49.75
	Wheat	Sprinkler	53361.11	51273.13	1.70	26.19
	Potato	Sprinkler	98024.13	93538.60	3.10	11.39
	Flower	Drip	5000.00	1430.74	2.80	0.40
Summer	Pearl Millet	Sprinkler	15082.45	12494.82	0.81	3.84
	Millet	Sprinkler	22099.55	19458.53	0.63	2.66
	Choli	Drip	22564.00	17279.54	0.71	12.94
	Groundnut	Sprinkler	86250.00	83289.00	0.38	7.09

Note: TMI=traditional method of irrigation
Source: authors' own estimates based on primary data

The two determinants of physical productivity of water are yield and irrigation water dosage. Whereas the two determinants of water productivity in economic terms are: gross return, input costs and amount of water applied (Kijne *et al.*, 2003). With the reduction in irrigation water dosage resulting from adoption of efficient irrigation technology as seen earlier, and with probable reduction in cost of other inputs such as fertilizers and labour and enhancement gross returns from crop produce owing to yield increase, the water productivity of the crops in both physical and economic terms change remarkably. Comparisons show that both physical productivity of applied water and water productivity in economic terms are higher for MI irrigated crops. The differences are very significant.

For instance, in the case of cluster bean, the physical productivity of water has gone up from 0.56kg/m^3 to 1.15kg/m^3 of water, whereas the water productivity in economic terms has gone up from Rs.7.68/m^3 to Rs.15.77/m^3. Water productivity in economic terms was found to be highest for chilli (Rs.148.1/m^3), which went up from just Rs. 21.2/m^3. This has happened because of high reduction in applied water, in addition to high increase in net income. Water productivity in pomegranate was estimated to be Rs. 41.4/m^3 under MI system, whereas no farmer was found to have raised the crop under flood method of irrigation and harvested.

5.2.6 Cost benefits of Drips and Sprinklers for Selected Crops

For analyzing the benefit cost ratio for different MI systems, we have considered the major crops for which MI systems are used in the region. Though it is already known that adoption of MI system is often associated with changes in cropping pattern from the traditional ones to those which are amenable, for our analysis we have only considered the farmers who have introduced the system without changing the crop. As a result, the values of net income used for B-C analysis will not match with the net income figures shown against the same crops in Table 11. The reason for choosing this methodology is that otherwise it would be difficult to attribute the incremental benefits accrued after MI adoption entirely to the technology, or in other words the risk farmers are willing to take by adopting a new crop, often a cash crop which involves market risk, also will have to be given the credit along with the MI technology.

Table 12 provides the B-C analysis of nine crops, which are irrigated by MI systems. Dhawan (2000) had earlier noted that the economic dynamic of drip irrigation is a function of the crop type, which determines the incremental income, and for high valued crops the incremental income resulting from yield improvement is likely to be very high. The B-C ratio ranges from a lowest of 0.72 for cotton to a highest of 5.93 for cluster bean. The B-C ratio was second highest for fennel. The findings do not corroborate with the general observations from earlier research pertaining to B-C ratios for MI irrigated crops. For instance, though cluster bean is not a high valued crop, the B-C ratio is very high in this case, which is mainly because of the low net income without MI system for the only plot for which data were available, and the low capital cost of the sprinklers used for irrigating it. In that context, it is important to remember that for many crops, viz., cluster bean, castor, cotton, fennel and wheat, the sample size is very small, with just one in three cases.

Table12: Benefit Cost Analysis of MI Systems for Different Crops

Season	Name of the crop	Number of observations	Net Income (Rs/Ha)		Cost of WST (Rs/ha/ annum)	BC Ratio
			Before WST	After WST		
Kharif	Cluster bean	1	4200.00	20575.00	2763.45	5.93
	Castor	1	46500.00	57500.00	10707.79	1.03
	Groundnut	26	10415.75	28232.83	3680.93	4.89
	Cotton	1	64000.00	70200.00	8629.43	0.72
	Fennel	2	12333.33	36220.00	5512.99	5.24
Winter	Wheat	3	20922.22	53361.11	8102.00	4.49
	Potato	11	52552.08	74110.61	5556.06	4.47
Summer	Pearl Millet	7	9548.57	16036.90	4396.48	2.07
	Millets	4	11856.43	22099.55	2641.02	3.71

Source: authors' own estimates based on data from primary

Having said that, it is to be noted here that the adoption of MI systems, as noted by Kumar *et al*., (2008a) and also found in our earlier analysis for the area in question, is often associated with changes in cropping pattern. Because of this, the above analysis had limited applications. It is extremely difficult to assess the economic impact of MI systems in real life situations, which are more complex. Many times, the adoption of MI goes along with farmers' decision to introduce crops such as groundnut, potato and chilli that are high valued, and that are incidentally very amenable to MI systems. Hence, the incremental income benefit would be much more than our estimates. The cases, where the adopter farmers had grown the same crop before adoption of MI are very rare in most cases (examples are cluster bean, cotton, millets, castor and fennel). The two exceptions are groundnut and potato.

We will see in the next section (section 5.3) that the incremental income of the adopter farmers is very high in contrast to the not so impressive benefit-cost ratio for MI systems for many crops because of the changes in crop composition, which is not captured in the B-C analysis. The adoption of certain new crop such as fennel, pomegranate and vegetables increase the net income substantially, but do not get captured in the b-c analysis of the MI system used for the crop owing to the methodological limitation. For instance, the net return is Rs. 524250/ha for chilli with micro irrigation; and Rs.81662/ha for pomegranate with MI; Rs.

52822/ha for cotton with MI against Rs. 15082/ha for summer bajra. Hence, the real incremental economic benefit is realized through shift to high valued crops that give very high return per unit of land.

5.3 Impacts of Adoption on Overall Returns from Farming

For the adopters, a combination of factors can help change the overall net return from farming. They are: 1] the shift in cropping pattern towards those which yield higher returns per unit area of land; 2] changes in net return from crops which are under MI systems owing to the beneficial impacts of micro irrigation technology such as yield improvement, improvement in quality of produce and saving in cost of inputs; and 3] changes in livestock composition towards those which yield higher net returns per animal, changes in animal holding size or improvement the livestock rearing practices. The farmers can also increase their net returns by expanding the area under irrigation, which might be at the cost of increased groundwater use. However, this cannot be counted as the impact of MI systems or the high valued crops, as the objective of the agricultural water management interventions was to reduce the use of groundwater for irrigation. Therefore, we have considered the changes in net return per unit of land after the adoption.

Table 13 shows the change in composition of income of the adopter families before and after adoption of MI systems. It can be seen that the income from crop production had increased substantially to the tune of Rs. 98,342 per annum, whereas that from dairying had gone up by Rs. 13,912 per annum and that from sale of water to neighbouring farmers is Rs. 175. Hence, the average total incremental income is Rs. 112429. The estimates are based on current prices and the income figures for the post adoption scenario are not adjusted to inflation. Still, one can say that these figures are exceptionally high. Such high jumps in annual income of a farm household can change the entire household dynamic which can either be positive or negative, especially when we consider the fact that most of it is realized from select high valued cash crops like chilli newly introduced by the farmer, which are susceptible to both production and market risks. Therefore, this aspect of income impact needs much more careful and intensive study from a sociological angle.

Table 13: Impact of Adoption on Farm Income

Particular	Agriculture	Dairy	Water selling	Others
WST Adaptor				
Before	109587.72	45684.21	175.44	0.00
After	207929.82	59596.49	350.88	0.00
Incremental benefit	98342.11	13912.28	175.44	0.00

Source: authors' own estimates based on data from primary survey

5.4 Changes in Overall Groundwater Use for Farming

A major skepticism of the strategy of following the MI route of conserving groundwater in north Gujarat was that even large-scale adoption of MI systems and water efficient crops would not result into reduction in groundwater draft by farmers. Conversely, it was argued that with reduction in water requirement per unit of land achieved through water use efficiency improvements, the farmers would have greater incentive to expand the area under irrigation by allocating the "saved water". Further, as argued by Peter McCornick (per. Communication), with higher income return from every unit of water pumped, the farmers would be tempted to invest more in well irrigation for growing high valued cash crops.

But, field surveys showed that in most situations, the irrigated area expansion did not occur after the adoption of MI systems and water-efficient crops like pomegranate, though the area under the crops amenable to MI systems or water-efficient crops increased. This is because such expansion was followed by reduction in area under some of the traditional crops. One reason for this was that they were already irrigating their entire land, as "electricity", and not "water", was a constraint in expanding irrigation. The region is experiencing power supply rationing with total power supply to farm sector in a day limited to 8 hours. In a few situations, where the land holding was large, and it was practically impossible to irrigate them fully due to limited hours of power supply, the farmers resorted to expanding the irrigated area as water requirement per unit of land reduced with MI adoption. But, even in such situations, the income from farming increased remarkably. Hence, in both the situations, the water productivity (Rs/m^3) got enhanced, and in most situations the aggregate groundwater use at the farm level reduced.

Another important criticism of the strategy was the increased dependence of the project on MI systems for improving water productivity at the basin level. Some critiques argued that use of MI systems would only result in "applied water saving" and not "real water-saving" as according to them, the return flows under conventional method of irrigation would be available for reuse, and the real water saving can occur only if there is reduction in crop ET. But, north Gujarat has alluvial aquifers with deep vadoze zone. In such situations, the return flows would not be available for reuse, and instead would be part of the total water depleted water, consisting of "non-recoverable deep percolation" and soil evaporation (see Allen *et al.*, 1998 for details). Hence, MI adoption actually led to real water saving at the basin/aquifer level in north Gujarat. This was also confirmed by field investigations and discussions with well drillers.

Scholars have argued that the water-saving and energy saving (depending on the type of system) benefits from the use of MI systems do not result in income benefits for most farmers who are not confronted with positive marginal cost of using water/electricity. Further, it was argued that they are not confronted by opportunity cost of over-pumping groundwater for irrigating their own fields. As a result, they have minimum incentives to adopt water saving technologies under the current policy regime (see Kumar *et al.*, 2008a; Kumar and Amarasinghe, 2009). But, the NGI interventions also showed that it is possible to motivate farmers to adopt water-saving micro irrigation systems without providing subsidies, even in the absence of efficient electricity pricing in the farm sector that can encourage efficient water use in agriculture. One strong incentive for farmers to go for MI systems was the reduction in water level "drawdown" and the consequent reduction in incidence of well failures. This was mainly due to drastic reduction in pumping resulting from improved water productivity. Another incentive was the higher income farmers obtained from the use of MI devices for most crops.

The estimates of average farm level water use for different crops before and after adoption of MI system are presented in Table 14. The total farm level water use went down from 34,870 m^3 to 27,343 m^3. The total reduction in groundwater use is 7,527m^3. Based on the data available at the macro level that around 24,285 ha of land has been brought under MI in the three districts of north Gujarat, consisting of Banaskantha, Mahesana and Patan, during the past 4-5 years (see Table 2), the annual saving in groundwater for irrigation is estimated to be 56.90 MCM per annum.

Table 14: Farm Level Groundwater Use Before and After Adoption

Name of the Crops	Before WST Adoption		After WST Adoption	
	Water use (m^3)	Area (Ha)	Water use (m^3)	Area (Ha)
Monsoon				
Cluster bean	442.72	0.174	11.45	0.009
Sesamum	0.00	0.026	0.00	0.014
Castor	2256.30	0.286	108.00	0.014
Groundnut	4678.82	0.835	5784.04	1.100
Chilli	40.35	0.004	9.32	0.003
Alfalfa	48.65	0.009	663.24	0.052
Brinjal	78.51	0.013	3.11	0.003
Kola	-	-	2.37	0.004
Pomegranate	-	-	157.92	0.047
Pearl Millet	134.21	0.011	-	-
Green Gram	2.95	0.004	-	-
Cotton	840.51	0.118	372.55	0.106
Fennel	68.92	0.028	34.26	0.020
Winter				
Mustard	1122.87	0.177		
Wheat	1161.65	0.148	37.78	0.019
Tomato	-	-	99.37	0.011
Potato	14087.39	1.009	18691.56	1.469
Flower	-	-	12.42	0.004
Rajgaro	63.16	0.018		
Summer				
Pearl Millet	7707.54	0.921	864.94	0.172
Millet	1661.00	0.146	269.44	0.031
Fodder Bajra	402.37	0.019		
Vegetable	72.37	0.005	221.51	0.039
Total	**34870.28**	**3.95**	**27343.26**	**3.12**

Source: authors' own estimates based on data from primary survey

If we assume that around 50,000 ha of the irrigated area in the alluvial parts of the region would be under MI systems, the total reduction in groundwater use would be around 112 MCM per annum. If we assume that nearly 100,000 ha of the groundwater irrigated crop in the alluvial districts of north Gujarat comprising Mahesana, Banaskantha, Gandhinagar and Patan, is put under MI systems, the area under MI adoption will be around 11 per cent of well-irrigated area. This is quite achievable. The water saving in that case would be around 224 MCM per annum. When compared to the total groundwater over-draft in these districts, which is 690 MCM (IRMA/UNICEF, 2001), this is a significant water saving.

5.5 Making MI Systems Viable for Poor Water Buyer Farmers

A tentative design for MI system based irrigated production from small plots of water-buying farmers was worked out by IRAP. This system includes: 1] an underground storage tank, for collecting the water delivered through concrete pipes from distant tube wells; 2] a HDPE lining for the tank for preventing seepage and percolation of the stored water from the tank; 3] a low horse power electric motor for lifting water from the tank and pressurizing the MI irrigation system; 4] a precision micro irrigation system which can irrigate plots, size of which is determined by the storage tank and the amount of water which the farmers can buy from the well owner; and 5] a mix of high valued crops (other than orchard crops) which are of short duration, and which give high returns per unit of land) and which are also not high risk from the point of view of production and market[2].

The size of the storage tank is determined on the basic premise that the tank should be able to store enough water for meeting the requirements of all crops grown in his plot under MI method during the time interval between two irrigation services. The equation is:

Storage volume of tank $(V_s) = \sum_{i=1}^{n}\{10PET_i * A_i\} * t$ ……….. (9)

Here, PET_i is the maximum daily potential evapo-transpiration for crop i (mm); A_i is the area under crop i in ha; n is the maximum number of crops standing in the field at any point of time in the entire crop year; and t is the average time duration between two water deliveries received by the water buyer in days. Since the economic viability of drip irrigation is as much a function of the capital cost of the system (which in this case includes the cost of storage tank and pump set), as the net returns from crops chosen for precision irrigation, the viability of the system would improve when the duration between two irrigation services is short as farmers can manage irrigation with smaller size tank.

The capacity of the pump for lifting water from the storage tank can be worked out on the basis of the following criteria: the number of hours for which the pump is expected to be run in a day should be less than the total number of hours of power supply in the farm; the daily water requirement of all the crops grown in the plot should be met on the same day, which means daily watering; and the pump should have adequate residual pressure to run the MI systems.

Hence, the pump capacity = $\sum_{i=1}^{n}\{10PET_i * A_i\}/T] * \mathrm{W} * \mathrm{H}/75 * \mu$ ……….. (10)

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[2] Some of the crops identified are: chilly; brinjal; tomato; potato; cotton; fennel; groundnut; and tobacco. All these crops are successfully grown by farmers in the region and fetch good prices in the market. While some of them are fast perishable (chilly, tomato and brinjal) some have good shelf life (tobacco, fennel and potato).

Here, T is the maximum number of hours for which power supply is available in a day; μ is the efficiency of the pump set expressed in fractions; and H is the total head (m), which is the sum of the maximum head required at the sprinkler head, the pressure losses in the system and the suction head.

Now the economic viability of adoption of MI systems for water buyers is a function of the incremental income from all the crops irrigated and the cost of the storage tank plus the drip irrigation system (see Equation (10) adapted from Equation (1)).

The benefit-cost ratio for MI systems in case of water buyers can be estimated as:

$$\sum_{j=1}^{n}\{A_j * NI_{MI-irrigation.j}\} - \sum_{i=1}^{m} A_i * NI_{trad-irrigation,i}\} \Big/ C_{MI+STORAGE\ TANK+PUMP} \quad \ldots (11)$$

As regards the numerator in the equation, the incremental return from unit area of all the crops is a function of the types of crops chosen, the proportional area under each crop and the type of MI technology chosen. As regards the denominator, the cost of the storage tank is a function of the tank capacity. This again is a function of the area irrigated; the ET demand for the crops selected; and the time duration between two irrigation service deliveries which the farmer receives from the well owner (see Equation (9)). While the area to be irrigated increases the tank storage requirement, thereby its cost, it also increases the net returns and incremental net return from drip irrigated plot, the values in the numerator. Hence, it can be concluded that the economic viability of adopting MI system for water buyers improves with the frequency of water delivery and increase in percentage area under high valued crops. This also means that the farmers have to take risk in ensuring that the available area is put to high valued crops, which often pose a lot of risk from the point of view of both production and marketing. Security of tenure is another big issue which these water buyers would be confronted with when it comes to obtaining irrigation services from well owners, as the water buyers have to make a lot of investments for constructing tank and installing MI systems and pump sets.

In order to analyze the economic feasibility of the system for a small or marginal farmer, we have considered a total irrigated land of 0.4 ha. It is assumed that the farmer grows five different crops in equal proportions of 0.10 ha each during the winter season. Here, two crops viz., groundnut and potato, are assumed to be grown in rotation, as they are grown in different seasons and are irrigated by the same MI system, i.e., micro sprinklers. The crops considered are: groundnut, chilli, potato, castor and fennel. The net incremental return from these crops estimated for a net cultivated area of 0.40 ha and gross cultivated area of 0.5 ha is Rs. 20,800 (see Table 15 for detailed calculations).

The frequency of water delivery was assumed to be once in 7 days. The capacity of the storage tank was estimated to be 112 m^3 based on the assumption that the ET demand per day would be 4mm (0.004*7*4000=112). The cost of the storage tank is estimated to be Rs. 15,000 including the cost of digging, cost of lining using HDPE and bricks and installing a 2-HP pump set. The tank is made by digging out earth, and lining the surface with an HDPE sheet, and lining the edge with brick for stability.

Table 15: Results of a Simulation for MI Irrigated Crops for a Small or Marginal Farmer

Name of Crop	MI Technology	Average Net Income with WST	Average net Income without WST	Incremental Income (Rs)* (3)-(4)*0.1
Groundnut	Sprinkler	27894.17	11133.0	1676.0
Castor	Drip	51150.00	21070.10	3607.0
Chilli	Drip	524250.00	411833.33	11241.0
Fennel	Drip	23730.29	12333.0	1140.0
Potato	Sprinkler	98024.13	60684.0	3734.0
			Total	20800.0

Source: authors' own estimates based on data provided in Table 11

The annualized cost of the tank system (depreciation), estimated for a discount rate of 8 per cent and for a life of four year is Rs.4500. The cost of the MI systems, with 0.1 ha of micro sprinklers and 0.3 ha of inline drips, after subsidies, is worked out to be Rs. 26,975 (see Table 16 for details of cost of different types of MI systems). The annualized cost of the MI set for a 10 year life is Rs. 4019.

We work out the capacity of pump set to create a pressure of 1.5kg/m^2 at the sprinkler nozzle and to discharge sufficient water to meet the daily water requirement of 16 m^3 within reasonable time duration to be 2 HP. The total number of hours for which it has to run is estimated to be 480 for irrigating 0.40 ha for 150 days, for an estimated daily water requirement 4mm, each day pumping out 16 m^3 of water. The energy consumption would be 720 units (KWhr) and Rs. 500 per annum. The price farmers have to pay for this would be Rs. 500 (@ Rs. 0.50 per KWhr). Hence, the total annual incremental cost is Rs. 9019 against an incremental return of Rs. 20800. The B-C ratio is nearly 2.10. Hence, the system is economically viable.

Table 16: Unit Cost of Different Types of MI Systems

Types of micro-irrigation system	Total cost of micro-irrigation system (Rs/ha)	Subsidy on micro-irrigation system (Rs/ha)	Net cost of micro-irrigation system (Rs/ha)
1. Micro Sprinklers	79206.01	38392.09	40813.92
2. Mini Israel Sprinklers	88938.22	40540.54	48397.68
3. On Line Drips	53429.60	24791.13	28638.47
4. Inline Drips	133147.65	59360.78	73786.87

Source: Primary survey

Apart from increased farming risk, one important issue concerning large-scale adoption of MI systems by small & marginal water buyer farmers is the blanket denial of new electricity connections to farmers for agricultural uses in the region. This was done to check further overdraft of groundwater in the region, which is in the "over-exploited" category. This is becoming a serious stumbling block to the water buyer farmers who are interested in adopting MI systems for their crops as they would need separate pressurizing devices. While diesel engines can be the substitute for the electric motors, they would work out to be expensive when used for running drip/sprinkler systems. This policy constraint needs to be addressed at the earliest. This can even become a problem for tube well owners, who are using pressurized MI systems, during years of droughts. The reason for this is that when water level drops, the residual pressure available at the well outlet drops, affecting the performance of MI systems.

6. Setting up Demonstrations of MI Systems for Marginal Farmers

Field evidence from north Gujarat suggests that once the above mentioned issues are addressed, farmers would take the risk and go for MI systems with high valued crops, thereby raising the income from every unit of groundwater used. The shareholders of four tube well companies who also belong to the small & marginal holder category have already started growing high valued crops with MI systems, after being motivated by the staff of SOFILWM. They have adopted a wide range of high valued crops, viz., brinjal, tomato, fennel, cauliflower, chilli and tobacco, and are irrigated by drip systems. These farmers receive water from the shared tube wells under high pressure and therefore could connect drip systems in their plots directly to the delivery pipes of the tube wells. Also, there is security of tenure for these farmers so far as irrigation service is concerned, which gives them strong incentive to adopt MI systems and derive benefit out of it. They have successfully harvested crops in one season already.

In spite of the constraints imposed by the denial of power connections in agriculture, a couple of water buyer farmers, one from Mahesana district and the other from Patan district, could be persuaded by SOFILWM to adopt MI systems, as per the designs prescribed by IRAP in this report as pilot demonstrations. These farmers have been possessing low capacity mono block pump-sets even prior to such restrictions from State Electricity Board coming into force. They have already adopted drip systems for irrigating small plots of cash crops with the help of new underground storage systems built.

7. Findings

- The MI devices adopted by farmers in north Gujarat region are: online drips for cotton, fennel and castor; inline drips for brinjal, cauliflower, tomato and chilli; micro sprinklers for potato and groundnut; mini sprinklers for alfalfa and overhead sprinklers for wheat, bajra and cluster bean.

- Contrary to the conventional belief that water-saving MI technology adoption, which often results in "applied water saving" per unit area of irrigated crop, motivates farmers to expand the area under irrigation and as a result of which no water saving is achieved in reality at the farm level, our research in north Gujarat shows that the area under irrigation has not increased after MI adoption. Instead, there has been some reduction in gross cropped area (from 4.07ha to 3.21ha), while the area under crops that are more amenable to MI systems such as potato, groundnut, cluster bean and chilli had actually increased.

- The area under cereals such as wheat, millet, pearl millet and rajgaro had reduced substantially with MI adoption and introduction of high valued crops at the farm level, and is not compensated by the improvements in yield due to use of MI systems. The reduction in cereal production can have significant implications for domestic food security of the adopter farmers the immediate term. But, more importantly, continued replacement of traditional cereals by cash crops and fruits, which would eventually occur as a result of large-scale MI adoption, will have serious implications for regional food security in the medium and long term.

- Overall, MI technology adoption had resulted in reduction in water application for the crops, which were brought under the system. The extent of reduction in water application was found to be varying widely across crops. The figures do not fully corroborate with the arguments by scholars that it would be a function of the crop type and type of device, and that the saving would be higher for row crops as compared to field crops; higher for drips as compared to sprinklers. In some cases, the extent of reduction in water use was found to be high for field crops. The technology adoption had also resulted in improvement in yield of most of the crops covered by the technology. On an average, the net returns from MI irrigated plots are higher than that of plots irrigated by conventional method for most crops, while for the high valued crops such as chilli the incremental income was exceptionally high.

- The water productivity of the crops irrigated by MIs, in both physical and economic terms, was found to be much higher than that of their counterparts irrigated by traditional method. This was the result of changes in all the determinants of water productivity, i.e., the crop yields and input costs, which in turn affect the numerator, i.e., net income, and the irrigation water dosage, the denominator. In the case of chilli, the water productivity in economic terms had increased from Rs. 34.9/m^3 to Rs. 146.9/m^3. In the case of brinjal, it increased from Rs. 45/m^3 to Rs. 119/m^3 of water.

- The benefit-cost analysis of MI-systems for select plots, in which the crop has not changed after adoption, shows significant variations in B-C ratio across crops from as low as 0.72 to a highest of 5.96. The size of sample for many crops was too insignificant here. This has happened because 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. 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.*, 2008a), and as a result the incremental benefits would far exceed our estimates. Having said that, carrying out benefit-cost analysis of MI systems involves complex considerations of what crops farmers were growing prior to adoption, what new crops farmers choose along with the technology and whether the risk taking tendency of the adopter farmers is associated with the confidence in precision irrigation technology.

- The overall impact of MI adoption which is also associated with introduction of some high valued crops such as chilli, pomegranate, tomato and other vegetables, on the income of adopter families is very significant, as the average income rise is to the tune of Rs.112429 per annum. Such high jumps in annual income of a farm household can change the entire household dynamic which can either be positive or negative, especially when we consider the fact that most of it is realized from select high valued cash crops like chilli, which are subject to high degree of production and market risks.

- Adoption of MI systems with the introduction of new water-efficient crops had resulted in significant reduction in water use at the farm level. The average reduction in water use at the farm level was estimated to be 7527m^3 per farm, whereas at the regional level, the total groundwater saving for irrigation was estimated to be 59 MCM per annum. If we assume that nearly 100,000 ha of the groundwater irrigated area in the four alluvial districts of north Gujarat is covered by MI systems in the next few years, then the total reduction in groundwater use possible would be around 225 MCM per annum. This is a quite significant when compared to the groundwater over-draft from these districts.

- Technical criteria evolved for design of MI systems that are amenable for water buyers of north Gujarat shows that its economic viability improves with the frequency of water delivery and increase in percentage area under high valued crops. This also means that the farmers have to show greater risk taking ability as such crops pose a lot of risk from the point of view of both production and marketing.

- A system was designed for irrigating plots of 0.4ha in size for water buyers using MI system was worked out. The system includes a storage tank with HDPE and brick lining, a 2-HP pump-set and the MI device with micro sprinklers and drips. Economic simulation using results of primary data collected from the field shows that MI systems would be viable for small & marginal farmers who buy water even without considering the cost saving due to reduction in irrigation water requirements, with an annual incremental return of Rs. 20,800 against an annualized cost of Rs. 9019 for building the storage system, installing pump set and installing the MI sets. The system is being implemented as pilot demonstration in the fields of two water buyer farmers, one from Mahesana district and the other from Patan district.

8. Conclusions and Policy

We have seen that adoption of MI systems is leading to large-scale impacts at the farm level from both physical and socio-economic perspectives. Not only, the reduction in water use is significant, but the income enhancement is quite phenomenal. Having obtained positive results from using the MI systems for various crops that are amenable to MI systems, the farmers are showing increasing preference for growing those crops, replacing traditional cereals. The new crops include vegetables, high valued cash crops and fruits. In the immediate term, decline in cereal production will have significant implications for domestic food security of the adopter families. But, large-scale adoption of MI systems in the alluvial district of north Gujarat, which would eventually result in replacement of traditional cereals by high valued cash crops, can have significant implications for regional food security in the medium and long run, while creating positive impacts on the region's groundwater balance.

But phenomenal rise in farm income can change the entire household dynamic, either positively or negatively, especially when we consider the fact that most of it is accrued from select high valued cash crops that are subject to high degree of production and market risks. This aspect of income impact needs much more careful and intensive study from a sociological angle, which is beyond the scope of this study.

The next challenge is to reach the benefits of adoption of water-efficient irrigation technologies to the small and marginal farmers of the region, many of whom are water buyers and shareholders of partnership tube wells. The technical criteria evolved for design of MI systems for water buyers of north Gujarat situation show that its economic viability improves with the frequency of water delivery and increase in percentage area under high valued crops. Subsequently, a system for irrigating plots of size 0.40 ha for water buyers was designed, wherein it was assumed that the buyers would receive water once in seven days from their well owning counterparts. Economic simulation using results of primary data collected from field for various cash crops shows that MI systems would be an economically viable proposition for the small & marginal farmers belonging to this category, if they adopt a combination of high valued cash crops such as chilly, castor, groundnut, fennel and potato.

This also means that the farmers have to show greater risk taking ability as these crops often pose a lot of risk from the point of view of both production and marketing. These risks need to be covered through proper institutional interventions of agricultural extension and provision of processing and marketing infrastructure. Effective extension services are needed to make sure that the poor small & marginal farmers successfully grow high valued vegetables and other cash crops to secure good yields. This should include soil testing to identify micro nutrient deficiency does not occur; and agronomic inputs for proper plant growth. Excellent marketing infrastructure need to be created to make sure that harvested produce is given adequate treatment and processing wherever needed; and the producers are able to sell the harvest when the market conditions are good, thereby securing remunerative prices.

Security of tenure is another big issue which water buyers would be confronted with. Another important issue concerning large-scale adoption of MI systems by small & marginal farmers, who do not own individual wells, is the blanket denial of new electricity connections to farmers for agricultural uses in the region. This policy constraint needs to be addressed at the earliest. This can even become a problem for tube well owners, who are using pressurized MI systems, during years of droughts as water level drops drastically in those years.

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