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Hydrological and Farming System Impacts of Agricultural Water Management Interventions in North Gujarat

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ABSTRACT

Groundwater over-exploitation is a common phenomenon in many arid and semi arid regions of the world. Within India, north Gujarat is one of such 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. The overall objective of the study was to examine the water demand management interventions on farming system, livelihood patterns, food and nutritional security and poverty. The study was based on the primary data collected from north Gujarat. The study suggests that the micro irrigation (MI) technology adoption had resulted in reduction in water application and improvement in crop yield varied from crop to crop. On an average, the net returns from MI irrigated plots are higher than that of plots irrigated by conventional method. 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. The benefit-cost analysis of MI-systems shows significant variations among different crops. The overall impact of MI adoption on the income of adopter families is striking, exceeding one lac rupees per annum. Such high escalations in annual income of a farm household can change the entire household dynamics. 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 was estimated to be 7527m^3 per farm, whereas at the regional level, the total groundwater saving for irrigation was estimated to be 224MCM per annum.

Keywords: Groundwater, water productivity, farming system, micro irrigation, benefit-cost analysis

JEL: Q10, Q15, D61

I

INTRODUCTION

Numerous research studies were conducted in the past on the physical and socio-economic impact 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 (Palanichamy *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 (Kumar and Palanisami, 2011). But, all these analyses are based on individual plot level assessment of physical, economic, environmental or social variables.

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But, introduction of micro irrigation (MI) systems or agricultural water management technologies can change the dynamics of the entire farming system (Kumar *et al.*, 2008; 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. 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, 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 family labour and mechanisation of farms (Dhawan, 2000). If the adopter family is not able to divert the saved domestic labour to other production functions, system adoption can actually lead to increase in input costs, instead of saving in labour cost, often projected as a benefit of MI systems. Shifts in cropping pattern can potentially impact on the livestock holding of farmers, milk production and income from dairying and overall composition of farm economy (Kumar, 2007; Kumar and Amarasinghe, 2009). Hence, individual plot level assessments of physical and socio-economic impacts could be often misleading.

There is need to understand the overall changes in the farming system resulting from adoption of MI systems and high valued crops. A related concern is how the use of groundwater for agriculture in a region varies as a result of adoption of water-saving irrigation technologies, and water-efficient crops. In lieu of the fact that groundwater depletion affects the poor farmers more adversely (Dubash, 2000; Kumar, 2007), such concerns are actually valid while pursuing the goal of sustainable groundwater management.

1.1 *The North Gujarat Sustainable Groundwater Management Initiative*

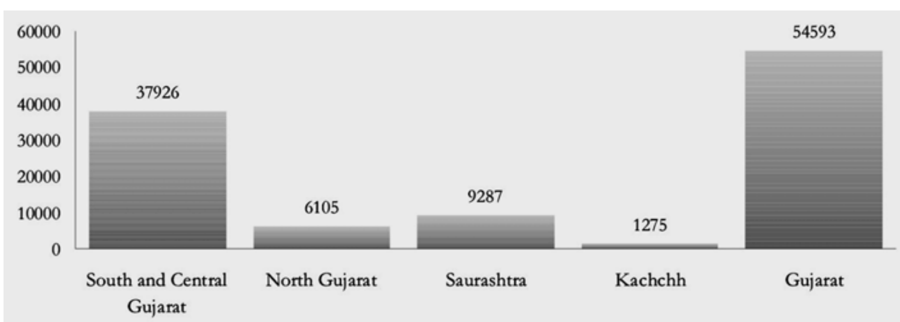
With an annual draft of 231 BCM, India stands atop with regard to groundwater withdrawal for agriculture (Kumar, 2007). According to the official estimates of groundwater development, which considers only the hydrological data, only 23.1Mham out of the 43.2Mham of renewable groundwater in the country is currently utilised. But, from 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 (Government of India, 2005).

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 *et al.*, 2004). Hence, managing groundwater is crucial for the survival of the rural communities in that region.

IWMI's (International Water Management Institute) initiative in north Gujarat which started 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 focus of the strategy was improving water productivity in agriculture. The North Gujarat Initiative, currently being managed by Society for Integrated Land and Water Management (SOFILWM), focused on introducing water-efficient irrigation technologies; water-efficient crops that generate high returns per unit of both land and water; and practices that improve the primary productivity of land.

1.2 *Groundwater Management Strategy in North Gujarat*

According to some estimates made 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 Government of Gujarat, 1996 cited in IRMA/UNICEF, 2001) Figure 1), the total water use was estimated at 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).



Source: IRMA/UNICEF, 2001.

Figure 1. Per Capita Renewable Freshwater Availability in Gujarat by Region (MCM)

From the foregoing analysis it is clear 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 a 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 which are as follows: (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 crops that are highly water-efficient in terms of net return per unit of water consumed (₹/ET); and (3) improving the primary productivity of land through improvement in soil nutrient management measures.

The strategies were built on the assumption: (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 has not been widely recognised. On the contrary, as argued by Molle and Turral (2004), some scholars believe that use of MI systems would eventually increase the consumptive use of water. Their contention is that while the amount of water applied to crops could be reduced through efficiency improvements, the consumptive water use remains the same. But, since the farmers perceive a reduction in the amount of water pumped for irrigation, they might expand the area under irrigation, increasing the consumptive use of water.

But, in the case of north Gujarat 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 (Allen *et al.*, 1998). In sum, use of micro irrigation technologies would reduce the consumptive fraction (CF) leading to real water saving (Kumar *et al.*, 2008). 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.*, 2008). 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.

The physical achievements made as a result of various interventions over the past seven years in the region are summarised in Table 1. The total area under sprinkler and drip irrigation systems in the villages selected for field interventions and that in the villages falling outside the project area was around 24,285 ha.

TABLE 1. KEY PHYSICAL ACHIEVEMENTS OF NORTH GUJARAT INITIATIVE

Sr. No. (1)	Type of activity (2)	Project villages: No. of farmers (3)	Project villages: Total area (ha) (4)	Outside the project villages: No. of farmers (5)	Outside the project villages: Total area (ha) (6)
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.

II

OBJECTIVES

The objectives of present research are as follows: (i) to study the water demand management interventions adopted by different categories of farmers such as small/marginal, medium and large farmers in north Gujarat region; (ii) to analyse the impact of these interventions on the farming system, livelihood patterns, food and nutritional security, poverty and gender issues, division of labour for different categories of farm households; and (iii) to analyse 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

III

APPROACH, METHODS AND TOOLS

The approach used in the study involved comparing the plots, fields and farms of the farmers before and after the adoption of new crops and water-saving irrigation technologies. The variables 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.

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

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

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 annualised 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 annualised cost of the MI system was apportioned among them.

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

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

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:

$$NI_i{}^1{}_i = NI_i - C_{MI,i} \qquad \text{....(3)}$$

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

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

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 per cubic metre) for crop '*i*' was estimated as:

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

Here,Yi is the yield of crop '*i*' (kg per hectare); and Δ_i is as explained above.

The economic productivity of water in crop production ∂_i (₹ per cubic metre) for crop '*i*' was estimated as:

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

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. The underlying assumption in the estimation is that all the water applied to the crop is eventually depleted from the system. This is a reasonable assumption given the semi-arid to arid climate and deep unsaturated zone in the region's aquifers.

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

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:

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

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.

3.1 *Data Sources and Types*

The study covered 49 villages of eight talukas from two districts of north Gujarat viz., Banaskantha and Mehsana, 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 analyses the impacts of various interventions at the plot, field and farm level.

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: (1) area under each crop; (2) the inputs such as seed cost; labour (days); (3) cost of fertiliser and pesticide used; (4) number of watering and hours of irrigations for each watering (hours per irrigation per ha); (5) 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); (6) yield of various crops including both main product and by-product (kg/ha) and (7) the average milk outputs for different animals (litre per day); the cost of various MI systems (₹ per hectare).

The individual components of the farming system that are considered for the 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 analysed 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.

IV

RESULTS AND DISCUSSION

4.1 *Who are the Adopters?*

From Table 2, 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. 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 per cent more land than the non-adopters (Table 3). 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 buffaloes, 1.21 cross bred cows and 0.07 indigenous cows).

TABLE 2. AVERAGE FAMILY SIZE OF ADOPTERS AND NON-ADOPTERS

Particulars	Total family size	Adult male	Adult female	Children	
				Male	Female
(1)	(2)	(3)	(4)	(5)	(6)
WST adopters	8.22	2.58	2.61	1.68	1.34
Non-adopters	6.83	2.40	2.48	1.08	0.90

TABLE 3. AVERAGE FARM HOLDINGS OF ADOPTERS AND NON-ADOPTERS

(ha)

Particulars	Total land holding size	Cultivable land	Cultivated land	Irrigated land
(1)	(2)	(3)	(4)	(5)
WST adopters	3.79	3.76	3.74	3.74
Non-adopters	2.76	2.75	2.74	2.68

4.2 *Changes in Water Application for Different Crops*

As noted by Kumar *et al.*, (2008), 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*., 2008).

Table 4 shows that with the adoption of MI system, the total irrigation water application rate had reduced significantly for many crops. The reduction is more than 50 per cent in some cases, while insignificant in some others. As pointed out earlier, the extent of reduction is a function of the technology used for irrigation. This again is determined by the crop. For most vegetables, drip irrigation is used (chilly, 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.

TABLE 4. IRRIGATION WATER USE FOR DIFFERENT CROPS BEFORE AND AFTER ADOPTION OF MI

(m^3/ha)

Name of the season (1)	Name of the crop (2)	Before adoption of WST: Method of irrigation (3)	Before adoption of WST: Irrigation water use (4)	After adoption of WST: Method of irrigation (5)	After adoption of WST: Irrigation water use (6)
Monsoon	Cluster bean	Traditional method of irrigation	2549.00	Sprinkler	1305.00
	Castor		7890.10	Drip	7695.00
	Groundnut		5602.80	Sprinkler	5258.20
	Chilli		11500.00	Drip	3540.00
	Brinjal		5966.70	Drip	1180.00
	Green Gram		840.00	-	-
	Cotton		7150.60	Drip	3510.00
	Fennel		2455.25	Drip	1728.00
	Alfalfa		-	Sprinkler	12815.10
	Kola		-	Drip	540.00
	Pomegranate		-	Drip	3334.00
Winter	Mustard	Traditional method of irrigation	6337.01	-	-
	Potato		13964.90	Sprinkler	12721.40
	Rajgaro		3600.00	-	-
	Tomato		-	Drip	9440.00
	Flower		-	Sprinkler	3540.00
Summer	Pearl Millet	Traditional method of irrigation	8368.20	Drip	5030.80
	Millet		11338.60	Sprinkler	8776.10
	Fodder bajra		20850.00	-	-
	Vegetable		13750.00	-	-
	Choli		-	Sprinkler	5611.50

As regards actual impact, in the case of cluster bean, the water application rate dropped from 254.8 mm to 130.5 mm. In the case of cotton, the extent of reduction is more than 50 per cent from 715 mm to 351 mm. In the case of chilly, the extent of reduction was nearly 70 per cent (i.e., from 1150 mm to 354 mm). This is an exceptionally high value. In the case of summer bajra (pearl millet), the water application rate reduced from 836.8 mm to 503 mm. The total water application rate for pomegranate was estimated to be 333 mm. 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.

4.3 *Changes in Yield of Different Crops*

The analyses of crop yields showed interesting trends. For many of the 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 per cent (Table 5). In the case of chilly, the yield increase was 25 per cent. But, for some crops such as brinjal and summer bajra, the yield was lower under micro irrigation. In the case of summer bajra, this pattern of reduced yield with micro irrigation can be explained by the poor distribution uniformity obtained in water application through the overhead sprinklers.

TABLE 5. YIELD OF IRRIGATED CROPS WITH AND WITHOUT MI SYSTEM

(qtl/ha)

Before adoption of WST			After adoption of WST		
Name of the season (1)	Name of the crops (2)	Average yield (3)	Name of the season (4)	Name of the crops (5)	Average yield (6)
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	-		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			

But these unusual findings with regard to yield no way mean that with the adoption of MI systems, the yield for these crops would go down. The reason is that the figures presented in Table 5 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 the 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 fertilisers and provision of adequate irrigation to meet the crop water requirement, for obtaining higher yields, along with using MI systems.

4.4 *Changes in Area under Different Crops*

Some marked changes in area under crops were noticed after the adoption of MI systems. The average gross cropped area reduced from 4.07 ha to 3.21 ha. But, these changes seem to affect only select crops. Table 6 shows that the 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, area under bajra and wheat reduced substantially, while area under mustard became nil. 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 some 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. Potato, groundnut and chilly are amenable to micro irrigation systems, and the farmers in the area are extensively irrigating these crops with MI systems. This observation validates our assumption that after realising 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 6. AREA UNDER DIFFERENT CROPS OF ADOPTERS BEFORE AND AFTER ADOPTION OF MI

(ha)

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

4.5 *Changes in Inputs for Livestock and Outputs*

Table 7 shows that the average number of milch animals (per farmer) belonging to all the three categories of livestock, viz., buffalo, crossbred cow and indigenous cow, of the adopter farmers, had increased post adoption, though the rise is not substantial. More importantly, the average milk yield has also gone up for all the three categories of livestock, with significant increase in the case of crossbred 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 the 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 7. YIELD AND GROSS INCOME OBTAINED BY FARMERS FROM DIFFERENT TYPES OF LIVESTOCK BEFORE AND AFTER ADOPTION OF MI SYSTEMS

Type of animal (1)	Total in-milk animal (2)	Total milk production (lt/day) (3)	Milk price (₹/lt) (4)	Dry animal (5)	Calves (6)	Gross income (₹/day) (7)
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 illustrates this. In spite of lower 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.*, 2004). This also might have contributed to increasing the availability of green fodder of the adopter households at the farm level.

4.6 *Changes in Net Return and Water Productivity of Different Crops*

Table 8 provides 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 annualised 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 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 8. 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 (₹/ha)	Modified net return (₹/ha)	Water productivity Physical (kg/m^3)	Water productivity Economic (₹/m^3)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Before adoption of WST			
Monsoon	Cluster bean		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	TMI	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.

The two determinants of physical productivity of water are yield and irrigation and the dosage of water. 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 fertilisers 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. Since we have assumed that all the water applied to the crop is eventually depleted from the aquifer system (see Section III on approach and tools), the improvement in applied water productivity results in real water productivity gain at the aquifer level. It can be seen that the differences in water productivity values are significant.

4.7 *Cost Benefits of Drips and Sprinklers for Selected Crops*

For analysing 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 9. 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 9 provides the B-C ratio 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.

TABLE 9. BENEFIT-COST ANALYSIS OF MI SYSTEMS FOR DIFFERENT CROPS

Season (1)	Name of the crop (2)	Number of observations (3)	Net income (₹/ha) Before WST (4)	After WST (5)	Cost of WST (₹/ha/ annum) (6)	B-C Ratio (7)
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

Having said that, it is to be noted here that the adoption of MI systems, as noted by Kumar *et al*., (2008) 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 chilly which are high valued and 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 following section 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 crops 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 ₹ 52,4250 per hectare for chilli with micro irrigation; ₹ 81,662 per hectare for pomegranate with MI and ₹ 52,822 per hectare for cotton with MI against ₹ 15,082 per hectare for summer bajra. Hence, the real incremental economic benefit is realised through shift to high valued crops that give very high return per unit of land.

4.8 *Impacts of Adoption on Overall Returns from Farming*

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 generate higher yield and net returns per animal, changes in animal holding size or improvement in 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.

The income from crop production had increased substantially to the tune of ₹98,342 per annum, whereas that from dairying had gone up by ₹ 13,912 per annum and that from sale of water to neighbouring farmers is ₹ 175. Hence, the average total incremental income is ₹ 11,2429 (Table 10). 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 dynamics which can either be positive or negative, especially when we consider the fact that most of it is realised from select high valued cash crops like chilly 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 10. IMPACT OF WST ADOPTION ON FARM INCOME

(₹/year)

Particular	Income from			
	Agriculture	Dairy	Water selling	Total
(1)	(2)	(3)	(4)	(5)
Before WST	109587.72	45684.21	175.44	155447.40
After WST	207929.82	59596.49	350.88	267877.20
Incremental benefit	98342.11	13912.28	175.44	112429.80

4.9 *Changes in Overall Groundwater Use for Farming*

A major skepticism of the strategy of agricultural water demand management for conserving groundwater in north Gujarat was 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[1] (personal communication), with higher income return from every unit of water pumped, the farmers would be tempted to invest more in tapping groundwater 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. One reason for this was that they were already irrigating their entire land. The region is experiencing power supply rationing with total power supply to the farm sector in a day limited to eight 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 earlier, the farmers resorted to expanding the irrigated area post MI adoption. But, even in such situations, the income from farming increased remarkably. Hence, in both the situations, the water productivity (₹ per cubic metre) got enhanced, and in most situations the aggregate groundwater use at the farm level reduced.

Other 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 semi-arid to arid climate and 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, consisting of "non-recoverable deep percolation" and soil evaporation (Allen *et al*., 1998 for details). Hence, MI adoption actually led to real water saving at the basin/aquifer level. This was also confirmed by field investigations.

Some scholars have expressed concern that farmers in the region have limited incentives to adopt water saving technologies under the current policy regime. The reasons they cited were: the water-saving and energy saving benefits from the use of MI systems do not translate into income benefits for most farmers who are not confronted with positive marginal cost of using water and electricity; and the farmers are not confronted by opportunity cost of over-pumping groundwater (see Kumar *et al*., 2008; Kumar and Amarasinghe, 2009). But, the North Gujarat Initiative interventions showed that it is possible to motivate farmers to adopt water-saving MI 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 the incidence of well failures. This was mainly because of reduction in pumping owing to improved water productivity. Another incentive was the higher yield and income they obtained post-MI adoption.

The estimates of average farm level water use for different crops before and after adoption of MI system show that the total farm level water use went down from 34,870m^3 to 27,343m^3. The total reduction in groundwater use is 7,527m^3. The annual saving in groundwater for irrigation was estimated to be 56.90 MCM for the current level of MI adoption. It is assumed 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 Mehsana, 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 overdraft in these districts, which is 690 MCM (IRMA/UNICEF, 2001), this is a significant water saving.

4.10 *Major Findings*

Contrary to the conventional belief that water-saving MI technology adoption, which 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 real water saving is achieved at the farm level, the area under irrigation has not increased after MI adoption in north Gujarat. 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 in the immediate term. More importantly, 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. The extent of reduction in water application varies from crop to crop. Since, all the water applied to the crop is treated as water depletion from the aquifer, the reduction in water application can be treated to be resulting in real water saving at the field level. 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. The benefit-cost analysis of MI-systems for select plots, for which crop shift has not taken place after adoption, shows significant variations in B-C ratio across crops from as low as 0.72 to a highest of 5.96. But, most farmers simultaneously changed the crop with introduction of MI system. Therefore, the analyses which considers the crop 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*., 2008), 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 on the income of adopter families is remarkable, crossing one lac rupees per annum. Such high jumps in annual income of a farm household can change the entire household dynamics. This does not necessarily need to be positive always, especially when we consider the fact that most of it is realised from select high valued cash crops like chilli, which are susceptible to high degree of production and market risks. Finally, 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 was estimated to be 7527m^3 per farm, whereas at the regional level, the total groundwater saving for irrigation was estimated to be 224 MCM per annum.

V

CONCLUSIONS AND POLICY

Our analyses show 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 the use of MI systems for various crops, 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, this will cause decline in cereal production affecting domestic food security of the adopter families. But, large-scale adoption of MI systems in north Gujarat, which would eventually replace 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 a phenomenal rise in farm income can change the entire household dynamics, 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 analysis from a sociological perspective. The domestic and local food security impacts of large-scale adoption of MI systems would be a matter of concern with the increasing popularity of MI systems in several semi-arid and arid, water-scarce regions of India, and the tendency of the farmers to modify the cropping system to make it more amenable to MI.

These are the major challenges for India. While improving water productivity in agriculture is extremely important for sustaining agriculture production and ensuring food security (Kumar, 2003), the technological solutions to achieve them can cause significant negative impact on regional food security (Kumar and van Dam, 2009). But, even domestic and local food security can be at risk. There are two reasons for this. First, the families will have to depend on food purchased from the market. While the quality of the commodity can be controlled by the farmers, large reduction in cereal output can cause food shortage in the local market with consequent increase in prices, all affecting the access of local population to food and nutrition. Second, large-scale adoption of MI systems, with associated change in cropping system in a region can result in significant boost in production of high valued crops that are friendly to MI in that region, with resultant drop in the price of the produce (Kumar and van Dam, 2009). This in itself can affect the ability of the families to purchase food from the market as their farm income can severely suffer.

NOTE

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