SECURING WATER FOR FOOD

Market Analysis: Desalinated Water for Irrigation and Domestic Use In India

Prepared for Securing Water for Food: A Grand Challenge for Development in the Center for Development Innovation
U.S. Global Development Lab
Submitted by DAI Professional Management Services

SECURING WATER FOR FOOD: A GRAND CHALLENGE FOR DEVELOPMENT

USAID FROM THE AMERICAN PEOPLE

Government of the Netherlands

SWEDEN

science & technology
Department: Science and Technology
REPUBLIC OF SOUTH AFRICA

M. Dinesh Kumar
Executive Director
Institute for Resource Analysis and Policy, Hyderabad, Telangana, India
Email: dinesh@Irapindia.org and dineshcgiar@gmail.com

ACRONYMS GLOSSARY

$	U.S. dollar
1 Vigha	4 acres
FaBF	Byrraju Foundation
BIS	Bureau of Indian Standards
CGWB	Central Ground Water Board
CVM	Contingent valuation method
GoI	Government of India
GWSSB	Gujarat Water Supply and Sewerage Board
Ha	Hectare
HP	Horsepower
KW	Kilowatt
KWp	Kilowatt per pour
MI	Micro irrigation
Mm	Millimeters
MoRE	Ministry of Renewable Energy
NF	Naandi Foundation
NGOs	Non-governmental organizations
NRIs	Non-resident Indian
PET	Potential evapotranspiration
pH	Potential of hydrogen
PHED	Public Health and Engineering Department
Ppm	Parts per million
PV	Photovoltaic
REEDS	Rural Economic and Educational Development Society
RO	Reverse osmosis
Rs.	Rupees
SOHF	Sai Oral Health Foundation
sq.	Square
TDS	Total dissolved solids
VDC	Village development council
WTP	Willingness to pay

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report seeks to analyze whether conditions exist in India that might make small scale or household desalination for agriculture and potable use economically viable. The report takes a deductive approach, starting with a panorama of India's hydrology, geohydrology and weather and focusing towards those regions with the climatic, geo-hydrochemical and agricultural conditions that might be best suited for desalination technology.

To conduct this analysis, the report begins with desk research across India to identify regions with high aridity, extremely limited availability of surface, brackish groundwater, and crops of sufficient market value to justify capital expenses like a desalination device.

First, it tackles geographic factors, identifying the regions of India with high groundwater salinity and overlays it against regions where there is insufficient surface water or rainfall for raising crops. Then, the report examines how various regions and states of India are able to overcome naturally-occurring water scarcity via interventions like canals and water subsidies. Through this approach, the report identifies regions suffering from freshwater scarcity for irrigation and human consumption.

Water markets are also shaped by agricultural policy and subsidies. Many Indian states are pursuing public interventions to increase their agricultural productivity. The report surveys Indian states that have policies surrounding drip and sprinkler irrigation, electricity (for pumping water, lifting water, and applying water) and solar photovoltaic (PV) systems. These electricity subsidies incentivize groundwater pumping and reduce its cost.

With an understanding of geographic conditions, the report then turns to uses for water, discussing the interface between available water, weather, and crop selection and their implications for marginal economic returns from the use of irrigation water. Farmers calibrate both the area they have under cultivation and the crops they select to water availability in order to maximize their returns. Farmers signaled an openness to purchase expensive irrigation water for growing higher value crops if water for irrigation could be supplied on a reliable basis and their profit margins exceeded 1.04.

The desalinated water is for household use as well, so the report discusses existing models for potable water utilities that may be in competition with the desalination device. The provision of potable water ranges from charitable endeavors undertaken by NGOs and religious sects, to community partnerships between NGOs or non-resident Indians and village leaders, locally administered utilities, and private sector actors operating for profit. Unsurprisingly, the success of these endeavors is predicated on an awareness of customer needs, but rural communities appear to be willing to pay high prices for reliable, fresh water.

The desk research guided the selection of four regions for in-depth analysis and field research: the Somnath/Junagadh districts in coastal Saurashtra; Banaskantha district in North Gujarat; Jodhpur district in Western Rajasthan and Bhathinda district in Southwestern Punjab.

The research considered each region and its crops in turn examining the water price scenarios under which cropping with desalinated water may be profitable for a range of high value crops, with canal-supplied water being the principal competitor. For this the net water productivity values for these crops ($ per m^3 of water) were estimated, considering the price of desalinated water and the cost of pumping water from the wells. The report profiles individual farmers to provide greater context for this information.

Ultimately, farmers' willingness to pay for desalinated water for irrigated agriculture is highly dependent on what economic opportunities it provides for the farmers (i.e., marginal returns from the use of water) in a given setting. These economic opportunities are determined by the following:

1. What kind of crops suited to the climatic conditions, which are not viable with the locally available water, can be grown with the desalinated water;
2. Incremental income that can be derived from the newly introduced crop;
3. The cost of technologies for control of production environment that are needed for raising the crop and their implications for crop productivity;
4. What kinds of markets exist for the crops; and,
5. Whether the farms have easy access to the market.

The study concludes that the demand for expensive desalinated water for irrigation does exist and is highest in the hot and dry regions of North Gujarat, Western Rajasthan (most potential) and Southwestern Punjab.

INTRODUCTION

Purpose of the Study

The purpose of this study is to carry out a market analysis for desalinated water in India, aimed at assessing the demand potential for desalinated water that can be used for irrigation and human consumption. To better understand where demand might be concentrated, the study takes a deductive approach starting with the whole of India and focusing on four target regions. The first part of the report features an extensive review of literature on water markets across India, covering both water markets for irrigation and drinking water supply; an analysis of secondary data on water resource endowments in different regions, particularly groundwater resources covering their quantity and quality dimensions, agriculture—area under different high value crops, inputs subsidies in different regions. The second part of the report covered an in-depth analysis of farming enterprises in four regions having marginal quality groundwater, covering details of crop inputs and outputs, and water markets, in order to examine which crops will be economically viable to be irrigated with fresh water produced from small-scale solar powered desalination plants, at different price levels.

Background: Water Markets in India

India is the eighth largest country (by landmass) in the world, with a wide range of geographic zones and climates. From the northern mountains of the Himalayas to the arid regions of Rajasthan to the coasts of the Gulf of Kutch, the many regions of India, both water rich and water scarce, constitute extensive and intensive water markets for irrigation estimated at 20 million hectares (m. ha) for the entire pump irrigation market in India (Mukherji 2005)[1]. These markets exist for many reasons: 1) acute physical shortage of water for irrigation; 2) groundwater depletion coupled with the high cost of accessing water through wells; 3) poor quality groundwater. Some regions are plagued with limited availability of surface water while others cannot afford water, with millions of farmers lacking the resources to invest in their own wells.

[1]The estimates provide by researchers range from more than half the gross area irrigated by wells (Shah, 1993) to 20 m. ha as per Mukherji (2005) for the entire pump irrigation market in India, to 1/6th of the gross well irrigated area (Saleth, 1999). These estimates correspond to different years. As per the estimates provided by Shah (1993), the area irrigated by groundwater markets was around 20 m. ha in the year 1993, and as per Saleth (1999), the same was around 7.5 m. ha by 1999, suggesting wide differences in the extent of groundwater market for irrigation.

Regardless of the formality of the water markets, multiple factors and conditions propagate unsustainable or inequitable access to water for irrigation amongst productive users:

- **Property & Resource Rights**: "Water trading" is a common practice among neighboring farmers in India. But such water trading constitutes informal water markets, wherein the well owners did not have ownership rights over the water that was offered to the potential buyer, and for the buyer water access is not guaranteed.

- **Economic Inequality**: The terms of water trading vary from place to place, with arrangements made for payment for irrigation services obtained on the basis of hours of irrigation provided, bulk sales for an entire season, or total crop yield. Unregulated water trading sales has a negative overall impact on access equity in groundwater and the current institutional and policy regimes governing the use of groundwater do not mitigate this disparity. Many farmers using wells with electric pumps also receive heavily subsidized access to electricity, resulting in near-zero marginal cost of pumping; these benefits are rarely transferred to the water buyers. The monopoly price ratio is very high in groundwater trading, and the selling price of water has more to do with the monopoly power of the well owners and less to do with the cost of production of water (Kumar et al., 2013). While the benefits of being able to produce water at a low cost are not transferred to the water buyers (Kumar et al., 2013), society bears the cost of depleting this resource.

- **Environmental Impact**: Given the low cost of both electricity and groundwater, well owners often over-extract groundwater with serious consequences for groundwater reserves. Groundwater quality is also a consistent problem. Large, population-dense regions have unsuitable drinking water with salinity levels (TDS), exceeding 1,000 ppm. In many cases, salinity of water exceeds 2,000 ppm—the upper level of salinity beyond which the water becomes unsuitable for irrigating most crops (GoI, 2010). In areas without access to surface water alternatives, only a very small portion of the cultivated land is irrigated due to acute shortages of good quality water. Farmers therefore concentrate their production on high value fruits, vegetables and flowers to compensate with high returns per unit volume of irrigation water. Some farmers have developed workarounds for water quality issues, such as blending poor quality groundwater with salinity-free canal water. Other quality issues, like arsenic and fluoride, continue to plague farmers.

Overall, water markets have a very high impact on efficiency of water use (Mukherji, 2005; Kumar et al., 2011; Palanisami, 2009; Shah, 1993). The key lesson learned from these studies is that farmers tend to resort to buying water when: 1) the cost of abstraction is very high; 2) the land is fragmented into many small parcels; 3) water is needed only for a limited period during a crop year; 4) there is high uncertainty associated with accessing groundwater through drilling. The net income returns for farmers using irrigation are fixed to the cost of used water. Farmers bearing higher costs for irrigation are maximizing returns by selecting higher yield or higher value crops per unit of land.

METHODOLOGY

Market Analysis in the Agriculture Sector

The primary focus of this market analysis for desalinated water in the agriculture sector will be based on identifying situations where:

- Cost of producing desalinated water is low, and
- Demand for water is great at relatively high prices.

Additional analysis will be done to determine the market viability of desalinated water, including:

- Estimated economic value of water, using the concept of surplus value product or incremental (market) value of the outputs generated from the use of unit volume of water (Young, 1996).
- Willingness to pay, by the farmers, based on the value of the uses in irrigation.

The following steps were followed for the market analysis:

1. ***Spatial analysis to identify ideal locations for desalinated water use for irrigation.*** This analysis utilized three different spatial layers of data to determine overlapping regions meeting necessary conditions of market success:

    a. ***Availability of groundwater sources:*** Identification of regions with limited surface water, but having plenty of marginal quality groundwater--with highly dependable aquifer reserves possessing salinity in the range of 2,000-4,000 parts per million (ppm). Areas identified by geohydrology or geo-hydrochemistry maps from the Central Ground Water Board and State Groundwater departments.

    b. ***Areas where well failures were rampant*** – from agricultural census (on well failures and declines in well yields), and which were also close to areas having marginal quality groundwater.

    c. ***Areas of high value agriculture***, or regions that were suitable for such crops by virtue of the climatic conditions, and where access to good quality water for irrigation will lead to both the expansion of their cultivated areas and increase the income from them significantly.

2. ***Willingness to pay*** for water by developing and disseminating a survey to farmers, with the goal of understanding how much desalinated water the farmers will purchase for irrigating their crops at different levels of pricing.

3. ***Current purchasing power***, specifically for crop irrigation with agriculture-quality water in areas where groundwater markets exist, and what net returns they get out of crop production in rupees per cubic meter (m^3) of water. The ratio of "overall net return from irrigated crop production" with purchased water ($\$/m^3$ of water) and the price at which water is sold in the market in $\$/m^3$ **(∅)**; and the price at which desalinated water could be made available to the farmers (β) in $\$/m^3$ can be used to find out what returns farmers have to get from the use of desalinated water for irrigated production per unit volume of water (Y) for water purchase to be economically feasible (as given in Equation 1 below).

$$Y = (\beta \times \emptyset)$$

Equation 1: Returns per unit volume of water

Here ∅ is called the profit margin coefficient. The overall net return from irrigated crop production per unit volume of irrigation water is the overall water productivity for the cropping system that is irrigated. The methodology for estimation of water productivity for cropping systems is available in Kumar (2005) and Kumar et al. (2010).

4. ***Landscape assessment of crop returns*** ¸ per m^3 of water[2]. Water productivity analysis will be carried out for the existing high value crops, through the use of primary data on crop inputs, outputs, and produce prices[3]. For estimating the input cost (of irrigation water), the actual cost of irrigation was used. The quantity of water used for irrigating the crops was obtained along with data on other inputs to estimate the gross and net water productivity of different crops. The analytical procedure for estimation of gross and net water productivity of crops in economic terms is discussed in Annex 1.

---

[2] Here we will consider 'crop water productivity' that could be achieved with good quality water for irrigation for our analysis of WP of individual crops. If the available land is irrigated with marginal quality water, then estimate of 'marginal productivity of water' that could be obtained by replacing poor quality water with desalinated water will be considered for analysis and the total area under the crop irrigated with marginal quality water will be used for demand estimation.

[3] If such crops are not grown in the regions under study, their WP estimates from neighboring areas with similar climate will be used.

Marginal productivity of water derived from the use of desalinated water was also estimated for situations where farmers were using marginal quality water to obtain sub-optimal yields. In this case, the yield increment owing to the use of improved quality irrigation water against the total volume of water used in irrigation was considered for marginal productivity of water.

5. ***Analysis of irrigation subsidies***, as embedded in private and public schemes in the water-scarce regions that are under investigation. Subsidies under consideration include both energy subsidies and direct subsidies, in terms of cost per unit volume of water or cost per unit area of irrigation. This will give an indication of the extent of subsidies that can be offered to the desalination technology for lowering the cost, in view of the social benefits they generate. In the case of electricity subsidies, the energy subsidy offered to farmers per unit (kilowatt hour) of electricity supplied in the agriculture sector (μ) in $/KWhr was obtained through various state power utilities. This was converted into electricity subsidies per unit volume of groundwater (£) in $\$/m^3$ using the estimates of electricity required to pump a unit volume of groundwater (È) in $KWhr/m^3$ under different water level conditions as given in Equation 2.

$$£ = \mu \times \grave{E}$$

Equation 2: Electricity subsidy per m3 of groundwater pumped

The government has heavily subsidized solar photovoltaic (PV) systems to support irrigation in rural areas (Bassi, 2016), as well as reduce carbon emissions. In these cases, the study calculates the extent of subsidy available per KW (kilowatt) of installed capacity in different states. Based on the average number of hours of solar power generation possible in a year and the efficiency of the PV system, the total electricity generated per KW will be estimated, and the energy subsidy per unit of electricity and water could be estimated. The highest of the two (i.e., electricity subsidy and subsidy for solar PV system) will be used to ascertain the maximum subsidy that can be considered for water produced using the new desalination technology. This will be subtracted from the actual cost of desalinated water from the new technology to arrive at the price of desalinated water (β).

6. The values of net crop water productivity in economic terms for different crops with ***different imputed prices of desalinated water*** (over and above the current costs incurred by the farmers for pumping underground water) and profit margin coefficient (∅) will be estimated for each case (Y/β) in order to identify the crops which are economically viable to be irrigated with water from the desalination system.

Market Analysis for the Drinking Water Sector

The market analysis for the use of desalinated water in the drinking water sector focused first on identifying rural areas where large-scale sales of safe drinking water is the norm. Additional analysis was conducted on macro level data on incidence of fluorides, salinity, nitrates and arsenic in groundwater, available in the form of a map, to identify areas in need of drinking water sources with improved water quality. Analysis was also done on the sources of untreated water, cost of production of treated water, price of water ($/m^3), quantity of water purchased by the households per day, and the total market size.

The data on electricity and other subsidies available to the agencies running the treatment plants in rural areas is also collected wherever available to estimate the actual economic cost of producing safe drinking water. The data is from a review of published and grey literature on drinking water market in rural areas, telephone interviews of bottled water supply company officials, and representatives of NGOs promoting safe drinking water markets in rural areas.

The analysis also includes a field survey with heads of household to collect data on: quantity of water purchased per day, the price of water per m^3, and the amount of time people spend collecting safe drinking water from treated water suppliers (the opportunity cost of this time is added to the price of water to arrive at the actual cost of obtaining treated water).

The areas where the costs incurred by communities for obtaining safe drinking water are higher than the cost of water production using the desalination technology (after factoring in the subsidies) will be the "target areas." The potential market size for the water will be estimated based on population sizes affected by poor quality water for drinking in the target areas and the average quantity of safe drinking water purchased per capita.

ANALYSIS: GROUNDWATER ACROSS INDIA

Areas with Marginal Quality Groundwater

Figure 1 shows the spatial extent of salinity in shallow groundwater in India (Source: GoI, 2010). This mapping is based on data obtained from observation wells maintained by the Central Ground Water Board CGWB and spread across the country. Water samples are obtained from these wells pre and post monsoon for analyzing electrical conductivity. The map shows areas affected by coastal salinity and inland salinity (GoI, 2010). The coastal salinity is due to both ingress of seawater and intrusion of seawater. The two regions which have extensive coastal salinity are Saurashtra and Kachchh in Gujarat, affecting all the coastal districts.

Annex 2 shows the names of districts, which have salinity levels exceeding 2,000 ppm. As the title suggests, many of these districts have salinity in certain areas, and not in the entire geographical boundary. Spatial analysis shows that salinity in the Western state of Gujarat is extensive along the coastline but localized in Andhra Pradesh and Tamil Nadu. In addition, rainfall in coastal Gujarat is much lower as compared to coastal Andhra Pradesh and coastal Tamil Nadu (TN), as the latter two regions receive rainfall from both the Southwest and the Northeast Monsoon.

Further, unlike coastal Gujarat, most coastal districts of Andhra Pradesh and TN have access to surface irrigation from tanks and canals, which reduces dependence on groundwater for irrigation.

In coastal Gujarat, a three to four km narrow coastal strip has alluvium and limestone aquifers. This area has high groundwater salinity and the soils are also saline, rendering it unsuitable for irrigated crop production. The inland areas, which have hard basalt rocks, have poor groundwater potential and are also affected by saline intrusion resulting from landward movement of saline water. Irrigated agriculture is quite extensive here, and demand for good quality water for irrigation is also high.

This region could also explore desalinating marginal quality ground water from the coastal areas and transporting it inland.

Inland salinity is pervasive in the alluvial areas of North, Central, and South Gujarat, Kachchh, Western Rajasthan, South Western Punjab, and Haryana. In Western Rajasthan, in many areas within the salinity-affected region, groundwater salinity is excessively high (far exceeding 4,000 m S/cm or 2,600 ppm), rendering it unfit for irrigation. Geographies with fresh groundwater or marginal quality groundwater (with TDS less than 1,300 ppm or in the range of 1,300-2,600 ppm, respectively) (Figure 2, based on GOR & Rolta India Ltd.) generally practice irrigated agriculture[4]. Due to poor quality (desert) soils and water scarcity, crop cultivation is practiced in areas where groundwater salinity is below 2,600 ppm, especially in areas where it is less than 1,300 ppm. In Gujarat, in places where both groundwater and soil salinity levels are excessively high, irrigated agriculture is not practiced. Inland salinity exceeding 2,000 ppm is encountered in Telangana, Rayalaseema region of Andhra Pradesh, Northern and North Western Karnataka, and Tamil Nadu. In all these states, irrigated agriculture is practiced with groundwater except at these hot spots, as the salinity level is less than 2,000 ppm.

---

[4] The author's field research in coastal Saurashtra, north Gujarat, western Rajasthan and south western Punjab has shown that many food crops and forage crops are irrigated with marginal quality groundwater, when fresh groundwater is not available. However, most vegetables, fruits and flowers require water of much lower salinity—less than 500 ppm, which was also confirmed during the field work.

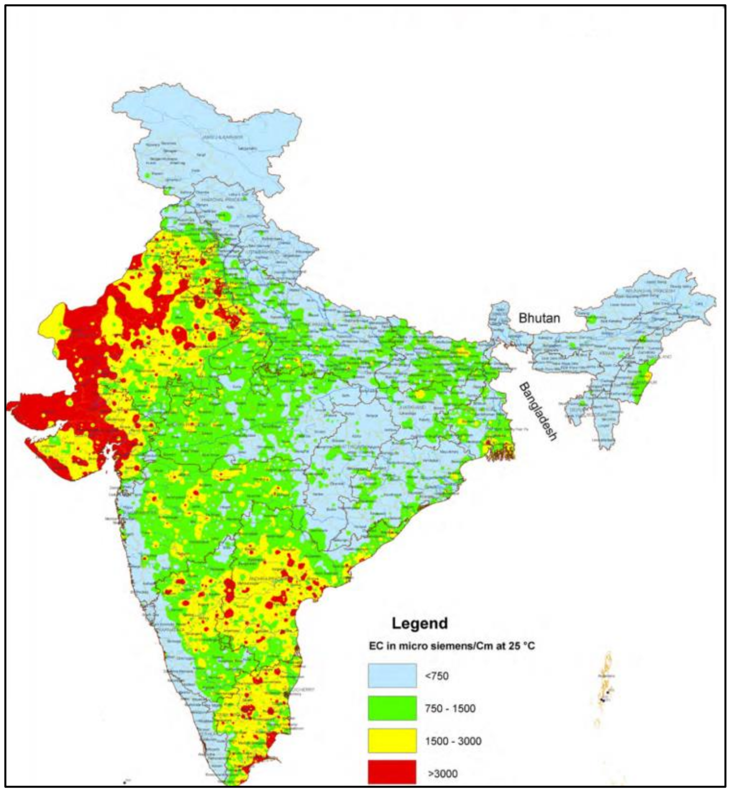

Figure 1: Groundwater salinity levels in India (Source: GoI, 2010.)

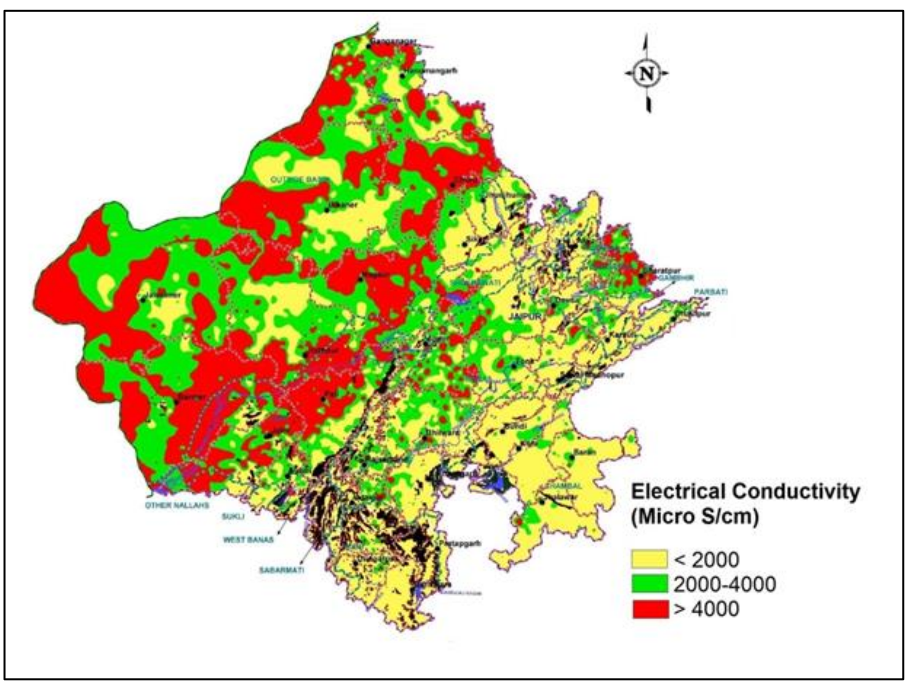

Figure 2: Pre Monsoon Groundwater Salinity in Rajasthan: Average for 2005-09 (Source: GOR and Rolta India Ltd. 2010).

Groundwater Contamination from the Point of View of Potability

High levels of salinity --measured in terms of total dissolved solids (TDS) – renders groundwater unfit for drinking. Per the Bureau of Indian Standards (BIS), the permissible level is 1,000 ppm for potable water, though some Indian states have adopted more liberal standards, with water sources of higher salinity (up to 1,500 ppm) often used for drinking water when no alternatives are available. There are other sources of chemical contamination of groundwater in India. They are: fluoride, nitrates and arsenic. The permissible level of fluoride for drinking water supply is 1.5 ppm. The permissible level of nitrate is 45 ppm. The permissible level of arsenic is 0.05 ppm or 50 parts per billion. Figures 3, 4 and 5 shows the districts, where groundwater is affected by these contaminants in terms of the percentage of administrative blocks affected, for fluorides, arsenic and nitrates. This assessment is based on spot data on the incidence of high levels of these contaminants in groundwater, as obtained from the observation wells in these blocks, as the actual data on the areal extent of contamination are not available. These maps do not suggest the degree of contamination within a certain locality, and instead suggest the areal spread of contamination.

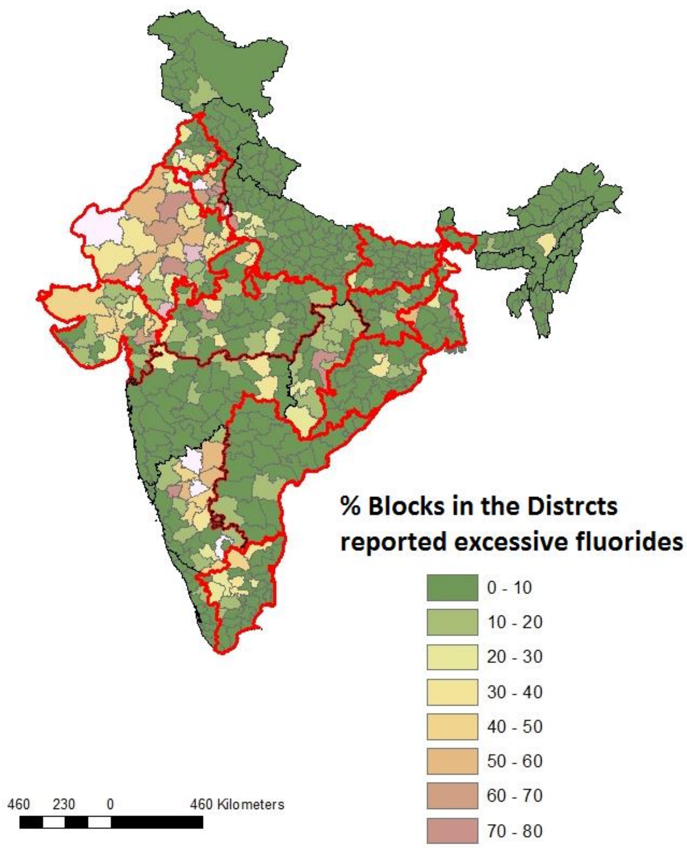

Figure 3: Districts Affected by fluoride contamination in Groundwater.

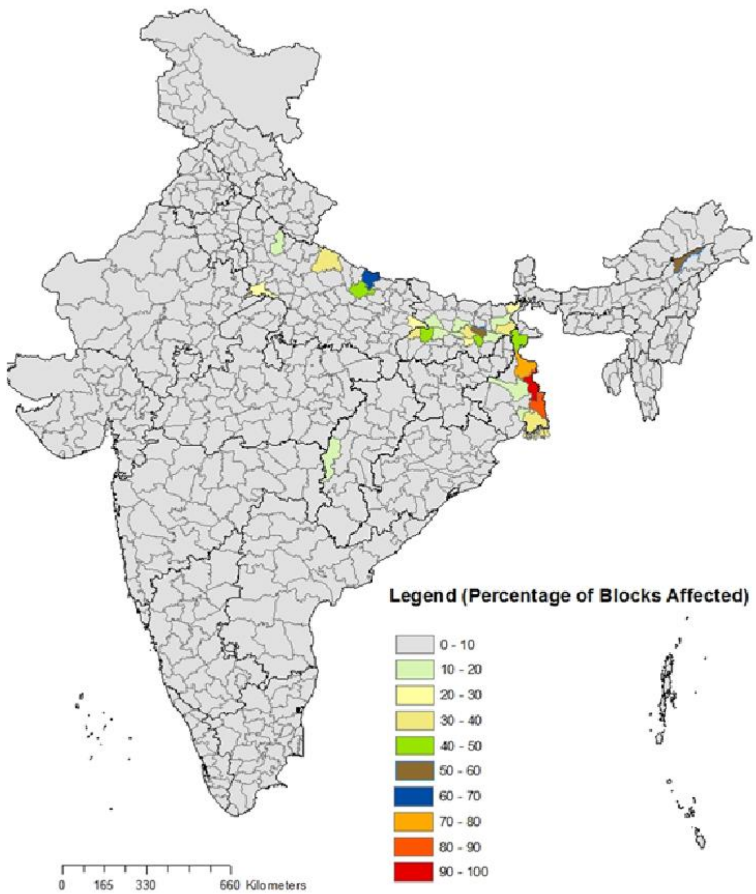

Figure 4: Districts Affected by High concentration of Arsenic in Groundwater.

Chemical contamination of groundwater with fluoride, nitrates, and arsenic is also a concern in India. The incidence of fluoride in groundwater is very high in Rajasthan, Gujarat, Telangana and Andhra Pradesh. Since groundwater has been a major source of water supply in rural areas for several decades, the increasing incidence of unacceptable levels of salinity, fluoride, and arsenic in groundwater threatened the sustainability of rural water supply systems based on dug wells, bore wells, tube wells, and hand pumps. In Gujarat, Karnataka, Telangana, and Andhra Pradesh, the governments are now increasingly promoting regional water supply schemes, based on surface water sources, which are free from chlorides and other minerals.

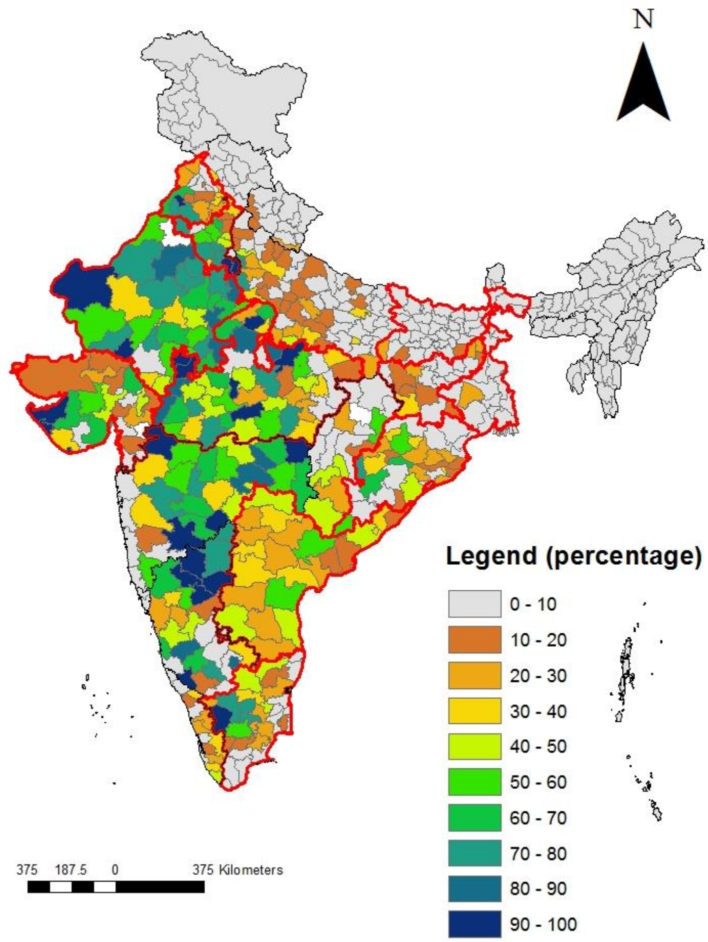

Figure 5: Districts Affected by High Concentration of Nitrates in Groundwater in India (under preparation).

Groundwater Availability

The depth to water table has direct implications for the cost of pumping a unit of groundwater, as does the type of geological formations that must be drilled through to access the aquifer. India has three distinct geological formations:

1. ***Unconsolidated, alluvial formations*** are mainly in the Indo Gangetic alluvial plains encompassing almost the entire Punjab, Uttar Pradesh, Bihar, Haryana, West Bengal and Assam; the alluvial Cambay basin in Gujarat; and coastal strips of Gujarat, Maharashtra, Karnataka, Andhra Pradesh, West Bengal and Kerala, and some pockets along Tapi river valley in Maharashtra.
2. ***Semi-consolidated formations*** of sedimentary sandstone are found in pockets of Kachchh district in Gujarat, Western Rajasthan and some parts of Madhya

Pradesh. Laterite formations are found in large parts of Kerala, and some parts of South Karnataka.

3. ***Consolidated formations*** or hard rocks include Deccan trap formations, crystalline rocks and sandstone and limestone aquifers. Consolidated formations cover two-thirds of India's geographical area, and are extensive in Maharashtra, Madhya Pradesh, Telangana, Andhra Pradesh, Karnataka, Southern Rajasthan, Odisha, the entire Western part of West Bengal and North-Eastern hill states and Jammu & Kashmir.

India's depth to the water table varies with climate and geology, as well as seasonally. In the alluvial areas in periods of low to medium rainfall, and in semi-arid and arid regions, the depth to groundwater table is generally high due to excessive pumping, and limited recharge from rainfall. These areas also experience consistent annual declines in the water table, with average annual abstraction exceeding recharge in most years. The presence of static groundwater resources in these formations enables levels of pumping that exceed recharge. In the medium to high rainfall regions, with semi-arid and sub-humid climatic conditions, the groundwater table does not show annual decline, as abstraction is less than annual recharge from rainfall.

In the plains, underlain by hard rock under similar climatic conditions, groundwater occurs in weathered formations. The depth to water table is generally large during summer months due to intensive groundwater use in those regions. Nevertheless, unlike deep alluvial formations, water table cannot drop too low here because the deeper formations generally do not have much water. The available water in the weathered formation gets abstracted during the monsoon and winter seasons, leaving no water in the shallow formations for use during summer months. In low rainfall years, the aquifers, which are merely dependent on recharge from rainfall, get emptied during winter. Such conditions force farmers to drill deep to abstract the limited water in the fractured rocks underlying the weathered strata.

But, unlike alluvial areas, the hard rock areas experience high seasonal fluctuation in water table conditions, with significant rise in water levels post monsoon, recharging from rainfall and low specific yield of the formation. This can be seen from the comparison of groundwater contour maps of post monsoon (December) and pre monsoon (May) of the year 2011 (Figure 6 and Figure 7). In the hard rock areas, the rise in water table is very significant post monsoon, whereas in deep alluvial areas, the rise is insignificant. Though hard rock geological formations are found under different climatic (from arid to semi-arid to sub-humid to humid) and topographical conditions in India (from plains to plateau to mountainous areas), the groundwater condition is poor everywhere, especially in the undulating areas and hilly areas. This peculiar situation is due to poor recharge rates and significant groundwater outflows reducing the utilizable recharge to an insignificant amount.

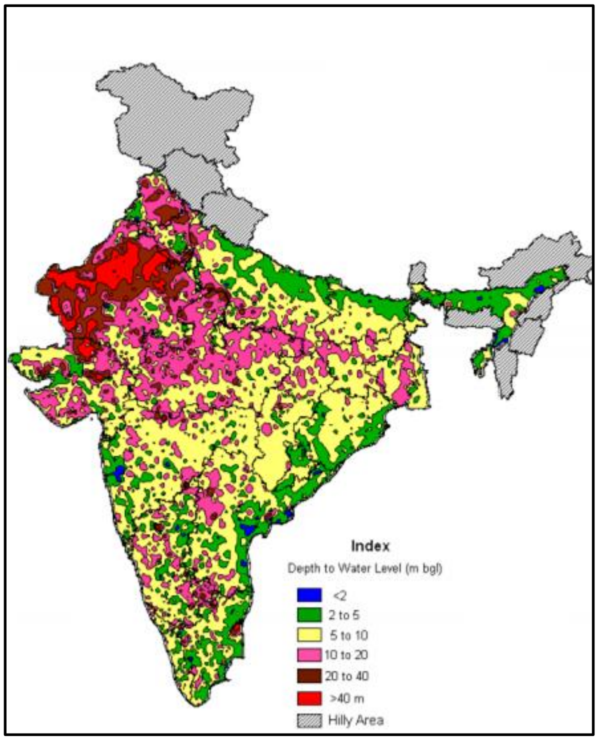

Figure 6: Depth to Water Table in May 2011.

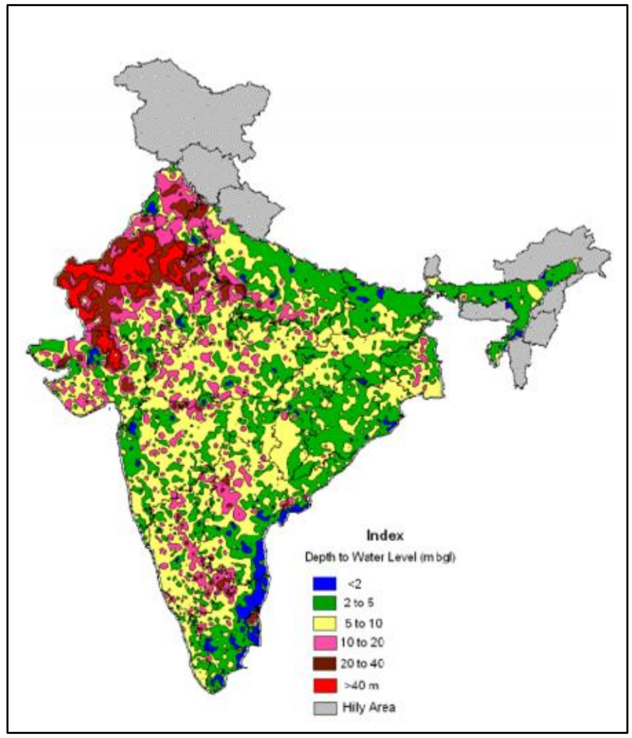

Figure 7: Depth to Water Table in December 2011 (Source: GoI 2012).

ANALYSIS: IRRIGATION SUBSIDIES

One of the reasons for low adoption of water management technologies in agriculture is the pervasive subsidies given for irrigation water (in the case of public irrigation schemes) and electricity, supplied by the public utilities for private well irrigation. In the absence of these subsidies, the farmers have to make high investments to access irrigation water in many situations. With surface water, the cost of supplying water to irrigators from public systems is very high in situations when water from reservoirs is conveyed over long distance or when heavy lifting of water is involved. The Water Resources Department does not charge the full operations and maintenance cost of supplying water to the farmers, excluding the life cycle costs and, in most cases, charges only a small fraction of the operations and maintenance expenditures. The water charges are not based on volumetric water delivery and instead, a crop-area based method of charging is used. There is no measurement of water delivery to the farmers' fields, except in some pilot projects where water user authorities (WUAs) are promoted by the government through NGOs (Bassi and Kumar, 2011).

Subsidies in Public Surface Irrigation

Some argue that heavy subsidies for public irrigation are disincentives for farmers to invest in water-efficiency. Therefore, it is important to understand the level of subsidies involved in irrigation. It also gives an indication of the extent of subsidy support which government can offer for non-conventional alternatives for water production and supply. Table 1 provides data on irrigation investments in terms of capital expenditure, area irrigated, operations and maintenance costs and revenues from collection of irrigation charges. The expenditure on various Major and Medium irrigation schemes built so far is annualized and presented as the Capital Expenditure during the year 2012-13 in Column #2. This is not the investment made during that particular financial year. The cumulative capital expenditure to date (2012-13), adjusted to inflation or the expenditure at constant prices, on various schemes built so far is presented in Column #3. In addition, there are working expenses incurred every year, towards operation and maintenance of schemes and payment of salaries and wages of the agencies involved in their operation and management. These figures are presented in Column #4. The cost of irrigation water supply per unit irrigated area (Column #7) was estimated by adding up the annualized capital expenditure and working expenses and dividing it by the present gross irrigated area. The estimated receipt from the users (Rs/ha) is subtracted from this to arrive at the average annual subsidy per unit of irrigated area (Rs/ha) in Column #9.

As Table 1 shows, subsidies for irrigation vary remarkably across states. If we leave states such as Mizoram, Jammu & Kashmir, Himachal Pradesh and Meghalaya, which are not known for investments in public irrigation and Jharkhand whose irrigation schemes are ongoing, the subsidy varies from a highest of Rs. 103,962 per ha in Andhra Pradesh to Rs. 2,995 per ha in the case of Chhattisgarh. The investment in per ha terms is very high in Andhra Pradesh, and one of the reasons for this is the very high working expenses, due to the large number of (river) lift irrigation schemes built recently by the erstwhile government of Andhra Pradesh (under its Jalayagnam project), incurring substantial cost for energy for lifting water. In fact, the annual working expense (Rs. 83,942 million) is very close to the annualized capital cost. The second highest irrigation cost in per ha terms is in Maharashtra (Rs. 68,498 per ha) which has the largest number of irrigation projects in the country, followed by Gujarat (Rs. 63,543 per ha). Rajasthan, which is the second most important state in terms of canal irrigated area, incurs considerably low expenditure on public irrigation. One important reason for this is that most of the irrigation is from IGNP canal, which transfers water to irrigate more than 1.0 m. ha of land from a barrage on Sutlej River in Punjab, whose cost was incurred by Punjab. A significant part of the project cost is not reflected in the capital expenditure against the state.

The irrigation cost is very low in Chhattisgarh, Rajasthan, Bihar, Punjab, Haryana and West Bengal. If we leave aside Rajasthan as an outlier for the reason mentioned above, the following trend can be inferred from the data: 1) the cost of irrigation is generally very low in the water-rich states (Bihar, West Bengal, Chhattisgarh and Uttar Pradesh); and, 2) the cost of irrigation is high in the water scarce states, which have also made substantial capital investments in irrigation development in the very recent past (Andhra Pradesh, Maharashtra and Gujarat), and low in their counterparts, which have invested in irrigation systems several decades ago such as Punjab and Haryana. One probable reason for the high cost to the former is the large-scale water transfers involved in providing irrigation (from water rich catchments to water-scarce and drought prone regions), difficulty in getting viable sites for construction of reservoirs and the consequent need to use energy to lift water, and the poor dependability of the schemes that reduces the actual irrigated area per unit volume of storage created.

Table 1: Subsidies in Public (Surface) Irrigation in Major and Medium Projects in India (2012-13)

State	CapEx during the year	CapEx up to year end	Working expenses	Gross receipts	Gross irrigated area-canals	Estimated supply cost	Estimated receipt	Estimated irrigation subsidy
	(In RS 100,000)				In thousand hectares	(RS per hectare)		
Andhra (Undivided)	930017	8347720	839421	19325	1683	105110	1148	103962
Assam	5320	104371	12136	38	33	52896	114	52782
Bihar	81615	1124718	39947	1706	1522	7988	112	7876
Chhattisgarh	34291	556395	30238	35723	962	6710	3715	2995
Goa	1592	132157	2846	704	8	55481	8795	46686
Gujarat	595642	4314691	55918	71413	913	71365	7822	63543
Haryana	72417	862446	92271	13912	2532	6504	549	5955
Himachal Pradesh	4885	67933	1450	33	8	79194	415	78779
J&K	6044	100762	6026	16049	427	2827	3759	-932
Jharkhand	37869	300225	4329	8689	7	646707	133157	513550
Karnataka	397216	4607013	33777	2379	1335	32293	178	32115

State	CapEx during the year	CapEx up to year end	Working expenses	Gross receipts	Gross irrigated area-canals	Estimated supply cost	Estimated receipt	Estimated irrigation subsidy
	(In RS 100,000)				In thousand hectares	(RS per hectare)		
Kerala	10763	354341	24960	1474	83	43039	1776	41264
Madhya Pradesh	320252	2196196	62275	13774	1569	24374	878	23496
Maharashtra	614569	7819226	178398	53189	1080	73423	4925	68498
Meghalaya	0	1873	55	0	78	70	0	70
Mizoram	0	96	2	0	15	14	0	14
Odisha	137645	1542022	47568	38759	1178	15724	3290	12433
Punjab	23851	693659	82117	5097	1516	6988	336	6652
Rajasthan	54222	1129991	137367	8721	2885	6641	302	6338
Tamil Nadu	105824	616633	52102	2538	678	23291	374	22917
Uttar Pradesh	97677	1589911	323415	19143	3874	10869	494	10374
Uttarakhand	25856	157952	23599	765	132	37397	578	36819
West Bengal	8607	234081	24026	992	560	5827	177	5650

Electricity Subsidies for Agricultural Groundwater Pumping

The right to use groundwater is linked to land ownership rights and there are no limits on the volume of groundwater that can be pumped (Saleth, 1996). Neither the state nor the central government levies any tax for groundwater use by private individuals. India is estimated to have around 23-25 million wells for agricultural use, and most of these wells are under private ownership. A total of around 232 billion cubic meters of water (23.2 M. ham, i.e., 193 M. acre-feet), on average, is pumped out annually by these wells to irrigate crop lands in India according to official estimates (GoI, 2012). In many semi-arid and arid areas of the country, groundwater is over-exploited, with secular decline in water table in the alluvial and sedimentary areas and fast seasonal drop in water levels in the hard rock areas. The well owners do not pay for the negative welfare effect of groundwater over-exploitation.

The characteristics of wells vary widely across regions depending on the geology and geohydrology – from shallow open wells to shallow bore wells and deep bore wells (Kumar, 2007). The depth of pumping groundwater also varies drastically – from a few meters in the Eastern Indo Gangetic (alluvial) plains (North Bihar, Eastern UP and West Bengal) and coastal Andhra Pradesh to more than a hundred meters in the alluvial plains of semi-arid to arid North Gujarat (Kumar, 2007) and Rajasthan (CGWB, 2016a & b). The depth to water table ranges from 20-200 meters in the hard rock areas of Peninsular India (CGWB, 2016b). In the heavily over-exploited areas, the depth to water is very large in both alluvium and hard rocks (GoI, 2012).

In many Indian states, the electricity to farm sector for pumping well water is supplied for free. The electricity charge is sometimes based on connected load of the pump (annual electricity charge is calculated on the basis of the installed capacity of the pump) and at the aggregate level, electricity supply is heavily subsidized. Only in West Bengal, and partly in Gujarat and Uttarakhand states is the electricity supply for groundwater pumping metered, with subsidized unit rates. West Bengal has the longest experience in metering power supply to agriculture and charge rates as high as Rs. 4.15 per KWhr. As Table 2 indicates, the extent of subsidy made available to the farmers varies from state to state. As per the data for the year 2013-14, only Tripura state has an agricultural power tariff, which is higher than the average cost of power supply. In all other states, there is power subsidies, and varies from Rs 1.75 in Assam to Rs. 8.67 in Jharkhand. However, the average cost of power supply also varies across states. It is highest in Jharkhand (Rs. 9.42) and lowest in Sikkim (Rs. 3.19). In the states where power subsidy prevails, the extent of subsidy varies from a highest of 100 percent in Tamil Nadu, Punjab, Himachal Pradesh and Puducherry to a lowest of 28 percent in Assam.

Table 2: Power Subsidies in Agriculture in Indian States

Name of State	Power Supply Cost (Rs/KWhr)	Agricultural Power Subsidy (Rs/KWhr)	Extent of subsidy in farm power (%)
Undivided Andhra Pradesh	5.63	5.19	92.14
Assam	6.29	1.75	27.82
Bihar	7.85	3.74	47.67
Chhattisgarh	4.11	2.57	62.51
Gujarat	4.96	2.78	56.10
Haryana	6.46	6.00	92.80
Himachal Pradesh	5.26	5.25	99.78
J&K	6.74	5.06	75.01
Jharkhand	9.42	8.67	91.96
Karnataka	5.05	1.98	39.24
Kerala	5.97	4.24	71.03
Madhya Pradesh	5.39	1.88	34.88
Maharashtra	5.84	3.26	55.78
Meghalaya	5.24	0.00	0.00
Punjab	5.78	5.78	99.99
Rajasthan	6.98	5.17	74.11
Tamil Nadu	6.46	6.46	100.00
Uttar Pradesh	7.06	4.82	68.25
Uttarakhand	5.10	2.82	55.18
West Bengal	6.13	1.98	32.26

Name of State	Power Supply Cost (Rs/KWhr)	Agricultural Power Subsidy (Rs/KWhr)	Extent of subsidy in farm power (%)
Arunachal Pradesh	8.24	-	-
Goa	3.72	2.66	71.44
Manipur	8.55	7.14	83.51
Mizoram	7.41	0.00	0.00
Nagaland	9.06	-	-
Puducherry	4.06	4.03	99.22
Sikkim	3.19	-	-
Tripura	5.10	-0.44	-8.70

Source: Estimates based on GoI (2014).

Ultimately, the following factors determine the amount of subsidy farmers get for pumping groundwater:

1. Depth to groundwater table; and
2. The actual subsidy per unit of electricity.

Hence, in areas where groundwater table is deep and where the actual amount of subsidy per unit of electricity is high, the subsidy farmers receive for each unit volume of water used will be exceptionally high. The states where groundwater table is deep are Punjab, Rajasthan and Gujarat. The amount of electricity subsidy per unit of electricity is also high in these states – from Rs. 5.78 in Punjab to Rs. 5.17 in Rajasthan to Rs. 2.78 in Gujarat. In Central Punjab, where water table is around 200 feet deep, the energy required to pump out a cubic meter of groundwater will be around 1.5 KWhr, and therefore the cost to the society in the form of subsidy will be Rs. 8.67 or $\$0.12/m^3$ of water. Similarly, in certain pockets in the alluvial areas of North Gujarat, where the water table is around 1,000 feet, the cost to the society for pumping a cubic meter of groundwater will be Rs. 18 or $0.27. Heavy subsidies (up to 85 percent) are offered to farmers using off grid solar PV systems for pumping groundwater in many Indian states such as Gujarat, Bihar, Rajasthan and Karnataka (Bassi, 2016).

Drip Irrigation Subsidies

With the aim of improving water and energy use efficiencies in crop production and saving water and energy used in agriculture, the state and central governments in India offer subsidies for adoption of drip and sprinkler irrigation systems for agricultural crops. However, the capital cost of installing drip and sprinkler irrigation systems depend on the type of crop, mainly the plant spacing and will be high for closely spaced crops such as eggplant, cauliflower and chilies, and low for distantly-spaced crops such as mango, coconuts, sapota and date palm. Accordingly, the pricing norms for various crops are worked out by the National Committee on Plasticulture. Table 3 gives the pricing norm for drip irrigation systems for various dripper-spacing and various plot sizes. The system includes the main drip line, the laterals, emitters, filter box and venture-meter. It can be seen from Table 3 that for the same spacing of drippers, the unit cost reduces with increasing plot size. Further, National Bank for Agriculture and Rural Development (NABARD) had come out with recommended spacing and cost norms for various horticultural crops. They are presented in Table 4.

The actual amount of irrigation subsidies available to the farmers from Central and state governments depend on the crop for which drip system is to be installed; the dripper-spacing norm adopted for the crop by NABARD; the respective cost norm for that spacing; extent of government contribution; and the actual area covered.

Table 3: Recommended Price (Rs) for Installing Drip Irrigation System for Different Plot Sizes

Dripper spacing (m x m)	Size of the plot in ha					
	0.4	1	2	3	4	5
12 x 12	10600	16700	25200	32600	53700	71300
10 x I0	12100	18000	27700	36000	57900	76900
9 x 9	12400	22100	35500	55900	61400	81100
8 x 8	12900	19900	31300	41700	65500	86200
6 x 6	14400	30200	51200	70300	105800	13 7400
5 x 5	15100	32800	56600	83100	117100	150800
4 x 4	16900	39300	63100	100700	142200	179300
3 x 3	17900	35600	71400	96100	130800	158300
3 x I.5	19700	40200	80500	109700	146100	180900
2.5 x 2.5	20000	39800	81400	111200	199500	239600

Dripper spacing (m x m)	Size of the plot in ha					
	0.4	1	2	3	4	5
2 x 2	21300	49800	86400	122700	164900	223400
1.5 x l.5	26100	55000	109500	165100	205900	281000
1 x l	26500	57600	96500	146500	199900	249200

Source: National Committee on Plasticulture Applications in Horticulture.

Table 4: Recommended Unit Cost of Drip Irrigation System for Various Crops

Crop	Spacing (m)	Cost (Rs/ha)	Cost ($/ha)
Coconut	8x8	23790	355.0
Sapota/Mango	10x10	17030	254.0
Orange/Guava	6x6	28010	418.0
Pomegranate	4.5x2.7	32010	478.0
Grapes	2.7x1.8	54370	811.0
Banana/Papaya	1.8x1.5	73010	1090.0
Sugarcane	[(0.75m+1.25m) x 0.15m] lateral spacing - 2.25m)]	60440	902.0
Vegetables	0.6x0.45	103020	1538.0
Mango	5x5	32060	479.0
Lychee	6x8	42000	627.0

Source: National Bank for Agriculture and Rural Development.

Except for the centrally sponsored schemes, the pattern of subsidies depends on the state, as seen in tables. In the case of centrally sponsored schemes, the subsidy contribution from the center is 40 percent, the state contribution is 10 percent and the remaining 50 percent comes from farmers. For the state schemes, the Central contribution is 40 percent for all states. The state contribution ranges from 10-40 percent. However, in Gujarat, farmers from tribal areas can get additional 25 percent subsidy through Tribal Department. In Madhya Pradesh, the state share is 40 percent for

SC/ST farmers, with the result that the farmers' contribution will reduce to 20 percent. Similarly, in Tamil Nadu, the state contribution for small and marginal farmers is 50 percent. However, there is a ceiling on the maximum subsidy that can be availed upon, as shown in Table 5, and this differs from state to state.

Table 5: Pattern of Government Assistance for Micro Irrigation in India

Particulars	Total Assistance (% of total System cost)	Central: State: Beneficiary Share (%)	Limit on Sprinkler Coverage	Ceiling on Subsidy
Centrally Sponsored Scheme	50	40:10:50	None	5 Ha. Per farmer
Andhra Pradesh	70	40:30:30	25 percent of target under MI	Rs 50,000 per farmer
Gujarat	50	40:10:50	None	Rs. 60000 per ha
Madhya Pradesh	70	40:30:30	None	5 Ha. Per farmer
Maharashtra	50	40:10:50		5 Ha. Per farmer
Rajasthan	60	40:20:40		5 Ha. Per farmer
Tamil Nadu	75	40:35:25		Rs. 43816 per acre for small & marginal farmers

The total Central assistance as capital subsidies for purchase of micro irrigation systems by farmers in select Indian states and the (estimated) state government assistance for the same are given in Table 6. The data is for 5 years, from 2009-10 to 2014-15, excluding 2013-14. It provides data for six major states in which area under micro irrigation systems (drips and sprinklers) is significant. The total assistance has increased over the years from 5.85 billion rupees in 2009-10 to Rs. 10.73 billion in 2014-15. Over the eight-year period from 2005-06 to 2012-13, a total financial assistance of Rs. 50.06 billion was made available from the central government funds as capital subsidy for micro irrigation systems. The maximum subsidy was given to undivided Andhra Pradesh, followed by Maharashtra.

Table 6: Central and State Subsidies for Micro Irrigation Systems in Selected States of India (Amount in Crore Rupees)

States	2009-10		2010-11		2011-12		2012-13		2014-15		(Estimated) State Subsidy	Total Subsidy
	Release	Achievement	Release	Achievement	Release	Achievement	Release	Achievement	Release	Achievement	(in crore Rs)	(in Crore Rs)
Undivided Andhra Pradesh	143.11	178.29	240	240	287.2	287.2	289.93	270.21	199.08	417.1004	364.96	782.06
Gujarat	44.47	54.26	120	120	166.64	166.95	182	182.01	140.68	137.064	34.27	171.33
Haryana	2.12	3.85	13.61	14.02	19.93	16.67	30	25.71	23.004	16.3121	20.39	36.7
Karnataka	63.81	86.85	92.54	89.45	109.65	91.65	140.65	151.22	124.25	117.4018	29.35	146.75
Madhya Pradesh	34.75	42.87	79.61	31.22					66.5011	67.1405	50.36	117.5
Maharashtra	107.07	132.26	222.37	222.65	249.8	249.8	150.18	152.21	177.5	135.3779	33.84	169.22
Rajasthan	56.93	60.73	120	116.2	130.95	128.24	110	103.47	75	95.1625	71.37	166.53
Tamil Nadu		25.58	65.91	77.97	66.25	66.25	83	132.35	56.627	87.5654	76.62	164.19
Sub Total	452.26	584.69	954.04	911.51	1030.42	1006.76	985.76	1017.18	862.6421	1073.1246	681.16	1754.28

Source: based on data provided in Global Agri Systems (2014) *National Mission on Micro Irrigation-Impact Evaluation Study*, Final Report Submitted to the Dept. of Agriculture and Cooperation, Ministry of Agriculture, GoI, New Delhi.

One crore=10 million

Note: In some states and in certain years, the actual financial achievement in terms of disbursal of subsidies is more than the amount of funds released by the Union government. This is because the states run their own schemes, in which they seek Central assistance. The state contribution for such state-run schemes is higher than their contribution in centrally sponsored schemes, as discussed in Table 5 of this report. Because of this reason, the estimated state assistance (Column #12 of Table 6), which is based on the norm on state contribution for centrally-sponsored schemes, will be slightly less than the actual state assistance provided by the respective states to farmers.

Subsidies for Solar PV Pumping Systems

The central government subsidy for solar PV systems is 40 percent with a cost ceiling of Rs. 76,000 per KWp ($1,150 per KWp), for a maximum installed capacity of 5 KWp. On top of this, the state governments also offer subsidies. The extent of total government subsidy for solar pumps for irrigation is as high as 85 percent in Rajasthan to 90 percent in Bihar.

To decrease the number of farmers using diesel engines to pump or transport water, in September 2014, the Ministry of Renewable Energy (MoRE) announced a financial assistance of Rs. 4 billion ($60 million) for the year 2014-15, to state governments for installation of solar PV water pumping systems with capacity in the range of 0.1 HP to 5.0 HP. A target of 100,000 solar PV pumping systems were to be installed for drinking and irrigation purposes by the state agriculture and rural water supply departments during the first year. The total financial support available to the state governments was around $720 million, for a five-year period, as per the recommendations of the 14th Finance Commission beginning 2014-15, and the target is to replace around one million diesel pumps. Farmers lifting water from canals or wells can also obtain solar pump financing through a combination of national and state capital subsidies and interest subvention determined by a Coordination Committee set up at the state level.

ANALYSIS: DEMAND FOR DESALINATED WATER FOR IRRIGATION

Farmers relying on expensive desalination systems will likely divert the water supplied to economically efficient uses to maximize the returns, and hence they will be willing to purchase water at high prices. The two important factors which will determine the demand for irrigation water in an area in quantitative terms are:

1. The extent of irrigation at which the marginal yield or marginal net income from irrigating the crop will be positive;
2. The total area under the crop, which requires irrigation water for obtaining optimum yield.

Regarding the first variable, if the available soil moisture from monsoon rainfall is significantly below levels required for optimum crop growth (PET) or if the crop is likely to experience moisture stress at certain critical stages of growth with consequent adverse effects on yield, the demand for irrigation water will be considerable. Such regions are those where the evapo-transpiration (ET_0) during the rainy season exceeds the effective rainfall/snowfall (P_e) or water available in the soil profile from precipitation. Hence, the marginal yield and marginal net income from the use of irrigation water will be high and continue to be positive for a much wider range in irrigation dosage as compared to a high rainfall region (see the hypothetical chart in Figure 8). The very low to low rainfall regions of Western Rajasthan (200 mm-400 mm) and Kachchh and Banaskantha districts of Gujarat (350 mm to 450 mm), which also experience high to very high aridity experience this condition[5]. Hence, the amount of water required for supplementary irrigation of kharif crops (rainy season crop), which must come from renewable, natural sources, will be high.

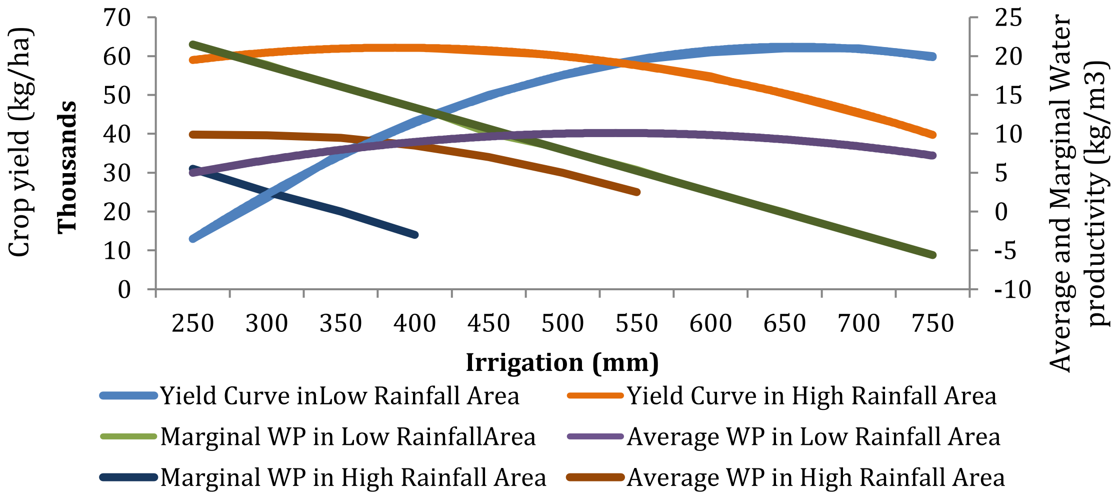

Figure 8: Hypothetical Yield and Water Productivity Response Curves for Irrigation in Two Distinct Rainfall Regimes.

If rainfall is low to very low and if the renewable water resources in the locality (surface runoff plus groundwater recharge) are also very low when compared to the amount of

---

[5] There are two phenomena which need mention here. First is the relation between rainfall and PE. The regions that have low (mean) annual rainfall have high annual PE, and vice versa. Also, regions that have low (mean) annual rainfall have high values of CV in rainfall, which increases the drought proneness.

arable land available for cultivation, farmers often cultivate less land so that their crops' water needs equal the water supply (which is the sum of effective rainfall and renewable surface and ground water). Very high aridity in these regions increases irrigation water demand per unit of cultivated area. In such situations, the farmers are likely to only plant low value but reliable yield crops due to fear of economic losses, as high value crops mean a high risk investment, since yields decline significantly in arid settings. Farmers are also likely to irrigate their crops into deficit if they cannot correctly anticipate water availability, in which case optimum yield suffers. As a result, the unmet demand for irrigation water is high in these areas of low water supply.

In low to medium rainfall areas with high aridity, such as alluvial areas of North Gujarat, most of Saurashtra region in peninsular Gujarat, Rayalaseema region of Andhra Pradesh, Southwestern Punjab, Haryana, and North Western Rajasthan, and large parts of Telangana and North and North-Western Karnataka, water supply issues are less dire but still significant. In these areas, rainfall and supplementary irrigation is generally sufficient to meet water demand for kharif crops, also known as monsoon crops, with second season (winter) crops sustained with renewable water from reserves. However, the amount of renewable water available may not be sufficient to bring the entire area into production during the winter season. The demand for irrigation water to increase agricultural production is generally high in such areas, as a winter crop rotation will not be feasible without irrigation.

Table 7: Rainfall and PE Regimes of States in the Very Low to Medium Rainfall Region

Name of State	% Area with Rainfall below						% Area with Evaporation (PE)			
	<300 mm (very low)	300-600 mm (low)	600-1000 mm (medium)	1000-1500 mm (High)	1500-2500 mm (Very high)	>2500 mm (Extremely High)	<1500 mm (low)	1500-2500 mm (medium)	2500-3500 mm (high)	>3500 mm (Very High)
Gujarat	10.88	39.08	47.27	2.77	-	-	-	-	88.53	11.47
Rajasthan	41.80	32.45	25.75	-	-	-	-	-	100.00	-
Maharashtra	-	-	85.86	6.93	7.21	-	-	37.96	56.23	5.81
Madhya Pradesh	-	-	95.71	4.29	-	-	-	56.94	42.89	0.17
Andhra Pradesh	-	-	97.83	2.17	-	-	-	52.70	47.30	-
Karnataka	-	-	88.01	3.65	5.67	2.67	-	62.82	37.18	-
Tamil Nadu	-	-	96.52	2.98	0.50	-	-	64.56	35.44	-

Source: authors' own estimates based on Pisharoty (1990) using GIS.

Table 7 shows the proportion of area under different rainfall and PE regimes in the states (viz., Rajasthan, Gujarat, Maharashtra, MP, Tamil Nadu, AP and Karnataka) which fall mostly in the very low to medium rainfall zone. Table 8 shows the proportion of the area under different rainfall variability levels in these states. As mentioned above, the areas of very low rainfall coincide with areas of very high aridity, indicated by high PE values, and areas of low to medium rainfall coincide with areas of high aridity. This is also evident from Figure 9 and Figure 10. If the climate allows cultivation of high value crops (in terms of $/ha of land), and if it is possible to manage adequate supply of good quality water, farmers will be willing to risk growing high-value fruits and vegetables. Market potential for costly irrigation water exists in these circumstances due to the high opportunity cost of not irrigating the crop, in terms of economic losses. Further, the aggregate demand for high quality water is high due to the following:

- Presence of large amount of uncultivated land, which can be put to productive use by filling the gap between crop (ET_0) and effective rainfall (P_e) for crop protection (first case)

- Presence of good amount of land lying un-cultivated in the winter season, which can be put to irrigation under controlled conditions (second case).

Such regions also need to have a good amount of marginal quality groundwater, which can be treated to meet the water deficit. Our analysis in the previous section shows that the hyper arid and arid areas also have saline groundwater (both inland and in the coastal strips).

Table 8: Rainfall Variability Regimes of Select States in the Low to Medium Rainfall

Name of State	% Area with Rainfall Variability in the range of				
	<25% (low)	25 - 30% (medium)	30 - 40% (high)	40 - 50% (very high)	> 50%
Gujarat	0.24	27.12	44.30	17.11	11.22
Rajasthan	8.33	24.08	23.04	30.71	13.84
Maharashtra	37.67	62.33	-	-	-
Madhya Pradesh	49.71	50.29	-	-	-
Andhra Pradesh	62.64	37.36	-	-	-
Karnataka	29.15	70.85	-	-	-
Tamil Nadu	7.73	92.27	-	-	-

Source: authors' own estimates based on Pisharoty (1990) using GIS.

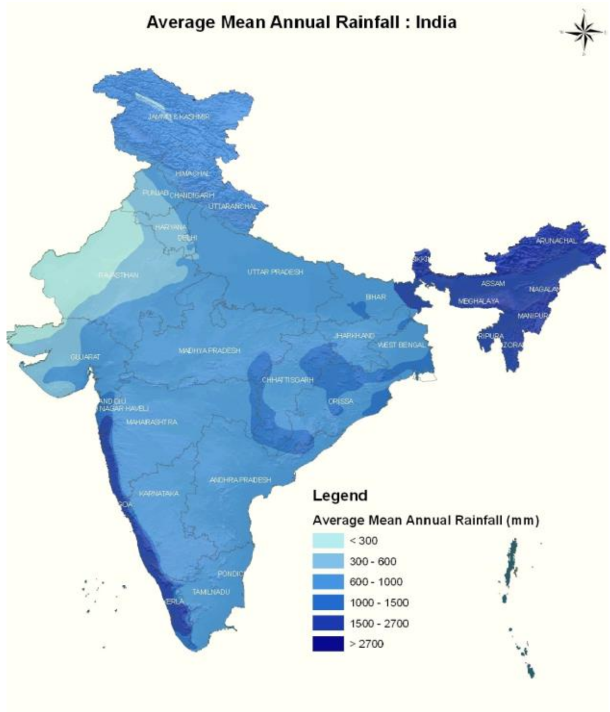

Figure 9: Map showing the Rainfall Isohyets of India.

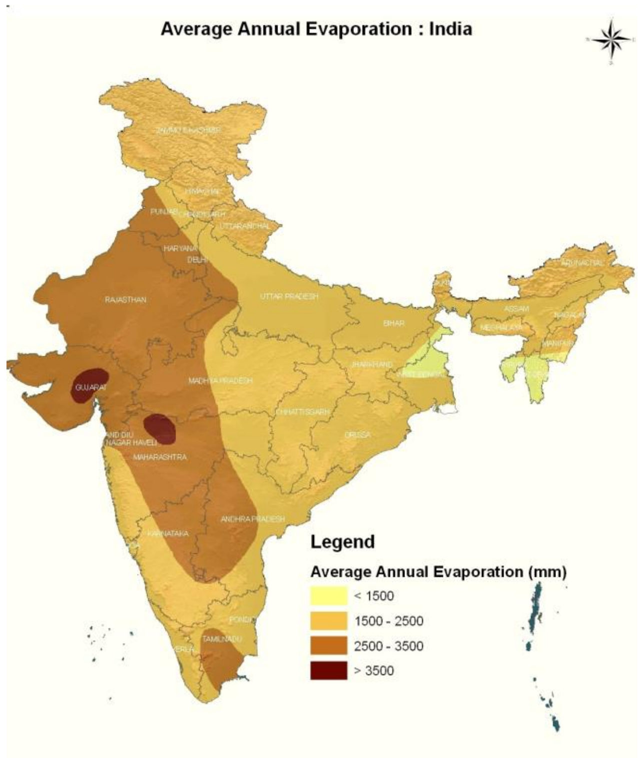

Figure 10: Annual evaporation in India.

Cropped Area, Irrigated Area and Cropping Pattern

The following analysis examines how much demand exists for desalinated water for irrigated crop production, using the key variables in the irrigation demand function discussed above. First, the current crop disposition of the six states with marginal quality groundwater (Andhra Pradesh (erstwhile); Gujarat; Karnataka; Tamil Nadu; Punjab and Rajasthan) were analyzed for land area under cultivation in kharif and winter seasons to see what scope exists for expanding areas cultivated and yields per hectare through the provision of irrigation water.

A quick review of crop patterns of the six states shows the following trends:

- In water-scarce states, the area under cultivation is lesser as compared to those which experience lower degree of water stress. Arable land under cultivation is a mere 40.76 percent in Gujarat, followed by 67 percent in Tamil Nadu and 71 percent in Karnataka. Punjab, in which a large network of canals connects a countryside of rich alluvium, is the most intensively farmed state, with wheat and rice as the primary farm outputs. Rajasthan has a strikingly high area under cultivation at 73 percent, but pearl millet, is mostly grown under rain fed conditions in the state. The area under wheat, which is an irrigated winter crop, is hardly 22 percent of the food crop area. The results are presented in Table 9.

- Significant variation in cropping pattern across regions is expected within individual states, owing to spatial differences in water endowment. Such spatial variations in resource endowment are large in Gujarat, Rajasthan, Andhra Pradesh and Punjab. For instance, there is large variation in water endowment between South Gujarat and the rest of the state (including North Gujarat, Kachchh and Saurashtra). Similarly, there is significant variation in water endowment between coastal Andhra Pradesh and Rayalaseema with the former well endowed with canal networks and groundwater, and latter being absolutely water scarce.

- Significant variation exists in climate and water resources between North Western Rajasthan and South Rajasthan, with the latter experiencing moderate to high rainfall with semi-arid climate, with undulating terrain. There is also beg variation in water endowment between Central Punjab and Southwestern Punjab, with the latter having saline formations and limited water supplies for irrigation from canals.

Table 9: Total Area under Crops, Food Crops and Cereals in the Salinity-Affected States

Particulars	Andhra Pradesh	Gujarat	Karnataka	Punjab	Rajasthan	Tamil Nadu
Total area under crops (ha)	8997755	11445900	9754676	6194600	18897572	5020615
Area under food crops (ha)	6342999	4665400	6953084	5586500	13750705	3376502
Percentage area under FCs (%)	70.49	40.76	71.27	90.18	72.76	67.25
Area under Cereals (ha)	5294635	3708500	4684899	5576000	10796372	2658805
Percentage area under Cereals (%)	58.84	32.40	48.02	90.01	57.13	52.95

Source: Dept. of Agriculture and Cooperation, Ministry of Agriculture, GoI, 2012-13.

Table 10: Total Land Area under Different Crops in Different Seasons in the Salinity-Affected States

Season	Andhra Pradesh	Gujarat	Karnataka	Punjab	Rajasthan	Tamil Nadu
Kharif	4289278	8446800	6910758	3237500	15744615	3966453
Winter	3551485	6486200	3018863	3526200	11234803	2265805
Summer	274097	1410700	997570	97100	3291750	1211643
Additional Land Available for Cropping during Winter	737793	1960600	3891895	-288700	4509812	1700648

Source: Dept. of Agriculture and Cooperation, Ministry of Agriculture, GoI, 2012-13.

Regarding cropping intensity, we have analyzed the crop cover in different seasons, considering the area under perennial crops and area under crops that extend to two seasons (kharif-winter). The results are presented in Table 10. The following pattern can be observed from the results. The area under crop cover is much less in winter as compared to rainy (kharif) season in Karnataka, Rajasthan, Tamil Nadu and Gujarat, the difference being an indicator of the scope for crop intensification, if water is made available. The largest scope for intensifying cropping in the existing sown area seems to be in Rajasthan, followed by Karnataka, Gujarat and Tamil Nadu. There is no scope in Punjab, as the crop cover in winter is larger than that of kharif. The scope in Andhra Pradesh is very limited.

In order to get a clear picture of the cropping intensity in the salinity-affected areas of the State, detailed analysis is done for those districts which are affected by groundwater salinity (as per CGWB data base provided in Annex 1). The analysis included seven states, namely, erstwhile Andhra Pradesh, Gujarat, Haryana, Karnataka, Punjab, Rajasthan and Tamil Nadu.

The results are presented in Table 11. The figures show that the extent of difference between kharif cropped area and winter cropped area (shrinkage in cropped area during winter in relation to cropped area during kharif season) is much higher in the salinity-affected districts when compared to the entire salinity-affected state for six out of the seven states studied.

Table 11: Total Land Area under Different Crops during Seasons in the Salinity-Affected Districts in the Selected States

Season	Andhra	Gujarat	Karnataka	Punjab	Rajasthan	Tamil Nadu	Haryana
Kharif	3550880	7924800	4277620	1428200	14043172	2753088	2014071
Winter	2777870	2481100	2645322	1241000	9723634	1531411	3221259
Summer	71377	436400	413412	6100	3067120	912222	453017
Additional Land Available for Cropping during Winter	773010	5443700	1632,298	187200	4319538	1221677	1207188

Source: author's own estimates based on data from Dept. of Agriculture and Cooperation, Ministry of Agriculture, GoI, 2012-13.

In the salinity-affected districts, the crop cover during winter is much less as compared to the crop cover during kharif season. For instance, in the case of Gujarat, the crop cover during winter is only 2.48 m. ha as against 7.92 m. ha during kharif season. In the case of Rajasthan, the crop cover during winter is 9.72 m. ha, whereas that during kharif season is 14.0 m. ha. As winter crops in these (low to medium rainfall) states are generally irrigated, the significant reduction could be due to severe shortage of water. Even in Punjab, where the winter cropped area at the state level was higher than the kharif cropped area, in the salinity-affected districts, the scenario is different, with winter cropped area shrinking.

Hence, there is significant scope for expanding area under cultivation in these states though provision of irrigation water. The only state which has higher area under crop cover during winter as compared to kharif is Haryana.

Presence of High Value Crops

Analysis was conducted to determine what extent the current cropping pattern is dominated by high value crops (fruits, vegetables, flowers, spices and other cash crops). Eight states were considered for analyzing existing cropping patterns based on ranges in groundwater salinity: Andhra Pradesh, Gujarat; Karnataka, Maharashtra, Punjab, Rajasthan, Tamil Nadu, and Telangana. Earlier studies have already shown that the economic returns from the use of water are low in cereals such as rice, wheat, pearl millet, maize and sorghum) and pulses such as grams (green and black), soya bean, and high for fruits (pomegranate, papaya, lemon, banana and grapes) vegetables and cash crops such as cotton, fennel and castor (based on Kumar et al., 2010; Kumar, 2005).

Annex 3, Annex 4 and Annex 5 show the area under different fruits, vegetables and cash crops, respectively, in different districts of the eight states considered.

Figure 11(shows the districts having significant area under fruit crops, out of the eight states chosen. The state which grows the largest amount of fruits and vegetables, in terms of the number of different varieties of fruits and the total area under fruit crops, is Andhra Pradesh (present Andhra Pradesh and Telangana). Six varieties of vegetables and nine different varieties of fruits are grown in the erstwhile Andhra Pradesh. This is followed by Gujarat (seven varieties of fruits and six varieties of vegetables), Punjab and Rajasthan. The fruit crops are mango, sapota, banana, grapes, lemon, citrus (kinnow), orange, gooseberries, papaya, dates, pomegranate, guava, watermelon and musk melon. Of these, dates are grown only in Kachchh in Gujarat and Rajasthan. However, there is no data on date palms in any of the government reports.

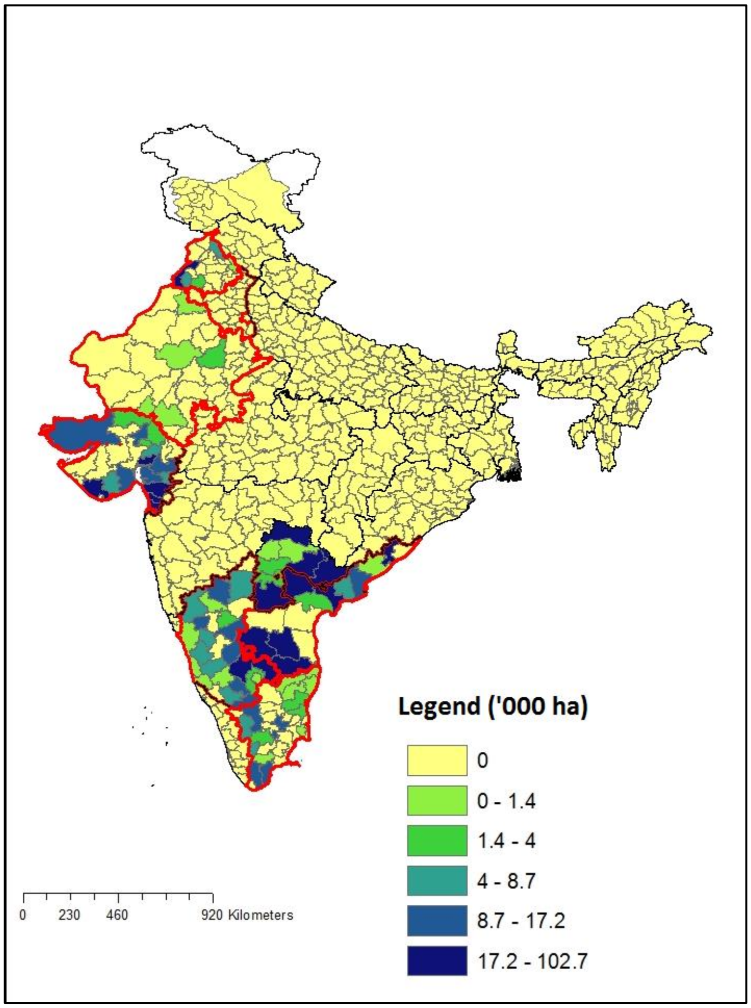

Figure 11: Area under different high value fruit crops in different water-scarce regions (source: based on Ministry of Agriculture & Farmers Welfare, 2016).

There are a wide variety of vegetables grown in these water-scarce regions. They are: potatoes, onion, tomatoes, okra, eggplant, cabbage, cauliflower, carrots, chilies, bottle gourd, coriander leaf, green peas, and bitter gourd. Figure 12 (source: based on Ministry of Agriculture & Farmers Welfare, 2016) shows the districts having significant area under these vegetable crops, in these eight districts.

In addition to the fruits and vegetables, several cash crops are grown in these regions. The most important among them are: cotton, castor, groundnut, fennel and cumin. Cotton is grown in vast areas in Gujarat. The only two states where cumin is grown are Gujarat and Rajasthan. Castor is grown in large areas in Gujarat, followed by Rajasthan and Andhra Pradesh. Chilies are grown in Gujarat, Rajasthan and Andhra Pradesh. Figure 13 shows the districts having significant area under cash crops.

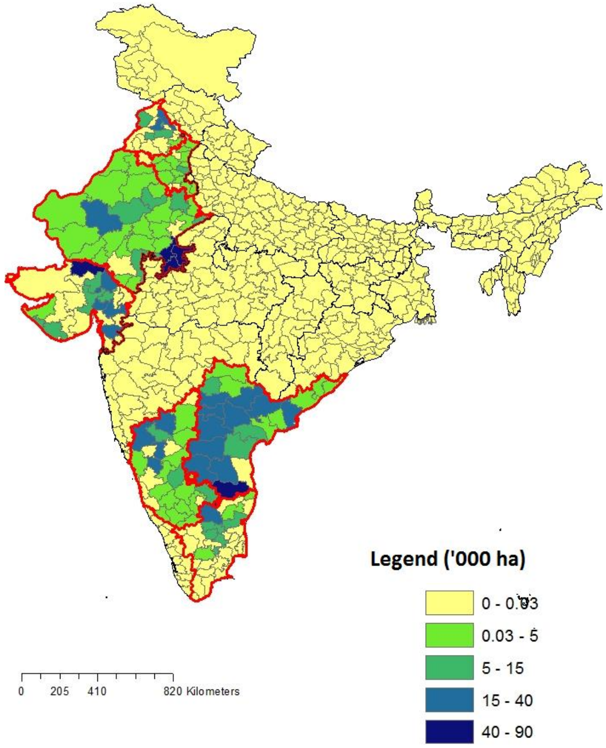

Figure 12: Area under Vegetable Crops in Selected Districts of India.

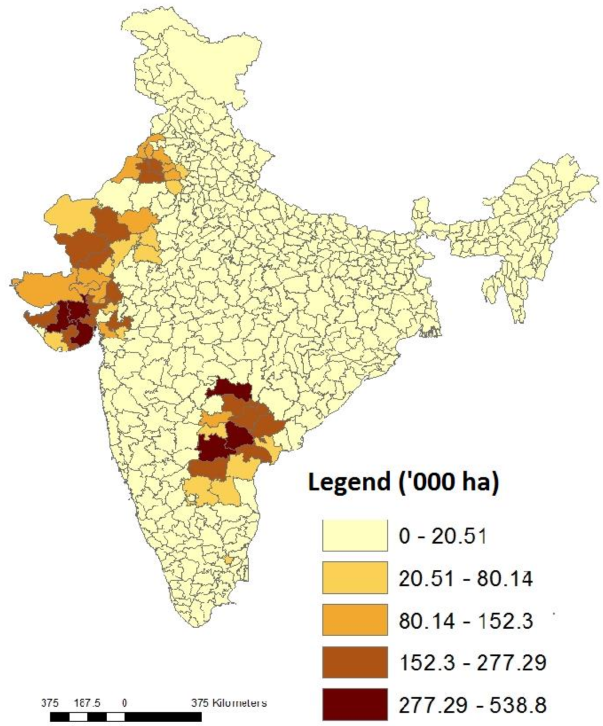

Figure 13: Area under Cash Crops in Selected Districts in India.

The estimated total area under fruits, vegetables and cash crops in these states are given in Table 12.

Table 12: Area under Fruits, Vegetables and Cash Crops in the Salinity-Affected States/Districts

Type of crops	Total area under the crop in the selected states affected by salinity ('000 ha)	Total area under the crops in the salinity-affected districts ('000 ha)
Fruits	1278.00	713.39
Vegetables	1674.84	1012.10
Cash Crops	8228.48	7061.35
Total Area	11181.3	8786.94

Source: Dept. of Agriculture and Cooperation, Ministry of Agriculture, GoI, 2012-13.

Some areas cannot be counted as areas having a market for desalinated water. Some areas which do not face problems of poor quality ground water are falling in parts of the states. Such areas are there in Rajasthan (South Rajasthan), South and Central Gujarat, Central and North Eastern Punjab, large parts of Andhra Pradesh, Telangana, Karnataka and Tamil Nadu. Hence, those areas have to be excluded from our estimation. The total area under fruits, vegetables and cash crops in the salinity-affected districts is assessed to be 713.4 thousand ha for fruits, 1.012 m. ha for vegetables and 7.061 m. ha for cash crops (only cotton, castor and fennel). The total area comes to 8.786 m. ha. The total area under crops in these districts is 53.84 m. ha. The area under high value crops comes to around 16 percent of the gross cropped area in the eight states. The figures have been calculated using the data available in Annex 1 on salinity-affected districts and the data provided in Table 12. This is a substantial area. However, field research to quantify the economic returns from these crops in relation to irrigation water will give us an indication of which of these crops could be grown with desalinated water in an economically viable manner, and in which regions.

ANALYSIS: POTENTIAL FOR SOLAR POWER WORK IN SELECTED AREAS

Incident solar radiation is an important weather parameter to determine the efficacy of solar powered pumps. The annual direct normal irradiance measured in kilowatt hours per m2 per day across India is given in Figure 14. The figures indicate the amount of solar power that can be produced by the solar PV system of unit capacity. As the map suggests, it is very high (6.5 to 7.0 KWhr/m2 per day) in large parts of Western Rajasthan, almost the entire Gujarat; high (5.0-5.5 KWhr/m2) in Telangana, Tamil Nadu, Karnataka and most parts of Andhra Pradesh, and moderately high (4.5-5.0 KWhr/m2 per day) in the entire Punjab, and most parts of Haryana. In most of the regions where saline groundwater exists, the incident solar radiation is also high, and it is very high in the regions where saline aquifers are extensive (Rajasthan and Gujarat).

As a coincidence, the areas with excessively high groundwater salinity also receive very high solar radiation, which increases the technical feasibility of using solar power for running the desalination system to convert marginal quality groundwater into freshwater. Solar powered pumps are already in use in states such as Rajasthan, Gujarat, Karnataka, Telangana and Andhra Pradesh.

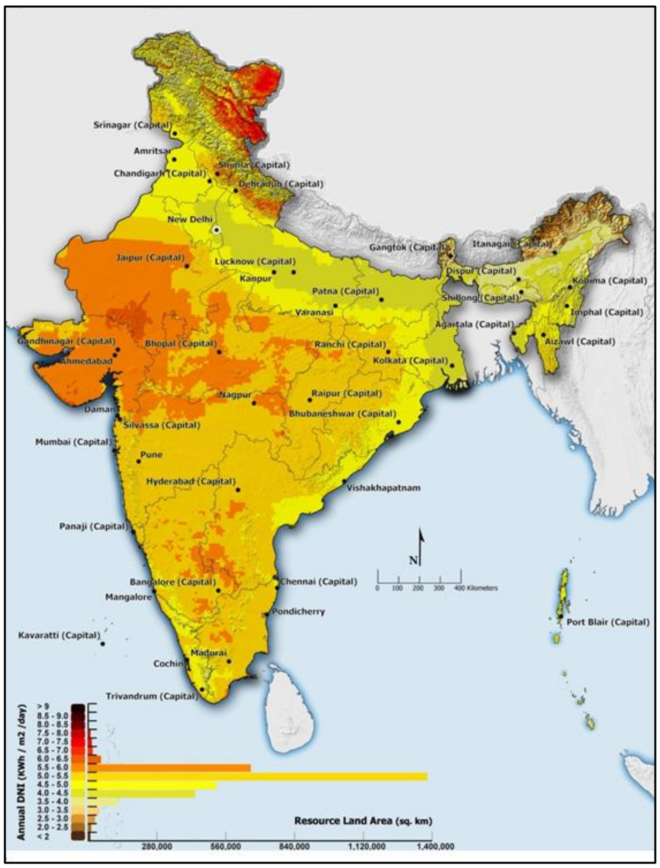

Figure 14: Annual Direct Solar Irradiance in India.

ANALYSIS: CURRENT EXPENDITURE OF FARMERS IRRIGATION WATER IN THE INFORMAL MARKET

The prices for water in the informal market are often prohibitively high, especially when the water sellers enjoy high monopoly power, created by a situation in which there are many buyers against a few sellers. Prices are only indicative of the values it can generate for the buyer. Hence, the cost incurred by well owners for producing water should not be used as a basis for fixing the price of water.

Two different situations were analyzed to determine the price farmers are willing to pay for water against the values it generates from use in crop production. Results from the analysis of groundwater markets in Eastern Uttar Pradesh and South Bihar (Kumar *et al*., 2013) were reviewed to understand the level of profit margins they will like to secure. The ratio of the over net water productivity in crop production in economic terms (Rs/m^3) and the unit price of water paid by farmers (Ø); and the potential net return farmers could secure from the use of desalinated water can become the basis for arriving at the prices that make irrigated production with that water a viable proposition.

The ratio was found to be varying from a highest of 16.7 for water buyers in electric well commands of Eastern UP to a lowest value of 3.98 for water buyers in the diesel well commands in the same region (Table 13). The values for Eastern UP electric well commands, which were located very close to the flood plains of the Ganges river, were not included due to the lower cost of accessing water compared to the diesel well commands owing to shallow water table depth and the higher returns from irrigated production due to the presence of nutrient-rich soils.

Table 13: Ratio of the Net Return from Crop Production per Unit Volume of Water and the Unit Price for Water Buyer Farmers

Region	Price of irrigation water (Rs/m^3)	Overall net water productivity in crop production (Y) (Rs/m^3)	Ratio $\emptyset$
Eastern Uttar Pradesh (electric well command)	0.65	12.66	16.72
Eastern Uttar Pradesh	2.81	10.93	3.98
South Bihar (electric well command)	1.48	13.43	9.61
South Bihar (diesel command)	2.15	17.35	8.18

Source: Estimates based on primary data collected for a sample of 240 farmers from Eastern UP and South Bihar with equal number in each category in 2008.

This profit margin coefficient (i.e., 3.98), which corresponds to an irrigation water supply cost of Rs. 2.81/m^3, however, cannot be directly applied in the market analysis of desalinated water. In the case of the groundwater market considered here, the cost of the resource (or the opportunity cost of resource depletion) is not borne by the buyers, as water is not scarce in Eastern UP and South Bihar. Farmers buy water as they do not have the wherewithal to invest in wells and water abstraction devices. They pay only for the pump irrigation service, covering the cost of investment for well construction and pumping costs plus well owners' profits. The cost of resource will be especially relevant in the case of water scarce regions (where desalination technologies will be tried). In those regions, it is likely that the well owners will also charge the resource cost from the water buyers and the latter pay a much higher price for water in such areas for the same kind of cropping systems. This cost should be subtracted from the net income earned from every unit of water as well as added to the unit cost of irrigation water to arrive at the modified value of the profit margin coefficient for water scarce regions.

An average of Rs. 4 per m^3 of water is assumed as the resource cost in the regions considered for the water market analysis. The amount which the farmers indicated as the price they are willing to pay for water in the four locations where the survey was conducted is between of Rs. 3 per m^3 to Rs. 10 per m^3. The price indicated was Rs. 3/m^3 in the fresh groundwater area of coastal Saurashtra, Rs. 10/m^3, in the fresh groundwater area of North Gujarat, and Rs. 6.25/m^3 in the salinity-affected area of Western Rajasthan. The total cost of irrigation water, or the price farmers pay for irrigation water, therefore will be Rs. 6.81/m^3. This is the value of β. The modified value of the overall net water productivity in crop production (Y) owing to increase in cost of irrigation is (10.93-

4.0= 6.93). This makes the value of the profit margin coefficient (∅), 1.04 ((10.93-4.0)/6.81=1.04).

The foregoing analysis suggests that if the farmer has to invest in desalination technology for converting marginal quality water for use in irrigation, incurring a cost of Rs. x per m^3, he/she needs to get a minimum net return of Rs. 1.04X/m^3 of water, even after subtracting the said cost from the gross returns over and above the input costs which consider the cost of irrigation due to the existing irrigation infrastructure. If the profit margin coefficient in a given crop irrigated with desalination water at a price X is higher than 1.04, then the particular crop is viable at that price of desalinated water. In addition, there can be subsidy for desalination water, as new water is created using the technology, preventing the depletion of locally available freshwater. If this is passed on to the consumers, it will increase the net water productivity in economic terms and reduce the actual price farmers pay for water, thereby rending a profit margin coefficient less than 1.0 (before subsidy) being acceptable. This can create incentive for them to purchase the expensive desalinated water. A profit margin of 1.0 should be acceptable in certain areas, as expressed by some farmers in the water scarce region of North Gujarat and Western Rajasthan with the willingness to spend as high as half the net return they get from crop production for purchasing irrigation water, when confronted with the question as to how much they are willing to pay for desalinated water in the absence of alternative sources, if they were able to grow high value crops using it.

ANALYSIS: ESTIMATED REVENUE FOR FARMERS FROM IRRIGATED PRODUCTION OF HIGH VALUE CROPS

In order to ascertain the level of returns farmers could get from irrigated production of high value crops in the regions of our interest (i.e., the areas where marginal quality groundwater is found), the data from one of the regions is analyzed. The region under study is the alluvial belt of North Gujarat, which has large tracts under saline groundwater formations. The area covered in Banaskantha district of North Gujarat, however, has more or less the same climatic conditions as that of the saline groundwater areas of that district. The crops selected for the analysis are such that the marginal yield and returns from the use of irrigation water are same as the yield and net return, respectively from irrigated production (Table 14). The highest net return per cubic meter of water was secured in the case of green chilies (Rs. 161.6/m^3), followed by eggplant (Rs. 130.9/m^3), tomatoes (Rs. 54.7/m^3), pomegranate (Rs. 41.6/m^3) and fennel (Rs. 40.6/m^3). This is indicative of the economic values that can be generated from the use of desalinated water. Wheat, alfalfa, potatoes and groundnut have much lower water productivity in economic terms.

However, these are estimates based on the farming systems that existed seven to eight years ago. There has been major transformation of agriculture in many water-scarce regions of the country, especially in the North Western region, the Western region and Southern region, with increase in area under high value crops and introduction of new high value fruits, vegetables and flowers. The impact of this transformation on crop water productivity in economic terms or the economic value of water use in agriculture will be analyzed later in this report, wherein we will be discussing the results of primary data collected from selected field locations.

Table 14: Net Return from Irrigated Crop Production per m3 of Water

Name of the crop	Type of WST	Water use and irrigation water productivity (old results)						Irrigation water productivity (new results, with income adjusted to inflation)			
		Total irrigation water use (m³/Ha)	Net income (Rs/ha)	Net income after WST depreciation (Rs/ha)	Physical WP (Kg/m³)	Economic WP (Rs/m³)	Economic WP after WST depreciation (Rs/m³)	Net income (Rs/ha)	Net income after WST depreciation (Rs/ha)	Economic WP (Rs/m³)	Economic WP after WST depreciation Rs/m³ ($/m³)
Groundnut	Sprinkler	5258.21	27894.17	24031.4	0.41	9.36	7.7	30683.59	26434.57	10.29	8.5 (0.13)
Green chilies	Drip	3540	524250	520162.2	21.19	148.09	146.94	576675	572178.41	162.9	161.6 (2.44)
Alfalfa	Sprinkler	12815.1	55349.57	48513.6	12.64	7.36	5.67	60884.53	53364.99	8.1	6.2 (0.094)
Eggplant	Drip	1180	86650	82562.2	21.19	122.96	118.99	95315	90818.41	135.26	130.9 (2.0)
Cotton	Drip	3510	52822.88	29617.5	1.13	18.81	12.44	58105.17	32579.29	20.69	13.7 (0.20)
Fennel	Drip	1728	23730.29	18034.8	0.92	45.6	36.91	26103.32	19838.24	50.16	40.6 (0.62)
Kola	Drip	540	9800	6559.7	11.11	18.15	12.15	10780	7215.71	19.96	13.4 (0.2)
Pomegranate	Drip	3333.96	81662.5	67988.3	1.26	41.37	37.8	89828.75	74787.18	45.51	41.6 (0.63)
Wheat	Sprinkler	1957.5	53361.11	51213.0	2.55	27.26	26.16	58697.22	56334.27	29.99	28.8 (0.44)
Potatoes	Sprinkler	12721.42	98024.13	93512.8	2.71	12.49	11.38	107826.55	102864.1	13.74	12.5 (0.19)
Tomatoes	Drip	9440	475000	469646.1	12.71	50.32	49.75	522500	516610.71	55.35	54.7 (0.83)

Source: Estimates based on Kumar et al. (2010).

MARKETS FOR SUPPLY OF TREATED WATER IN RURAL AREAS

Undivided Andhra Pradesh

Various organizational models, ranging from charities to the private sector, supply potable water to villages in undivided Andhra Pradesh. Examples of these organizations and their approaches include:

- **Charitable**: The Sai Oral Health Foundation (SOHF) operates community water purification plants on a small scale and focuses on areas severely affected by fluorides. They work directly with the communities and villagers. Though the gram panchayat allowed them establish the plant and access the water source, the systems are managed centrally by SOHF with operations conducted by the foundation's local workers. They do not charge for the water. The charitable model adopted by the SOHF serves a limited number of communities suffering from both poor quality water and poverty.

- **Community partnership**: The Rural Economic and Educational Development Society (REEDS) established reverse osmosis plants with contributions from the community and grants from the District Collector and the village panchayat. The plant is fully controlled and managed by the village panchayat and run with a budget and operations plan. A salaried person oversees plant operations and water sales. Workers operate the slow sand filter systems and maintain the micro filters.

  Charges for water depend on the communities' ability to pay. In some villages, communities are charged $0.044 per 20 liters versus $0.03 in other plants. In another village, the president of the gram panchayat is unwilling to charge for water. The entire cost of the plant was borne by the rural water supply and sanitation department. Initially, REEDS maintained the system for two years and then handed it over to the village panchayat. Treated water is provided free of charge to all the villagers, who collect the water from the plant in their vessels and pots (in the REEDS villages, there is no provision for transportation of water to the households).

  The gram panchayat model adopted by the rural water supply and sanitation department in collaboration with REEDs is considered successful. Although there is no water quality monitoring, the people in the village are happy with the functionality and effectiveness of the system. The Byrraju Foundation (BF) is another example of a community-partnership for water supply. A major share of the project is financed through individual contributions. The gram panchayat provide space for the plant and giving BF access to sources of untreated water. Initially, either BF or the technology provider manages the plants. Since the capital expenditure from BF is low, it hands over the plants to the village development council once the foundation recovers its capital (in less than two years). The establishment of a Village Development Council (VDC) is part of the overall village development activities taken up by Byrraju Foundation in their adopted villages.

The VDC takes the responsibility for managing the systems with technical support from the foundation. It fixes the water price independently. A water charge of $0.030 for 20-liters generates profits for VDC. The VDC employs the workers to operate and manage the plant and also takes part in the management. The profits from the plant are expected to be used for the overall development of the village as well as plant maintenance. Water quality monitoring is done with the help of local colleges as well as through the foundation's in-house facilities. The general public can view the results of water tests on display at the plant. All the plants have machines for cleaning the water cans, and are cleaned prior to every filling. The community-oriented model of BF is not only economically viable but also sustainable due to the successful takeover of the plants by the VDCs.

- **Hybrid models**: Naandi Foundation's (NF) approach is close to a private sector model, where the contributions of the community are limited. Most of the capital is raised through the foundation's own investments or bank loans. NF also uses the public funds like Member of Parliament/ Member of Legislative Assembly funds as initial capital for setting up plants. In villages, NF enters a tripartite agreement with the gram panchayat and the technology provider, such as Water Health India. The duration of this agreement varies from village to village (five to eight years in the sample villages). NF or the Water Health India staff maintains the plants. NF is also involved in awareness building and promotional activities. Water is sold in 12 and 20 liter cans at a price of $0.022 and $0.033, respectively. Money is deposited at the NF headquarters or collected by Water Health India every week. Water quality monitoring (bacteriological, chemical and physical) is done on a regular basis to ensure safety of the water supplied.

  Intensive promotional activities were taken up in the villages for improving the service area coverage, but despite these awareness building activities, coverage was low after two years. One of the reasons for low coverage is that substantial numbers of households from scheduled castes and scheduled tribes in this village migrate for long time periods. This indicates the scale of operation does not breakeven, as the number of households determines plant size. Despite NF's private sector approach, between high capital costs and a large migrant population in the service area, the sustainability of their model is doubtful.

- **Market-based pricing**: Market-based solutions are also being pursued by the Safe Water Network, Bala Vikasa and Water for People. They provide the technology and capital from foundation and government grants for safe drinking water, and operate through local NGO partners to build and run RO systems in the villages with community participation. A partnership is established with the local panchayat to get land for building the plant and electricity connection for running it. They organize awareness programs among the community members on the health benefits of consuming good quality drinking water to generate local demand. The water price is set to recover the capital and operations and maintenance costs.

Gujarat

Large areas in Gujarat experience high levels of salinity in groundwater either due to their proximity to the sea or due to inherent salinity in the water-bearing formations. Many areas are also affected by high levels of fluoride in groundwater, exceeding the permissible level of 1.5 ppm for potability (Kumar, 2002). Most of these areas also do not have perennial sources of surface water. In light of this, Gujaratis avail themselves of water supplied from: canals and other public infrastructure; community partnerships led either by local agencies, religious sects; or managed by communities (but funded by emigrants), or private sector water sales.

- **Canals**: The Sardar Sarovar Narmada canal based pipeline scheme covers over 10,000 villages in the state for drinking water supply, and the water supplied from it is free from salts.
- **Other public infrastructure**: Hundreds of villages in Gujarat do not have access to the canals. As a result, many of these villages get water from local public sources (tube wells, bore wells and open wells), which have salinity below 1,500 ppm, for meeting their domestic water needs other than drinking and cooking throughout the year.

The remaining villages get water from regional water supply utilities using surface water, except during summer when these sources dry up. When surface water is unavailable, Gujaratis turn to:

- **Private Supply**: The price of water ranges from Rs. 20-25 per 20 liters can for home delivery from commonly used private provisioning (depending on the distance) to Rs. 18 per 20 liters can for collection at the plant[6]. Plants are built in rural areas to

[6] A study carried out in 2001 in North Gujarat, which was known for excessive levels of salinity and fluorides in groundwater, had the following conclusions to make on the mushrooming of RO industry for demineralized water: 1) some consumers reported of getting relief from ailments such as constipation and urinary tract infection after consuming RO treated water; 2) the sale of

cut down their operating costs—the companies are trying to balance water quality with low land use and transportation costs. The private agencies manage their own transportation facilities for distributing the water cans in the villages and neighboring towns. Not all of these areas face severe problems of salinity that require mandatory government intervention.

- **Community-based interventions**:
    - Non-resident Indians (NRIs): Gujarat is known for being the original home of prosperous NRIs, who live in the United States, United Kingdom, and many other countries in the West. They still maintain their roots in the native villages. In several villages, which experience shortage of good quality potable water (due to groundwater contamination and pollution), the native NRIs have donated funds to set up RO plants. A committee from the village manages the operation and maintenance of these plants. The community gets the land from the village panchayat for free. In such cases, a nominal change of Rs. 2 per 20 liters can is charged from the households, which collect water from the plant. For home delivery, the charge is kept at Rs. 5 per 20 liters can.
    - Religious sects: The *Swaminarayan Sanstha* (a Hindu religious sect) has been active in the water management in the state for nearly three decades and was heavily involved in water harvesting and groundwater recharge activities in Saurashtra region. In the villages severely affected by salinity and therefore do not have any source of potable water, the institution has begun to set up RO plants and run them as a social service. The amount charged for households ranges from Rs. 4 per (20 liter) can for collection at the plant to Rs. 6 for home delivery. The amount covers the cost of operation and maintenance.

      In some cases, religious and private philanthropic institutions are made to pay a nominal price for the water to act as a deterrent against water waste and its non-potable uses.

- **Local interventions**: In several salinity-affected villages, the Gujarat Water Supply and Sewerage Board (GWSSB) has also built RO plants, and handed them over to the village panchayats to run. The panchayat gets subsidized electricity to run the plant from the state electricity utility. GWSSB intervenes only in those villages

---

pouches produced more margin as compared to big cans of 10 or 20 liters; 3) the price of 10-liter packaged water for the year-round customers is Rs. 1500 or Rs 4.1per can; 4) the packed drinking water in pouches has a large market catering to the people at large as it has an 'any time, any place type of market spread; and, 5] there are a good number of investors who were willing to invest extra money required for obtaining ISI certification for their operations, as they knew about the quality consciousness of their clientele (Indu, 2002).

where locally available water is non-potable (i.e., exceeding 1500 ppm). The members of the village households are expected to collect the water from the plant and home delivery service is not provided. The amount charged by the panchayat for the treated water is only Rs. 2 per 20 liters can. Since the operations and maintenance cost is much lower, compared to those run by the Swaminarayan Sanstha, the water charges are also less. In the district of Kheda, around forty villages (especially from Khambat and Petlad) are served by RO plants set up by GWSSB.

- **Private sector sales**: In villages not served by NRIs, the Swaminarayan Sanstha or GWSSB, households depend on private suppliers for potable water. Private agencies have become major players in the supply of safe water in rural areas (and urban areas) of the state where the water supplied for domestic uses contained high levels of salts and fluorides but not exceeding the levels of 1,500 ppm in case of TDS and 1.5 ppm in case of fluorides that mandate public intervention. One major difference between the RO water supplied by the panchayat and private suppliers is temperature; private suppliers provide chilled water.

Rajasthan

Unlike the myriad approaches adopted in undivided Andhra Pradesh and Gujarat, Rajasthan has opted to build public-sector funded and operated reverse osmosis (RO) plants. Since pollution previously went unchecked, to address water contamination, the state of Rajasthan set up over 1,000 RO plants in rural areas of the state to provide clean drinking water to the villages. The villages with higher levels of fluoride content than permissible are given priority. The plants will be set up in areas with a population of at least 1,000 people. The state government will install an RO plant with a capacity of filtering 500 liters of water every hour. Areas with higher populations will have RO plants with corresponding capacity levels.

In the first phase, the state government set up 360 plants in Jodhpur division, 150 plants in Ajmer division, 300 plants in Bharatpur division, 30 each in Bikaner and Kota divisions, 100 in Jaipur and 40 in Udaipur division. The project aims to provide at least 40 liters of filtered drinking water to each family every day where RO plants are set up. The water distribution will be monitored by the local panchayat of the village. Parallel to this, Public Health and Engineering Department (PHED) has also installed RO plants with an ATM card-like concept in association with a crude oil exploration company, starting with two villages namely, Kawas and Bheemada. With the machine, the water drawee inserts the card and enters the value in the machine to get the water at any time for the cost of Rs 5 for per 20 liters.

OVERALL MARKET ASSESSMENT FINDINGS

Irrigation Water Market

1. There are many regions in India which receive very low to low rainfall, such as Western Rajasthan, North Gujarat, Saurashtra, Southwestern Punjab, Rayalaseema, coastal Saurashtra, Telangana, North Western Karnataka and parts of Tamil Nadu. These regions also experience very high to high aridity and drought proneness. These regions also have large amount of cultivable land. These factors in combination increase the demand for irrigation water.

2. Renewable freshwater resources, comprising surface runoff in the basins of the region and replenished ground water, are extremely limited. The availability of freshwater decreases significantly in drought years. Water scarcity for agriculture is severe, with low intensity cultivation and irrigation.

3. Given limited public irrigation regulations, groundwater resources in these regions are depleted. Irrigated agriculture is largely sustained through heavy subsidies in water, energy and irrigation equipment (drips and sprinklers).

4. Western Rajasthan, North Gujarat, coastal Saurashtra, Southwestern Punjab, certain parts of Haryana, Rayalaseema (Andhra Pradesh), Telangana, North Western Karnataka and parts of Tamil Nadu have marginal quality groundwater (with electrical conductivity in the range of 1,500-3,000 µS/cm). In the alluvial areas of Western Rajasthan, North Gujarat, Southwestern Punjab and Haryana, it is plentiful. In some cases, this water is used for irrigating some low value cereals and fodder crops, with low yields.

5. Many of these areas also have other mineral contaminants in the groundwater: fluorides, chlorides, nitrates and arsenic. Potable water is increasingly becoming scarce in these areas. Such areas also include areas outside the salinity-affected regions.

6. Analysis shows the unmet demand for fresh water for irrigation is very high in the saline groundwater areas, namely, Western Rajasthan, North Western Gujarat, Southwestern Punjab and Rayalaseema, as they coincide with regions of very low to low rainfall, very high to high aridity, and high drought proneness.

7. This is evident that i) only a portion of the cultivable land is under cropping even during the rainy season, and during droughts, monsoon crops fail; and, ii) a very small portion of the land is under cropping in the winter season in both the very low to low rainfall areas and low to medium rainfall areas. Additional water, if made available, can be used to expand the cropped area during monsoon;

provide supplementary irrigation to kharif crops; intensify cropping with irrigated winter and summer crops; and replace marginal quality groundwater used for irrigating certain crops.

8. Analysis shows that farmers in these regions also grow some high value: i) fruits (citrus, sapota, pomegranate, dates, orange, watermelon, grapes and banana); ii) vegetables (tomatoes, cucumber, eggplant, cauliflower, cabbage, carrot, okra, onion, chilies, etc.); and, iii) other cash crops (cotton, castor and fennel).

9. The total area under fruits, vegetables and cash crops in the salinity-affected districts of the eight states chosen was assessed to be 713.4 thousand ha for fruits, 1.012 million ha for vegetables and 7.061 million ha for cash crops (only cotton, castor and fennel). The total area under these crops is 8.786 million ha. Field research to quantify the economic returns from these crops in relation to irrigation water will give us an indication of which crops could be grown with desalinated water in an economically viable manner, and in which regions.

10. The economic value of irrigation water (expressed as the net income from crop production per unit volume of water) is very high for some of these crops. It is as high as \$2.44/m^3 for green chilies, to \$2/m^3 for eggplant, \$0.83/m3 for tomatoes to approximately \$0.63 for pomegranates and fennel.

11. Analysis of existing water markets in Eastern UP and South Bihar show that in the informal markets, irrigation charge farmers pay can be as high as 25 percent of the net return they get from irrigated production in \$ per m^3 of water, though on an average, the price was 14 percent of the net return.

12. The actual subsidies farmers enjoy for irrigation water through electricity subsidy for pumping in these regions is very high due to the large depth to water table and the large subsidies for every unit of electricity supplied.

13. Capital cost subsidies in public irrigation is high in regions of scarcity (approximately \$1,000/ha) and also high for recently built infrastructure. The energy costs for groundwater pumping (\$/m^3 of water) are high in regions of water scarcity and depleted resources (approximately \$0.1/KWhr). The societal cost for pumping groundwater is in the range of \$0.12-0.27 per m^3 of water. Subsidies for micro irrigation systems from both national and state governments have increased over the years and water scarce states are the largest beneficiaries. The total subsidy since 2009-10 is around \$1.1 billion at current prices.

14. Initial analysis shows that it will be economically viable to grow some of the high value crops with desalinated water, and the demand for the water will be high for: i) intensifying cropping & irrigation of high value crops; and, ii) replacing

crops irrigated with marginal quality water by high value crops which need high quality water.

15. More irrigated crops will become viable if the financial assistance being offered by the government to well irrigators in the form of various input subsidies (such as that for electricity, micro irrigation systems, and solar PV systems) is extended to desalination technology via capital subsidies for the system (including solar PV system).

Drinking Water Market

1. The market for desalinated (demineralized) drinking water is growing fast in the rural areas of many regions that are heavily dependent on groundwater for water supply due to the widespread problem of chemically contaminated water.
2. Reverse osmosis systems are set up to demineralize groundwater and make it potable for supply to rural areas that do not have alternative sources of fresh water. The market for RO drinking water in the villages started developing in the late 1990s in areas with severe chemical contamination.
3. Four distribution models are prevalent. The first is plants set up by a government agency and run by gram panchayats, wherein the communities get water at a heavily subsidized price, sufficient to cover the operations and maintenance cost (Rs. 4-5 per 20 liters can). These models exist only in villages that have severe groundwater contamination problems (with TDS exceeding 2000 ppm). The second model is hybrid RO plants that recover the full cost (including the capital cost) through charging for water. The third are those supported by NGOs and run as community-partnerships. The capital cost is borne by the NGO using financial support from government and/ or private philanthropy. Finally, private companies also set up RO plants and sell water in villages and towns to make profit, with prices ranging from Rs. 20- Rs 25 for a 20-liter can ($0.30 to $0.38 for 20 liters).
4. The first round of analysis suggests, given the success of private sector operators selling water for a profit, rural communities are willing to pay premium prices for good quality (demineralized) water supply.

DETAILED FIELD INVESTIGATION FINDINGS

As discussed in the methodology, there are two approaches proposed to generate demand for desalinated water used in irrigation. The first is to ask the farmers directly their willingness to pay (WTP) and clarify the amount of water they will buy in different seasons. The second approach, which is indirect but more realistic, is to look at the economic value of water used in irrigating different crops in the selected regions; identify for which crops the surplus value product (net economic returns) from the use of desalinated water (Rs/m^3 of water) for irrigation exceeds the price of desalinated water by the order of magnitude of the coefficient, θ (See the methodology) under different water cost/pricing scenarios; and then identify the crops that will be viable and the water requirement per unit area. Obviously, as price of desalinated water decreases, more numbers of crops will give higher economic returns than the price of water by an order of magnitude equal to the coefficient, i.e. θ.

Detailed field surveys were carried out in four locations where groundwater salinity exists. Farmers are also making significant investment in obtaining water, and therefore are also growing high value crops that yield high returns per unit volume of water. In each field location, as often as possible, the study identified areas where farmers are growing crops with marginal quality ground water and areas where farmers are growing crops with limited good quality groundwater in order to understand how the farmers in saline groundwater areas will respond if good quality groundwater is available. The field locations are Somnath/Junagadh districts in coastal Saurashtra; Banaskantha district in North Gujarat; Jodhpur district in Western Rajasthan and Bhathinda district in Southwestern Punjab. The first region is semi-arid with coastal climate. Banaskantha district has semi-arid to arid climatic condition. Both Jodhpur and Bhathinda have arid climatic conditions.

The villages chosen in Somnath district are salinity affected and those in Junagadh district are inland villages and have good quality groundwater. The villages in Vav taluka of Banaskantha district are salinity-affected, and those in Palanpur taluka have good quality groundwater. Detailed data on the farming enterprise was collected using a structured questionnaire answered by 30-40 farmers sampled from each location. Data was collected on the following: the socio-economic profile of the farmers; the land holding; access to assets such as wells, irrigation equipment such as pump sets, drips and sprinklers; the farm inputs for crops grown in different seasons such as labor (for land preparation, weeding, irrigation and harvesting), seeds, fertilizer and pesticides, use of machinery, irrigation – number of irrigations, duration of each watering; the outputs of wells/sprinkler nozzle or drippers; number of drippers/sprinkler nozzles in each plot; crop yield; and prices obtained per kg of produce. In addition, interviews were conducted with a few farmers from each location to gain insights into the economic value of crops produced from water and the willingness to pay for water. The sample size for each location is as follows: 40 in the case of coastal Saurashtra; 36 for North Gujarat; 25 for Western Rajasthan; and 21 for South-Western Punjab.

Along with the questionnaire, in depth interviews were conducted with selected farmers, who grow high value fruits, vegetables, flowers and nuts/spices in all the four locations. Field notes based on these interviews are in Annexs 6a, 6b, 6c and 6d, which document interviews conducted in the four locations: coastal Saurashtra, North Gujarat, Western Rajasthan and Southwestern Punjab, respectively.

The empirical outputs of the data analyses obtained through the survey and in depth interviews are also presented in tables below. The first convey the following: 1) cost of farm; 2) gross farm returns per unit of land for various crops grown in different seasons (Rs/ha); 3) the net return per unit of land (Rs/ha of water) presented in Table 15); and, 4) the average volume of irrigation water applied per ha; and 5) the gross return per unit volume of water and net return per unit volume of water (net water productivity in economic terms) for various crops (Table 16)(in cases where the method of irrigation is conventional flooding, we do not mention the "technologies for irrigation water application" in the tables). Graphical representations of net water productivity in various crops are in Figure 15. The analytical procedure followed for arriving at these estimates is available in Annex 1. The findings are presented by region in subsequent sections.

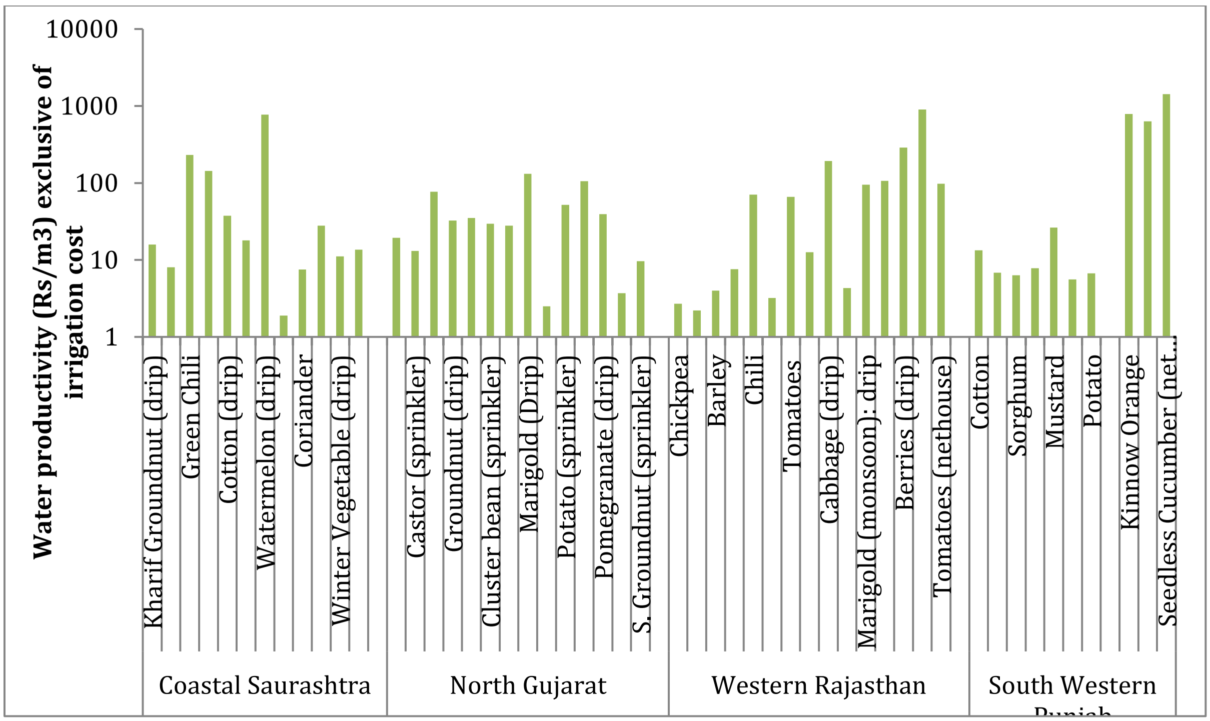

Figure 15: Water productivity of crops from four regions.

Coastal Saurashtra

In coastal Saurashtra, with growing scarcity of water and saline intrusion, there is significant transformation of agriculture with cash crops and horticultural crops replacing food crops. The new crops are also amenable to drip systems, which are becoming widespread. This is enabled by provision of capital subsidies for purchase of drips and sprinklers by the state and central government. Subsidies compromise 45 percent to 60 percent of drip systems in Gujarat, with higher rates in areas experiencing groundwater depletion.

1. Wheat, grown during winter, has almost disappeared from the area. Now areas under cash crops, such as cumin, coriander, castor, chilies and vegetables are considerably large during the winter season. Most of these crops are also risky. Farmers in salinity-affected areas are also opting for coconuts and banana plantations, irrigating them with saline groundwater using drip systems, with adverse impact on yield and income. In areas with fresh groundwater, crops that yield high returns, such as chilies and vegetables are becoming routine crops. Watermelon is also preferred during summer months.

2. Ground water availability and salinity levels in the open well water keep fluctuating in the coastal (hard rock) districts. In abnormally wet years, there is plenty of water in the wells, and the irrigation demand is low. However, the situation dramatically changes in drought years, where in even kharif crops require irrigation inputs to survive. Normally, water level rises during monsoon season and drops after winter -- 50 to 75 feet. However, there is no significant rise in groundwater levels in poor rainfall year.

3. The net irrigation water productivity for cash crops (Rs/m^3 of water) is higher than conventional food crops (wheat and pearl millet). The net WP with fresh groundwater, varies from Rs. 143.6/m^3 (\$2.1/m^3) for coconuts (projected) to Rs. 230.3/m^3 for green chilies to Rs. 774.5/m3 (\$12/m^3) for watermelon. For conventional field crops, it is in the range of 1.9/m^3 for wheat to Rs. 13.6/m^3 for summer vegetables to Rs.27.8/m^3 for cumin to Rs 7.5/m^3 for coriander to Rs 15.9/m^3 for kharif ground nut. The projection of water productivity for coconuts (currently grown with saline groundwater), under freshwater irrigation scenario, suggests that with salinity free groundwater, the yield of the crop will double the one grown with saline groundwater.

4. Water markets are quite extensive, though not deep. Farmers buy water on an hourly basis for risky cash crops (Rs. 80 to Rs. 100 per hour), and for one-third of the share of the total crop for food crops. The future demand for water in the area ranges from 50 percent of the area during winter to the entire land under cultivation by farmers who buy water. In summer, the demand is for nearly one-third of the area. The market demand for irrigation water is also a function of quantum of rainfall and salinity of groundwater, as they change the quantity and quantity of well water. Increase in yield is a significant driver for buying fresh water and is as high as 100 percent for coconuts.

5. The farmers tacitly relate the price of water to the volume of water. The willingness to pay ranged from Rs. 500 per ha per watering to Rs. 840/ha/watering; from Rs. 14,400 per ha of irrigation for all of the winter season to Rs. 30,000 per ha for seven months of irrigation for coconuts. The WTP for water is also linked to the marginal returns per unit of water, as evident from the higher WTP for younger plantations of coconuts, whose growers reported their

willingness to pay a water charge that is one-fourth of the net return per unit volume of water from crop production, as they expected better growth of the plantation resulting in higher yield and income, owing to irrigating with good quality water.

Alluvial North Gujarat

1. Farming in alluvial North Gujarat (especially in Banaskantha district) has undergone transformation in the past 10-12 years, with growing water scarcity, greater knowledge of water-efficient irrigation technologies, increased access to credit and increased knowledge about growing new crops that give higher returns.

2. In the areas with fresh groundwater, new crops are being introduced, such as papaya, pomegranate, tomatoes, flowers, watermelon and chilies. In addition, the areas of potatoes, groundnut and fennel increased, reducing areas with traditional crops such as wheat, mustard and pearl millet. The new trend among farmers is to go for high value cash crops, which are also compatible with micro irrigation for maximum benefit. Salinity has hindered adoption of MI in saline groundwater areas of Western Banaskantha. Groundwater salinity in deeper aquifers range from 2,100-2,400 ppm, and, in shallow aquifers, higher (3,100 ppm) as measurements indicate.

3. In the salinity-affected areas of Western Banaskantha (Vav taluka), resource rich farmers are using saline groundwater for irrigation, at the cost of yield and slow land degradation. In some crops (e.g., cumin), the yield had drastically declined over the past 30 years – from 1,400 kg/vigha to 400 kg/vigha. The farmers perceive doubling of yield and land quality improvement as a significant benefit from using fresh water for irrigation. They are willing to pay for good quality groundwater. These farmers include those who have canal water access in some of their parcels.

4. Water productivity for crops in the fresh groundwater area are Rs. 19.3/m^3 for castor under drips; Rs. 13.1/m^3 for castor under sprinklers; Rs. 32.5/m^3 for groundnut under drips; Rs. 35.2/m^3 for the same crop under sprinkles; Rs. 39.3/m^3 for pomegranate; Rs. 52.0/m^3 for potatoes; Rs. 131.7/m^3 of water for marigold; Rs. 105.6/m^3 for watermelon; and Rs. 77.2/m^3 for fennel. According to the farmers in the salinity-affected areas, water productivity for cumin, mustard, pearl millet, castor, jowar and cotton grown in these areas will be more than doubled with the use of fresh water for irrigation, as yield doubles and irrigation requirement reduces. This is evident from the experience of the same farmers in their respective canal irrigated plots.

5. Farmers' willingness to pay for water is high in both salinity-affected areas and areas facing groundwater mining (fresh groundwater areas). Farmers often relate the WTP to the prevailing market price of water. However, the reported WTP increased once the actual economic value of irrigation water is revealed to them. In the salinity-affected areas, the WTP ranged from Rs. 5,000/ha per watering to Rs. 6,400/ha per watering; and it increased to one third of the net return per unit volume of water, when they were explained about the quantum of benefits derived from water use. In the fresh groundwater areas, it ranges from Rs. 6,400 per ha per watering (under TMI); one fourth to one half of the net income from every unit of water. The highest WTP for water (one half of the net income) makes the profit margin coefficient equal to 1.0.

6. In terms of area, the demand for water is as high as the current irrigated area in the salinity-affected areas, nearly 70 percent of the area irrigated during winter in freshwater areas. In the fresh groundwater areas, demand for water is lower in the summer season. The farmers in salinity-affected areas want to irrigate the entire land in all seasons, using the purchased water. They value good quality water more than their counterparts in the fresh groundwater areas.

Western Rajasthan

1. In Jodhpur district of Western Rajasthan, which is one of the most sparsely cultivated regions in India due to very high aridity, water shortage, poor quality desert soils, and agricultural transformation are significant in areas close to the city of Jodhpur. Farmers like to cultivate vegetables, as there is a market year-round, but the rainfall is very scanty. Therefore, a year-round demand for irrigation water exists in the region. Overall, ground water salinity levels have increased in the wells over time, as water levels drop and water from deeper strata, with higher concentrations of minerals, is being pumped out through tube wells.

2. The water level rise during the rainy season (monsoon) is insignificant, yet there is a 10-foot decline in water levels per annum. The tube wells have widely replaced open wells. The depth of tube wells ranges from 250 feet to 500 feet.

3. There is large-scale adoption of high value vegetables and flowers, as well as some dry land fruits by farmers who have land in the periphery of the city. In these areas, the quality of groundwater is good. The crops are green chilies, tomatoes, cabbage, carrot, eggplant, seedless cucumber, marigold (flower), berries, pomegranate, sapota and sweet lime. Some of these crops are financially risky, especially flowers, chilies, cabbage and tomatoes, which generally have very high returns. On the other hand, in the areas with marginal quality groundwater, the cropping pattern is dominated by wheat, pearl millet,

sorghum and cotton, with low yields and returns. Farmers do allocate some land for growing cash crops such as fennel, and some vegetables.

4. There is significant variation in net water productivity of crops, in economic terms, from as low as Rs. 0.1/m^3 for pearl millet to Rs. 3.2/m^3 for onion to Rs. 94.6/m^3 for monsoon (marigold) flower to Rs. 106.1/m^3 for winter flower to Rs. 193.0/ m^3 for summer cabbage to Rs. 287.8/m^3 for berries to Rs 903.5/m^3 for seedless cucumber. The major factors driving this significant change in water productivity are the value of the produce and the amount of irrigation water required. The huge fluctuation in the price of the produce during a single season also complicates the estimation of real economic value.

5. There is year-round demand for water in Western Rajasthan, owing to farmers growing different types of vegetable crops in all seasons. The summer water demand is as high as 150 m^3 per day per ha of irrigation during summer. The reported willingness to pay for water is as high as half of the net return per unit volume of water, which makes the profit margin coefficient equal to 1.0. One third of the gross return from crop production as payment for irrigation services was also found to be the norm in the area.

6. Comparative analysis of WP of different crops grown under different conditions (traditional method of irrigation, drip irrigation, drip irrigation in poly house) shows that for the same crop, WP is highest for crops cultivated under green houses and irrigated with drips and foggers, followed by crops irrigated with drips and lowest for crops cultivated under flood method of irrigation. The high WP under the first two methods of cultivation was owing to reduced water consumption, and enhance yield via controlling irrigation and the microclimate. Use of home grown seeds reduces the input costs significantly, but organic produce fetches premium price (see Box 1).

Box 1: Organic Vegetable Cultivation with Home Grown Seeds

Tarachand belongs to the Mali community, which traditionally cultivates vegetables. He runs a vegetable stand on the highway. The fresh vegetables produced in his farm are brought to the stand for sale. He has high turnover at his stand due to regular customers.

He has a tube well, jointly owned by five brothers. The depth of the well is 500 feet, and depth to water level is 180 feet. The pump capacity is only 7.5 horsepower, as water table is high. The tube well is located in the fresh groundwater zone of Jodhpur. The well has good yield and water level has not declined over the past 12 years. The electricity connection for his tube well is metered (as his well is located in the urban area and the connection is non-agricultural). He pays around Rs. 4,000 to Rs. 5,000 in two months for the electricity. He often sells water to neighboring farmers, but charges only Rs. 50 per hour for water.

Tarachand grows cabbage, spring onions and ridge gourds. Cabbage is planted in September after 45 days of nursery. The crop is harvested after another 45 days. The crop is given a total of 25 irrigations, i.e., almost once every two days. The crop was cultivated in 2.5 vigha of land and it took 3.5 hours to provide one watering for the entire plot. He does not use chemical fertilizers for his vegetables and purely depends on organic manure (animal droppings). He used two trucks of manure last year at a cost of Rs. 40,000 for the 2.5 vigha, which is also available for the subsequent crop to be harvested from the same plot during the year. The labor was 15 days. Tarachand's family members are also engaged in the farming. The total revenue he earned from the sale of cabbage was Rs. 200,000 per vigha. He mentioned that he did not purchase any seed from the market, and uses his own seeds for his nursery. The net income per vigha is Rs. 177,000.

The second crop, spring onion, is also grown in the same plot after a short fallowing time. The total duration of the crop is 60 days, during which 20 watering are given to the crop. Each watering takes 3.5 hours. The total income from the produce was Rs. 100,000 from two vigha of cropped land. He did not invest anything for the seed, which is home grown. The amount of labor was almost same as that of cabbage.

Southwestern Punjab

1. Southwestern Punjab has been agriculturally less advanced than the rest of the state, due to hyper arid climatic conditions, groundwater salinity in many areas, and limited access to water from public canals. The farmers generally grew cotton, rice and green peas after blending of the limited supplies of canal water with marginal quality groundwater. In the fresh groundwater areas, they grew mandarin oranges (a citrus fruit), pomegranate and guava.

2. Over the past five to six years, the water situation had dramatically improved with increased allocation of water from canals to the region. Farmers have increased the area under rice cultivation, and replaced gram with wheat. However, introduction of canal water had raised the water table in many areas, rendering the land unsuitable for growing kinnow.

3. Farmers in areas with good vertical drainage and access to good quality groundwater or salt free canal water are still growing kinnow, owing to the high profitability of the crop. Some farmers are also growing high value vegetables (seedless Chinese cucumber, tomatoes, pumpkin, etc.) and flowers using groundwater employing modern production technologies, such as net house and poly house, and given the ability to control water delivery under well irrigation.

   One farmer had already built an RO plant to supply high quality water for irrigating exotic flowers and vegetables in net house and poly house. The ability to derive maximum economic benefit from farming (flowers) is found to be highly sensitive to maintaining the chemical quality of water (the pH and salinity) and therefore the farmer had invested in desalination system (see Box 2).

4. The investment being made by farmers for erecting net house and poly house (i.e., Rs. 400 per sq. m for poly house and Rs. 330 per sq. m for net house) is far higher than that required for micro irrigation systems such as drips (less than Rs.10 per sq. m. of cropped area), and water production technologies such as desalination systems (around Rs.30 per m^3 of water). These technologies enable farmers to produce high value crops. Hence, if water is the only constraint, the willingness to invest in water technology will be high.

5. The net returns from production of flowers and exotic vegetables irrigated with expensive water in the poly house are significantly higher than the cost of production and supply of irrigation water through RO. The water productivity ranged from Rs. 634.3/m^3 for Gerbera daisies to Rs. 786.3/m^3 for Mandarin orange plantation to Rs. 1,418.7/m^3 for seedless cucumber. However, what needs to be considered is kinnow, the gestation period of three to four years, when the trees

actually start fruiting. Whereas in the case of cucumber, the returns are much faster, as the crop duration is only four months, and two to three crops can be harvested in the poly house/net house.

6. Returns for traditional crops grown in the tube well irrigated areas are as low as Rs. -0.2/m^3 for green gram to Rs. 6.8/m^3 for rice paddies to Rs. 7.8/m^3 for wheat to Rs. 26.2/m^3 for mustard.

Box 2: Farmer Using Desalinated Water for Precision Farming

Lakhinder Palsigh, who has been in the flower farming business for ten years, has a large, seven-acre farm and tube well that is 160 feet deep. He installed an RO system one and a half years ago, and the plant produces 1,000 liters of water an hour. In spite of having access to canal water, Lakhinder invested in a RO system because the water was alkaline and had high pH (above 8.5) and TDS (2,000 ppm). The water was unfit for growing flowers.

The total capital investment for RO plant was Rs. 175,000 ($3000). Lakhinder used poly house and net house with drip irrigation and foggers for controlling micro-climate to grow high value flowers and vegetables. He had a commercial electricity connection for his farm, which ensured 24-hour power supply to his farm, unlike farmers in the rural areas who obtained free power supply only for a limited six hours. He pays Rs. 8 per unit of electricity.

For the past year, Lakhinder has been growing high-demand Gerbera daisy. The saplings are purchased from the nursery at a price of Rs. 32.25 per plant. He grows the flowers in an area of 2880 m^2 under polyhouse, with micro-climate control. The saplings are planted on raised, 2.5 feet wide beds, with drainage channels that are one foot wide. The plant density is six plants per square meter. The plants are irrigated using drip systems, with each bed having two laterals of drips, kept at a spacing of eight inches

The total investment for the polyhouse was Rs. 1,215,360 (app. $19,000). For an average life of ten years and at a discount rate of nine per cent, the annualized cost is Rs. 218,764. The life of Gerbera daisy plant is three years, and the flowering starts one hundred days after planting the sapling. During summer months (March to July), watering is around 10,000 liters a day, and during the rest of the year it takes 4,000 liters of water per day for the plot. The cost of fertilizers, neem oil and micronutrients, is Rs. 20,000 per month, with the cost of labor at Rs. 20,000 per month. The electricity costs Rs. 5,500 per month during summer and Rs. 3,000 per month during the winter.

Each plant produces three flowers per month, on average, and continues to flower for nine months. For nearly three months in a year, disbudding of the plants takes place, and there is no harvest during this period. The total production comes to nearly 466,560 flowers annually for a plot of size 2880 m^2. Each plant is capable of producing flowers for up to three years. The peak season for the flower, with respect to market demand, is June to July. The price during these months reaches Rs. 9 per flower. The peak season for harvest is October to March 15, when the price will range from Rs. 4 to Rs.7. With an average price of Rs 5 per flower for the first year, the gross income from sales is approximately Rs. 1,555,000 rising to Rs. 2,332,000 in the second and third years. With the cost of saplings at Rs. 557,280 and accounting for all other inputs (including the polyhouse), but excluding the cost of irrigation, the net income exclusive of irrigation cost comes to Rs. 670,000 during the first year and Rs. 1,437,000 during the second and third year. With a total water input of 2340 m^3 per annum, the average water productivity is Rs. 634.3/m^3.

ASSESSING THE WILLINGNESS TO PAY FOR DESALINATED WATER IN THE FOUR FIELD LOCATIONS

The field investigations demonstrate that for several high value crops, the net water productivity in economic terms (Rs/m^3) is quite high. If farmers have to purchase irrigation water from a desalination plant (that uses water from an existing groundwater source), the demand for that water (the amount for which they are willing to pay the price) will depend on: 1) which crops grown with the water will produce sufficient profit margins; 2) how much area they will use to grow those crops; 3) the hydro-meteorological conditions that determine the irrigation water requirement. For farmers to consider crops, irrigated with purchased water, to be viable, the profit margin coefficient (the ratio of the net WP in economic terms and the price of water) has to be higher than the value earlier estimated (i.e., 1.04). The net economic return from production of an irrigated crop per unit volume of water depends on the crop type (whether low valued or high valued), the incremental yield obtained (kg/ha) from the use of purchased water, the price of the produce in the market (Rs/kg) at the time when the crop is harvested, and the amount of water used per ha.

This economic equation suggests that when the price of water increases, the net water productivity in economic terms (Rs/m^3 of water) reduces for a given crop owing to increase in input costs, and the reduction in profit margin (Net WP/Price of water) will be disproportionately higher, as the value of the denominator also increases along with the numerator. Hence, as the price of water increases, a lesser number of crops will be viable. While the feasibility of growing a particular high value crop (flower, fruit or vegetable, or spice) in an area will largely depend on the agro climate, the precision farming techniques and the technologies for controlling the production environment, such as poly house and net house, will enable the growth of these crops under adverse, climatic conditions. Nevertheless, the adoption of such technologies will also increase the cost of crop production. Therefore, if natural, environmental conditions conducive for growing are readily available, the cost of desalinated water (Rs or $ per m^3) will be crucial in deciding the demand for that water.

The amount of land available for irrigation expansion determines the amount of area in which the crop is cultivated. Also, the more arid the climate, the more water is needed for irrigation per unit area. Therefore, the demand of irrigation water is determined by: 1) the available groundwater in the locality is not suitable in terms of chemical quality (like the groundwater salinity-affected areas of coastal Saurashtra, North Gujarat, Western Rajasthan and Southwestern Punjab); 2) or the available good quality groundwater is not sufficient. Therefore, demand for desalinated groundwater is likely to be high in regions where aforementioned conditions exist. However, small desalination schemes will be viable only in the first type of areas, which have salinity-affected groundwater.

To examine what kind of cropping systems is environmentally feasible in these areas, and what returns the farmers could obtain if they adopt these cropping systems, analysis has been completed for the farming systems in their neighborhood with similar climate and socio-economic conditions and where good quality groundwater is available. The underlying premise is that once good quality groundwater is supplied through desalination technologies, farmers in the former area will adopt the crops that meet the economic viability criteria of profit margin coefficient.

The net economic water productivity values estimated for various crops under different pricing scenarios for the desalinated water (the values of profit margin) are presented in Table 17 for all the four regions. Here it is assumed that the product water will have salinity in the range of 200-400 ppm, which is the salinity of the water used for growing the crops considered for the analysis, with the exception of pomegranate. To estimate the net water productivity in economic terms, the assumed cost of desalinated water (in Rs/m^3) was subtracted from the values of net WP provided in the last column of Table 16. This means that the cost of desalinated water (Ø) considered in Table 17 is over and above the cost of water abstraction using the existing irrigation system, which is already considered in the estimation of net WP figures provided in Table 16. With an increase in prices, net WP in economic terms reduces, and the profit margin reduces more sharply.

Based on the estimated values of profit margins for various crops under different pricing scenarios, the crops that will be viable with desalinated water will be identified, and accordingly the willingness to pay for desalinated water in the area at different prices will be estimated. As Table 17 shows, as the price of water increases from $0.2 to $2.0, irrigation with desalinated water becomes viable for lesser number of crops.

In the case of coastal Saurashtra, only one crop (watermelon) is viable when the price becomes $2.0/$m^3$. Whereas five crops, namely, cumin, chilies, coconuts and watermelon will be viable at the lowest price (i.e., $0.20/$m^3$); three crops are viable when the price become $0.50/$m^3$; the same three crops are viable when the price is raised to $1.0/$m^3$. Only two crops, watermelon and green chilies are viable when the price is raised to $1.50/$m^3$.

In the case of North Gujarat, no crop is viable at a price of $2.0/$m^3$. One crop becomes viable at a price of $1.0/$m^3$ (marigold). Three crops become viable when the price is reduced to $0.50 (fennel, watermelon and marigold). Five crops, pomegranate, fennel, watermelon, tomatoes and marigold will be viable when the price is reduced to $0.20/$m^3$. However, as suggested by an earlier analysis, there are other vegetables, which will be profitable under a high-water price, including chilies and eggplant (which are grown in the region) given the fact that they have very high water productivity in economic terms.

In the case of Western Rajasthan, six crops, marigold, cucumber, tomatoes, berries, cabbage and chilies will be viable at the lowest price scenario (i.e., $0.20/m^3). At the next higher price ($0.50/m^3) also, all these crops will be viable. In the third price scenario (i.e., $1.0/m^3), four will be viable. At prices of $1.50 and 2.0 per m^3 of water, two crops namely, berry and seedless cucumber will be viable.

In the case of Southwestern Punjab, as per the estimates provided, three crops, mandarin oranges, seedless cucumber and Gerbera daisy, will be viable under all price scenarios. It is important to note that there are many other crops, which are economically viable in the nearest region of Western Rajasthan at high prices, such as marigold, which could also be viable in this region, given the similar climatic conditions that exist.

The survey also asked farmers their ‘willingness to pay' for irrigation water, though the approach did not yield definitive results. The farmers could report the price at which water is traded in the market for the existing cropping system (discussed in the relevant sub-sections of the respective regions in Section 5 of this report). These prices are very low – in the range of Rs. 3.25/m^3 to Rs. 10/m^3 of water. In addition, the farmers could only indicate what proportion of the net return from future crop production they could part with, given the price of desalinated water, if they adopt high value crops that yield very high net income per unit volume of water. These figures ranged from 25 percent to 50 percent of the net income.

Table 15: Cost of Inputs, Outputs, Gross Return and Net Return per Ha of Land in Four Locations

Crop	Depth to water table (post winter) (feet)	Total Input Cost (Rs/ha)	Total Irrigation Cost (Rs/ha)	Average Yield (kg/ha)	Gross Return (Rs/ha)	Net Return (Rs/ha)	Salinity of Groundwater (ppm)
	Coastal Saurashtra						
Kharif Groundnut (drip)	29.0	53170	4926.0	3284	113238	60068	200-400
Kharif Vegetables (drip)	29.0	85926	4926.0		156250	70324	200-400
Green Chilies (drip)	29.0	127883	8620.0		937500	809617	200-400
Coconut (drip)	29.0	87739	14777.0		540000	452261	200-400
Cotton (drip)	29.0	25346	8620.0	4191	230497	142758	200-400
Pearl Millet (kharif)	29.0	86738	2492.0	2500	65625	40279	200-400
Watermelon (drip)	29.0	39872	4926.0	260416	260417	173678	200-400
Wheat	29.0	64467	6157.0	4079	59246	19374	200-400
Coriander	29.0	66511	4926.0	2367	118388	53921	200-400
Cumin	29.0	117551	4926.0	1368	192708	126197	200-400
Winter Vegetable (drip)	29.0	52205	6157.0	NA	156250	38699	400-500

Crop	Depth to water table (post winter) (feet)	Total Input Cost (Rs/ha)	Total Irrigation Cost (Rs/ha)	Average Yield (kg/ha)	Gross Return (Rs/ha)	Net Return (Rs/ha)	Salinity of Groundwater (ppm)
Summer Vegetable (drip)	29.0	53170	4926.0	NA	101771	49566	400-500
	North Gujarat						
Castor (drip)	144.0	24139	832	2,183.0	69841	45701	400-500
Castor (sprinkler)	144.0	22601	949	2,300.0	76667	54066	400-500
Fennel (drip)	144.0	42995	1178	2,221.0	219948	176953	400-500
Groundnut (drip)	144.0	41853	425	2,389.0	132639	90786	400-500
Groundnut (sprinkler)	144.0	48143	559	2,413.5	143722	95579	400-500
Cluster bean (sprinkler)	144.0	17057	249	770.8	49545	32488	400-500
Tomatoes (Drip)	144.0	807307	6610	128889.0	1355556	548249	200-400
Marigold (Drip)	144.0	88550	753	14687.0	352188	263637	200-400
Wheat (sprinkler)	144.0	37677	4473	3431.0	84367	46689	400-500
Potatoes (sprinkler)	144.0	113379	812	51364.0	319260	205880	400-500
Watermelon (drip)	144.0	105566	851	33111.0	252889	147322	200-400
Pomegranate (drip)	144.0	213124		36458.0	638020	424896	1540.0

Crop	Depth to water table (post winter) (feet)	Total Input Cost (Rs/ha)	Total Irrigation Cost (Rs/ha)	Average Yield (kg/ha)	Gross Return (Rs/ha)	Net Return (Rs/ha)	Salinity of Groundwater (ppm)
Pearl millet (sprinkler)	144.0	32732	2995	3578.0	86723	53990	400-500
Groundnut (sprinkler)	144.0	42065	1903	2840.0	141080	99015	400-500
	Western Rajasthan						
Pearl Millet	360.0	3801	419	375.0	4218.8	418.2	2,000-2,300
Sorghum	360.0	4907	421	360.0	8700.0	3793.1	2,000-2,300
Green Gram	360.0	4510	437	350.0	5250.0	740.3	2,000-2,300
Rice paddies	360.0	8200	437	375.0	20625.0	12425.5	2,000-2,300
Chickpea	360.0	7836	383	375.0	13125.0	5288.9	2,000-2,300
Wheat	360.0	6202	417	1773.0	28278.4	22075.9	2,000-2,300
Barley	360.0	8336	410	1396.0	33750.0	25413.8	2,000-2,300
Mustard	360.0	4834	419	1021.0	17333.3	12499.8	2,000-2,300
Chilis	150.0	122174.3	35210	15000.0	1158900.0	1036725.7	200-400
Onion	150.0	103620.5	29558	31250.0	122913.0	19292.5	200-400
Tomatoes	150.0	110761	20136	25000.0	723625.0	612864.0	200-400
Carrot	150.0	82030	23905	9375.0	227325.0	145295.0	200-400

Crop	Depth to water table (post winter) (feet)	Total Input Cost (Rs/ha)	Total Irrigation Cost (Rs/ha)	Average Yield (kg/ha)	Gross Return (Rs/ha)	Net Return (Rs/ha)	Salinity of Groundwater (ppm)
Cabbage: drip	180.0	91917	23167	NA	1250000.0	1158083.0	200-400
Bt Cotton	150.0	102972	24847	3125.0	152750.0	49778.0	200-400
Marigold (monsoon): drip	100.0	459795.5	29558	62500.0	1406250.0	946454.5	200-400
Marigold (winter-summer): drip	100.0	451315.5	21078	62500.0	1406250.0	954934.5	200-400
Berries (drip)	100.0	261110	11110		1090000.0	828890.0	200-400
Seedless Cucumber (poly house)	360.0	748164.6	13694	80000.0	1480000.0	731835.4	200-400
Tomatoes (net house)	360.0	506944.0	13694	117180	1171875.0	664931.0	200-400
	Southwestern Punjab						
Cotton (kharif)	145.0	20238.17	1454	5300.0	116566.7	96328.5	400-500
Rice paddies (kharif)	145.0	30080.85	1246	7529.0	107845.6	77764.7	400-500
Sorghum (kharif)	145.0	20005.00	830	1000.0	29375.0	9370.00	400-500
Wheat (winter)	145.0	22904.75	1246	4761.0	76267.5	53362.8	400-500
Mustard (winter)	145.0	20539.75	1246	2916.0	77135.0	56595.3	400-500

Crop	Depth to water table (post winter) (feet)	Total Input Cost (Rs/ha)	Total Irrigation Cost (Rs/ha)	Average Yield (kg/ha)	Gross Return (Rs/ha)	Net Return (Rs/ha)	Salinity of Groundwater (ppm)
Barley	145.0	14080.00	830	5000.0	62500.0	48420.0	400-500
Potatoes (winter)	145.0	26746.00	1246	39167.0	101666.7	74920.7	400-500
Green Gram (winter)	145.0	11330.00	830.0	37500.0	11250.0	-80.0	400-500
Mandarin Orange	80.0	42587.0	0	335 kg/tree*	306000.0	263413.0	200-400
Daisy Flowers (poly house+ RO Water)	30.0	2044170.3	107073		7197917.0	5153746.7	200-400
Seedless Cucumber (net house+ RO Water)	30.0	840672.5	49859	85694.0	2142367.0	1301694.5	200-400

Source: Estimates based on primary data from farmer surveys.

*10-year average of fruit yield starting from the year of planting.

Notes: 1) The estimate of input costs (Column 3) includes cost of all inputs including the cost of MI systems (annualized) and the cost of production of irrigation water. 2) The total irrigation cost figures in Column 4 includes the annualized capital cost of the well/tube well & pump sets per ha of land; and the variable cost of pumping water for irrigation per ha of the crop. In the case of Saurashtra, a figure of Rs. 45,000 was considered as the investment for construction of open wells and Rs 35,000 for installing a submersible pump set, as farmers could not recall.

Table 6: Farm Outputs per Unit Volume of Water for Various Crops in Different Locations

Crop (technology)	Depth to Water Table (post winter) (feet)	Total Irrigation Water Use (m³/ha)	Gross Return per Cubic Meter of Water (Rs/m³)	Net Water Productivity in Economic Terms (Rs/m³)	Salinity of the Groundwater (ppm)
	Coastal Saurashtra				
Groundnut (kharif: drip)	29.0	3768.0	30.0	15.9	200-400
Kharif Vegetables (drip)	29.0	8789.0	17.8	8.0	200-400
Green Chilis (drip)	29.0	3515.0	266.7	230.3	200-400
Coconut (saline/freshwater)	29.0	3150.0	171.4	143.6	200-400
Cotton (drip)	29.0	3817.0	60.4	37.4	200-400
Pearl Millet	29.0	2241.0	29.4	18.0	200-400
Watermelon (drip)	29.0	400.0	1093.8	774.5	200-400
Wheat	29.0	10040.0	5.90	1.9	200-400
Coriander	29.0	7200.0	16.4	7.5	200-400
Cumin	29.0	4537.0	42.5	27.8	200-400
Winter Vegetable (drip)	29.0	3515.0	44.4	11.1	400-500
Summer Vegetable (drip)	29.0	3655.0	27.8	13.6	400-500

Crop (technology)	Depth to Water Table (post winter) (feet)	Total Irrigation Water Use (m^3/ha)	Gross Return per Cubic Meter of Water (Rs/m^3)	Net Water Productivity in Economic Terms (Rs/m^3)	Salinity of the Groundwater (ppm)
	North Gujarat				
Castor (drip)	144.0	2362.0	29.6	19.3	400-500
Castor (sprinkler)	144.0	4125.0	18.6	13.1	400-500
Fennel (drip)	144.0	2292.0	95.9	77.2	400-500
Groundnut (drip)	144.0	2791.0	47.5	32.5	400-500
Groundnut (sprinkler)	144.0	2718.0	52.9	35.2	400-500
Cluster bean (sprinkler)	144.0	1104.0	44.9	29.4	400-500
Tomatoes (Drip)	144.0	19691.0	68.8	27.8	200-400
Marigold (Drip)	144.0	2002.0	175.9	131.7	200-400
Wheat (sprinkler)	144.0	18506.0	4.6	2.5	400-500
Potatoes (sprinkler)	144.0	3957.0	80.7	52.0	400-500
Watermelon (drip)	144.0	1395.0	181.2	105.6	200-400
Pomegranate	300.0	10800.0	59.1	39.3	1540.0
S. Pearl millet (sprinkler)	144.0	14689.0	13.6	3.7	400-500

Crop (technology)	Depth to Water Table (post winter) (feet)	Total Irrigation Water Use (m^3/ha)	Gross Return per Cubic Meter of Water (Rs/m^3)	Net Water Productivity in Economic Terms (Rs/m^3)	Salinity of the Groundwater (ppm)
S. Groundnut (sprinkler)	144.0	10341.0	29.6	9.6	400-500
Western Rajasthan					
Pearl Millet	360.0	3820.0	1.1	0.1	2,000-2,300
Sorghum	360.0	5513.0	1.6	0.7	2,000-2,300
Green Gram	360.0	2466.0	2.1	0.3	2,000-2,300
Rice paddies	360.0	6197.0	3.3	2.0	2,000-2,300
Chickpea	360.0	1967.0	6.7	2.7	2,000-2,300
Wheat	360.0	9865.0	2.9	2.2	2,000-2,300
Barley	360.0	6318.0	5.3	4.0	2,000-2,300
Mustard	360.0	1644.0	10.5	7.6	2,000-2,300
Chilis	150.0	14650.0	79.1	70.8	200-400
Onion	150.0	6000.0	20.5	3.2	200-400
Tomatoes	150.0	9300.0	77.8	65.9	200-400
Carrot	150.0	11500.0	19.8	12.6	200-400

Crop (technology)	Depth to Water Table (post winter) (feet)	Total Irrigation Water Use (m^3/ha)	Gross Return per Cubic Meter of Water (Rs/m^3)	Net Water Productivity in Economic Terms (Rs/m^3)	Salinity of the Groundwater (ppm)
Cabbage (drip)	180.0	6000.0	208.3	193.0	200-400
Bt Cotton	150.0	11500.0	13.3	4.3	200-400
Marigold (monsoon): drip	100.0	10000.0	140.6	94.6	200-400
Marigold (winter-summer): drip	100.0	9000.0	156.4	106.1	200-400
Berries (drip)	100.0	2880.0	378.47	287.8	200-400
Seedless Cucumber (poly house)	360.0	810.0	1827.2	903.5	200-400
Tomatoes (net house)	360.0	6816.0	171.9	97.6	200-400
	Southwestern Punjab				
Cotton	145.0	7261.0	16.1	13.3	400-500
Kharif rice paddies	145.0	11474.0	9.4	6.8	400-500
Sorghum	145.0	1492.0	19.7	6.3	400-500
Wheat	145.0	6831.0	11.2	7.8	400-500
Mustard	145.0	2160.0	35.7	26.2	400-500
Barley	145.0	8691.0	7.2	5.6	400-500

Crop (technology)	Depth to Water Table (post winter) (feet)	Total Irrigation Water Use (m^3/ha)	Gross Return per Cubic Meter of Water (Rs/m^3)	Net Water Productivity in Economic Terms (Rs/m^3)	Salinity of the Groundwater (ppm)
Potatoes	145.0	11130.0	9.1	6.7	400-500
Green Gram	145.0	400.0	28.1	-0.20	400-500
Mandarin Orange	80.0	335.0	913.4	786.3	200-400
Gerbera daisy (Poly house)	30.0	8125.0	885.9	634.3	200-400
Seedless Cucumber (net house)	30.0	917.50	2335.0	1418.7	200-400

Source: Estimates based on primary data from field survey.

Table 17: Net Water Productivity in Economic terms ($/m³) and Profit Margin Coefficient for Various High Value Crops in the Four Study Regions at Different Price Scenarios

Crop Name	Crop Water Productivity and Estimated Profit Margin Coefficient at Different Prices of Desalinated Water									
	$ 0.2		$ 0.50		$ 1.00		$ 1.50		$ 2.00	
	WP	Ø	WP	Ø	WP	Ø	WP	Ø	WP	Ø
Coastal Saurashtra										
Coconut	1.96	9.80	1.93	3.32	1.16	1.16				
Green Chilies	3.26	16.32	2.96	5.93	2.46	2.46	1.995	1.31	1.46	0.73
Watermelon	11.44	57.23	11.145	22.29	10.65	10.65	10.14	6.76	9.64	4.82
Cumin	0.22	1.09			1.43					
Cotton	0.39	1.81								
North Gujarat										
Watermelon	1.39	6.94	1.09	2.18	0.59	0.59				
Marigold	1.78	8.90	1.48	2.96	0.98	0.98				
Pomegranate	0.39	1.98								
Fennel	0.96	4.80	0.66	1.32						
Tomatoes	0.22	1.09								

Crop Name	Crop Water Productivity and Estimated Profit Margin Coefficient at Different Prices of Desalinated Water									
	$ 0.2		$ 0.50		$ 1.00		$ 1.50		$ 2.00	
	WP	Ø	WP	Ø	WP	Ø	WP	Ø	WP	Ø
Western Rajasthan										
Chilies	0.864	4.32	0.565	1.13						
Tomatoes	0.79	3.95	0.49	0.98						
Cabbage	2.702	13.51	2.4	4.80	1.90	1.90	1.395	0.93		
Marigold	1.78	8.90	1.48	2.96	0.98	0.98				
Berries	4.128	20.64	3.83	7.66	3.33	3.33	2.835	1.89	2.32	1.16
Seedless Cucumber	13.38	66.90	13.085	26.17	12.59	12.59	12.09	8.06	11.58	5.79
Tomatoes (net house)	1.266	6.33	0.965	1.93						
Southwestern Punjab										
Kinnow	11.62	58.12	11.32	22.65	10.82	10.82	10.32	6.88	9.82	4.91
Gerbera daisy	13.122	46.69	9.04	18.08	8.54	8.54	8.04	5.36	7.54	3.77
Seedless Cucumber	21.13	105.67	20.84	41.67	20.33	20.33	19.83	13.22	19.34	9.67

Source: Analysis based on the data presented in Table 10.

It is quite obvious that attempts by government agencies, such as the state water resources department, to supply good quality water through canals to these water-scarce regions at heavily subsidized prices will reduce the willingness to pay for desalinated water. In these situations, farmers will prefer expensive desalinated water only for crops which are extremely sensitive to water quality parameters, such as salinity and pH (like the case of the farmer growing Gerbera daisy with RO water in Text Box 2), and their size will be very small. Others will use the heavily subsidized good quality water for traditional cropping systems – dominated by cereals – though they might grow some vegetables that are not feasible with marginal quality groundwater. The lack of control over water delivery in the field and the required irrigation schedules in canal systems will prevent farmers from taking up crops sensitive to excessive watering.

Enterprising farmers in acutely water-scarce regions are willing to purchase expensive desalinated water to grow high value crops, when there are no cheaper alternatives, almost throughout the year in North Gujarat, Western Rajasthan, Southwestern Punjab, and (in winter and summer) in coastal Saurashtra. Socio-economic changes such as the rapid growth in the demand for fruits, vegetables and flowers and the consequent expansions in the areas cultivating these crops, especially in the peripheries of cities encourage this trend. Incremental returns from these crops through the use of good quality water will be very high. The environmental conditions in the water scarce regions are also favorable for adopting high value fruits, vegetables and flowers. Greater access to technologies used for controlling the production environment (net house, poly house, etc.), enabled by increased availability of capital subsidies, will reduce the production risks. In order to encourage farmers to use desalinated water for crop production, the price of water from conventional sources has to be increased substantially to reflect its scarcity. There is enormous scope for raising the price of good quality water in the water-scarce regions. Also, there is scope for raising the tariff of electricity used for pumping groundwater for irrigation. This can be complemented by subsidies for desalination technologies to further boost adoption of this technology.

SYNTHESIS OF FINDINGS

Many semi-arid and arid regions in India are facing acute water shortage. The amount of water available for irrigated agriculture in these regions is far less than what is available locally from surface and underground sources. As the limited surface water resources are already over-appropriated, groundwater is overexploited to meet various needs. This is leading to aquifer depletion. These regions are agriculturally prosperous with diversified cropping systems – cereals, oil seeds, spices, fiber, vegetables and fruits. There is a significant unmet demand for irrigation water in these agriculturally prosperous regions, owing to vast tracts of arable land, low rainfalls and high aridity. The demand is almost perennial in North Gujarat, Western Rajasthan and Southwestern Punjab. Many of these regions are underlain by vast saline aquifers. The most important among them are North Gujarat, coastal Saurashtra region in Gujarat, Western Rajasthan and Southwestern Punjab. Currently, the farmers in the saline groundwater areas grow low value crops that are resistant to salinity and obtain low yields and income. They look for alternative water sources to meet their growing needs. Desalination of marginal quality groundwater can be one of these alternatives.

Irrigated agriculture in these regions is characterized by heavy input subsidies. Subsidies exists for services like water supplied through canals from public irrigation infrastructure, electricity supplied for pumping groundwater, and installing micro irrigation systems—such as drips, sprinklers and systems for control of production environment. While subsidies for energy produce negative welfare outcomes due to wasteful and inefficient use of groundwater and electricity, which, in turn, causes aquifer depletion, capital subsidies for drips, sprinklers and production control technologies can produce positive welfare effects, by generating higher economic value for the water and other inputs used as well as saving water (if they are properly used).

Even in the most water-scarce regions (Wav taluka of Banaskantha district in North Gujarat), heavily subsidized water is supplied through canals for irrigation, despite the average net economic returns generated from the use of unit volume of water when used in irrigation are much higher than the price they are currently paying for unit volume of that water. Because of heavy subsidies for water and electricity, they do not adopt high value crops, which involve greater production and market risks. There are risk-taking farmers who grow high value crops, using precision farming technologies, earning very high income in all the four regions surveyed.

Marginal quality groundwater, which is abundant in these regions, can be treated using desalination technologies and then used for farming. Analysis shows that these regions have favorable environmental conditions for growing several high value fruits, vegetables and flowers. The enterprising farmers who also have access to good quality water can grow some of these crops (chilies, eggplant, cauliflower, tomatoes, seedless cucumber, watermelon, marigold, Gerbera daisy, mandarin oranges and berries), which fetch very high prices in the market. Some farmers also use technologies to control production environment. Improved access to good quality groundwater can boost the production of these crops, which have growing markets.

The WTP for desalinated water for irrigated agriculture is highly dependent on what economic opportunities it provides for the farmers (i.e., marginal returns from the use of water) in a given setting. These economic opportunities are decided by the following: 1) what kind of crops suited to the climatic conditions, which are not viable with the locally available water, can be grown with the desalinated water; 2) incremental income that can be derived from the newly introduced crop; 3) cost of technologies for control of production environment that are needed for raising the crop and their implications for crop productivity; 4) what kind of market exists for the crops; and, 5) whether the farms have easy access to the market.

If the availability of desalinated water makes it possible to grow sensitive, high value crops throughout the year with the use of production control technologies (poly house, net house, drip irrigation, plastic mulching and pesticides), and if a good market exists for these crops, there will be perennial demand for it in any climatic condition. The production control technologies include: 1) water management technologies (RO for water quality, drip irrigation for precision irrigation and mulching for evaporation control and seed germination); 2) greenhouses (net house and poly house with foggers) for temperature, radiation and humidity control; 3) and expensive seeds of high yielding crop varieties.

The influence of this economic opportunity on WTP is evident from the higher reported willingness to pay for water in North Gujarat, which is experiencing consistent decline in groundwater availability, quality, and an increase in cost of pumping water, as compared to coastal Saurashtra—where the water quantity and quality situation keeps varying from year to year. Nevertheless, the WTP for water is higher for plantation crops, as achieving year round water security is crucial for saving the long-term investments. Economic opportunities also drive a higher WTP for water used for producing vegetables and fruit crops by farmers in Western Rajasthan.

The value of a resource gives an indication of the price users are willing to pay for it. The surplus value product from the use of a resource in a particular economic activity is the economic value of the resource in that activity. In the case of irrigated crop production, the net economic return per unit volume of water applied to the crop or the net water productivity in economic terms (Rs/m^3) can be considered as the surplus value product from the use of irrigation water, or the economic value of water in irrigated crop production. Thus, the net water productivity of a crop (\$/m^3) can indicate the price that farmers are willing to pay for water to irrigate that crop. The net economic return from crop production per unit volume of water or the WP of crops in economic terms vary with change in crop type, change in methods of irrigation and production control technologies.

Crops, such as marigolds and Gerbera daisy daisies, fruits (kinnow, berries, watermelon), and some vegetables (chilies, tomatoes and cabbage), yield very high economic return per unit volume of water, as the values are much higher as compared to some commonly grown vegetables (such as potatoes and cluster bean) and cash crops (castor and ground nut), and far higher than the traditional cereal crops. Many of these crops, however, are also high risk in terms of production and market. Production risk is applicable to many fruits and vegetables (mandarin oranges and chilies). Market risk, resulting from wide fluctuation in price of the produce, is more applicable to marigold, though many of the fruits and vegetables experience price fluctuations. The use of precision farming technologies helps mitigate production risks in many crops.

There is however, significant variation in water productivity amongst crops and regions. Watermelon grown in coastal Saurashtra (under drip irrigation) generates a value of Rs. 774.5/m^3 of water; coconuts at Rs. 80.9/m^3 with saline groundwater and Rs. 161.8/m^3 with fresh groundwater; and chilies at Rs. 232.2/m^3. Marigold flowers produced in North Gujarat generate a value of Rs. 131.7/m^3; watermelon generates Rs. 105.6/m^3 of water, and fennel generates Rs. 77.2/m^3 of water. Chilies and tomatoes grown in Western Rajasthan (under traditional method of cultivation) produce a net economic return of around Rs. 70.8/m^3 of water and 65.9/m^3, respectively; cabbage produces a net return of Rs. 193.0/m^3 of water under traditional method of cultivation and irrigation. Tomatoes under net house produce a net return of Rs. 97.6/m^3 of water. Marigold produces a net return of Rs. 94.6 to 106.1/m^3 of water in monsoon and winter, respectively. For berries (under drip irrigation), the net economic return was as high as Rs 287.8/m^3 of water. In Southwestern Punjab, mandarin oranges grown with canal water produces a net return of Rs. 786.3/m^3 of water. Seedless cucumber in Western Rajasthan (under poly house) had a net return of Rs. 903.5/m^3 of water, and in Southwestern Punjab, it was as high as Rs. 1418.7/m^3. Whereas for some of the traditional cereal crops, it is quite low: Rs. 2.5/m^3 for wheat, Rs. 3.7/m^3 for pearl millet in North Gujarat, even under sprinkler irrigation. For the traditional cash crops such as castor and summer ground nut, it is higher (Rs. 9.6/m^3 for summer groundnut and Rs. 19.3/m^3 for castor with drips) than that of traditional crops.

The net water productivity, in economic terms, increases with the use of precision irrigation technologies (drip irrigation) and production control (precision farming) technologies, such as net house and poly house with drip irrigation and foggers. The productivity also increases with cultivation practice, transplanting of seeding from nursery against direct seeding, and plastic mulching. In the case of tomatoes in Western Rajasthan, it was Rs. 97.6 against Rs. 65.9. What is equally important is the fact that crops, such as seedless cucumber and Gerbera daisy, which have very high water productivity in economic terms (Rs. 1418.7/m^3 and Rs. 903.5/m^3 for seedless cucumber in SW Punjab and Western Rajasthan, respectively; and Rs. 634.3/m^3 for Gerbera daisy in SW Punjab), could be grown only with the help of net house and poly house. Hence, the price that people will be willing to pay for water may also increase if they start using precision farming techniques and good agronomic practice.

The significant improvement in yield and net returns through the use of good quality groundwater and the ability to grow crops that give high returns per unit area of land will be a major determinant for the farmers to purchase expensive water in the saline areas.

Farmers are already investing substantial amount of capital for production technologies, such as seeds and seedlings of high value vegetables (tomatoes, seedless cucumber), fruits (watermelon) and flowers (marigold and Gerbera daisy), as these crops obtain very high yields, and high quality produce. For watermelon, the cost of seeds is Rs. 34,000 per kg and the cost of seeds per ha of cultivation of the crop is Rs. 102,000 ($1500). For papaya, the seedling cost is Rs. 43,500 per ha, at Rs. 15 per seedling ($654). The seed cost is Rs. 180,000 per ha ($2,700 per ha) for marigold cultivation and Rs. 60,000 per ha ($900) for tomatoes (requiring 600 gram of seeds per ha at Rs. 100,000 per kg). For cucumber, the cost of seeds is Rs. 6 per plant, and with a plant density of 25,000 per ha, the cost is Rs 150,000 ($2,255) per ha of planting. For Gerbera daisy flowers, the seedling cost is Rs. 32.25 per plant, and with a plant density of 6 per sq. m., the initial investment for planting becomes Rs. 2,000,000 ($30,000 per ha) for a three-year life of the crop. The graphical representation of the cost figures for these six crops is in Figure 16.

The capital investment for production technologies ranges from Rs. 422 per sq. m for poly house and Rs. 330 for net house, after a 50 percent capital subsidy from the National Horticultural Mission. With an expected life of ten years for the poly house and eight years for the net house, with a discount rate of 9 percent, this works out to an annual cost of Rs. 654,000 per ha ($9,82) for poly house and Rs. 546,000 per ha ($8,223) for net house. These high capital investments motivate farmers to use the facility year round.

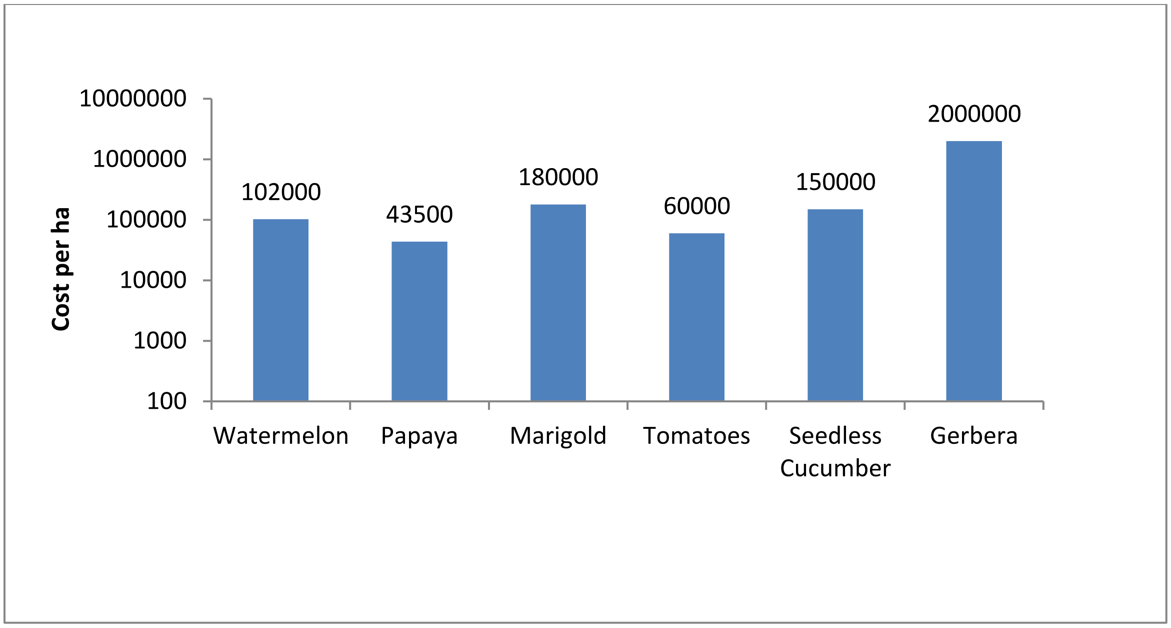

Figure 16: Cost of seed (Rs) per ha.

Though the Contingent Valuation Method (CVM) employed to assess the willingness to pay for desalinated water did not yield any definitive results, it showed that the WTP is quite high in Western Rajasthan and North Gujarat and was as high as 25 percent to 50 percent of the net return from crop production. This can be attributed to the fact that irrigation water input is critical for crop production, even during the kharif season, due to the high aridity and very low rainfall. Farmers had the technical skills to raise flowers and vegetables, which fetch very high prices in the market.

Small-scale desalination viability is determined by the location, type of crop, and the time of year for which it is environmentally and socio-economically feasible, and by whether the farmer has the necessary technical skills. With easy access to precision farming technologies, it is possible to grow high value exotic vegetables, fruits and flowers, which were once alien to these hot, arid, and water-scarce regions, provided technical training is available for the farmers. With the presence of niche market in the vicinity, investing in an expensive desalination system for treating water will be viable if there is high return from the use of treated water.

Given the wide range in the net economic return (exclusive of irrigation cost) per unit volume of water generated from the use of water for crop production (from around Rs. 70/m^3 for tomatoes to Rs. 1,418.5/m^3 for seedless cucumber), it is quite evident that the viability of using desalinated water for a given high value crop, or the number of high value crops for which the desalination technology will be viable, depends on the cost of water use. In other words, the demand for desalinated water is a function of the price, or in other words, lowering the price will increase the total demand for the water, as more crops could be irrigated with the water in an economically efficient way.

With five different price scenarios for desalinated water, the simulation was carried out with to identify viable crops, where the net economic return per m^3 of water exclusive of irrigation cost exceeds the price per m^3 of water with a profit margin coefficient of 1.04. This profit margin coefficient considered for our analysis has a strong empirical basis in the sense that the water prices considered for estimating the profit margin coefficient were obtained during the field survey as the price which farmers are willing to pay for the water for the existing cropping pattern. The farmers, in two of the salinity-affected belts of two water-scarce regions, expressed that they will be willing to pay as much as half of the net income they get from the use of water purchased from the market as the price for water. The prices considered are: \$0.20 per m^3 of water; \$0.50 per m^3 of water; \$1.0 per m^3 of water; \$1.50 per m^3 of water; \$2.0 per m^3 of water.

Under the lowest price scenario of \$0.20/m^3 of water, several vegetables, cash crops, fruits and nuts are viable. They are: 1) chilies, tomatoes, cabbage and seedless cucumber (vegetables); 2) marigold and Gerbera daisy (flowers); 3) fennel and cumin (spices); 4) kinnow, watermelon and berries (fruits); and, 5) coconuts.

Under the second lowest price scenario (i.e., \$0.5/m^3 of water), several vegetables, cash crops, fruits, nuts and flowers are viable. They are: 1) chilies, tomatoes, cabbage and seedless cucumber; 2) marigold and Gerbera daisy; 3) kinnow, berries, watermelon and pomegranate; 4) fennel; and, 5) coconuts. Chilies are grown extensively in Saurashtra, North Gujarat and Western Rajasthan and have become a profitable crop for the farmers in these regions due to the growing market for this crop. Papaya, which is also grown extensively in North Gujarat and is highly profitable (in terms of return per ha of land), is found to be unviable even at this price, precisely because it is a water-intensive crop.

Under the third price scenario, i.e., \$1.0/m^3 of water, the following crops are found to be viable: 1) tomatoes, cucumber, green chilies (Saurashtra and Western Rajasthan) and cabbage; 2) marigold and Gerbera daisy; and, 3) berries, kinnow, watermelon and pomegranate; 4) fennel; and 5) coconuts. Tomatoes, whose market is growing consistently, are grown extensively in North Gujarat, Western Rajasthan and Southwestern Punjab. Marigold is grown in North Gujarat, Western Rajasthan and Southwestern Punjab, and demand for this flower is growing even in small towns.

In the fourth price scenario (\$1.5/m^3 or Rs. 100 per m^3), the following crops are found to be viable: 1) cabbage in Western Rajasthan and seedless cucumber grown in both Western Rajasthan and Southwestern Punjab, and chilies in coastal Saurashtra; 2) watermelon, mandarin oranges and berries; and, 3) only Gerbera daisy, grown in poly house. Our survey covered berries grown in Western Rajasthan only. However, this crop is viable in North Gujarat due to similar environmental conditions, specifically soils and climate. Cabbage is widely grown in North Gujarat, though our survey did not capture this crop. Seedless cucumber and cabbage can also be grown in North Gujarat.

In the highest price scenario, all these crops, except chilies will be viable. However, as per the estimates, watermelon will be viable only in Saurashtra, which has heavy clayey soils that reduces the frequency of water application. It may not be viable in North Gujarat, where it yields a net economic water productivity of only Rs 105.6/m^3. Overall, the analysis shows that all the four regions have at least one crop that is viable with desalinated water, if the price of water is kept at \$1.0/m^3, with Southwestern Punjab, coastal Saurashtra and Western Rajasthan having three crops each. If the price is \$1.5/m^3, three out of the four regions will have at least one crop. Southwestern Punjab and Western Rajasthan will still have three viable crops. Even under the highest price of \$2.0/m^3 of water, all the three crops from Southwestern Punjab will be viable; and Western Rajasthan will have two crops, with coastal Saurashtra having one crop.

According to the study, the demand for expensive desalinated water for irrigation is highest in the hot and dry regions of North Gujarat, Western Rajasthan and Southwestern Punjab, and this demand could be year-round given the extremely low rainfall. Enterprising farmers, who are quick to acquire knowledge about raising high value crops and precision farming technologies, will first adopt the desalination technologies. The probability of adoption will increase with a closer proximity to urban centers. With farmers beginning to use precision farming technologies in these regions, the viability of using this water is high as farmers could grow high value exotic fruits, vegetables and flowers. Institutional interventions, such as that of the National Horticulture Mission through subsidies for precision farming systems are very instrumental in promoting the use of desalinated water for crop production in these regions.

The macro level analysis (results of which are presented in the first phase report) has shown that subsidies exist for surface irrigation water, electricity used for groundwater pumping, and purchase of micro irrigation systems. The capital cost subsidies in public irrigation is high in regions of scarcity (approximately \$1,000/ha) and also high for recently built irrigation infrastructure. Energy costs and energy subsidies for groundwater pumping (\$/m^3 of water) are high in water scarce regions (approximately \$0.1/KWhr). The societal cost for pumping groundwater ranges from \$0.12-0.27 per m^3 of water. Subsidies for MI systems from both national and state governments increased over the years; water scarce states were the largest beneficiary. Since 2009-10, the total subsidy since is around \$1.1 billion at current prices.

In the case of desalinated water use for crop production, there is no depletion of fresh water resources from the natural water system, and every unit of freshwater, produced from marginal quality groundwater for irrigating crops, produces positive results for society. Hence, capital subsidies can be provided to the farmers setting up desalination plants for producing good quality water for crop production. This subsidy can be in the range of \$0.2 to 0.3 per m^3 of water, if we take into account the current level of subsidy for canal water used for irrigation and electricity supplied for groundwater pumping. This level of subsidy will increase the demand for desalinated water for agriculture, and it will improve the economic viability of irrigating more crops with desalinated water in the four regions studied.   Simultaneously, the subsidies for water from public irrigation schemes and electricity supplied for groundwater pumping in agriculture can be reduced in these areas to further improve comparative economics of using desalinated for growing high value crops, making more irrigated crops viable. The growing demand for fruits, vegetables and exotic flowers in cities will further boost adoption of desalination technologies in farming within the vicinity of urban centers.

CONCLUSIONS

Two methods were employed to study the technical feasibility and socio-economic viability of using expensive desalinated water for agricultural production in areas affected by groundwater salinity and where marginal quality groundwater is used for irrigation due to acute shortage of freshwater resources. The first method was a direct one in which the farmer is confronted with the question of how much he/she will be willing to pay for the water, which is used for raising crops. The second one was a proxy method in which the economic value of water use in agriculture was assessed by estimating the surplus value product from the use of good quality water for various crops, to ascertain an affordable price for farmers. In order to use the proxy method, the cropping systems of farmers using good quality well water in the nearby areas, falling in the same agro climatic setting as that of the saline groundwater area, were studied.

The study covered four locations from three states of Western India, coastal Saurashtra, North Gujarat, Western Rajasthan and Southwestern Punjab. These regions are agriculturally prosperous with diversified cropping systems, but have very high un-met demand for water for irrigation owing to vast tracts of arable land, low rainfall and high aridity. With very limited surface water resources, the limited fresh groundwater resources were mined. The regions also have abundant marginal quality groundwater, which is used for crop production, generating low yields and income. It shows that the surplus value product from the use of water for crop production (or the net economic return from crop production per unit volume of irrigation water), varies widely amongst crops from the lowest values for some of the traditional cereal crops (i.e., wheat, rice, pearl millet) to higher values for cash crops (i.e., groundnuts, potatoes, cotton, coriander and cumin) to the highest values for crops (i.e., watermelon, kinnow, berries [fruits], marigold, Gerbera daisy [flowers] and seedless cucumber, chilies and tomatoes [vegetables], and coconuts). The difference in economic value of water use between low value crops to high value crops can be as high as 1:500 even in the same agro climatic region.

Therefore, the question is not whether small-scale desalination will be economically feasible for agriculture or not. Instead, the question is for which crop the technology becomes most viable, both environmentally and socio-economically, in a particular region, and whether the farmers have the required technical skills to grow the crop. All of the four regions surveyed (namely, coastal Saurashtra, North Gujarat, Western Rajasthan and Southwestern Punjab) are suitable for growing some high value crops that yield remarkably high return per unit volume of water. Given the absolute physical scarcity of fresh water in these regions and the emerging market for exotic vegetables, fruit and flowers that yield very high return per unit volume of water, farmers in areas closer to cities will be able to procure expensive desalinated water to grow such crops. The simulation study showed a profit margin of more than 1.04, under the highest price scenario ($2.0/m^3) of irrigation water, for these crops. Easy access to technologies for control of the production environment and the impressive institutional support from National Horticultural Mission and the State Agricultural Departments through capital subsidies will make it easier for highly enterprising farmers to adopt these new crops, in hot and arid regions.

Among the four regions analyzed, the highest potential for desalinated water appears to exist in Western Rajasthan, due to the acute scarcity of fresh water, and the good market for fruits, vegetables and flowers. If a capital subsidy is provided to farmers who set up desalination plants, on the basis of the production capacity, more crops will become viable, owing to major increase in profit margins, and resulting in a disproportionately high increase in demand for desalinated water. Subsidized water will not only increase the net water productivity in economic terms (Rs/m^3), but also reduce the actual price farmers will pay for the water. Significant financial resources are currently diverted by the state governments for subsidizing electricity for pumping groundwater in agriculture and subsidizing irrigation water from public systems in water scarce regions. Some of these subsidies (especially in the agricultural power sector) produce negative welfare effects in semi-arid and arid water-scarce regions through groundwater depletion. Part of these resources can be diverted for subsidizing desalination systems in regions with acute scarcity of freshwater, with an aim to bring down the cost of desalinated water.

The study also validates that analyzing the economic value of water use in crop production is a more viable way of assessing the farmers' ability and willingness to pay for expensive desalinated water for agricultural production, versus using the Contingent Valuation Method (CVM). The CVM did not yield any definitive results for farmers' willing to pay prices. One reason for this is that farmers who are currently using marginal quality groundwater rarely grow high-value crops and therefore do not have a quantitative understanding of how much income can be earned from every unit of good quality water in farming. Consequently, they tend to relate the WTP with the price of water being traded by neighboring well owners.

REFERENCES

Bassi, N. (2016) Managing groundwater energy nexus in India: The curious case of using solar irrigation pumps with drip systems, in: Micro Irrigation Systems in India: Emergence, Status and Impacts. Viswanathan, P. K., Kumar, M. D., & Narayanamoorthy, A. (Eds), Springer, Singapore, pp. 155-167.

Bassi, N. and M. D. Kumar (2011) Can Sector Reforms Improve Efficiency? Insight from Irrigation Management Transfer in Central India, International Journal of Water Resources Development, 27(4):709-721.

Central Ground Water Board (2016a) Groundwater year book 2014-15, Rajasthan State, Regional Office Data Centre-Jaipur Region, Central Ground Water Board, Western Region, Jaipur, January 2016.

Central Ground Water Board (2016b) Groundwater Scenario of India January 2016, Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation, Faridabad.

Central Water Commission (2015) Financial Aspects of Irrigation Projects in India, Information System Organization, Water Planning and Projects Wing, Central Water Commission, Ministry of Water Resources, Government. of India, December.

Government of India (2010) Ground Water Quality in Shallow Aquifers of India, Central Ground Water Board, Ministry of Water Resources, Government of India, Faridabad, India.

Government of India (2012) Ground water year book 2011-12, Central Ground Water Board, Ministry of Water Resources, Government of India, Faridabad, Haryana, India.

Government of India (GoI) (2014) Annual report (2013-14) on the working of State power utilities & electricity departments, Power & Energy Division, Planning Commission, Government of India, New Delhi.

Government of Rajasthan and Rolta India Limited (2013) *Hydrogoelogical Atlas of Rajasthan,* Prepared under the India-EU State Partnership Programme, Ground Water Department, Government of Rajasthan, Jaipur.

Indu, Rajnarayan (2002) Fluoride Free Drinking Water Supply in North Gujarat: The Rise of Reverse Osmosis Plants as a Cottage Industry-An Exploratory Study, Report submitted to IWMI-Tata Water Policy Research Program, International Water Management Institute-Field Office, VV Nagar, Gujarat, India, July, 2002.

Kumar, M. Dinesh (2007) Groundwater Management in India: Physical, Institutional and Policy Alternatives, Sage Publications, New Delhi

Kumar, M. Dinesh, Ankit Patel, R. Ravindranath, OP Singh (2008) Chasing a Mirage: Water Harvesting and Artificial Recharge in Naturally Water-scarce Regions, Economic and Political Weekly,43 (35), August 30-September 05, 2008.

Kumar, M. Dinesh, OP Singh and MVK Sivamohan (2010) Have diesel price hikes actually led to farmer distress in India? Water International, 35 (3): 270-284.

Kumar, M. Dinesh, C. A. Scott and OP Singh (2011) Inducing the Shift from Flat Rate or Free Agricultural Power to Metered Supply: Implications for groundwater depletion and power sector viability, Journal of Hydrology, 409, 1-2, 28 October, 2011.

Kumar, M. Dinesh, Christopher A. Scott and O.P. Singh (2013) Can India raise agricultural productivity while reducing groundwater and energy use? International Journal of Water Resources Development, 29 (4): 557-573.

Mukherji, Aditi (2005) The Spread and Extent of Irrigation Rental Market in India, 1976-77 to 1997-98: What Does the National Sample Survey Data Reveal?," Water Policy Research Highlight, IWMI-Tata Water Policy Program, VV Nagar.

Ministry of Agriculture and Farmer Welfare (2016) Horticulture Statistics at a Glance 2015, Horticulture Statistics Division, Dept. of Agriculture, Cooperation and Farmer Welfare, Ministry of Agriculture and Farmer Welfare, Government. of India, published by Oxford University Press, New Delhi.

Palanisami, K. (2009) Water Markets as a Demand Management Option: Potentials, Problems and Prospects, in R. Maria Saleth (Ed), Promoting Irrigation Demand Management in India: Potentials, Problems and Prospects, Strategic Analyses of the National River Linking Project (NRLP) of India: Series 3, International Water Management Institute, Colombo, Sri Lanka.

Reddy, V. Ratna (2016) Techno institutional models for managing water quality in rural areas: case studies from Andhra Pradesh, India, International Journal of Water Resources Development, http://dx.doi.org/10.1080/07900627.2016.1218755.

Saleth, R. M. (1999) Water Markets in India: Economic and Institutional Aspects. In Markets for Water: Potential and Performance, ed. K.W. Easter. Kluwer, Dordrecht, the Netherlands.

Shah, T (1993) Groundwater Markets and Irrigation Development: Political Economy and Practical Policy, Oxford University Press, New Delhi.

Young, R. A. (1996) Measuring economic benefits for water investments and policies, World Bank Technical Paper 338, Washington, 1–119.

ANNEX 1: ESTIMATION OF WATER PRODUCTIVITY OF IRRIGATED CROPS

Various Definitions

Water productivity of crops in economic terms (or net water productivity of crops) is defined as the ratio of net income obtained from crop production per unit volume of water used for producing that crop. The economic water productivity can be estimated in relation to either the total amount of water consumed for crop production (Evapo-transpiration (ET)) or the total volume of irrigation water used in the farm. Since in this case, we are concerned with the amount of water applied by the farmers to their crops and the cost incurred for the same, the denominator used in water productivity estimates is the total volume of irrigation water used.

The gross return per unit volume of water is the gross return from production of a crop per unit volume of irrigation water used. The gross return takes into account the revenue earned from the sale of crop main product and by-products.

The net water productivity exclusive of irrigation cost is the ratio of the net income from crop production, exclusive of irrigation cost, and the volume of irrigation water applied. In estimating the net income exclusive of irrigation cost, the input cost, which is subtracted from the gross return to arrive at the net income, will include the cost of all inputs except that of irrigation water.

Analytical Procedure

The gross return from crop production (GR_{Crop}) is estimated by using the following equation:

$$\mathrm{GR}_{Crop} = \left[\left(Y_{MP} * FHP_{MP}\right) + \left(Y_{By-P} * FHP_{By-P}\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

The net return from crop production NI_{crop} for those crops having by-products which do not get used for dairying will be estimated as:

$$NI_{Crop} = \left[\left(Y_{MP} * FHP_{MP}\right) + \left(Y_{By-P} * FHP_{By-P}\right)\right] - C_{Input} \quad \ldots\ldots\ldots \text{(2)}$$

Here, Y_{MP} is the yield of main product (Quintal) per ha; FHP_{MP} is the farm harvest price of main product (Rs/kg); Y_{By-P} is the yield of by-product (Quintal/ha) and FHP_{BY-P} is the farm harvest price of by-products (Rs/kg); C_{input} is the total cost of all inputs used for crop production per ha. The cost components considered for estimating input cost are: cost of seeds, machinery hiring charges, labor (for land preparation, sowing, weeding, irrigation and harvesting), fertilizers and pesticides, production and supply of irrigation water, MI systems (drips and sprinklers) and the technologies for control of production environment (poly house and net house).

The irrigation cost was estimated by adding up the annualized capital cost of the system (wells, tube wells, pump sets in the case of private irrigation source) obtained using the discounting technique (based on the life of the system in years and the discount rate) and the annual operation cost. The life of tube well was assumed as 15-20 years and that of the pump was assumed as 15 years. The total annual cost was apportioned among various irrigated crops on the basis of the total volume of irrigation water used by each crop in a year or the duration for which a particular crop occupies the land in a crop year. The life of the MI system was assumed as 10 years. In the estimation, the MI system cost was not included in the irrigation cost and instead considered as part of the other input costs.

For the purpose of simulation to analyze the demand for desalinated water, a tentative price of desalinated water will be imputed, along with the prevailing cost of irrigation and other inputs to arrive at the total input cost so as to estimate water productivity of the crops irrigated with desalinated water.

In the case of crops, which have rain fed yield, the incremental income over the income from rain fed production should be considered.

In situations where farmers are using marginal quality water for irrigation for an entire area, the incremental income due to improved yield will have to be considered.

The gross return per unit volume of water in crop production of crop i can be estimated as:

$$GWP_{Crop\ I} = GR_{Crop,\ i}/V_{Crop,\ i} \dots\dots\dots\dots \ (3)$$

The net economic water productivity (or water productivity in economic terms) of crop i can be estimated as:

$$WP_{crop\ i} = NI_{crop,\ i} / V_{crop,i} \ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Where V_{crop,i_i} is the volume of water applied to crop i. In the case of drip/sprinkler irrigated crops, the volume of water applied to the crop is estimated by multiplying the number of drip emitters/sprinkler heads and the discharge of the emitter/sprinkler nozzle and the total number of hours of irrigation (no. of irrigations X hours of irrigation per watering). In the case of flood irrigated plot, the discharge is either measured using a bucket and stopwatch (wherever possible) or estimated by using the following equation:

$$Q = (PHP \text{ X } 75 \text{ X } \mu / (1000 \text{ X } H)) \ldots\ldots\ldots\ldots \text{(5)}$$

Where PHP is the pump horsepower; Q is the discharge in m^3/sec; H is the total head (suction + delivery) and μ is the pump efficiency. Where measurement of discharge was not possible, estimated values of pump efficiency for the pumps, whose discharge was measured, were used.

To start with, the gross and net return from crop production will be estimated for different crops, as per the actual costs of irrigation water and other inputs incurred by the farmers. Accordingly, the gross return per unit volume of water and net water productivity in economic terms will be estimated by dividing the gross return and net return, respectively by the volume of water used for irrigation.

The analysis will be repeated for different scenarios with added price of desalinated water to see which of the crops will be economically viable, for a given price of the water. This will be done by estimating the value of (∅**),** the profit margin coefficient for different high value crops under different price scenarios for desalinated water. With a decrease in price of desalinated water, not only will the net water productivity that farmers have to secure will decrease, but the water productivity which they actually secure will increase, thereby improving the economic viability.

ANNEX 2: NAMES OF STATES AND DISTRICTS WHERE SALINITY EXCEEDING 3000 µS/CM IS ENCOUNTERED IN PARTS (SOURCE: GOI, 2010)

Name of State	Parts of Districts Having TDS higher than 2000 ppm (3000 µS/cm)		
Andhra Pradesh	Anantapur, Kurnool, Cuddapah	Nellore, Prakasam, Guntur	Krishna, East Godavari, Srikakulam, Visakhapatnam
Delhi	North West	West Delhi	South Delhi
Gujarat	Ahmadabad, Amreli, Anand, Bharuch, Rajkot, Sabarkantha, Surat, Vadodara	Bhavnagar, Banaskantha, Dahod, Porbandhar, Junagadh, Surendranagar	Jamnagar, Kachchh, Kheda, Mehsana, Navsari, Patan, Panchmahals
Haryana	Bhiwani, Faridabad, Fatehabad, Gurgaon	Hissar, Jhajjar, Kaithal, Mahendragarh, Panipat	Rewari, Rohtak, Sirsa, Sonepat
Karnataka	Bijapur, Bagalkot, Belgaon, Bellari	Chitradurga, Chikmangalur, Devangiri,	Dharwar, Gadag, Gulbarga, Haveri, Raichur, Udupi
Maharashtra	Ahmadnagar, Akola, Amravati, Buldaba	Chandrapur, Jalna, Jalgaon, Nasik	Parbhani, Satara, Wardha
Madhya Pradesh	Bhind	Indore	Ujjain
Punjab	Bhathinda, Firozpur,	Faridkot, Mansa,	Muktsar, Sangrur
Rajasthan	Ajmer, Alwar, Barmer, Bharatpur, Bundi, Bikaner, Churu, Chittorgarh, Dhaulpur	Dausa, Ganganagar, Hanumangarh, Jaipur, Jaisalmer, Jalore, Jhunjhununn, Jodhpur, Karoli, Nagaur, Neemuch	Pali, Raja Samand, Sirohi, Sikar, Sawai Madhopur, Tonk, Udaipur
Tamil Nadu	Coimbatore, Chennai, Cuddalore, Dindigul, Dharmapuri, Thanjavur, Thoothukkudi,	Erode, Pudukottai, Ramanathapuram, Salem, Karur, Namakkal,	Thiruchirapalli, Tirunelveli, Vellore, Villupuram, Virudhanagar

		Perambalur, Thiruvannamalai	
Telangana	Mahbubnagar, Nalgonda	Khammam, Warangal	Medak
Uttar Pradesh	Agra, Aligarh	Hathras	Mathura
West Bengal	Haora, Mednipur	North 24-Pargna	South 24-Pargana

Note: Districts where high level of salinity is encountered in minor/local spots are not included in the list.

ANNEX 3: AREA UNDER FRUIT CROPS IN DIFFERENT DISTRICTS OF SELECTED STATES IN INDIA ('000 HA)

State	District	Gooseberries	Banana	Citrus	Grapes	Guava	Mango	Papaya	Pineapple	Pomegranate	Sapota	Watermelon	Cucumber
Andhra Pradesh	E. Godavari		15.47										
Andhra Pradesh	Prakasam			17.01				1.51			2.74		
Andhra Pradesh	Kurnool												
Andhra Pradesh	Rangareddy				0.82	3.15							
Andhra Pradesh	W. Godavari		7.86								0.56		
Andhra Pradesh	Chittoor				0.08		67.3	1.1					
Andhra Pradesh	Kadapa		14.75	11.84			23.37	5.15		0.15			
Andhra Pradesh	Mahbubnagar			26.58							0.58		
Andhra Pradesh	Nizamabad				0.35								
Andhra Pradesh	Anantapur		8.74	64.24		2.1		7		3.66	3.95		
Andhra Pradesh	Krishna					1.54	59.84						
Andhra Pradesh	Guntur									1.41	1.57		
Andhra Pradesh	Karimnagar									0.12			
Andhra Pradesh	Srikakulam												
Andhra Pradesh	Medak				0.04	0.69		0.94		0.57			
Andhra Pradesh	Nalgonda			102.71									
Andhra Pradesh	Khammam					0.75	43.33						

State	District	Gooseberries	Banana	Citrus	Grapes	Guava	Mango	Papaya	Pineapple	Pomegranate	Sapota	Watermelon	Cucumber
Andhra Pradesh	Adilabad						24.2						
Andhra Pradesh	Vizianagaram		7.76				47.63						
Andhra Pradesh	Warangal						29.6						
Andhra Pradesh	Visakhapatnam				0.25								
Gujarat	Baroda	0.89	10.21	2.745				2.13		0.65			
Gujarat	Anand	1.58	16.1	5.52				2.63					
Gujarat	Banaskantha									1.62			
Gujarat	Ahmedabad												
Gujarat	Junagadh						21.03				4.91		
Gujarat	Surendranagar												
Gujarat	Sabarkantha							1.68		0.62			
Gujarat	Gandhinagar	0.71		2.051									
Gujarat	Valsad						29.4				3.11		
Gujarat	Navsari						23.94				6.32		
Gujarat	Kutch						8.5	2.54		1.96			
Gujarat	Amreli						6.75						
Gujarat	Kheda	**2.58**		2.229									
Gujarat	Tapi							1.85					
Gujarat	Jamnagar												
Gujarat	Mehsana	1.97		10.431						0.48			

State	District	Gooseberries	Banana	Citrus	Grapes	Guava	Mango	Papaya	Pineapple	Pomegranate	Sapota	Watermelon	Cucumber
Gujarat	Baruch		15.88					1.28					
Gujarat	Narmada		7.81										
Gujarat	Bhavnagar			7.1				0.93			2.81		
Gujarat	Valsad						29.4				3.11		
Gujarat	Navsari						23.94				6.32		
Gujarat	Kutch						8.5	2.54		1.96			
Gujarat	Amreli						6.75						
Gujarat	Surat		8.15				8.85				2.11		
Haryana	Sonipat												
Haryana	Ambala												
Haryana	Rohtak												
Haryana	Fatehabad												
Haryana	Jind												
Haryana	Jhajjar												
Haryana	Gurgaon												
Haryana	Hissar												
Haryana	Kurukshetra												
Haryana	Yamuna Nagar												
Haryana	Panipat												
Haryana	Karnal												

State	District	Gooseberries	Banana	Citrus	Grapes	Guava	Mango	Papaya	Pineapple	Pomegranate	Sapota	Watermelon	Cucumber
Haryana	Gurgaon												
Haryana	Bhiwani												
Haryana	Faridabad												
Tamil Nadu	Tiruvallur											0.79	
Tamil Nadu	Dindigul	1.14			0.24						1.72		
Tamil Nadu	Tirupur	0.65											
Tamil Nadu	Krishnagiri				0.06						0.33		
Tamil Nadu	Tirunelveli	2.58	8.63		0.72						0.39		
Tamil Nadu	Thoothukkudi	0.48	9.76								0.36		
Tamil Nadu	Theni	0.41	6.01		1.78						0.46		
Tamil Nadu	Coimbatore		8.35		0.2								
Tamil Nadu	Thiruvannamalai											0.26	
Tamil Nadu	Vellore										0.54		
Tamil Nadu	Virudhanagar										0.57		
Tamil Nadu	Namakkal										0.46		
Tamil Nadu	Erode		12.1										
Tamil Nadu	Dharmapuri												
Tamil Nadu	Villupuram											1.73	
Tamil Nadu	Trichy		8.87									1.19	
Tamil Nadu	Kancheerpuram											0.2	

State	District	Gooseberries	Banana	Citrus	Grapes	Guava	Mango	Papaya	Pineapple	Pomegranate	Sapota	Watermelon	Cucumber
Tamil Nadu	Cuddalore		3.98										
Tamil Nadu	Salem												
Karnataka	Kolar		3.72				46.77	0.37			3.4	0.92	
Karnataka	Belgaum				2.24			0.23			1.82	0.39	
Karnataka	Chikkaballapur a				2.36		14.15				2.1		
Karnataka	Bangalore (R)				2.08								
Karnataka	Haveri		3.5								1.87	1.66	
Karnataka	Raichur												
Karnataka	Gadag												
Karnataka	Bellary		4.4					0.49		1.7	2.2	0.31	
Karnataka	Hassan								0.03		1.03		
Karnataka	Mysore		6.66									0.75	
Karnataka	Chamarajana gara		12.01					0.32				0.65	
Karnataka	Davangere												
Karnataka	Chitradurga		5.57					0.89		6.31			
Karnataka	U. Kannada								0.42				
Karnataka	Udupi								0.21				
Karnataka	D. Kannada								0.36				
Karnataka	Bijapura				8.67					1.53			
Karnataka	Ramanagara						22.36						

State	District	Gooseberries	Banana	Citrus	Grapes	Guava	Mango	Papaya	Pineapple	Pomegranate	Sapota	Watermelon	Cucumber
Karnataka	Dharwad						9.61				1.77		
Karnataka	Bagalkote									1.36			
Karnataka	Chikmangalur		6.94						0.03				
Karnataka	Bangalore (U)				0.86								
Karnataka	Kodagu								0.01				
Karnataka	Kannada												
Karnataka	Shimoga		6.03						1.58				
Karnataka	Mandya						6.15	0.5			2.06	0.91	
Karnataka	Koppal							0.65		1.68		0.5	
Karnataka	Tumkur		5.21				14.12						
Karnataka	Gulbarga		3.89					0.44					
Rajasthan	Jaipur												2.84
Rajasthan	Hanumangarh												0.07
Rajasthan	Sirohi												0.11
Rajasthan	Nagaur												0.1
Rajasthan	Udaipur												0.12
Punjab	Jalandhar												
Punjab	Kapurthala												
Punjab	Patiala												
Punjab	Ludhiana												
Punjab	S.A.S. Nagar												

State	District	Gooseberries	Banana	Citrus	Grapes	Guava	Mango	Papaya	Pineapple	Pomegranate	Sapota	Watermelon	Cucumber
Punjab	Hoshiarpur			6.78									
Punjab	Amritsar												
Punjab	S.B.S Nagar												
Punjab	Moga												
Punjab	Tarn Taran												
Punjab	Ferozpur			26.52									
Punjab	SM Sahib			5.94									
Punjab	Bhathinda			3.38									
Punjab	Ropar			1.08									

Source: Horticulture Statistics at a Glance 2015, Horticulture Statistics Division, Dept. of Agriculture, Cooperation and Farmer Welfare, Ministry of Agriculture and Farmer Welfare, GoI, 2016.

ANNEX 4: AREA UNDER VEGETABLE CROPS IN SELECTED DISTRICTS OF INDIA

District-Wise Horticultural data 2012-13 ('000 ha)															
State	District	Eggplant	Cabbage	Carrot	Cauli-flower	Green chilies	Musk Melon	Okra	Onion	Peas	Potatoes	Tapioca	Tomatoes	Garlic	Coriander
Andhra Pradesh	E. Godavari	13.3										15.7			
Andhra Pradesh	Prakasam	4.6						3.6							
Andhra Pradesh	Kurnool	4.3		0.3				4.1	16.1						
Andhra Pradesh	Rangareddy	3.8						4.1					18.5		
Andhra Pradesh	W. Godavari	3.7										0			
Andhra Pradesh	Chittoor	3.7		0.2				5.4	9.7				24.6		
Andhra Pradesh	Kadapa	3.7		0.7				4.7	5.1				13.8		
Andhra Pradesh	Mahbubnagar	3.7						3.4	8.5				14.6		
Andhra Pradesh	Nizamabad	3.7		0.2					4.6						
Andhra Pradesh	Anantapur	3.6		0.2					5.4				14.7		
Andhra Pradesh	Krishna	3.5													
Andhra Pradesh	Guntur			0.2								0.3	10.9		

District-Wise Horticultural data 2012-13 ('000 ha)															
State	District	Eggplant	Cabbage	Carrot	Cauli-flower	Green chilies	Musk Melon	Okra	Onion	Peas	Potatoes	Tapioca	Tomatoes	Garlic	Coriander
Andhra Pradesh	Karimnagar			0.1				3.7							
Andhra Pradesh	Srikakulam			0.2					4.6			0.2			
Andhra Pradesh	Medak							5.7	5.3				22.8		
Andhra Pradesh	Nalgonda							4.2					15.7		
Andhra Pradesh	Khammam							3.9					12		
Andhra Pradesh	Adilabad							3.1							
Andhra Pradesh	Vizianagaram							3.0							
Andhra Pradesh	Warangal							3.0					12.2		
Andhra Pradesh	Visakhapatnam	3.4		0.3								0.2			
Gujarat	Baroda	9.9			2.5			5.3					4.1		
Gujarat	Anand	8.3	2.2								5.0		3.9		
Gujarat	Banaskantha	6.1	3.7		5.2			4.2			43.3		6.1		
Gujarat	Ahmedabad	5.1			3.1								2.9		
Gujarat	Junagadh	4.1	2.7					1.7					1.8		
Gujarat	Surendranagar	5.8	1.7					3.7							

District-Wise Horticultural data 2012-13 ('000 ha)															
State	District	Eggplant	Cabbage	Carrot	Cauli-flower	Green chilies	Musk Melon	Okra	Onion	Peas	Potatoes	Tapioca	Tomatoes	Garlic	Coriander
Gujarat	Sabarkantha				6.6						11.9				
Gujarat	Gandhinagar	3.2	1.7					2.9			7.3				
Gujarat	Kheda				2.6								3.1		
Gujarat	Tapi	3.9						9.2							
Gujarat	Jamnagar												2.8		
Gujarat	Mehsana										7.4		3.5		
Gujarat	Surat	5.3						10.1							
Haryana	Sonipat			1.8	4.8	0.8									
Haryana	Ambala			2.2	1.6	1									
Haryana	Rohtak			1.8	2	0.9									
Haryana	Fatehabad			1.3		0.9									
Haryana	Jind			1.2	1.3	1.3									
Haryana	Jhajjar			1.3											
Haryana	Gurgaon			1.0		2.2									
Haryana	Hissar			1.0		1									
Haryana	Kurukshetra			0.9	1.4										
Haryana	Yamuna Nagar				2.8										
Haryana	Panipat				3.4	1.1									

District-Wise Horticultural data 2012-13 ('000 ha)															
State	District	Eggplant	Cabbage	Carrot	Cauli-flower	Green chilies	Musk Melon	Okra	Onion	Peas	Potatoes	Tapioca	Tomatoes	Garlic	Coriander
Haryana	Karnal				2.8	1.5									
Haryana	Gurgaon				2.2										
Haryana	Bhiwani					1									
Haryana	Faridabad			0.8											
Tamil Nadu	Tiruvallur			2.7			0.1								
Tamil Nadu	Dindigul			0.7											
Tamil Nadu	Krishnagiri			0.2											
Tamil Nadu	Coimbatore						0								
Tamil Nadu	Thiruvannamalai						0.1								
Tamil Nadu	Namakkal											14.5			
Tamil Nadu	Dharmapuri											18.4			
Tamil Nadu	Villupuram											11.5			
Tamil Nadu	Trichy											5.1			
Tamil Nadu	Kancheerpuram														
Tamil Nadu	Cuddalore														
Tamil Nadu	Salem			0.0			0					14.3			
Karnataka	Kolar			1.4		1.4							9.7		
Karnataka	Belgaum			0.7		6.8			7.1				6		

District-Wise Horticultural data 2012-13 ('000 ha)															
State	District	Eggplant	Cabbage	Carrot	Cauli-flower	Green chilies	Musk Melon	Okra	Onion	Peas	Potatoes	Tapioca	Tomatoes	Garlic	Coriander
Karnataka	Chikkaballapura			0.6									2.9		
Karnataka	Bangalore (R)			0.4											
Karnataka	Haveri					5.7			9.7				4.3		
Karnataka	Raichur					4.6	0.2								
Karnataka	Gadag					1.3			33.6						
Karnataka	Bellary					2.8	0.1								
Karnataka	Hassan					1.9						0.1			
Karnataka	Mysore					1.8	0								
Karnataka	Chamarajanagara						0.1					0.1	3.1		
Karnataka	Davangere						0.1								
Karnataka	Chitradurga						0.1		14.0						
Karnataka	Bijapura								17.8						
Karnataka	Bagalkote								14.1						
Karnataka	Chikmangalur											0.2			
Karnataka	Kodagu											0.1			
Karnataka	Kannada											0.6			
Karnataka	Mandya												3.9		
Karnataka	Koppal														

District-Wise Horticultural data 2012-13 ('000 ha)															
State	District	Eggplant	Cabbage	Carrot	Cauli-flower	Green chilies	Musk Melon	Okra	Onion	Peas	Potatoes	Tapioca	Tomatoes	Garlic	Coriander
Karnataka	Tumkur												0.9		
Karnataka	Gulbarga			0.2			0								
Rajasthan	Ajmer					0.482			0.755	0	0.000			0.005	0.119
Rajasthan	Jaipur					0.877			2.512	0	0.020			0.053	0.048
Rajasthan	Dausa					0.52			0.037	0.007	0.001			0	0
Rajasthan	Tonk					0.395			0.035	0.111	0.023			0.002	0.031
Rajasthan	Sikar					0.129			7.689	0	0.008			0.124	0.01
Rajasthan	Jhunjhunu					0.238			2.517	0	0.002			0.613	0.002
Rajasthan	Nagaur					0.58			7.801	1.141	0.004			0.1	0.006
Rajasthan	Alwar					0.131			9.926	0.063	0.052			0	0.126
Rajasthan	Bharatpur					0.185			0.069	0.063	2.840			0.002	0.001
Rajasthan	Dholpur					0.164			0.001	0.062	5.254			0.006	0
Rajasthan	S. Madhopur					2.043			0.201	0.043	0.014			0.022	0.234
Rajasthan	Karoli					0.108			0.024	0.001	0.015			0.002	0.003
Rajasthan	Bikaner					0			0.096	0.026	0.009			0.001	0.04
Rajasthan	Churu					0			0.089	0	0.000			0.001	0.023
Rajasthan	Jaisalmer					0.15			0.013	0	0.000			0	0.001
Rajasthan	Ganganagar					0.39			0.022	0	0.192			0.036	0.002

District-Wise Horticultural data 2012-13 ('000 ha)															
State	District	Eggplant	Cabbage	Carrot	Cauli-flower	Green chilies	Musk Melon	Okra	Onion	Peas	Potatoes	Tapioca	Tomatoes	Garlic	Coriander
Rajasthan	Hanumangarh					0.12			0.023	0	0.120			0.02	0
Rajasthan	Jodhpur					1.261			12.257	0	0.018			4.931	0.229
Rajasthan	Barmer					0.24			0.101	0	0.000			0	0.001
Rajasthan	Jalore					0.464			0.3	0	0.036			0.006	0.001
Rajasthan	Pali					0.371			0.179	0	0.004			0.005	0.007
Rajasthan	Sirohi					0.114			0.001	0	0.133			0.009	0.004
Rajasthan	Kota					0.39			0.017	0.054	0.172			7.439	36.704
Rajasthan	Baran					0.51			0.047	0.027	0.032			9.901	45.89
Rajasthan	Bundi					0.63			0	0.918	0.073			1.226	1.244
Rajasthan	Jhalawar					0.397			1.339	0.021	0.104			7.919	72.186
Rajasthan	Banswara					0.377			0.037	0.006	0.002			0	0
Rajasthan	Dungarpur					0.146			0.004	0	0.000			0	0.001
Rajasthan	Udaipur					0.783			0	0.043	0.000			0.019	0.029
Rajasthan	Pratapgarh					0.177			0.408	0.004	0.000			4.166	0.042
Rajasthan	Bhilwara					0.886			0.055	0.041	0.017			0.575	0.003
Rajasthan	Chittore					0.191			0.404	0.188	0.017			6.145	1.853
Rajasthan	Rajsamand					0.367			0	0	0.003			0.271	0.039
Punjab	Jalandhar						1.8				20.1				

District-Wise Horticultural data 2012-13 ('000 ha)																	
State	District	Eggplant	Cabbage	Carrot	Cauli-flower	Green chilies	Musk Melon	Okra	Onion	Peas	Potatoes	Tapioca	Tomatoes	Garlic	Coriander
Punjab	Kapurthala						1.6				9.1				
Punjab	Patiala						0.5			1.9					
Punjab	Ludhiana						0.2				6.0				
Punjab	S.A.S. Nagar						0.2								
Punjab	Hoshiarpur									6.6	16.1				
Punjab	Amritsar									5.1	5.3				
Punjab	S.B.S Nagar									1.9					
Punjab	Moga									5.9					
Punjab	Tarn Taran									1.4					

Source: Horticulture Statistics at a Glance 2015, Horticulture Statistics Division, Dept. of Agriculture, Cooperation and Farmer Welfare, Ministry of Agriculture and Farmer Welfare, GoI, 2016.

ANNEX 5: AREA UNDER CASH CROPS IN DIFFERENT DISTRICTS IN THE SELECTED STATES

State	District	Area (000 ha) under		
		Cumin	Castor	Cotton
Andhra Pradesh	E. Godavari		0.046	16.845
Andhra Pradesh	Prakasam		13.103	67.044
Andhra Pradesh	Kurnool		67.038	154.994
Andhra Pradesh	Rangareddy		3.307	60.233
Andhra Pradesh	W. Godavari		0	6.425
Andhra Pradesh	Chittoor		0.192	0.543
Andhra Pradesh	Kadapa		2.215	28.876
Andhra Pradesh	Mahbubnagar		85.6	222.536
Andhra Pradesh	Nizamabad		0.015	20.498
Andhra Pradesh	Anantapur		24.386	27.643
Andhra Pradesh	Krishna		0.02	64.514
Andhra Pradesh	Guntur		2.963	187.397
Andhra Pradesh	Karimnagar		0.239	251.375
Andhra Pradesh	Srikakulam		0	9.952
Andhra Pradesh	Medak		1.307	128.865
Andhra Pradesh	Nalgonda		6.837	297.824
Andhra Pradesh	Khammam		0	184.77
Andhra Pradesh	Adilabad		0.198	370.363
Andhra Pradesh	Vizianagaram		0.001	14.658
Andhra Pradesh	Warangal		0.886	276.412
Andhra Pradesh	Nellore		0.018	7.195
Andhra Pradesh	Visakhapatnam		0	3.013
Gujarat	Baroda			

State	District	Area (000 ha) under		
		Cumin	Castor	Cotton
Gujarat	Anand		1.4	3.3
Gujarat	Banaskantha		78.2	32.3
Gujarat	Ahmedabad		28	209.2
Gujarat	Junagadh		0.6	49.9
Gujarat	Surendranagar		39.7	499.1
Gujarat	Sabarkantha		73.4	107.1
Gujarat	Gandhinagar		30.3	113
Gujarat	Kheda		9.1	21.5
Gujarat	Tapi			4.3
Gujarat	Jamnagar		6.3	192.6
Gujarat	Mehsana		60.4	57.2
Gujarat	Bharuch		4.9	118.4
Gujarat	Dahod		0.4	0.01
Gujarat	Panchmahals		3.6	9.8
Gujarat	Patan		48.9	68.5
Gujarat	Narmada		0.3	40.6
Gujarat	Amreli		2.2	269.4
Gujarat	Kutch		75.4	76.9
Gujarat	Bhavnagar		0.6	301
Gujarat	Porbandhar		0.3	7.1
Gujarat	Rajkot		12.9	356.9
Gujarat	Vadodara		14.8	166.3
Gujarat	Surat		0.3	1.3
Haryana	Sonipat			1.987
Haryana	Ambala			0.004

State	District	Area (000 ha) under		
		Cumin	Castor	Cotton
Haryana	Rohtak			10.757
Haryana	Fatehabad			85.542
Haryana	Jind			66.780
Haryana	Rewari			1.788
Haryana	Palwal			0.876
Haryana	Sirsa			198.745
Haryana	Mewat			0.079
Haryana	Mahendragarh			4.461
Haryana	Kaithal			10.148
Haryana	Jhajjar			0.014
Haryana	Gurgaon			0.181
Haryana	Hissar			145.604
Haryana	Kurukshetra			0.002
Haryana	Yamuna Nagar			
Haryana	Panipat			0.066
Haryana	Karnal			0.014
Haryana	Bhiwani			62.612
Haryana	Faridabad			0.122
Tamil Nadu	Tiruvallur			1.320
Tamil Nadu	Dindigul			2.155
Tamil Nadu	Krishnagiri			1.506
Tamil Nadu	Madurai			5.182
Tamil Nadu	Nagapattinam			0.675
Tamil Nadu	Ramanathapuram			1.576
Tamil Nadu	The Nilgiris			0.005

State	District	Area (000 ha) under		
		Cumin	Castor	Cotton
Tamil Nadu	Thiruchirapalli			16.928
Tamil Nadu	Theni			1.173
Tamil Nadu	Sivagangai			0.161
Tamil Nadu	Virudhanagar			
Tamil Nadu	Thanjavur			1.015
Tamil Nadu	Vellore			7.725
Tamil Nadu	Perambalur			24.280
Tamil Nadu	Tuticorin			3.751
Tamil Nadu	Pudukottai			0.010
Tamil Nadu	Karur			0.063
Tamil Nadu	Erode			0.696
Tamil Nadu	Ariyalur			8.634
Tamil Nadu	Coimbatore			0.558
Tamil Nadu	Tirvannamalai			2.510
Tamil Nadu	Namakkal			2.735
Tamil Nadu	Dharmapuri			13.662
Tamil Nadu	Villupuram			6.944
Tamil Nadu	Trichy			
Tamil Nadu	Kancheerpuram			
Tamil Nadu	Cuddalore			5.067
Tamil Nadu	Salem			
Karnataka	Kolar			
Karnataka	Belgaum			
Karnataka	Chikkaballapura			
Karnataka	Bangalore (R)			

State	District	Area (000 ha) under		
		Cumin	Castor	Cotton
Karnataka	Haveri			
Karnataka	Raichur			
Karnataka	Gadag			
Karnataka	Bellary			
Karnataka	Hassan			
Karnataka	Mysore			
Karnataka	Chamarajanagara			
Karnataka	Davangere			
Karnataka	Chitradurga			
Karnataka	Bijapura			
Karnataka	Bagalkote			
Karnataka	Chikmangalur			
Karnataka	Kodagu			
Karnataka	Kannada			
Karnataka	Mandya			
Karnataka	Koppal			
Karnataka	Tumkur			
Karnataka	Gulbarga			
Rajasthan	Ajmer	13.360	0.262	17.738
Rajasthan	Jaipur	0.280	0.900	0.179
Rajasthan	Dausa	0.000	0.050	0.300
Rajasthan	Tonk	4.626	0.880	1.691
Rajasthan	Sikar	0.023	0.060	0.343
Rajasthan	Jhunjhunu	0.000	0.200	0.443
Rajasthan	Nagaur	46.590	0.169	44.745

State	District	Area (000 ha) under		
		Cumin	Castor	Cotton
Rajasthan	Alwar	0.000	0.010	16.508
Rajasthan	Bharatpur	0.000	0.540	1.529
Rajasthan	Dholpur	0.000	0.000	0.600
Rajasthan	S. Madhopur	0.002	0.000	0.250
Rajasthan	Karoli	0.000	0.010	0.176
Rajasthan	Bikaner	6.108	0.000	1.720
Rajasthan	Churu	3.113	0.000	0.420
Rajasthan	Jaisalmer	29.740	0.000	0.142
Rajasthan	Ganganagar	0.000	0.728	131.443
Rajasthan	Hanumangarh	0.000	0.777	172.385
Rajasthan	Jodhpur	106.058	39.249	26.252
Rajasthan	Barmer	137.370	37.502	0.040
Rajasthan	Jalore	122.620	87.067	0.907
Rajasthan	Pali	15.341	6.519	9.935
Rajasthan	Sirohi	4.657	43.519	2.807
Rajasthan	Kota	0.007	0.110	0.140
Rajasthan	Baran	0.003	0.000	0.140
Rajasthan	Bundi	0.008	0.090	0.950
Rajasthan	Jhalawar	0.015	0.000	0.030
Rajasthan	Banswara	0.000	0.070	12.081
Rajasthan	Dungarpur	0.000	0.435	1.356
Rajasthan	Udaipur	0.172	0.270	3.155
Rajasthan	Pratapgarh	0.157	0.010	1.180
Rajasthan	Bhilwara	4.706	0.940	50.773
Rajasthan	Chittore	0.707	0.010	17.855

State	District	Area (000 ha) under		
		Cumin	Castor	Cotton
Rajasthan	Rajsamand	0.028	0.000	7.032
Punjab	Jalandhar			
Punjab	Kapurthala			
Punjab	Patiala			1.000
Punjab	Sangrur			11.000
Punjab	Faridkot			15.000
Punjab	Muktsar			88.000
Punjab	Mansa			90.000
Punjab	Ferozpur			113.000
Punjab	Bhathinda			151.000
Punjab	Barnala			9.000
Punjab	Ludhiana			1.000
Punjab	S.A.S. Nagar			
Punjab	Hoshiarpur			
Punjab	Amritsar			
Punjab	S.B.S Nagar			
Punjab	Moga			2.000
Punjab	Tarn Taran			

ANNEX6A: FIELD NOTES FROM COASTAL SAURASHTRA

In Saurashtra: One *Vigha* = 1600 sq. m (0.40 acre).

Coastal Area Affected by Salinity in Groundwater

September 06, 2016
Village Adri, Veraval, Somnath district

We first visited a village, named Adri in Veraval taluka of Somnath district in coastal Saurashtra. The location is approximately seven km away from the coastline. We interviewed a farmer named Jatva Rambhai Jadhav bhai. He owns seven vigha of land.

He has an open well in his farm, which is approximately 60 years old. His father constructed the well, which has a depth of 200 feet. During monsoon season, the water level is 75 feet. This falls to 125 feet after winter, depleting to 175 at the peak of summer. Thus, the water level fluctuation during monsoon in a normal year is around 100 feet (30 m).

He has a drip irrigation system for irrigating the crops in the entire farm. He showed us bills revealing that the total investment for the system was Rs. 137,000. The total government subsidy was Rs. 59,000, leaving the farmer with a net expense of Rs. 78,000.

The area is salinity-affected. In a normal year, the salinity in the well water reduces and water becomes potable after good monsoon rains. By the end of December and into January, the water becomes salty. In spite of this, the farmer manages to irrigate his crops with that water. Poor rainfall and droughts can impact the quantity and quality of the well water, leaving the farmer without water for winter cropping.

The farmer recently shifted from conventional food crops and oil seeds to banana (annual crop) in nearly two vigha of land. He irrigates the banana plants with a drip system. He receives around Rs. 100 per plant (around 120 bananas per plant and Rs. 0.7 per piece), or Rs. 30,000 per vigha of crop. He also has coconut plants in the same field, which are two to three years old and not yet bearing fruit. He began growing coconuts because the plant can survive in high salinity environments. Since the coconut trees are still young, he can continue raising other crops in the farm. For instance, he still grows groundnut during kharif season, which requires one to two irrigations depending on rainfall magnitude and pattern. He also prefers cucumber and watermelon crops, which are suited to the area's climate.

He previously grew wheat in winter. However, the yield was only 500 kg/vigha (which is around 3,125 kg/ha). The farmer said this was not a good yield and that if he had higher-quality water, the yield would increase by 100 kg/vigha. He also thinks that if he had access to good quality water year round, he could increase the number of coconut plants.

He has a few mature coconut trees along the border of his farm. He gets around Rs. 600 from each tree (Rs 5 per nut and around 120 nuts per plant). With good quality water, the yield of coconuts will go up by 15 percent, and he can get an additional Rs. 150 per plant. He also mentioned he does not conduct deficit irrigation for the crop. When there is shortage of water, he reduces the crop area. During the summer, there generally is no cropping and he uses the available well water for livestock and the few coconut plants.

He will buy water for 3.5 vigha in winter (50 percent of the area) and 2.5 vigha in summer. Based on current prices in the area, he is willing to pay only Rs.80 per vigha per watering. He estimates that he will require around 8-10 irrigations in winter and another 10 in summer.

Village Supasi, Veraval Taluka, Somnath District

We met Jeevabhai Jadhav bhai, who is from the village of Supasi in Veraval taluka of Somnath district. The village is approximately seven to eight km from the coastline. He owns 7.5 vigha of land, and his brother owns the same amount of land next to his farm. He owns an open well, which is 150 feet deep, and uses rope to measure the water level.

After the monsoon season, the depth to water level is around 70 feet. By February and March, this falls to 125 feet. The depth to water level is highest (140 feet) during May and June. In other words, during the peak of summer, the depth of water column in the well is only 10 feet.

He grows groundnut in kharif season in about five vigha of land. He also grows jowar (sorghum) in around 2.5 vigha of land, which he uses for his livestock. He grows coriander in around 4.5 vigha of land in winter season and sells the seeds in the market. In summer, if he has sufficient water, he grows till in two vigha.

He had invested in a drip irrigation system for the entire farm, which he installed in the groundnut plot. He said his brother motivated him to use drip irrigation. He finds that the yield of groundnut is at least 20 percent higher with drips.

He is willing to purchase water and would like to use it to grow black gram during the summer. He thinks he can get 12-15 mann (one mann =20 kg) from a vigha of land, which will fetch Rs. 30,000 per vigha. If water is available, he hopes to buy 3 vigha during summer months to grow black gram. He is willing to pay nearly Rs. 40 per hour of irrigation, and it will require 10 hours to irrigate three vigha of land once. In other words, he is willing to invest only Rs. 130 to Rs. 140 per watering per vigha. However, after explaining the benefits, he is confident of investing Rs. 100 for every Rs. 2,000 of net income.

Adri village, Veraval taluka, Somnath District

We then met Govindbhai Parbatbhai Jotva. This man has nearly five vigha of land and grows groundnut and coconuts. His brother also owns five vigha. In one of his groundnut plots, he has four-month-old coconut plants spaced at 6 m x 6 m. In the next groundnut plot he has a one-year-old coconut plantation. The plants do not require separate inputs. The plants will mature in five years. After that, he will not be able to plant other crows as that would impact the growth of both the coconuts and the seasonal crops.

The water in his well becomes saline after the monsoon season, and coconuts are the only crop that he can irrigate with the saline groundwater. According to the farmer, the cropping pattern of the area has undergone major transformation with the replacement of banana and cereals. He said the area used to be well known for banana plants and that the plants used to produce high yields due to the coastal climate.

His brother owns mature coconut plants in the adjoining five vigha farm. He has roughly 40 trees per vigha. He irrigates the plantation with drips, two laterals per row of trees. The drip line runs for nearly 10 hours. Each plant is given 60 liters of water per day through the drips with 6 drippers per plant. The farmer invests nearly Rs. 450 per vigha for fertilizer each year and one truck full of farmyard manure (FYM) per vigha per year (Rs. 1,000 per vigha). The weeding costs around Rs. 1,000 per vigha while his yield is worth Rs. 1,000 per plant every year. We tried the tender coconut water, which was not sweet. He sells coconuts to the trader for Rs. 8 per coconut. He believes he could double the yield and income from coconuts with good quality water.

He is willing to buy water during both winter and summer and would pay Rs. 5,000 per vigha of watering (or 500 m^3 of water sufficient to irrigate one vigha for 7 months) for the matured plantation. However, he also pointed out that they will pay a higher amount for the younger plantation, as that will result in better growth of the plant and affect future yield prospects. Irrigation water productivity in coconuts irrigated with saline water is roughly Rs. 80.9/m^3 of water. The water productivity (exclusive of irrigation cost) will go up to Rs. 181.8/m^3 if fresh groundwater is available for irrigation, as the yield could double with good quality groundwater.

Fresh Groundwater Area (A Few KM Away from the Coastline)

September 07, 2016

We first met a group of three farmers in a village named Shariyakhana in Maliya taluka of Junagadh district. They were all unanimous in their opinion that groundwater availability (their only source of water for farming) is heavily dependent on annual rainfall. They said that with 40-50 inches of monsoon rains, they can irrigate the entire land during rabi (winter) season with drip irrigation. Without drip irrigation, they found it impossible to cover the entire land under irrigated production during the second season. Instead, they could only cover one third of the area (this was comprehendible because of the heavy clay soils, which cracks in the absence of soil moisture). They noted that the past couple of years had poor monsoon rain.

During summer months, only four to five wells in the village are functional, and only those farmers with functional wells raise crops during that season.

Farmer Name: KIritbhai Mohanbhai Bhuth

We also visited Kiritbhai Mohanbhai Bhuth's farm, which consists of nine vigha of land. He has an open well with a depth of 75 feet. The depth to water level after the monsoon rains is around 10 feet. After the winter, the water level falls to 50 feet, leaving only 25 feet of water in the well. In summer, the water level falls to 65 feet. The farmer mentioned he tracks his water level by counting the number of empty rings (steining wall).

He grows a wide variety of crops these days. In kharif, groundnut is the major crop. He has a standing crop of chilies in two acres, which he sowed during February this year. Chilies are a nine-month crop. He is growing a chilies crop for the first time. He said neighboring farmers have experience growing different types of vegetables and fruits, including chilies. During winter, he grows wheat (an indication of good quality of the water), onion, and coriander.

He installed a drip system for his chili crop in two vigha. For every row of the crop (spaced at four feet), there are two laterals running. The average lateral spacing is two feet while dripper spacing is 1.25 feet. The dripper discharges one liter per hour. He said that the discharge of the well goes down by nearly 25 percent in winter and 40 percent in summer. The capacity of his pump is five HP.

Farmer Name: Devjibhai Vasrambhai Heengariya

We talked to another farmer Devjibhai Vasrambhai Heengariya, who is an expert in vegetable cultivation, to get insights into chili cultivation. He said that on an average he gets around 2,000 kg of chilies from one vigha of land a month. The total production from harvest for five months is around 10,000 kg. He said the price of chilies in the markets fluctuates widely between Rs. 10 per kg to Rs. 70 per kg. He also said that around Rs. 20 per kg for chilies was quite common. Considering an average price of Rs. 15 per kg, the gross income from chili production comes to Rs. 150,000 per vigha. The total input cost – which includes fertilizers, pesticides, labor for weeding and harvesting and transportation – comes to half of this amount. Hence, the net income is Rs. 75,000 per vigha (i.e., Rs. 187,500 per acre).

The farmer irrigates his plot twice a week, with each watering taking four hours. During the cropping season, he has to irrigate his plot for seven months. The discharge of the dripper is one liter, and the spacing is 0.40 m X 0.75 m. Thus, the total water input is 85.440 m3 per week for the two-vigha plot. The total irrigation dosage is 0.74 m using drip irrigation. The water productivity exclusive of irrigation cost for irrigated chili production (under drip irrigation) is estimated to be Rs. 63.4/m3 (75,000/ (0.74 X 1600)).

This farmer also grows watermelon (Kiran-1 and Kiran-2 varieties) during summer. He receives approximately seven tons (7,000 kg) of watermelon from one vigha of land. He sells the produce in the market for Rs. 10 per kg. The highest input cost for watermelon comes from the cost of seeds. The price is Rs. 34,000 per kg and he required 0.50 kg of seeds for one vigha. The net income from watermelon, exclusive of irrigation cost, was Rs. 50,000 per vigha. This crop is also drip-irrigated. It takes only one hour to irrigate one vigha of watermelon, with dripper spacing of 0.40 m x 0.75 m. The crop will require around 12 irrigations during the entire season. The total water dosage is 64.0 m^3 (i.e., 12 x 5340 x 1/1000). He estimates water productivity, exclusive of irrigation cost, in watermelon to be Rs 780/m^3.

He is willing to purchase water, at a price of Rs. 60 per hour. He would buy water for three vigha of land in summer to grow watermelon.

Village, Mesvan, Keshod taluka, Junagadh district

We met three farmer brothers, who together own an open well, and farm 12 vigha of land. Unlike many wells in the village, their well has plenty of water. The depth of the well is 85 feet.

We first interviewed Jagdishbhai Dayabhai Goriya, one of the brothers. He said that they are able to irrigate the entire 12 vigha of land using drip irrigation throughout winter and summer in a good rainfall year. They installed the drip system in 2012-13 and have been using it for four years now. He previously would irrigate only half the land during summer months due to water shortages. He grows groundnut and black gram during kharif; wheat, cumin, coriander and green peas during winter; and pearl millet, till and vegetables during summer. The commonly grown vegetables are cucumber, long bean and chilies. He mentioned that during drought years, farmers suffered from a lack of water.

Because of increasing rates of diseases in groundnut and cotton, farmers are beginning to prefer vegetables to other crops. The farmer expressed willingness to purchase water from the market during drought years and was willing to pay one fourth of the net return he gets from every unit of water. He also indicated that he would buy water for irrigating the entire land during winter and summer months. He also indicated the WTP in terms of charges per watering per vigha as Rs. 300 based on the existing water rates in the village (this roughly makes it Rs 3 per m^3 of water, as a single watering for one vigha takes nearly 96-100 m^3 of water).

Farmer: Kantibhai Goriya

Kantibhai Goriya has a well, which yields only during kharif season. He buys water from his neighbor for winter cropping. Last year he invested in a 1,000-feet bore well, spending Rs. 90,000 and that was unsuccessful. He pays Rs. 100 per hour of irrigation to his neighbor, who offers him irrigation service. He buys water for eight vigha of land and pays Rs. 2400 per vigha for the entire season. His spends Rs. 19,200 per season on water. He grows coriander, cumin, green peas and castor. When questioned whether he prefers growing high value crops because of the high expenditure on water, he mentioned that growing high value crops such as chilies and bananas is not possible in the area due to adverse weather conditions.

Chandubhai Govindbhai Kalariya

The third farmer we met appeared to have some formal education. He has 12 vigha of land. Of this, drips irrigate six vigha while the remaining six vigha are unirrigated. Water availability has constrained the adoption of drip irrigation. He has two wells: one is 30 feet deep and the other is 85 feet deep. The drip system is installed in the farm with the deeper well.

During the winter of 2014-15 (a good rainfall year), the farmer grew wheat and cumin. During the summer, he grows till. The yield of till is 10-15 mann (20 kg) per vigha. The price is Rs. 75 per kg. He earns around Rs. 18,000 per vigha from till, and the total investment is Rs. 5,400 per vigha.

Cumin is a very risky crop and the yield can go from two mann to 12 mann per vigha. The price also varies from Rs. 20,000 to Rs. 30,000 per 20 kg (mann). This year, a water shortage in the summer of 2015 prevented him from growing any crops. He had planned to grow watermelon.

ANNEX6B: FIELD NOTES FROM BANASKANTHA DISTRICT, NORTH GUJARAT

In North Gujarat: One Vigha = 2,400 sq. m (0.60 acre)

Fresh Groundwater Area with Depletion

September 9, 2016
Village Batamal, Palanpur taluka

We met Premji bhai Choudhary, a farmer in his early 60s. He has 10 vigha of land and grows papaya and fennel as his major crops. His land is quite close to the Dantiwada irrigation reservoir. He introduced papaya in his farm three years ago, along with drip irrigation. He has an open well, which is only 150 feet deep, dug in 1987. A hard rock formation lies beyond the 150 feet strata. There is a 450 feet-long bore hole inside the well for tapping water from the consolidated rock formation lying underneath. The water availability in his well is heavily dependent on water storage in the reservoir. Not all the farmers in the village are lucky enough to have water in their wells. Some do not even get water for their livestock.

There are 3,500 papaya saplings in the five vigha plot. The total cost of the saplings was Rs. 15 per piece while the cost of FYM was around Rs. 6,000 for the entire plot. The labor for farming operations comes from a sharecropper who gets one eighth of the total gross income from the farm. The farmer installed the drip irrigation system, which has an average life of eight years, at an expense of Rs. 50,000 after a 50 percent subsidy obtained from the government. The farmer received a total income of Rs. 650,000 from the produce last year and the net profit was around Rs. 490,000 from the entire plot.

He mentioned that water input is dependent on the growth of the plant. The dosage keeps increasing during the first three months (growing stage): two hours in the first month; three hours in the second month; and five hours in the third month. Within three months, plants have reached maximum growth and the watering duration reaches eight hours.

The average spacing between laterals is 3.5 feet and the average spacing between drippers is 0.40 m. Hence he has 28,572 drippers in a plot of 12,000 sq.m (five vigha). The total amount of watering comes to 6,857 m^3 per month. However, the dosage falls to two hours during the winter season (i.e., for four months from November to February). The total is:

- March to May: 8,485 m^3
- June: No irrigation
- July to September: No irrigation due to monsoon

- October: Four hours of irrigation: 3428 m^3
- November to February: 2 hours of irrigation: 6857m^3

Hence the total amount of irrigation is 18,770 m^3 for an area of 12,000 sq. m. The depth of watering is 1.56 m.

Water productivity, exclusive of irrigation cost, in papaya is Rs. 26.6/m^3 based on a net income of Rs. 500,000.

The farmer also grows fennel, a seven-month crop. The dripper lines are spaced at 0.40 m x 1.20 m. There are 25,000 drippers in the plot. The five vigha sized plot is irrigated by drips in just two hours. The initial watering for one month is for two hours, i.e., 100,000 liters (100 m^3) in each watering. Then the dosage increases to 150 m^3 per watering for two months, with a frequency of every two days. In the next four months, he reduces the watering frequency to every four days with just two hours of irrigation per watering. This makes it to 3,000 m^3.

The total income from five vigha plot of fennel is Rs. 190,000. The total input cost is Rs. 60,000. Hence the water productivity, exclusive of irrigation cost, is Rs. 14.4/m^3.

He said that if he runs out of water, he would be willing to purchase water from the market but for just seven vigha of land. He will be willing to pay Rs. 400 per vigha per watering. However, when asked about the WTP in relation to the net income he gets, he indicated that he will pay a maximum of one fourth of the net income per unit volume of water as the price of water.

Village Akadi

In the afternoon, we went to another village named Akadi in Palanpur taluka. We met a farmer named Ashok Choudhary. He and his brother own a total of six ha (15 acre) of land. He appeared to be a prosperous farmer and is quite enthusiastic about this farming enterprise. He has a 100-feet deep open well with a 100 feet deep bore well inside. The well is nearly 10 years old. The village is also very close to Dantiwada reservoir (2.5km away). The depth to water level in the well is 90 feet. He mentioned that as long as there is water in Dantiwada reservoir, the well never goes dry.

The farmer is using mini sprinklers for the past five years. The entire six ha plot is under sprinkler irrigation. He has adopted mini sprinklers for reducing the labor cost. The cropping pattern chosen by his is amenable to sprinkler irrigation, with potatoes and groundnut being done in rotation. Groundnut is grown during both kharif and summer and potatoes are grown during winter.

As regards watering to crops, he gives irrigation to potato fields once in every three to four days. This is for a period of 75 days. Initially, a watering is given to wet the plot for nearly 16 hours. Hence, the total watering is for 89 hours. In a plot of size 6,400 sq. m, there are 81 sprinklers. The discharge of a sprinkler is 460 liters per hours. Hence, the total water application is 81 X 89 X 460/1,000 m^3 = 0.518 m. He obtained a total yield of 25,000 kg from the plot that he sold at an average price of Rs. 9/kg. The gross income was Rs. 225,000. The input cost was Rs. 72,000, which included a seed cost of Rs. 40,000, pesticide cost of Rs. 10,000 and labor cost of Rs. 22,000. The net income, exclusive of irrigation cost, therefore is Rs. 153,000.

He indicated that in the village farmers pay Rs. 150 per hour of irrigation. He sells water at Rs. 70 per hour. He will be willing to pay Rs 10 per m^3 of water, in case he runs out of water. But, he will buy water for only Rs. 200,000 for the whole year. This comes to around 4 ha of irrigation during the winter months. His gross income last year was Rs. 260,000 including around Rs. 600,000 from dairy farming.

September 11, 2016
Farmer No. 1

On September 11, 2016, we once again visited a village not affected by salinity. The village is Pakhanwa situated in Palanpur taluka of Banaskantha. The village is facing water shortage due to groundwater depletion. Groundwater is the only source of water for irrigation in the area. Of the many wells drilled in the area, only a few are successful. The cost of drilling here is less than that in the hard rock areas (Rs. 400 per feet).

We met three farmers there in the farm of Galba bhai Patel. He has four ha of land in one location and has a 275-feet deep tube well. The well is 190 feet deep. The pump capacity is 15 HP. He pays electricity charges based on consumption and the annual electricity charges come to Rs. 30,000. The meter was installed only one and half years ago and the well is only three years old.

During kharif, he grows: groundnut (seven vigha); castor (2.5 vigha); and fennel (three vigha). During winter, he grows: wheat (three vigha); and Rajgaro (seven vigha). During summer, groundnut and pearl millet are grown in a total of five vigha of land.

Summer groundnut is irrigated every four days using mini sprinklers. The sprinkler spacing is 9 m x 9 m. The nozzles discharge 470 liters each. After the first 25 days, full irrigation starts. The total number of irrigations is 25 during the 120-day cropping period, and the average duration of each watering is five hours. The total volume of water delivered to the field is 2,937 m^3 (for a 4,000 sq. m plot).

The total yield obtained from the plot is 21 bags of groundnut (1,050 kg). The gross income including that from by-product (Rs. 4,000 from 2,000 kg of groundnut shell) of groundnut is Rs. 64,000.

Regarding input costs, the seed cost is Rs. 5,500 (for 55 kg). The fertilizer and pesticide cost is Rs. 5,200. Labor cost is Rs. 7,500 and tractor is Rs. 3,900. The total input cost comes to Rs. 22,100. Thus, the net income (excluding the cost of irrigation water) is Rs. 42,100. Water productivity of irrigated groundnut, exclusive of irrigation cost, therefore is Rs. 14.6/m^3.

Fennel is another important cash crop and is an eight-month long crop. The crop sowing is in August and the harvest is in March. The farmer grows the crop in 3.5 vigha of land. The plant row spacing is one m and the crop is irrigated by a drip system. The drippers are spaced at 0.50 m in the laterals. He has a total of 13,600 drippers in the entire plot, and the discharge of these drippers is four liters per hour.

In the first month, when the plants are very small, the irrigation is for half-an-hour duration, and water is applied daily. In the next month, this is increased to one hour per watering every other day. In the subsequent months, irrigation is applied for two hours, once in every three days. Irrigation intensity is low during the last six months because of the winter. Hence, the total duration of irrigation comes to 150 hours, and the total water applied is 8,100 m^3 for the plot. The depth of irrigation is 0.99 m.

The total production he obtained during the last season was 117 mann (117 x 20 kg). The average price obtained was Rs. 2,000 per mann (ranging from Rs. 2,700 to Rs. 1,600). The gross income was Rs. 234,000. The total input cost was Rs. 82,300, including a labor charge of Rs. 56,000. The net income (excluding the cost of irrigation) is Rs. 151,700. Thus the water productivity, exclusive of irrigation cost, in economic terms was Rs. 18.5/m^3.

The farmers indicated that they used to buy water from his neighbor when he runs out of water in a particular season. They pay one third of the gross income to the water selling well owner in such cases. One farmer mentioned that he will pay to the extent of 50 percent of the net profit for obtaining water from the market if there are no alternative sources of water, when the seller has to produce water incurring high costs.

Saline Groundwater Area in Western Banaskantha

September 10, 2016

We visited a village named Savpura in Vav taluka of Banaskantha district. This is a border taluka of the district. This area is very close to the little Rann of Kachchh. The groundwater in the village is highly saline. The water in the shallow aquifer has higher level of salinity than in the deep aquifers. Some of the resource poor farmers still use some water from the shallow groundwater using open wells soon after the monsoon to irrigate their crops. The resource rich farmers however go for deep tube wells, investing around Rs. 800,000 – 1,000,000 per tube well (plus submersible pumps + the water distribution pipes). The village also started receiving water from SSP canal network three years ago. However, in the absence of the micro canal network, a large number of farmers are still taking water directly from the canal, using HDPE pipes.

Farmer No.2

We first visited the farm of Shankarbhai Bhagvanbhai Patel, a farmer with a great deal of land and cattle as well as two horses. He has 25 vigha of land in one location. He also has a large plot in another location (which receives canal water). We visited the farm irrigated by a tube well yielding saline groundwater. We measured the salinity of water in the well using a TDS meter. The TDS was 2,480 ppm. He drilled the tube well six years ago by investing Rs. 500,000. The tube well is 600 feet deep. The depth to water level is 270 feet. The first tube well was drilled 30 years ago, and it lasted for 25 years.

In the tube well irrigated area, he takes the following crops: pearl millet, jowar and castor (during kharif); and rabi, cumin, mustard and wheat (during rabi). During summer, he does not raise any crop as too much water will be required to irrigate the crops owing to the high aridity. In addition, he would need additional water to leach out the salts in the soil. In the process, the land could quickly become saline. The yield from these crops is as follows (Table 18):

Table 18: Crop Yields at Farm of Shankarbhai Bhagbanbhai Patel

	Yield	Watering
Castor	800 kg/vigha	07
Mustard	800 kg/vigha	05
Wheat	1000 kg/vigha	10
Cumin	400 kg/vigha	06
Kharif Peral Millet	700 kg/vigha	
Jowar	Only for feeding the animals and the weight not measured	

He mentioned that wheat is grown only occasionally and is for domestic consumption only. He uses a lot of FYM and the yield is quite good. He would not get the same yield if the crop is raised every year.

In the canal-irrigated area, he grows pearl millet, jowar and cotton during kharif. During rabi, he grows cumin. During summer, he grows pearl millet again. He gives seven irrigations to the summer crop and gets a yield of 6,000 kg/ha. He also mentioned that the yield during summer is two times the yield obtained during kharif season.

He mentioned that the yield of crops irrigated by canal water is two times higher than that of crops irrigated by wells. Further, the amount of irrigation required in the canal-irrigated plots is less than that in the well irrigated plots. For instance, in cumin, only four irrigations are given in the canal-irrigated plot, whereas it is six in the well irrigated plots.

Further, due to lack of fresh water, the land quality is poor. The application of saline water further degrades the land. The difference in land value is Rs. 300,000 per ha. He indicated that the salts in the soil could be leached if good quality water is applied for nearly one year.

He will be willing to buy water from the market, if the bore well dries up and there are no alternatives to getting good quality water from the field. He sees yield doubling as the greatest benefit. Also, applying saline groundwater will reduce the cropping prospects in the long run. He pointed out that cumin crop, which used to give a yield of 70 mann (1,400 kg) of cumin seeds per vigha 30 years ago, now yields only 20 mann

(400 kg). He will pay one third of the gross return from the crop produce for water. Alternatively, he mentioned that the price could be Rs. 1,600 per vigha per watering. He will buy water to irrigate the entire land of 25 vigha (six ha) in all the three seasons.

His plan is to grow horticultural crops such as date and teak in future. He mentioned about his neighboring farmer who has raised date palm. The sapling (tissue cultured) is priced Rs 3,500. The plant will start yielding in the fourth year.

Farmer No. 3
Savpura village, Vav taluka

We then went to interview a farmer named Manabhai Ramjibhai Patel. He has a tube well with meter connection. Two brothers together own nine ha of land. He trilled the well twelve years ago by investing Rs. 500,000. The tube well is 550 feet deep, and the water level is 220 feet deep. In the last twelve years, the W. L. has gone down by 50 feet from 170 feet in the beginning. There is always a 30 feet water column left above the position of the submersible pump in order to take care of the annual water level drawdowns. The water level fluctuation during monsoon in the area is around 10 feet.

We measured the salinity of water from the tube well, using a TDS meter. The TDS in the T. W. water was 2,140 ppm, and that of shallow groundwater (in the open well) was 3,710 ppm. The farmers expressed the opinion that the salinity of underground water prevents good yields (with the exception of castor). The farmer does have access to canal water in a different plot. The crops grown by the farmer in the tube well irrigated farm are as follows:

- Kharif: pearl millet; cotton; green gram and fodder (jowar).
- Rabi (winter): mustard; cumin and fennel
- Summer: No crops are raised, as the crops do not grow well in the saline water as salts start getting accumulated in the soil after two crops.

The production and watering dosages are as follows (Table 19):

Table 19: Production and Watering at Farm of Manabhai Ramjibhai Patel

	Production	No. of Irrigation
Cotton	800 kg/1.5 vigha	8-9
Pearl millet	2500 kg/ha	6-7
Mustard	1300 kg/ha	4-5
Fennel	1000 kg/ha	5-6
Cumin	180 kg/acre	4
Green gram	1000 kg/ha	2

Note: I ha= 2.5 acre; 1 acre =1.75 *vigha*.

Production costs: Rs. 22,000 per ha for fennel; Rs. 10,000 for mustard; and Rs. 22,000 for cotton. The method of growing of fennel is broadcasting. Therefore, the yield and quality of produce are lower as compared to Palanpur area. For pearl millet, the cost of cultivation was Rs. 6,000 per ha.

The farmer, Manabhai Ramjibhai, had purchased water from his neighbor before going for his own tube well 15 years ago. The yield difference between canal water and groundwater is 50 percent, meaning canal irrigation will double the yield for the same crop and under the same conditions of inputs. The farmer also mentioned that at the time of flowering, one or two irrigations with saline groundwater could increase yields. Furthermore, canal water is very good for achieving high growth of the plant.

He said he is willing to pay Rs. 1,600 per watering per ha of land for good quality water. On further probing, he indicated that he could pay as high as one third of the net return from irrigation as water charge, which means if he gets a net return of Rs. X/m^3 of water, he could pay Rs. 0.33x/m^3 of water, with a profit margin coefficient of 2.0. He added that he would buy water for 10 ha of land (from two seasons). When we have the example of cotton crop (where in the marginal return from the use of water was estimated to be very high, around Rs. 30,000), he said he will pay up to Rs. 10,000 per ha for getting the two initial irrigations.

In the village, many farmers are using water from SSP canals by directly lifting water from the man canal, branch canal or distributaries. They invest heavily for installing pumps on the banks of the canals, long HDPE and (underground) PVC pipes for transporting the water from the canal to their distant fields. The distance can be as far as seven km (in one case) depending on the distance of the field from the nearest canal carrying sufficient discharge to meet the demand.

One of the farmers we interviewed, Mr. Shankarbhai Galabhai Patel, invested Rs. 500,000 three years ago for PVC pipes and a 14 HP motor. The pipeline runs a distance of five km from the source canal point to deliver water to his farm. He irrigates two vigha of land from the canal water. He previously worked in the farm of the local resource person's father (Karsanbhai Choudhary). He appeared to be quite prosperous after taking crops in three consecutive years using canal water.

He grows kharif pearl millet, alfalfa, cumin, wheat, castor and pearl millet (summer). Prior to this, he would grow only rainy season crops, namely, pearl millet, jowar and green gram.

Farmer No. 4
Name: Karnabhai Vanaji Patel

We then visited the horticultural farm of Karnabhai Vanaji Patel, which is located on the side of the highway. The village is Lakhni in Lakhni taluka (carved out of Tharad taluka of Banaskantha). Many farmers in the area grow pomegranate for the past 9 to 10 years. The farmer in question had raised a pomegranate farm six years ago, after learning from the neighboring farmers. These farmers had joined the field team of IWMI on an exposure visit to Maharashtra many years ago.

His horticultural farm is 4.5 acre in size, with a total of 825 pomegranate trees. They were yielding for the past four years and the farmer appeared to be quite happy with the income earned from the farm. Along with pomegranate, he also grows alfalfa in around four vigha of land.

He has a 500-feet deep tube well in his farm, which is 10 years old. The W. L is 300 feet deep. The salinity of groundwater used for irrigating the trees is 1,540 ppm (as measured at the site using a TDS meter).

He irrigates the pomegranate farm with drips. The tree plant spacing is 8 feet x 12 feet. There are six drippers provided to each plant from two dripper lines for each row of plants. The dripper discharge is eight liters per hour. He irrigates the plot once in every five days for nearly two to three hours during winter time (November to February). For flowering, the plot is left unirrigated during June and plants are put to water stress for one month. Once flowering starts, irrigation is increased to three to four hours (July to September). Irrigation is for four hours during the three summer months of March to May.

The total irrigation volume was estimated to be 8,553 m^3 for a plot of 7,920 sq. m (see Table 20). The average depth of irrigation is 1.08 m for a plot with matured trees.

Table 20: Irrigation at Farm of Karnabhai Vanaji Patel

	Volume in Liters	Duration
Summer	2851200	3 months
Winter	2376000	4 months
Monsoon	3326400	4 months

Each plant gives a yield of 15-20 kg. The price ranged from Rs. 30 to Rs. 40 per kg of fruits. The income from the crop is in the range of Rs. 525 to Rs. 700 per tree. The expenditure is Rs. 17 per plant for pruning. The labor charge is Rs. 40,000 and the machine charge is Rs. 10,000. The total input cost per year comes to Rs. 150.000, including fertilizers (chemical + FYM) and pesticides. The net income, exclusive of irrigation cost, from the plot is estimated to be Rs. 355,000 (Rs. 505,000 minus Rs. 150,000). Hence, irrigation water productivity (Rs/m^3), exclusive of irrigation cost, for pomegranate is Rs.41.5/m^3.

ANNEX 6C: FIELD NOTES FROM WESTERN RAJASTHAN

Fresh Groundwater Area

Village Bhilada

On the first day, I visited a village near the city of Jodhpur. The village is near a medium scale reservoir. Ramji Mali, a farmer who belongs to a community traditionally engaged in cultivation of vegetables, along with his farming partner had leased in 300 vigha of land (around 50 ha), from an educational trust. He alone has 140 vigha of land. The land had two tube wells and two open wells. He and his sharecropper pay Rs. 15,000 per vigha of land per annum.

The tube well, which is operational, is around 400 feet deep and had good quality water owing to the continuous seepage from the reservoir. The pump capacity is 20 HP. The depth to water level is 150 feet. There has been no decline in water level in the past five years since the time he had been using the farm. He grows a wide range of vegetable, flowers and other cash crops in his leased in farm, all for the market, and a few cereals for his domestic consumption and sale.

His crops include: chilies, cotton, cabbage, ground nut, carrot, onion, tomatoes, pearl millet, wheat, and marigold. With a variety of short and long duration crops, he has cropping and an irrigation demand throughout the year.

Last year, he grew chilies in 50 vigha of land. He sowed the chilies in July and harvested them in January. He had a nursery for the crop in his own farm. He cultivates cotton in 20 vigha of land, and the sowing of cotton seeds started in July and the crop is harvested in January. Cabbage was sown in 25 vigha of land. The crop was sown in August and the total duration of the crop is only 2.5 months. Pearl millet was sown in 10 vigha during kharif, starting in July.

He cultivated groundnut in 20 vigha of land; sowing is done in June and it lasts for five months, with harvesting done in October. Carrot was grown in 15 vigha of land. Carrots area six-month crop in the area and is harvested in the middle of winter.

During winter, onion was cultivated in 70 vigha of land and wheat in 20 vigha. A second time sowing of carrot and cabbage were also done for the same area during winter in 15 vigha and 25 vigha, respectively. He raised tomatoes in December in an area of 50 vigha, and the crop harvesting is completed within five months. The crop is grown twice during the year, with a two-month gap in between. The farmer also grew marigold for nearly four vigha of land; the direct seeding of the plant is made in July and the flower plucking is completed in the month of October.

As regards irrigation, it takes three hours to irrigate one vigha of land during kharif, three hours during winter, and four hours during summer. During kharif, the temperature is generally high with the monsoon, and the irrigation water demand drops slightly. Water demand is highest during summer months of March to June, and the onset of monsoon is only in the first or second week of July.

Chilies are given around 36 waterings, with six waterings a month on an average (depending on the rainfall). Cotton is given five waterings a month, and it amounts to 25 waterings for the whole of the season. Cabbage is given seven waterings a month (one watering in every four days) and it comes to 16 watering a season. Carrot is given a total of 24 waterings in six months. Tomatoes are given five waterings a month, with a total of 20 watering in four months. Wheat is given 15 waterings during winter. Onion is given 10 waterinsg per month; but the total no of waterings comes to only 30 waterings in four months.

The input costs, production and price obtained for different crops are as follows.

- Chilies
    - Raising the nursery: Rs. 30,000 per kg of seed used for seven vigha of land, which works out to be around Rs. 4,300 per vigha.
    - FYM: Rs. 7,000 per vigha, which is for the whole year (therefore half).
    - Chemical fertilizers (Urea and DAP): Rs. 1,000 per vigha.
    - Micronutrients: Rs. 1,000 per vigha.
    - Pesticide: Rs. 2,000 per vigha.
    - Labor for planting the saplings, irrigation, weeding and harvesting and transporting): 74 person days, with Rs. 200 per person per day.
    - Total production: 2,400 kg/ *vigha*.
    - Market price: ranged from Rs. 25 to Rs. 10 per kg and the average came to around Rs. 15 per kg.
    - Gross income: Rs. 36,000 per vigha.

- Carrot
    - Seed cost: Rs. 800 per vigha (Rs. 400 per kg, for 2 kg/vigha).
    - Fertilizer: Rs. 500 per vigha.
    - Labor: Rs. 8,000 for 40 labor days.
    - Total production: 1,500 kg/vigha.
    - Market price: ranged from Rs. 25 to Rs. 10/ kg, with an average of Rs. 15/kg.
    - Gross income: Rs. 22,500 per vigha.
    - Net income (exclusive of irrigation cost): Rs. 13,200 per vigha.

- Onion:
    - Seed cost: Rs. 1,100 per kg and a total of 1.5 kg of seed was used.
    - FYM: Rs. 3,000 per vigha.
    - Fertilizer: Rs. 1,000 per vigha.
    - Labor: 31 days (@ Rs 200 per labor-day) were spent in the farm, from planting to weeding, irrigation to harvesting.
    - Total production: 5,000 kg/vigha.
    - Market price: Rs. 4 per kg.
    - Gross income: Rs. 20,000.

    - Net income (exclusive of irrigation cost): Rs. 8,350/vigha.

- Tomatoes:
    - Seed cost: Rs. 10,000 per vigha, as the price of seed in the market is Rs. 100,000 per kg and a total of 100 gram of seeds were used per vigha of land.
    - Fertilizer: Rs. 500 worth of fertilizers per vigha.
    - Labor: 20 days, and hence the paid out cost for labor was Rs. 4,000 per vigha.
    - Yield: he harvested tomatoes from his farm three times, and the total yield was 4,000 kg per vigha.
    - Market price: Rs. 6/kg.
    - Gross income: Rs. 24,000.
    - Net income (exclusive of irrigation cost): Rs. 9,500 per vigha.

- Cotton
    - Seed cost: Rs. 1,000 per vigha.
    - FYM: Rs. 3,000 per vigha (useful for two seasons).
    - Fertilizer: Rs. 1,000 per vigha.
    - Pesticide: Rs. 1,000 per vigha.
    - Labor: Rs. 200 per day for 20 days + Rs. 2,500 for harvest.
    - Yield: 500 kg/vigha.
    - Gross income: Rs. 25,000 per vigha.
    - Net income (exclusive of irrigation cost): Rs. 14,000/vigha.

- Marigold:
    - Seed cost: Rs. 300,000 per kg (three hundred thousand rupees) and the farmer reported that he used 100 gram of seeds per vigha (imported from Japan).
    - Labor: ½ of that for onion (five labor days).
    - Irrigations: 30 over six months. It required three hours to irrigate the crop per vigha.
    - FYM: Rs. 3,000 per vigha.
    - Fertilizer: Rs. 1,000 per vigha.
    - Pesticide: Rs. 2,000 per vigha.
    - Production: 10,000 kg/vigha through 10 harvests.
    - Market price: Rs. 15 per kg. He also indicated that the price could range anywhere from Rs. 60 (peak demand season) to Rs. 5 per kg.
    - Total input cost: Rs. 36,000.
    - Gross income: Rs. 150,000 per vigha.
    - Net income (exclusive of irrigation cost): Rs. 113,000 per vigha.

Farmer No. 5
Chokha

We met one Tarachand, who belongs to the Mali community, who traditionally cultivates vegetables. He runs a vegetable shop on the highway. He brings the fresh vegetables he grows to the shop for sale. He seems to have regular customers who buy fresh vegetables from his shop. He has a tube well, jointly owned by five brothers.

The depth of the well is 500 feet, and depth to water level is 180 feet. The pump capacity is only 7.5 HP, as the water table is high. The tube well is located in the fresh groundwater zone of Jodhpur. The well has good yield and water level has not declined in 12 years.

Tarachand grows three vegetables: cabbage, spring onion, and ridge gourd. He plants cabbage in September after 45 days of nursery. He harvests the crop after another 45 days. The crop is given a total of 25 irrigations, i.e., almost once in two days. The crop was cultivated in 2.5 vigha of land and it took 3.5 hours to provide one watering for the entire plot. He does not use chemical fertilizers for his vegetables and purely depends on organic manure (animal droppings). He used two trucks of manure last year at a cost of Rs. 40,000 for the 2.5 vigha, which is also available for harvesting the subsequent crop from the same plot during the year. The labor involvement was for 15 days, with a total cost of Rs. 3,000 (it is his own family labor). The total revenue he earned from the sale of cabbage was Rs. 200,000 per vigha. He mentioned that he did not purchase any seed from the market, and uses his own homemade seed for raising the vegetable nursery.

He grew his second crop, spring onion, in the same plot after a short fallowing time. The total duration of the crop is 60 days, during which 20 watering were given to the crop. Each watering takes 3.5 hours. The total income from the produce was Rs. 100,000 from two vigha of cropped land. He did not invest anything for the seed, which is homegrown. The amount of labor was almost same as that of cabbage.

The electricity connection for his tube well is metered (as his well is located in the urban area and the connection is non-agricultural). He pays around Rs. 4,000-Rs. 5,000 in two months for the electricity. He often sells water to his neighbor (farmers) but charges only Rs. 50 per hour for water. The unit charge for electricity is Rs. 3.35.

September 25, 2016
Farmer No. 6
Shamji Pariyar
Chokha village

Two brothers jointly own 70 vigha of land. His is a classic example of how much a farmer can invest to improve the farming system and thereby economic conditions. Shamji Pariyar had in the past invested in drilling several failed tube wells, and finally decided to build anicuts. His land being located very close to a hilly catchment, he had ideal locations for building the anicuts and made a total investment of 21 lac rupees ($31,500). In addition, there was also a government anicut in the same area. The farmer had installed drip system in the entire 6 ha (35 vigha) farm five years ago.

Since the rainfall was very good this year, the water level in the tube well has come up to the ground level and artesian conditions prevailed for some time. Currently, the water table in the bore well is merely two feet below the ground. The farmer, Shamji Pariyar is a highly enterprising farmer. He converted the rocky land, which he inherited from his father, into one that produces fruits and vegetables. He raises his own fruit and vegetable nursery. He mentioned that during this year's heavy rains, his nursery was destroyed and he incurred a loss of Rs. 2,000,000.

His farm had several fruit crops: kinnow, sweet lime, a bush fruit (used for making pickles), pomegranate, kinnow, sapota and berr. He also grows several vegetables such as okra, eggplant, tomatoes and several flowers. He has three vigha of pomegranate (a three-year-old plantation), 10 vigha of berr, with five different varieties (some of which are as old as 10 years), sapota (25 trees), 20 trees of sweet lime, 15 vigha of flowers and four vigha of tomatoes.

We were more interested by flower cultivation in his farm, which he called gambling in the market due to the high price fluctuation in the market.

He is using costly seeds of marigold, which guarantees uniform growth, size and color of the flowers. The price of the seed is Rs. 350 for 70 seeds. He grows two varieties. One summer variety is sown in August and lasts until the end of November. The other winter variety is sown in October and lasts until March. The watering is once every two days for the summer variety and once in three days for the winter variety. The duration of watering is two hours per vigha.

A vigha of land requires around 10,670 seeds (with plants at an average spacing of 0.3 m x 0. 5 m) and the cost of seeds works out to be Rs. 53,350. One drip line (kept at a spacing of 1 m) covers two plants on both sides. The total number of drippers in one vigha plot of marigold is 5,335. The discharge rate for the dripper is four liters per hour.

The crop lasts for five months, and the plucking starts after two and a half months. In each month, the plucking is done four times and the total flower harvest in each plucking is around 150 gram of flowers per plant and 1,500 kg from one vigha. The total harvest is around 15 ton of flowers. The price fetched ranges from Rs. 10 to Rs. 60 per kg. The average price for the produce obtained is Rs. 15 per kg. The gross revenue is Rs. 225,000. The total labor involved was 50 persons per vigha, i.e., Rs. 10,000 per vigha. The FYM used was 10 tons per vigha, i.e., Rs. 5,000. The cost of pesticide was Rs. 3,000 per vigha and that of fertilizers was Rs 1,000 per vigha. Hence, the net income is Rs. 153,000 per vigha. This is a very high income for any crop. The total water use is 2,560m^3 per vigha for the summer variety (which lasts for four months) and 2,134m^3 per vigha for the winter variety, which lasts for five months.

The farmer had received subsidies for installation of drip irrigation to the extent of 70 percent, as he is one of the early adopters and capital subsidy was high in the initial stages of promotion of the technology in the state of Rajasthan.

The farmer is also doing intercropping of berries (*zyziphus*) and white (Lily) flowers. No separate watering arrangement is done for berries. The tree grows using the water applied for the flower, which is cultivated twice during the year. The tree spacing for berr is 6 m x 6 m and there are around 44 plants in one vigha. Berries require watering only during July to January. Though fruiting of the tree starts in the second year, it is removed in the budding stage itself. Harvesting starts in the third year onwards. The yield in the first year of harvest is around 20 kg per tree. As the tree matures, in the tenth year, the yield goes up to 250 kg per tree.

Berries fruit fetches a price of Rs. 18-25 per kg in Jodhpur market. Watering of the plot with intercropping of berries and flowers is also done as in the case of marigold. The average production in the third year is 900 kg/vigha and increases to nine tons per vigha. The annual revenue increases from Rs. 18,000 to Rs. 180,000. The annual input cost is around Rs. 40,000 per vigha (manure of animal droppings, labor for weeding and plucking fruits). Once the tree matures after four to five years, intercropping will not be possible. A matured tree requires around 50 liters of water a day. The amount of water required over a period of 7 months in a year is 44 x 50 x 210/1000 = 462 m^3/vigha. Hence, water productivity (exclusive of irrigation cost) is close to Rs. 300 per m^3.

Farmer No. 7
Kheru village, Jodhpur Tehsil

We visited a large farm owned by two entrepreneurs. One of the two partners, Praful Jain, owns 32 vigha of land in the farm. They have tried all modern farming techniques in the farm, though the land is of poor quality with very high sand content. They have gone for net house and poly house for producing tomatoes and cucumber. Three workers from Nepal manage the farm operations. The farm has three tube wells, with depth ranging from 500-600 feet. Water level is around 180 feet below ground.

They had invested in two net houses in the farm, each for an area of 4four vigha (6400 m^2). The investment for construction of net house was Rs. 305 per m^2, with the cost coming to Rs. 1,920,000. The investment for poly house construction was Rs. 270,000 (@ Rs. 422/m^2 of area). Both the poly house and net house had drip systems.

The crops, namely, tomatoes and cucumber are cultivated on raised beds. Each bed has a width of two feet and the spacing between beds is 2.5 feet. On each bed, there are two laterals running. The drippers are kept at a spacing of one foot, and the plants are at a spacing of two feet in a staggering (*zig zag*) fashion. The drippers have a discharge of two liters per hour and watering is given for one hour a day in the four vigha plot. The total water input in a single watering comes to 56.8 m^3 for the 14,200 plants. Watering is daily during the first month and then reduced to every alternate day for the next six months. The total water input is 1,704 + 5,112 = 6,816 m^3

In the case of tomatoes, the crop is of nearly seven-month duration and the production and harvesting of tomatoes starts after two months. Two crops are taken in a year. He continues harvesting for nearly five months on every alternate day, and each harvest gives an output of 1,000 kg (20 bags of 50 kg). Harvesting requires six persons to complete. Hence, the total labor requirement for harvesting alone is 450 (i.e., Rs. 200 x 450=90,000). The total production was 75 tons from a four-vigha plot. Tomatoes fetch a price of Rs. 10 per kg in the market (owing the superior quality of the produce), and therefore, the gross revenue is Rs. 750,000. The cost of raising nursery, including the cost of seeds, is Rs. 12,000 per vigha. The cost of fertilizers comes to Rs. 500 per vigha. The total input cost, including that of the net house and drips, but exclusive of the cost of irrigation water, comes to Rs. 315,000 (351,360/2 + 2,000+ 90,000+ 48,000=315,000). The net income, exclusive of irrigation cost, is around Rs. 435,000.

Hybrid cucumber is also planted in the same fashion as in the case of tomatoes and is irrigated using drips. The crop was raised three times during the last year in the poly house in an area of four vigha. Watering is given using fogger sprinklers to create moisture in the air during summer. Watering is done at a rate of 500 ml per plant once in a week for the first 20 days and thereafter, watering is given on every alternate day at a rate of 700 ml per plant. The total water input works out to be around 518 m^3 for the entire season. The total production of cucumber in one season was nearly 80 tons from 4 vigha. The price fetched was in the range of Rs. 17 - Rs. 20 per kg. The gross income therefore is Rs. 1,480,000 per season. Labor cost is 150 person days x 200= 30,000.

The farmer also grows eggplant and bottle gourd but in the open field using drip irrigation. However, the crops are sown for the first time in the farm.

Farmer No. 8
Chokha village

We visited another farm in Chokha village, which is located on the side of the state highway. The farmer is doing sharecropping with a farm laborer from another village. The laborer along with his family members are working in the farm for the past four years and gets 30 percent of the gross income received from the crops harvested. He has 80 vigha of land and is irrigated using two tube wells. The wells are located at a distance of one km from the farm and water is taken to the farm through underground pipelines.

The tube well is 250 feet deep and the water level is 150 feet deep.

The farmer is currently growing three main horticultural crops, namely, flowers, eggplant and chilies. When we visited, he had just harvested one round of chilies and was ready to go to the city to sell the produce.

Chilies are cultivated in vigha during the kharif season from July to October. Prior to that nursery preparation of the plant saplings takes two months. Harvesting starts after two months. The farmer reported that he gave 24 watering to the crop. Each watering took 24 hours for the five vigha plot. The amount of fertilizer applied (Rs. 300 for Urea and Rs. 1,300 for DAP) was for Rs. 1,600. Five trolleys of FYM were also applied, costing Rs. 10,000 in total. The cost of pesticides was Rs. 1,200. He plucked chilies ten times, each time harvesting around 600 kg. The total production was 6,000 kg. The price of chilies varied from Rs. 6 to Rs. 30 per kg, with an average of Rs. 15 per kg. The total amount of labor days involved was 35, costing Rs. 7,000.

Salinity-Affected Area

Farmer No. 9
Village Bhilada

We met Omprakash Hanumanram in the village. He owns a 12.5 vigha-farm in the village and a 500 feet deep tube well. He drilled the well four years ago, and the water level has decreased by 40 feet since then. The depth to water level now stands at 360 feet. The tube well replaced an open well, which was just 150 feet deep. As the water in the well dried up, he went for the tube well like many other farmers in the area. The total investment for drilling the T. W with the pump set was Rs. 300,000. He has a 22.5 HP power connection and the actual pump capacity is 24 HP. He pays Rs. 2,023 per month for the pump. Salinity affects the water in the well, and the TDS is 2,300 ppm. Tasting of the water suggested the water is alkaline.

He mentioned that because of the poor quality water, the yield of crops is merely half of what he could probably get with good quality water. We visited the farm and could see the poor growth of plants of fennel, cotton, tomatoes, jowar and eggplant.

He grows: jowar, cotton, and fennel are sown during kharif; wheat is grown during winter; and alfalfa year-round for feeding livestock. Wheat, which is a five-month crop, replaces cotton, which is grown in 6.5 vigha of land. Jowar was cultivated in three vigha of land and jowar (Sorghum) in 2.5 vigha of land. Cotton was sown in May and harvested after six months. Alfalfa was grown in 0.5 vigha of land. Throughout the year, he has a standing crop in the field, except for nearly one month when the land is kept fallow.

Sorghum, which was sown during July and harvested during September and used as fodder, was given five waterings, as the rainfall was very low last year. It takes six hours to irrigate one vigha. The labor input was Rs. 20,000 for six vigha of land cultivated (last year). FYM use was to the tune of five trolleys, costing Rs. 17,500 for the six vigha plot. The total harvest of jowar was 4,000 kg from the entire plot.

Cotton was sown in 6.5 vigha of land. The farmer gave 16 waterings to the cotton crop in four months, with four waterings a month. It takes six hours to complete one watering per vigha of plot. The seed cost was Rs. 10,000 (for 6.5 vigha) with a total of 4.5 kg of seeds used. The total labor cost was Rs. 4,500 for 6.5 vigha. The cost of FYM used (excreta of goat and sheep) in the plot was Rs. 30,000 for a six trolley load of manure, which is for the entire year. The total production of cotton was only 720 kg from the entire plot, with a total price of Rs. 35,000. Generally, he gets a yield of 200 kg/vigha. Thus, the net income was only Rs. 5,500 for the whole plot. He mentioned that both his yield and the price of cotton were low during the last harvesting season.

Demand for water increases after the monsoon during September through November, and then decreases. The demand rises during March, when wheat crop matures. If freshwater is available for purchase, he would buy water to irrigate his entire plot during winter season and half the land during summer season (when cotton had to be sown). When we discussed the cost of supplying high quality water, he indicated that he would go for several high value crops such as pomegranate, bottle gourd, okra, tomatoes, and chilies. He also mentioned that better quality water would increase his yield, and for cotton he could get 400 kg/vigha (instead of the usual 200 kg). The water requirement also decreases with better quality water, since the frequency of watering can be reduced to one watering for 10 days.

The price generally paid for water is Rs. 100 per hour of irrigation in the area (for the kind of discharge he gets from his well). This works out to be Rs. 3,750 per ha per watering (100 x 6 x 6.25). This is nearly Rs. 6.25 per m^3 of water. He said he is willing to pay up to half of the net income generated from the use of water for purchasing water from the market. This means that if high value crops are adopted, he would be willing to pay much higher price for the water in terms of rupees per m^3.

Farmer No. 10
Bhilada village

The second farmer we met in the salinity-affected area was Male Ram. The four brothers together own 60 vigha of land, and the tube well is five years old. The well is 400 feet deep and the depth to water level is 350 feet. The pump capacity is 30 HP. He pays Rs. 2,700 per month for electricity on flat rate basis for the 30 HP of connected load. The well water is saline. The farmer reported that the water level goes down by nearly 10 feet on an average every year.

During the last year, he grew: jowar, cotton, pearl millet and green gram in kharif season; and wheat, fennel and mustard during the winter season. He has a severe water shortage on his farm, in lieu of the fact that there is only one tube well to irrigate 60 vigha of land. He indicated that he needs to irrigate cotton every 15 days, but the severe water shortage makes this difficult. It takes six hours to irrigate one vigha of land in winter and kharif (summer) seasons. Over the last year, his total cotton production reached 1,000 kg/vigha last year, with eight irrigations during the four months. His neighbor, however, gave 16 irrigations to his cotton crop. The total input cost, including labor, fertilizer, pesticides and FYM and seeds was Rs. 20,000 for three vigha. The gross return from cotton was Rs. 60,000 from the three vigha plot, and the total input cost. The net income was Rs. 40,000 from three vigha of land.

For wheat, he gave 11 irrigations during the last season. The seed cost was Rs. 40 per kg. The total duration of watering during the entire season was 66. The yield was 320 kg/vigha of the plot, which is much lower than the standard yield in that area. The gross income was Rs. 320 x 19= Rs. 6,400 per vigha. The income from by product is another Rs. 640per vigha.

He indicated that though fennel is a cash crop grown in the region, it is also disease prone. He also indicated his willingness to buy water to improve his farming. He also indicated that he would invest nearly half of the net return from crop production exclusive of the irrigation cost for purchasing water. He said that he needs water for the entire 10 vigha September through November and during March.

ANNEX6D: FIELD NOTES FROM SOUTHWESTERN PUNJAB

Background

I conducted a two-day field visit to Bhathinda on 29-30 September. Large areas underlying Bhathinda have saline groundwater, while some pockets had fresh groundwater. This arid region receives very little rainfall (around 300-400 mm annually). The region is also known for irrigation water scarcity, as the availability of canal water for irrigation has been extremely limited in this region, unlike other parts of Punjab. The farmers in this region previously grew mandarin oranges and cotton (with blending of groundwater and canal water). Very little area was under rice paddies and wheat in lieu of shortage of good quality water.

However, in the recent past, Punjab government had substantially increased the allocation of surface water through canals and there has been a major shift in the cropping pattern with increase in rice paddies (kharif) and wheat.

In many areas, the water table had risen as farmers stopped using groundwater for blending with canal water. This had created an unfavorable environment for kinnow, which is very sensitive to waterlogging conditions, though quality of groundwater has improved in many pockets. Many farmers from the area had removed mandarin orange plantations and moved to conventional crops such as rice paddies, wheat, and fodder.

While increased access to saline-free canal water enabled farmers to take up rice paddies and wheat, water control remains an issue. Lack of control over water delivery in the field prevents farmers from growing water-sensitive crops such as mandarin oranges and vegetables. Access to good quality groundwater (free from salinity and with pH under control) with good sub-surface drainage provides the ideal condition for growing fruits such as mandarin oranges (a citrus fruit) and many vegetables (tomatoes, eggplant, potatoes, cabbage, cauliflower, chilies and pumpkin).

We first made an exploratory visit to the regional research center of Punjab Agricultural University (PAU), one of the most renowned agricultural universities in India. I met the heads of various research divisions, which are involved in research on horticultural crops. They are currently researching the following crops, namely, pomegranate, guava and mandarin oranges (a type of orange, grown widely in Southwestern Punjab, especially in Bhathinda and Fazilka districts).

The university is undertaking research on the use of desalinated groundwater for growing fruit crops such as kinnow, pomegranate and guava. One of the focus areas of the research is to understand the impact of using desalinated water on fruit yields.

The Regional Research Centre of PAU is using a membrane technology from Germany, which converts 90 percent of brackish water into clean water (the proportion of reject water is only 10 percent). The technology also ensures that even if one or two of the membranes become dysfunctional, the plant can work. As per the rough estimates provided by them, total cost of desalinated water is about INR 0.45 per liter including the annualized capital cost.

The university researchers refused to divulge any information on the impact of using desalinated water on the fruit production in the research farm. However, the research team informed us that one of the progressive farmers in the region is already using desalinated water through Reverse Osmosis technology for growing high value crops.

Groundwater Availability and its Use for Irrigation in Bhathinda District of Punjab

Bhathinda is a district in southwestern part of Indian State of Punjab and covers a geographical area of 3,367 sq. km. The district is composed of seven blocks: Bhathinda, Nathana, Rampura, Phul, Talwandi Sabo, Sangat, and Maur. The district is semi-arid with an average annual rainfall of only about 408 mm.

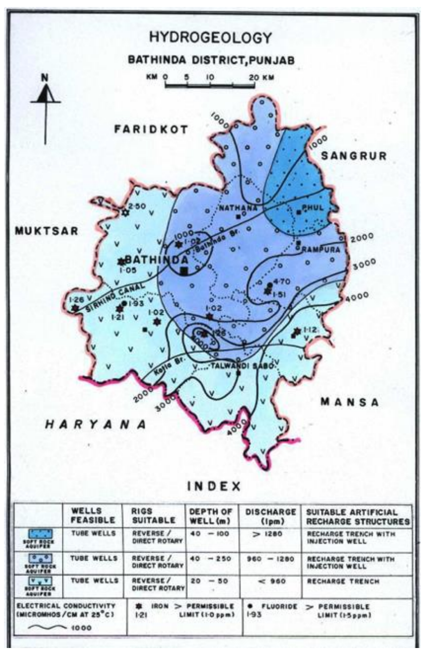

Figure 17

Net groundwater availability in the district is about 1.02 BCM, mostly occurring in alluvium formations. During the pre-monsoon season, the depth to groundwater level in the district varies from 20.39 m in Western and Southern part to 16.50 m in Northern part of the district. During post-monsoon, the groundwater level varies from 2.24 to 20.76 m below ground level. Average seasonal fluctuation in groundwater level varies from -0.03 to 2.5 m with maximum water level decline reported from the North-Central part of the district. Average discharge of water from the groundwater wells maintained by Central Ground Water Board (CGWB) varies from 1000-1736 liters per second. Block wise details are provided in Figure 17.

The net annual groundwater draft is about 119 percent of the availability, making it one of the overexploited groundwater areas in India. In Nathana, Phul, Rampura and Maur blocks, groundwater is severely over-exploited. More than 97 percent of the groundwater draft (1.2 BCM) is for irrigation. Further, groundwater in many parts of the district, especially Southwestern part, is saline with EC as high as 3,490 micro mhos and pH varying from 7.54 to 8.0.

Overall, about 76,000 ha of the cultivated area is under groundwater irrigation. Some of the horticultural crops under groundwater irrigation include tomatoes, capsicum, cucumber, chilies, pumpkin, and flowers (Figure 18 and 19).

Figure 18

Figure 19

Farmer No. 10

The first farmer we met, Lakhinder Palsigh had a large farm of seven acres. He has a tube well of depth 160 feet. The water level is at around 30 feet. He had installed an RO system nearly one and a half years ago. The plant produces 1,000 liters of water an hour. In spite of having access to canal water, he chose an RO system because the canal water was alkaline and had high pH (above 8.5). He found it unfit for growing flowers.

The total capital investment for RO plant was Rs. 175,000 ($3,000). He is using poly house and net house with drip irrigation and foggers for controlling microclimate for growing high value fruits and vegetables. He had a commercial electricity connection for his farm, which ensures 24-hour power supply to his farm and unlike farmers in the rural areas who get power supply only for a limited six hours, but free of charge. He pays Rs. 8 per unit of electricity. He has been farming for the last ten years and used to be in the business of flower wholesale.

For the past year, the farmer is growing Gerbera daisy, whose flower has a high demand in the market. He purchased the saplings from the nursery at a price of Rs. 32.25 per plant. He grows the flower in an area of 2,880 m^2 of plot under poly house, with microclimate control using the sun screens, fogger, etc. He plants the saplings on raised beds having width of 2.5 feet, with drainage channels of one-foot width in between. The plant density is six plants/sq. m. The plants are irrigated using drip systems, with each bed having two laterals of drips, kept at a spacing of eight inches.

The total capital cost for the poly house is Rs. 844 per sq. m, and the subsidy component is 50 percent. Thus, the cost for the farmer is Rs. 422/m^2. This includes the drips and the foggers. The total cost is Rs. 1,215,360 (app. $19,000). The total life of the installation can be considered as 10 years. Using discounting cash flow technique, for an average life of 10 years and discount rate of nine percent, the annualized cost is Rs. 218,764.

The life of the flower plant is three years, and the flowering starts after 100 days of planting of the sapling. During summer months (March to July), watering is around 10,000 liters a day and during the rest of the year, 4,000 liters of water per day is applied in the plot.

The cost of fertilizers, neem oil (pesticide) and micronutrients is Rs. 20,000 per month. The cost of labor (one permanent farm worker and one helper) is Rs. 20,000 per month. The electricity charge (combined for net house and poly house) is Rs. 5,500 per month during summer and Rs. 3,000 per month during the winter season.

As regards the production, each plant gives three flowers per month on an average, and this continues for nine months. For nearly three months in a year, disbudding of the plants is done, and there is no harvest during this period. The total production comes to nearly 466,560 flowers per annum from the plot of size 2,880 m^2. Each plant is capable of giving flowers up to three years. The peak season for the flower with respect to demand in the market is June to July and the price during these months touches Rs. 9 per flower. The peak season for harvest is October to March 15, when the price will be in the range of Rs. 4 to Rs. 7 per flower.

At an average price of Rs. 5 per flower, the gross income from sale of flowers comes to Rs. 1,555,000 for the whole year during the first year and Rs. 2,332,000 each in the second and third year. The major input cost is the cost of saplings (i.e., Rs. 32.25 x 6 x 2,880 = Rs. 557,280). After accounting for cost of all inputs including the poly house, but excluding the cost of irrigation, the net income exclusive of irrigation cost comes to Rs.

670,000 during the first year and Rs. 1,437,000 during the second and third year. With a total water input of 2,340 m^3 per annum, the average water productivity exclusive of irrigation cost therefore is around Rs. 640/m^3.

The farmer also grows seedless cucumber. It fetches a premium price in the market and the price ranges from Rs. 20 to Rs. 40 per kilogram. He grows the crop in the net house. The area of the net house is 4,376 sq. m. The total capital investment was Rs. 610 before subsidy and Rs. 305 after the 50 percent subsidy from National Horticultural Mission. It works out to be Rs. 1,334,680 ($20,070). Using discounting cash flow technique for a discount rate of nine percent and a life of eight years for the system, the annual cost works out to be Rs. 240,000.

He takes two crops in a year, with a one-month gap in between two crops. The first sowing is in the first week of September and lasts until January next year and the second crop is sown in February and lasts until May end.

Similar to the flower, beds of width 2.5 feet are prepared, with two rows of plants in each bed, in a diagonal fashion with spacing of 45 cm between plants. The spacing between beds is around 2.5 feet. He waters each bed with drips, with two dripper lines running along the bed, at a spacing of eight inches.

Once the seeds are planted and germinated, it takes 35-40 days for the plant to start fruiting. He harvests in the next four months. The total harvest is in the range of 35-40 ton for the 4,000 sq. m plot.

The cost of the seed is Rs. 6 per seed. This works out to be Rs. 66,000 for the seeds alone. The fertilizer cost is Rs. 70,000 for the entire plot for one season. Labor cost is Rs. 20,000 per month and works out to be Rs. 90,000 for the entire season (with crop duration of 4.5 months). Watering is done at a rate of 500 ml per plant once in a week for the first 20 days and thereafter, watering is increased to 700 ml per plant on every alternate day. The total water input works out to be 401.5 m^3 for the entire season. The gross income per season is Rs. 937,500 (37.5 x 20*1000=937,500). The total input costs, including that of the net house, but excluding the direct cost of irrigation, works out to be Rs. 346,000 ((240,000/2) + 66,000+70,000+ 90,000). Thus, net water productivity exclusive of irrigation cost for cucumber is Rs. 1473/m^3.

Farmer No. 11

Iqbal Singh is a progressive farmer, who has specialized in vegetable production and has been a recipient of two prestigious awards for innovative farming, one from Punjab Agricultural University and the other from the former Chief Minister of the State, Hon. Prakash Singh Badal, whose village is merely 10 km away from his village.

He grows kinnow, guava and several vegetables in his farm. He indicated that mandarin oranges require best quality water, and the water table should be deep. He uses canal water for irrigating mandarin oranges using small channels and trenches. The tree spacing is 6 m x 6 m. The total area under mandarin oranges is four acres.

The sapling is planted in February or September. Initially watering is done once in very week. Watering stops in the end of October (as winter starts), and pruning of the tree is done in January and thereafter watering is done once in a month until March. From April to August, the watering is done once in 15 days, and thereafter, the rains can take care of two months of water requirements. The quantum of water applied has to be increased from the first year till the seventh year when the tree grows to the full size.

He waters a single matured tree at 10 liters per day during summer months. The water requirement during the rest of the year (seven months) is just half this amount. This is in accordance with the recommendations of PAU for the crop in the area. The water requirement can be halved if drip irrigation is used. The total irrigation input for the crop per annum works out to be only 2,550 liters of water per plant and for one acre it comes to 280 m^3 of water. This is a gradual increase from a mere 120 liters of water per plant (13.2 m^3 per acre) in the first year.

Fruit production starts after three years of planting. Flowering starts in February and harvesting is done from mid-December onwards and nearly one and a half months. The fruit production is nearly 30 kg/tree in the first year of harvest (fourth year of planting) and gradually increases as the tree grows (to 40 kg in the second year to 70 kg in the third year) and becomes 150 kg/tree from a 10-year-old tree. The price of mandarin oranges can range between Rs. 5 per kg to Rs. 25 per kg. The farmer informed us that he got a price of Rs. 25 per kg last year.

As regards the inputs, no fertilizers are applied in the first year and from second year onwards, the dosage of fertilizer increases from 100 grams DAP and 50 grams potash to 1.25 kg DAP and 0.50 kg potash in the 5th year. Labor input is worth Rs. 15,000 per acre/year. This includes harvesting charges.

He has a 400 feet deep tube well. The depth to water level is around 80 feet. The quality of water in the well is good. He uses well water to grow vegetables using drip and sprinkler irrigation. He had raised tomatoes in 25 acres of land last year. Of these, five acres was under drip irrigation.

Sowing of the crop is done in November and harvesting is completed in June. The drip laterals are kept at a spacing of 4.0 feet for each row of the plant, and the drippers are at a spacing of 15 inches. Watering schedule was as follows. During November to March, irrigation is given once in a week, and during April to June, it is more frequent, once in two days. He reported that it took six hours to irrigate five acres of tomatoes in the drip-irrigated plot. The total cost of DAP and Urea per acre was Rs. 20,000. The total production was 25 tons per acre. He earned a total income of Rs. 100,000 per acre from the sale of tomatoes.