WORKING PAPER 60

Food Security and Sustainable Agriculture in India: The Water Management Challenge

M. Dinesh Kumar

International Water Management Institute

FUTURE HARVEST
IWMI is a Future Harvest Center supported by the CGIAR

Working Paper 60

Food Security and Sustainable Agriculture in India: The Water Management Challenge

M. Dinesh Kumar

International Water Management Institute

IWMI receives its principal funding from 58 governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR). Support is also given by the Governments of Ghana, Pakistan, South Africa, Sri Lanka and Thailand.

The author: M. Dinesh Kumar is Consultant and Project Director, North Gujart Groundwater Initiative of the International Water Management Institute (India Project Office, Vallabh, Vidhyanagar. Email: d kumar @ cgiar.org.).

Kumar, M. D. 2003. *Food security and sustainable agriculture in India: The water management challenge.* Colombo, Sri Lanka: International Water Management Institute (Working paper 60).

/ food security / water resources development / agricultural production / poverty / sustainability / economic growth / irrigated farming / farmers / groundwater development / environmental degradation / water requirements / water scarcity / irrigation water / salinity / ecology / crops / food production / water allocation / water market / water use efficiency / technology / India /

ISBN: 92-9090-521-2

Please direct inquiries and comments to: *iwmi@cgiar.org*

Contents

Abstract

Irrigation would continue to play an unquestionable role in achieving food self sufficiency, creating grain surpluses, stabilizing food prices, sustaining agricultural growth, absorbing labour force in rural areas, and alleviating rural poverty; all of which are vital for food security. Given India's unique food security policy, there is a growing need to manage water for agriculture. Recent research by many scholars and institutions have shown that the future water supplies are going to fall short of the demand from different sectors, with a differential negative impact on agriculture, if India continues to follow the same trajectory of water resource development and water use as in the past. Given the political economy of growth based on urbanization and industrialization, there will be a greater pressure to allocate an increasing quantum of water for industrial and municipal uses. This will pose a threat to food security at the aggregate level. The problems would be acute in semiarid Gujarat, Tamil Nadu, Rajasthan and Maharashtra, which also experience ever-increasing demand for water in all sectors.

The increasing resource degradation problems such as groundwater depletion, water logging, salinity, and land degradation would add to the challenges. Mainly, food security of the poor will be at risk, as they would face severe resource constraints not only in accessing water, but also in investing in land and water management. Already, regions such as Gujarat, which face groundwater depletion problems, land degradation, and frequent droughts are highly food insecure. On the other hand, in regions like Bihar and Orissa, low agricultural productivity and output, and high poverty rates leave millions, especially those in rural areas, undernourished.

Managing water for food security needs a multipronged approach. At the aggregate level, the irrigation water supplies and the demand for irrigation need to be balanced. This offers two challenges: water supply management and judicious intersectoral water allocation. At the next level, greater equity needs to be ensured in accessing and controlling water from aquifers and public systems. At the third level, farmers should maximize production from available land and water resources with the least environmental consequences such as land degradation and groundwater depletion, through efficient resource use. The existing water resource development technologies have a great bias towards the rich. In water abundant regions such as Bihar and Orissa, the poor still depend on the water for irrigation, purchased at prohibitive prices. In this paper, the author shows that under the current pricing system for electricity in the farm sector, the conventional water saving technologies favour the rich with greater opportunities.

The author argues that emerging technologies such as the treadle pump can, not only change the trajectory of water resource development, but also increase the ability of the poor in water rich regions to invest in irrigation, boost productivity and production, and effect food security. Microirrigation technologies can greatly enhance the ability of the poor to maximise production from limited water supplies they have access to. Integrated land and water management practices such as organic farming and agronomical activities would be the key to enhancing land and water use productivity on a sustainable basis; but small and marginal holders would face severe constraints in adopting them. Subsidies are needed for poor farmers to adopt technologies that would reduce their dependence on biomass, increase biomass use efficiency, and invest in integrated land and water management techniques to improve land and water use productivity.

The author argues that the allocation of tradable private property rights in water will lead to overall enhancement in the economic efficiency of water use and higher productivity in agriculture. The enforcement of tradable private property rights will ensure equitable access to water in water scarce regions for agriculture, and also for all classes. This is critical from the point of view of local and domestic food security. Moreover, as in water abundant regions, it can also provide the landless farmers with sufficient incentives to invest in development and transfer water for highly productive uses elsewhere, and generate income. The volumetric pricing of water from public canals and unit pricing of electricity in the farm sector with carefully designed structures, along with properly enforced water rights, can, not only improve the physical efficiency of the water use in agriculture, but also provide the rich and poor farmers with equal income earning opportunities from farming.

1.0 Introduction

Though the world has been changing remarkably over the past 25 years, food security still remains an unfulfilled dream for more than 800 million people living in the developing countries (Leisinger 1996). But the fact that the number of undernourished people has come down from the 1971 figure of 890 million, and that there has been an addition of 1.5 billion people to the population since 1971 show remarkable achievements in food security (FAO 1996 as cited in Leisinger 1996).

In Asia, where nearly 73 percent of the population of the less developed world live (World Population Data Sheet 1996, as cited in Leisinger 1996), the number of undernourished people declined from 701 million in 1969-71 to 512 million in 1990-92. What is more notable is that the percentage of undernourished people in the region has fallen dramatically from 37 to 16 (based on FAO 1996), while the region's population is growing at the rate of 2 percent per annum.

India wants to be self-sufficient in food and "food secured". Therefore, it is imperative for the national food security that we need to grow sufficient food within the country. At the same time, for domestic food security, we need to sustain economic growth to raise the income levels and purchasing power of the poor people. These apart, agricultural regulation through fixation of foodgrain procurement prices, regulation of consumer prices, and public distribution have an important role in ensuring food security at the domestic level, even if self sufficiency is achieved in food grain at the national level (Banik 1997; Goyal 2002). Governments intervene and control a large proportion of the marketed food supply in order to safeguard the farmers against low and unpredictable prices for their produce; but, inefficient pricing often leads to undesirable consequences regarding access to food supplies. However, this dimension of the food security problem is beyond the scope of the paper (Banik 1997).

Irrigation has contributed significantly in boosting India's food production and creating grain surpluses used as drought buffer. On the other hand, agriculture remains the backbone of India's economic growth, despite the major structural changes the economy is undergoing. Though differences of view exist among scholars over the impact of economic growth on poverty (Janaiah et al. 2000), several studies in the past have indicated that agricultural growth, especially in food grain production bears a negative impact on rural poverty (Ahluwalia 1978; Hazzle and Haggblade 1991; Rao 1994; Ghosh 1996; Desai and Namboodri 1998). According to Ravallion, Dev and Ajit, rural poverty is in correlation with relative food prices, which is affected by fluctuations in food supply (Ravallion 1998; Dev and Ajit 1998).

Recent studies also show that in the 1990s, there was no change in the rural poverty ratio, while urban poverty shows a decline by 10 percent when compared with that in 1980s. This coincided with the period, which recorded a stagnation in the growth of the primary sector, especially the agricultural sector, at 3.2-3.4 percent. The growth rate in the production of food grains also dropped to 1.2 percent during the 1990s, from 2.3 percent in the 80s (Datt 1999). All these lead to the unquestionable role that irrigation can play in stabilising food prices, and alleviating rural poverty, provided effective institutional interventions are in place. The growing need to manage water for agriculture in developing countries such as India has been mooted by several researchers due to its ability to reduce the incidence of poverty, and achieve food sufficiency (Chaturvedi 2000).

Owing to the fact that the net areas under cultivation and under food grains remain more or less saturated at the macro level (GOI 2002), irrigation is the key to enhancing agricultural production, and hence, the key to sustaining economic growth. The rural population (nearly 70 %) depends on agriculture for subsistence and employment. Irrigated agriculture remains the largest absorber of rural labour force, and therefore influences the livelihoods of millions of rural households, while its impact on farmer households is more direct. Expansion of irrigation will be the key to sustaining a fast growth in agricultural production and ensuring food security, at the national, regional and domestic levels. But, the farming practices that involve intensive use of irrigation and land cause the degradation of land and water resources. This, in turn, can threaten the long-term sustainability of irrigated agriculture itself.

In order to ensure food security on a sustainable basis, three concerns need to be addressed: the adequate supply of irrigation water to sustain the growth in agricultural production at the national level; the water security for poor farmers to grow food for subsistence; and the adequate economic incentives for farmers to maximise their production from the available land and water with least environmental consequences.

In India, the lion's share of diverted water is used for irrigation (Xie et al. 1993; WRI 1996; GOI 1999). The capacity to augment the existing irrigation potential through conventional technologies is fast reaching the limits (Kumar 2001). The irrigated areas, especially the command areas of surface irrigation schemes, are increasingly facing the threat of land degradation and productivity declined. On the other hand, the demand for water from urban domestic and industrial sectors is growing in leaps and bounds. This, coupled with the widening gap between the overall demand and supplies would severely limit water availability for producing food for the growing population. On the other hand, the poor, small and marginal farmers face several constraints in adopting agricultural technologies and agronomic practices needed to maximise the productivity of land and water. The Shortage of biomass limits the ability of farmers to adopt organic farming practices that are more sustainable. These are some of the major concerns of sustainable agricultural production and food security.

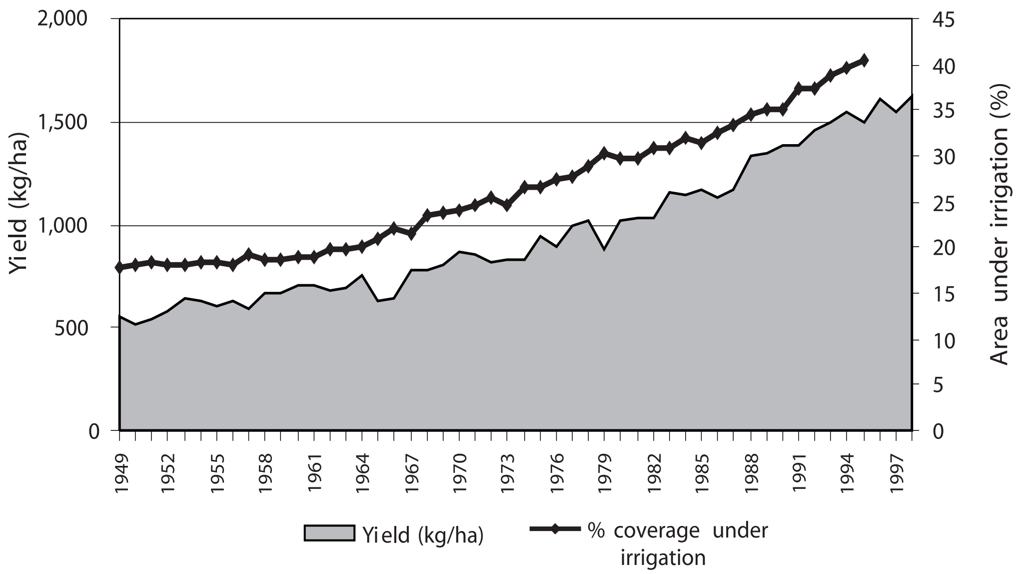
The paper analyses these concerns in depth, and suggests some sustainable technological and institutional alternatives. The first section analyses the implications of water problems such as the widening demand-supply gap, water and land resource degradation, and the growing competition the agricultural sector is facing from other sectors of water use in agricultural production, economic growth, and food security. The second section covers the irrigation technologies that could help resource poor farmers get access to and control over water resources for irrigation. The third section discusses the NRM technologies that help them use land and water resources efficiently and more productively, and their constraints. The fourth section discusses the changes in institutional framework governing water use for enhanced water productivity for agriculture, and equity in access to water for producing food grains.

2.0 Water, Agricultural Production and Economic Growth

Since independence, India has made substantial progress in the economic front with the per capita net national product recording a compounded growth rate of 1.7 percent (Datt 1997). The contribution of agricultural production to this progress in GDP growth during this period has been quite phenomenal, as its value grew 3.2 times in real terms (TERI 1998). Irrigation has been the key to enhancing grain production and ensuring food security at the national level, with two – thirds of the agricultural production coming from irrigated areas. The following figures illustrate this.

First, the growth in Total Factor Productivity (TFP) contributed significantly to the growth in crop outputs in India, i.e., 1.1 to 1.3 percent per annum, while conventional inputs such as irrigation and fertilizers contributed 1.1 percent. Irrigation investments also generated TFP growth apart from the output growth it makes as a conventional input through providing improved environment for crop technologies (Evenson et al. 1999). Second, the food grain production in the country saw a commendable growth from 50.8 million tonnes in 1950-51 to 203.04 million tonnes in 1998-99 (GOI 2002). The contribution of yield enhancements (average yield increased from 522 to 1620 kg/ha) resulting from the introduction of green revolution technologies and irrigation, to this growth, was more than the growth in cropped area (Evenson et al. 1999). Figure 1 shows that food grain yields increased almost consistently with the area percentage under irrigation from 1949-50 to 1998-99.

Figure 1. Growth in irrigation coverage and yield.



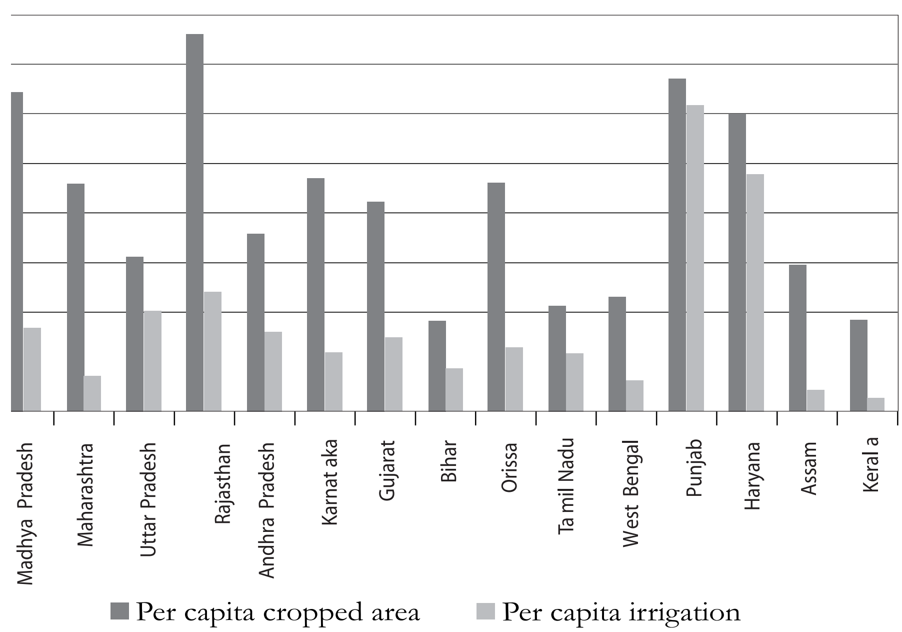
A large share of the growth of the country's agricultural production since independence has come from the northern region, mainly Punjab, Haryana and Western UP, which reaped the benefits of green revolution rather fast (table 21, Evenson et al. 1999). This was achieved by enhancing the use of conventional inputs such as irrigation and fertilizers, and by improving TFP through the adoption of new crop technologies. There has been significant expansion in irrigated agriculture in the region. Similarly, the annual growth in TFP during the period from 1956 to 1987 was 1.40 percent for the northern region comprising Haryana, Punjab and UP, as against the national average of 1.13 percent (Evenson et al. 1999).

The growth rate in TFP is the lowest for eastern region comprising Bihar, Orissa and West Bengal (0.75). Further, it has declined over three decades (1956-87) from 1.5 during 1956-65 to 0.70 during 1977-87 (Evenson et al. 1999). The grain yields are the lowest in Bihar (CWC, July 1998 as cited in table 3.21 of GOI 1999). There are many reasons for the low agricultural productivity in this region. The first is the low level of cultivation and irrigation. Irrigation, as per the population size, is the poorest in states like Bihar and Orissa when compared with that of states like Punjab and Haryana. In order to capture the population factor, the per capita cropped area and the irrigated area were estimated. While the per capita irrigated area is 0.31 ha for Punjab, 0.24 ha for Haryana, 0.12 ha for Rajasthan and 0.10 ha for UP, it is only 0.043 ha for Bihar. Though there are some states, which have a much lower per capita irrigated area such as Maharashtra and West Bengal, the situation in Bihar is noteworthy because of its lowest per capita cropped area (0.092 ha) among all the twelve states selected. The other states with very low per capita irrigated area have high per capita cropped area (Source: Author's own calculations based on agricultural census data (1998-99) and population census data 2001). The constraints imposed by low per capita cropped area and irrigation result in low yield levels.

Consequently, the low levels of farm surpluses, make it not possible for the farmer to invest in irrigation sources, expand irrigation, increase cropping intensities, enhance crop yields, and thereby push the agricultural growth. Though irrigation potential of groundwater is very high, the pace at which groundwater resource development takes place in the region is extremely low. The stage of the development of groundwater in (erstwhile) Bihar, expressed as a ratio of the gross draft and the replenishable groundwater resources, is only 23.3 percent (GOI 1999: p16). Poor irrigation also influences the level of the use of inputs such as fertilizers and pesticides, and hybrid variety of crops are some of the reasons resulting in low TFP.

Agricultural growth will be critical for reducing the region's high rates of unemployment and poverty, and improving food security. Socioeconomic deprivation is an important constraint in investing for irrigation development and increasing input use for maximizing agricultural outputs in regions in the water abundant Indo-Gangetic plains such as eastern UP, Bihar, and West Bengal (Shah 2000). The average per capita income (indicated by the per capita consumption expenditure) in the states such as Bihar and UP is far below the national average (GOI 2002: p35). The resource poor, small and marginal farmers in the region, prefer buying water from well owners, at prohibitive prices to irrigate crops (Ballabh and Chaudhary 2002), though it makes least economic sense for them.

Figure 2. Per capita cropping and irrigation in different states.



Having stated the foregoing, I would like to add the lack of financial resources in the state or the national government to invest in the water resource development sector, as the third challenge in fuelling the engines of economic growth. For instance, the inter-basin transfer of water from water abundant river basins to the water scarce ones could help augment the country's water supply potential in the order of 200-250 BCM (Chaturvedi 1999). However, this would cost to the tune of 20-25 billion dollars. Unavailability of finance is going to be a major stumbling block in opting for such projects.

According to Chaturvedi (2000), poor endowment of natural resources and environmental degradation are going to pose major challenges to sustainable economic growth in developing countries including India. Let us examine how far this argument is valid for India. First, the per capita availability of renewable fresh water in India, which is an important input for economic growth, is far less than that in many of the developed countries in the world (Glieck 1997). For instance, as shown in table 1, the per capita annual water resources (AWR) of India (2,085 m^3) is less than one – fourth of that of the USA (8,520 m^3), and only 2.2 percent of that of Canada, but more or less close to that of China and slightly less than that of Pakistan.

Table 1. Annual water resources and per capita AWR for five countries, including India.

Name of country	Annual water resources (km^3)	Per capita annual water resources*
India	2,085.00	2,085.00
USA	2,478.00	8,520.00
Canada	2,901.00	92,850.00
China	2,800.00	2,170.00
Pakistan	418.30	2,593.00

*The author's own calculation based on estimated population for the year 2000, using base population of 1995 obtained from World Resources table 8.1 and annual growth figures of 1990-1995 as provided in World Resources table 8.1.
Source: AWR figures are obtained from World Resource Institute (1996)

Second, there is increasing evidence of environmental degradation from across the country. In spite of the increasing public consciousness, degradation is likely to continue, though at a slightly slower pace. An important cause of environmental degradation is the poor efficiency in the use of natural resources for economic production purposes, mainly due to the lack of economic power to invest in conservation technologies, and this is a characteristic feature of developing countries like India. The per capita GNP of India is just one-thirtieth of that of a developed country like the US. Poor economic conditions might gravely impede India's ability to make large-scale investments in resource conservation for many years to come.

The demand for environmental resources such as water, land and biomass, and the rate of environmental degradation, in a cumulative sense, are increasing (manifested by land salinization, groundwater pollution due to excessive leaching of fertiliser residues, and the pollution of surface water due to the poor or lack of treatment of trade effluents disposed into natural water courses). Despite the gradual rise in average income levels and the per capita income levels,[1] the incomes are still not high enough for people to invest heavily in environmental management. This is

[1]The per capita income levels as captured by the monthly per capita consumption expenditure have increased significantly during 1983 to 1999-2000 from Rs 78.90 to Rs 98.50 in rural areas and Rs 111 to Rs 143.5 in urban areas (National Human Development Report, Government of India 2001).

compounded by the problem of high income disparity between the richest and the poorest. Though the inequality in income distribution has nearly declined over the past 20 years,[2] it is still very much significant.

2.1 Water scarcity and its implications for agriculture and food security

Many researchers have argued that increasing water shortage would be a major challenge to achieving global food security (Leisinger 1996). Since Independence, there has been a remarkable increase in water supplies for irrigation, rendered through the building of large and medium reservoir and diversion schemes, and rapid and widespread exploitation of groundwater. According to the Central Water Commission, the Ministry of Water Resources, for 1993-94, irrigation contributed to 52 percent of the food grain production in the country (source: CWC, MOWR, July 1998 as cited in table 3.21 of GOI 1999). But, most of the major schemes for irrigation had been planned and implemented much before the major advances in hydro sciences were made in the world. As a consequence, the efficiency of the utilisation of water for irrigation has been extremely low just as in many other developing countries (Chaturvedi 2000).

Further, the approach to planning, and development and management of water resources has been, by and large, centralised, sectoral and segmented. This approach has not only led to unsustainable development of water resources, but also caused several negative social, economic and environmental problems (Kumar and Ballabh 2000; World Bank/GOI 1998). As a matter of fact, Sandra Postel argues that most of the environmental problems associated with large water resource development projects are the result of poor water resource development and management, and not inherent in irrigation (Postel 1999). So far as adding to the existing capacity is concerned, the potential is fast reaching the limits. The reasons are many: viable sites for building new reservoirs are almost absent; the social and environmental costs of surface water resource development projects are prohibitively high; the storage of existing reservoirs is dwindling; and groundwater resources are showing increasing signs of depletion (Kumar and Ballabh 2000).

On the other hand, demand of water for agriculture is growing due to the increasing food grain needs of the growing population, and the growing preference for growing water intensive cash crops. In the urban and industrial sectors, the growth is rather rapid, owing to the faster growth in urban population and rapid industrialisation. As water becomes scarce, the financial and environmental cost of its use increases enormously. However, demand management, the key to minimising the environmental stresses caused by water scarcity, has not received adequate attention.

Several researchers and agencies have made projections of the future demand for water in India from all the four competitive use sectors, viz. agricultural, industrial, domestic and livestock drinking for the year 2025 (Seckler et al. 1998; GOI 1999; Ballabh et al. 1999 and Kumar 2001). The estimates by Ballabh et al. (1999) and Kumar (2001) involve national food security and agricultural growth concerns. In their projections, the causes of change are the population growth, growth in per capita income levels, growth in industrial production and the change in food consumption levels. I would here use my own estimates (Kumar 2001) as the basis for further discussion on the emerging water scenario in India.

[2]Inequality in distribution of income –as indicated by the consumption expenditure—has declined from 0.298 in 1983 to 0.258 in 1999-2000 (National Human Development Report, Government of India 2001).

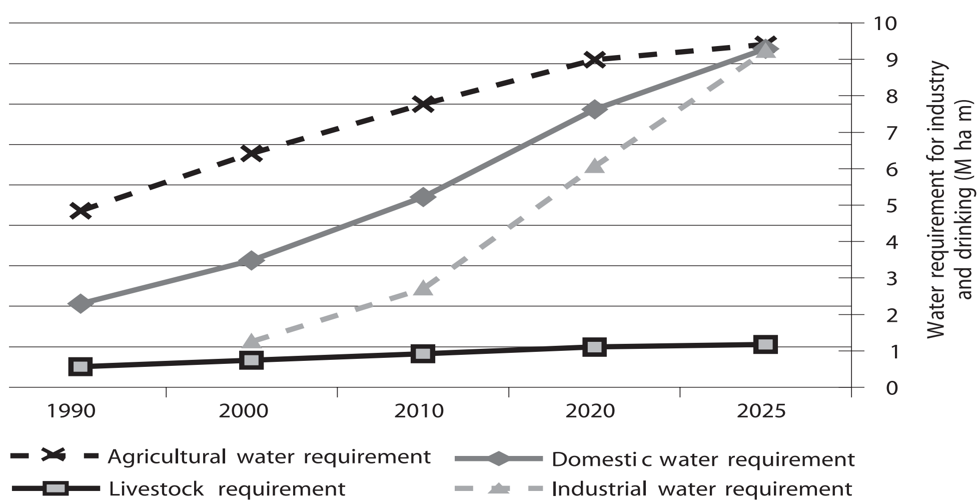
The estimates showed that the total water requirement for human and animal uses, industrial production and irrigated agriculture would be 104.50 M ha m in the year 2025. As per the estimates, agriculture would continue to be the major user of water in the year 2025 with a 81.13 percent share. The domestic water requirement is expected to grow from 4.70 percent in 1990 to 8.9 percent in 2025 and industrial water requirement from a mere 2 percent in 2000 to 8.83 percent in 2025 (figure 3, based on figure 2, Kumar 2001). The total water utilisation potential in 2025 as estimated as 78.3 M ha m, with an annual growth of 0.74 M ha m. The estimates involved two important considerations: the past growth trends in water development; and the growing public concerns about the social and environmental costs of water development projects.

A comparison of water requirement and utilisable supplies showed that, by the year 2025, the magnitude of the scarcity would be 26.20 M ha m. Thus, there will be greater competition between various sectors for the scarce water. In the absence of proper legal and institutional regimes under which water rights can be allocated among the competing sectors, rights will be politically contested, leading to conflicts. Let us have a closer look at the emerging scenario.

The urban water utilities are largely dependent on rural water resources for their supplies. Urban areas being economically and politically powerful (Banik 2000), manage to get the huge additional supplies required, from the rural areas. This can have major implications for irrigated agriculture, especially for the economically weaker groups. Already, conflicts exist over diversion of water from irrigation reservoirs to urban areas for drinking in the water scarce regions of Gujarat, Rajasthan and Maharashtra. Growing industrial water use can also come into conflict with irrigation. With the enormous increase in the financial and environmental costs of water use, in future, there will be greater pressure to reallocate the available water for the more efficient industrial uses. Over and above, the current political economy of growth based on industrialization and urbanization, encourages the re-allocation of available water in favour of industries and urban areas (Kumar 2001). This will deprive the people in the rural areas of the precious water needed to meet food production requirements.

Within irrigation commands, when supplies decline due to the increasing reallocation of water to other sectors, the rich and influential farmers grab the lion's share of the limited water and

Figure 3. Projected future water requirement in different sectors.



continue to enjoy as much access as when supplies were in plenty, often taking advantage of their location within the hydraulic system, depriving the less privileged poor farmers of their rights.

Another major source of threat to agriculture is pollution. Very few industries and municipal areas treat their effluents to safe levels, but use natural water bodies such as rivers and lakes as “sinks” for untreated and partially treated effluents. This deprives the communities living in those areas of the water for agriculture and domestic purposes. As industrial and municipal water use goes up, the effluent load also increases, and the magnitude of the threat too. Therefore, at the macrolevel, there are major threats to food security posed by growing water scarcity and pollution. The problems will be acute in the semiarid Gujarat, Rajasthan, Tamil Nadu and Maharashtra, which experience ever increasing demand for water from all sectors.

Apart from the lack of availability of sufficient water for agriculture, two important concerns which have implications for food security are: how much of the irrigation water is allocated or used for producing food grains; and the efficiency of the use of irrigation water in growing food crops. The first concern originates from the fact that, with shrinking water availability in both physical and economic sense, the rich farmers would allocate a larger share of their land to cultivations that yield higher cash returns, but are capital-intensive such as cash crops, horticultural crops and floriculture.

The best example is the north Gujarat region. With the rising cost of pumping groundwater, and the limited access to irrigation water owing to the regulated power supply and shared pumping hours, the farmers of the north Gujarat region have made major crop shifts. They are now growing cash crops such as castor, cotton, mustard and fodder crops, though they earlier used to grow more of food crops such as wheat, bajra and jowar. The farmers who purchase irrigation water are now allocating a significant share of such water for growing fodder as a survival strategy, as only dairying is viable. Such patterns of change are likely to adversely affect the prospects of the movement of grain surpluses from rural areas to urban areas. Further, given the differences in consumption pattern between the rich and the poor, the dairy products and fruits are likely to feed the rich, especially those in urban areas. The decline in food crop production would push up the grain prices in the local markets, resulting in problems of food security for the rural masses.

Another example is Chennai. With the increasing groundwater scarcity and farming increasingly becoming unviable, farmers in the region surrounding Chennai had started diverting water for urban uses (Palanisamy 1994), whereby they could fetch a price of up to Rs.50 per cubic metre of water.

The second concern stems from the fact that the productivity of irrigation is very poor in India. India diverted or used 569 m^3 of water per capita for irrigation in 1990, while China used only 401 m^3 of irrigation water per capita. The figures are far higher for countries such as the USA (table 2). At the same time, the per capita cereal production achieved in the country was only 221 kg, against 328 kg for China. The per capita irrigation withdrawal figures are far lower for Canada, while it produces 1674 kg of cereals per capita. The net result is that the cereal production per unit volume of irrigation water used is the second lowest for India, after Pakistan among the five countries.

While China produces 0.82 kg of cereal for every cubic metre of water used in irrigation, India produces only less than half. The difference cannot be simply attributed to differential productivity in irrigated agriculture through scientific planning of water use alone. There could be many reasons for higher cereal production in the case of China such as increased allocation of the available irrigation water to growing food grains, and the higher crop production from rain fed areas. But, given the fact that the cropland is much less in China when compared with India (95.98 M ha against 169 M ha), a higher production from rain-fed areas is possible only if the rain-fed

Table 2. Irrigation withdrawals and cereal production in five countries including India.

Name of country	Withdrawal of irrigation water per capita (m^3)/year	Irrigation withdrawal on crop land (m)	Irrigation withdrawal on NIA land (m)	Irrigation withdrawal on GIA (m)	Average per capita cereal production (kg)	Cereal per m^3 of irrigation water (kg)
India	569	0.31	1.07	0.74	221	0.39
USA	785	0.11	0.94	0.58	1,227	1.56
Canada	192	0.01	0.74	0.74	1,674	8.72
China	401	0.51	0.97	0.53	328	0.82
Pakistan	1,226	0.81	0.88		162	0.13

Note: The irrigation water withdrawal per cropland shown in table 2 was estimated using, the figures of per capita cropland (table 4 of Chaturvedi 2000) and per capita irrigation water withdrawals (Seckler et al. 1998). The figures of cereal production per cubic metre of irrigation water used were estimated by using per capita cereal production figures (table 4 of Chaturvedi 2000) and per capita irrigation water use figures (Seckler et al. 1998). The irrigation water withdrawal figures for the USA, Canada and Pakistan were estimated using per capita irrigation water withdrawal provided for that country in Seckler et al. 1998 and the population figures of those countries for the year 1990.

yield in China is significantly higher. Therefore, if we assume that water allocation pattern remains the same for both countries, the higher cereal production comes from better water use planning. What is done in China is to spread the available irrigation water in a larger area, and to use for irrigation in different seasons. As a matter of fact, the gross irrigated area in China is much higher than in India, and the irrigation water diversion on gross irrigated area is 0.53 for China against 0.74 for India.

Therefore, in brief, China seems to be tackling its food security problems through better planning of water use in irrigation, in spite of the lesser availability of irrigation water, while India produces much less with a higher level of irrigation water use.

2.2 Water resource degradation problems and impacts on food security

2.2.1 Groundwater depletion and its impact on food security

Groundwater accounts for more than 50 percent of the net irrigated area, and nearly 80 percent of the agricultural production from irrigated areas in the country. Its contribution to the nation's food basket is quite significant. Over and above, groundwater is a de-centralised and democratic resource. This is unlike canal irrigation wherein investment is mainly from the State, and access is restricted by topographic constraints. By virtue of this unique characteristic of groundwater, its contribution to local food security is great. In arid and semi-arid areas, the increased demand for water for agriculture and other uses is being met by excessive withdrawal of groundwater, leading to its depletion and quality deterioration. Table 3 provides the figures of a number of over-exploited talukas/blocks/mandals/watersheds[3] in eight states, which experienced problems of excessive withdrawal in 1995.

[3]Mandal is the unit for assessment of groundwater development in Andhra Pradesh, while watershed is the unit in Maharashtra, it is taluka in Gujarat, and block, in other states.

Table 3. Groundwater over-exploited blocks in India.

Name of state	Total number of blocks	Number of over exploited blocks	Overall status of groundwater development (%)
Punjab	118	62	94
Haryana	108	45	84
Rajasthan	236	45	51
Tamil Nadu	384	54	61
Gujarat	218	14	42
Karnataka	175	06	31
Uttar Pradesh	895	19	38
Andhra Pradesh	309	02	24
Total	2,722	247	-

Source: Groundwater Resources of India (CGWB, 1995).

Problems of groundwater depletion are encountered in both alluvial areas and hard rock areas. Examples are the alluvial areas of Punjab, Haryana, and Gujarat mainland, and the hard rock areas of Tamil Nadu, Karnataka and Saurashtra region of Gujarat. As shown by the table, the extent and degree of over-development is most severe in Punjab, with nearly 53 percent of the talukas affected by over-exploitation, and the overall stage of development touching 94 percent. In view of the fact that several blocks in Punjab are facing the problems of rising groundwater levels[4] and waterlogging, the degree of overdraft is very high in the areas of over-exploitation.[5] With secular decline in water levels, shallow wells dry up. As the investment for drilling tube wells reaches astronomical heights, the poor farmers lose out in the race of chasing the water table. They are either forced to purchase water from the rich well owners at prohibitive prices or shift to rain-fed farming practices. For instance, the tube well owners of Mehsana in north Gujarat charge as high as Rs70-Rs100 for an hour of irrigation service. In the first case, the economics of farming itself is adversely affected due to the rise in the cost of production, affecting the livelihood security.

In the second case, crops become highly vulnerable to the vagaries of monsoon with a very high incidence of failure during droughts. High inter-annual variability in rainfall, and frequent droughts are characteristic features of this low-medium rainfall region (IRMA/UNICEF 2001; Kumar 2002b). As a result, agriculture and rural economy become more and more vulnerable to droughts. The rich farmers are able to sustain tube well irrigation because of the flat rate mode of pricing electricity. Under the flat rate system, since the marginal cost of pumping is zero, the well-owning farmers can pump out excess water and provide irrigation services to the neighbouring

[4]The total area, which experienced the rise in water levels during 1979-99, is 13,903 km^2, i.e., 27.6 percent of the geographical area. Of this, in a total of 5628 km^2, the rise is above 5m during the 20-year period (Gulati 2002, Table VIII).

[5]During the period from 1979-99, nearly 31% of the area of Punjab experienced a water level drop in the range of 0-3m, 21 percent in the range of 3-5 m, 20.1 percent in the range of 5-10m, and 0.21 percent above 10m (Gulati 2002).

farmers through which they can even earn profits, after recovering the high capital investment for well construction, and the high fixed operating costs.

Again, when groundwater resources deplete and the cost of well construction and pumping increases, the system of trading water provides greater economic opportunities to well owners having large holdings, and lesser opportunities to those having smaller holdings and water buyers. This is because, for large farmers, the implicit unit cost of water is much lower when compared with that for small farmers. At the same time, a small farmer will not be able to raise the water charges to match the implicit cost of pumping, as the prices are determined by the market forces (Kumar et al.2001).

A recent analysis has shown that in deep tube well areas, if the State Electricity Boards start charging the full cost of electricity for pumping, the irrigated production of many crops would be unviable (IRMA/UNICEF 2001). This means that from a larger societal point of view, groundwater irrigation in such situations does not contribute to economic growth, but has negative ecological impacts.

In the case of hard rock areas, one of the immediate consequences of over-development has been the increase in the incidence of well failures. In such cases, the farmers are forced to deepen their wells or dig new wells, to sustain access to irrigation water. Here as well, the poor farmers, who do not have sufficient resources, lose out in the race. This situation has led to widespread emergence of groundwater markets. As hard rock areas have limited groundwater potential, water markets become monopolistic in nature (Janakarajan 2002). Gradually, irrigated farming itself becomes unviable for water buyers.

As groundwater contributes one-third of the agricultural GDP, it is a truism that depletion will have long-term impacts on the country's economic growth. But, recent evidence suggests that the impacts will be visible in the short term, rather. Severe problems of groundwater depletion are mainly experienced in hard rock regions of India,[6] which cover two-thirds of India's geographical area. These hard rock areas have very poor groundwater storage. Most of this is concentrated in the upper weathered zones. Excessive withdrawal leads to lowering of water levels and drying up of groundwater in the weathered zone. This also seems to cause reduction in the natural recharge occurring from annual rainfall. The farmers in these regions are forced to drill bore wells to chase the water which moves towards the deeper formations and get trapped in the cracks and fissures. Changing from large open wells to bore wells significantly reduces the ability to extract this renewable portion of groundwater.

The net result will be sudden, sharp and permanent reductions in the irrigation potential. However, this is not going to be compensated by a growth in well irrigation from the areas with underutilized potential such as Chhattisgarh, Orissa and Madhya Pradesh. There are two key reasons: the extremely poor demand (economic) for groundwater for irrigation due to the dominance of farmers with extremely poor economic conditions, and low irrigation requirements due to ecological reasons.

2.2.2 Waterlogging and salinity

The twin problems of waterlogging and salinity pose a serious threat to sustainability of agriculture in command areas. According to the *Report of the working group on Waterlogging, Soil,*

---

[6]Exceptions are the alluvial areas of north Gujarat and Punjab.

Salinity, and Alkalinity (GOI 1991) nearly 2.46 million hectares of land in command areas are affected by waterlogging due to rising groundwater levels. This trend is caused by excessive irrigation from canal water and under-utilisation of groundwater. The underlying cause is the incredibly low water rates and the poor control over water delivery. The problem of waterlogging is most severe in Haryana, followed by Punjab (table 4).

Waterlogging leads to salinity of groundwater and soils, causing permanent degradation of land and sharp productivity declines. Yield declines are reported from the canal-irrigated areas of Punjab, Uttar Pradesh and Haryana.

In coastal areas, salinity is caused by salinity ingress and seawater intrusion, and in inland areas, it is mainly due to rising groundwater levels (GOI 1999: p 94). For instance, a large tract of coastal area is affected by salinity in the Saurashtra area of Gujarat due to the intrusion of seawater in the coastal aquifers and seawater ingress. At the same time, rising groundwater levels in the command area of Mahi irrigation scheme cause soil salinity problems in South Gujarat (Kumar 2002b).

The area affected by salts, as the result of salinity and alkalinity, is reported to be as high as 3.3 million hectares in the country. Most of it is caused by salinity in groundwater in the command areas (GOI 1999).

Table 4. Extent of waterlogging and salinity in seven Indian states.

Name of state	Area water logged (‘000 ha)	Area affected by salts (‘000 ha)	% area water-logged	% salt -affected area
Bihar	619.70	224.00	3.56	1.29
Gujarat	172.60	911.00	0.88	4.65
Uttar Pradesh	430.00	1,150.00	1.46	3.91
Punjab	200.00	490.00	3.97	9.73
Haryana	249.00	197.00	5.63	4.46
Rajasthan	179.50	70.00	0.52	0.20
Tamil Nadu	16.19	140.00	0.12	1.08

Source: Author’s own estimates based on Government of India (1991), Ministry of Water Resources Report of the Working Group on “Waterlogging, Soil Salinity and Alkalinity.”

2.3 Land degradation and food security impacts

Land is an important resource for food production. Until recently, policy makers and policy analysts have not perceived land degradation as a threat to global food security. It has been widely assumed that at the global level, land is in abundance, and is less important than other factors in determining agricultural productivity (De Vries et al. 2002). Though the second statement has not been true in the case of India,[7] the problems posed by land degradation in irrigated lands other than those covered by canal commands has not yet become a central theme for policy discourses on food security. The waterlogging and salinity problems are concentrated in canal command areas of the alluvial

[7]The issue of stagnation faced in the growth of cultivated lands has been raised by many researchers in the past. Also, the issue of land degradation caused by water logging and salinity in canal command areas has been in the fore for quite some time.

plains of Punjab, Haryana and Uttar Pradesh while the problem of land degradation in well-irrigated areas, caused by irrigation with saline water or excessive use of fertilizers, is much graver as it can affect a larger area and is less apparent.

The current farming practices, which involve excessive use of chemical fertilizers and irrigation water, lead to salinization of soils and their consequent degradation. This is particularly important in the high production and productivity areas of Punjab, western UP and Haryana. These changes had major imperatives for the irrigation water requirement of crops, and farmers have to apply more water to maintain yield rates.

It is already established that the growth rate in food grain production has declined over the last few years (Katyal 1998). As regards agricultural production, the study by Evenson *et al*. (1999) shows that the contribution of TFP growth to the growth in agricultural output, which was the highest (1.39 %) during early green revolution (1966-77), had declined to 1.05 percent during 1977-87. It further argues that the contribution of inputs such as irrigation, fertilizers and research to raising TFP declined after the early green revolution period. For instance, the study shows that the elasticity of marginal TFP due to irrigation decreased from 0.28 during 1956 to 0.20 during 1977-87 (Evenson et al. 1999: table 30, p 61). This phenomenon, which is popularly known as the fatigue of green revolution, is attributed to the steady decline in the fertility (nutrient availability) of land, and general decline in soil health in the well-endowed areas. Since the basic resources have been used in an unsustainable manner, even to maintain the same level of production, larger inputs will have to be used. For example, 1 kg of fertilizer nutrient was sufficient to produce 15 kg of wheat in the seventies, whereas at present, 1.5 kg is required (Gadgil et al. 1999).

The following paragraphs illustrate the process of the degradation of land through irrigation. One immediate consequence of energisation of wells and the tube well revolution was the remarkable increase in the intensity of irrigation. The land, which used to receive irrigation water only once a year, started getting water in most of the cases in two seasons, and in a few cases in three seasons.

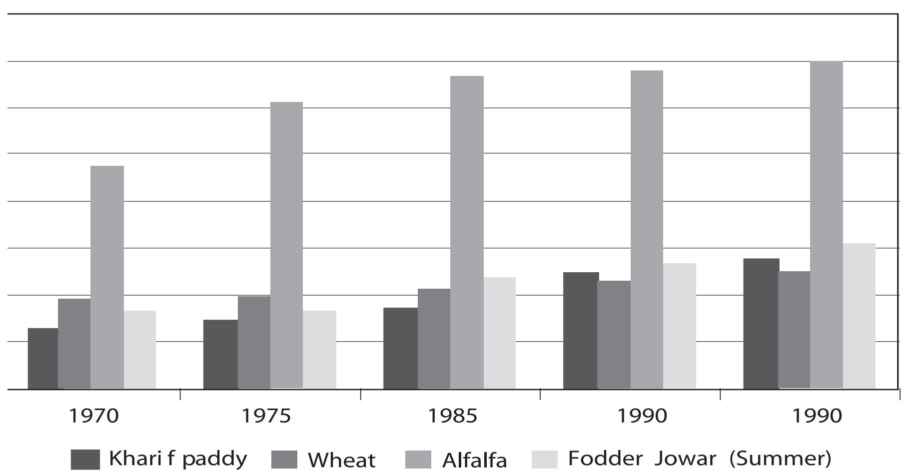
Excessive irrigation results in the leaching of minerals and organic matter into the soil. As the irrigated area increased, availability of organic manure per unit area of cultivated land got reduced substantially. Chemical fertilizers had to be used in greater quantities. These, in a way, substituted for the organic, bio-fertilizers, which fell far short of the requirements. The chemical fertilizers enhanced the secondary productivity of the soils. On the other hand, the organic fertilizers were necessary to maintain the soil structure; provide necessary soil nutrients; and maintain the primary productivity of the soils. Increased fertiliser use also became necessary for modern farming using green revolution hybrid varieties.

Studies carried out in the Daskroi taluka of the Ahmedabad District showed a remarkable increase in the rate of application of chemical fertilisers for crops namely, paddy, wheat, jowar and alfalfa, with the highest increase reported in the case of paddy, from 137 kg/ha in 1970 to 404 kg/ha in 2000. This results in breaking the soil structure. In a nutshell, three major changes in land use seriously impact land productivity: the increase in cropping and irrigation intensity; the increased rate of water application for each of the irrigated crops; and the increased rate of application of fertilizers.

Irrigation with saline groundwater also leads to soil salinity. A study carried out by GUIDE (Singh et al. 2000) cites groundwater over-exploitation as one of the major causes of inland salinity in Gujarat, just as the increased use of fertilizers, and the lack of soil nutrient management practices are. In many arid and semi-arid areas, farmers use high TDS groundwater for irrigation. This leads to the increase in soil salinity causing the hardening of soil surface and lump formation. In order to break the soil lumps to enable better growth of crops, farmers had to increase the water application rates. Thus, over a period of time, more salts get accumulated on the soil surface and the soils become saline. Excessive irrigation to leach the salts causes faster loss of organic matter and nutrients. All these ultimately result in soil degradation leading to a decline in water productivity and land use productivity. As a consequence, farmers are forced to increase irrigation for maintaining the yields. In the Daskroi taluka, the average number of waterings for *kharif* paddy went up steadily from 2.5 in 1970 to 5.5 in 2000 (figure 4). Similar differences were found in the case of wheat and summer jowar too. The average number of waterings for jowar went up steadily from 3.3 in 1970 to 4.75 in 1985 to 6.2 in 2000. For wheat, the increase in the number of waterings was only one over a period of 30 years. This reduces the economic returns from farming. The poor will be the worst affected, as economic constraints would limit their ability to invest more in farming.

The land resources that can be put to cultivation are shrinking due to a variety of reasons, the most important of which is urbanization. India is experiencing high rates of urbanization, in common with many Asian countries. The urban population growth is pitched at 3.0 percent against an overall growth in population of 1.2 percent. With the fast pace of urbanization, more and more agricultural land is being converted into non-agricultural uses. Under such a scenario, increased food grain production to meet the needs of growing population can be achieved only through intensified land use, with greater cropping intensity and greater use of agricultural inputs. This is because the contribution of yield enhancement in raising the total agricultural output tends to become less and less significant in the years to come. Yield increase in the important production areas, with very high levels of productivity, such as Punjab, is on the recession, as increasing water shortages, salinization, and leaching out present enormous problems (WRI 1995; Leisinger 2000).

Figure 4. Historical changes in irrigation rates, Daskroi, Ahmedabad.



2.4 Food security situation in India

The Food Insecurity Atlas of India prepared by the UN World Food Programme and M. S. Swaminathan Research Foundation on the basis of a food insecurity index[8] shows that Bihar and

[8]The Food insecurity index calculated for each state of India is a composite index taking into account five indicators for food availability, six indicators for access to food, and six indicators for food absorption.

Jharkhand are two “extremely food insecure” states in India (as cited in De Vries et al. 2002, figure 5, p 21). The poor agricultural productivity and production, and low level of food grain outputs resulting from the low level introduction of agricultural/crop technologies; poor rural infrastructure; high vulnerability of crop production to natural disasters such as floods and droughts; and high rates of unemployment and poverty, are some of the reasons for the high degree of food insecurity.

For instance, the annual growth rate of per capita Gross State Domestic Product (GSDP) is the lowest (1.2 % during 1991-92 to 1997-98) in Bihar among all Indian states, against 7.57 percent in Gujarat. It is 1.24 percent in UP and 1.64 percent in Orissa (SDP and population data obtained from the Central Statistical Organisation as quoted in Ahluwalia 2000). Similarly, the poverty ratio is the highest (54.96 %) in Bihar, and the second highest of 24.21 percent is in Gujarat (Planning Commission as quoted in Ahluwalia 2000).

On the other hand, Gujarat, according to the Atlas, is “severely food insecure”. Serious groundwater depletion, land degradation and the high degree of vulnerability of most parts of the State to droughts, the increasing allocation of scarce water from rural areas for industrial production and municipal uses are important factors causing agricultural output losses, and food insecurity problems in the State. In fact, groundwater depletion has increased the vulnerability to droughts of the most parts of the State, which do not have access to water supplies from surface sources and subjected to highly variable rainfall conditions (Kumar 2002b).

This is in spite of the high rate of economic growth achieved mainly through rapid industrialization (8.87 % annual growth) and the low percentage of people living below the poverty line. It is also important to note that the State recorded a very low growth rate in the agricultural sector, with the agricultural component of GDP growing at a slow rate of 1.42 percent during 1980-81 to 1997-98 (EPW Research Foundation, as quoted in Hirway and Mahadevia 1999). This once again reinforces the fact that unless we maintain steady growth in agricultural sector and food grain production, it is difficult to achieve food security, even with high levels of GDP growth and high average per capita incomes.

According to the Atlas, Madhya Pradesh, Rajasthan, Uttar Pradesh, Chhattisgarh, Orissa and Uttaranchal are also “severely food insecure” states. At the same time, states such as Andhra Pradesh, Maharashtra, Karnataka and West Bengal are “moderately food insecure”; Kerala and Tamil Nadu are “moderately food secure”; and Punjab and Himachal Pradesh are “food secure” (De Vries 2002: figure 5, p 21).

3.0 Irrigation Technologies in the Hands of the Poor

3.1 Technologies to change the trajectory of irrigation development

Though several arid and semi-arid parts of the country are facing groundwater depletion problems, there are several other regions, which do have abundant groundwater supplies, and in some cases surface water supplies too. Examples are the northeastern and eastern parts of the country such as eastern Uttar Pradesh, Bihar, North Bengal, Orissa and Assam. This region accommodates the largest number of poor people in the country (Shah et al. 2000). The groundwater resources in these regions largely remain under-utilized in spite of the fact that public irrigation facilities are very poor. High rates of illiteracy, poor economic conditions, and the lack of adequate rural infrastructure and experience with irrigated agriculture are the major constraints in these regions against tapping groundwater for wealth creating agriculture. Poor access to credit facilities for procuring modern water extraction mechanisms is another factor (Shah 2000).

With the conventional abstraction structures and mechanisms, the trajectory of the development of groundwater resources in the region is most likely the same as the projections made by the author. In order to change the trajectory of development, these regions need simple technologies that involve very little capital investment, and which can absorb the surplus labour force. This way, India can boost the rate of growth in groundwater development, which otherwise would remain slow, if conventional technologies are continued to pursue due to economic constraints.

Treadle pump, a manually operated pump, requires very low capital investments, while being much more energy efficient than traditional water lifting devises such as Denkul and Shena. The pump, which costs in the range of Rs 1000-Rs 1400, is highly suitable for millions of poor farmers in the region, who have postal stamp sized holdings. It can provide them the water security, essential for their livelihood. Treadle pump has already changed the face of rural economy in Bangladesh, where an estimated one million pumps are in use. Recent studies carried out in eastern India show that the adoption of treadle pumps leads to the irrigated area expansion, cropping intensities, enhanced crop outputs and yields, and a significant rise in income from farming, while farmers move from subsistence agriculture to wealth creating irrigated farming practices (Kumar 2000b; Shah et al. 2000). Therefore it is argued that the pump can create millions of micro-economies.

Studies conducted in Orissa also throw enough hard empirical evidence to show that pump adopting households enjoy greater food and nutritional security (Kumar 2000b). Treadle pump irrigation ensured increased output from irrigated agriculture, more importantly vegetables. The surplus production, which is sold in the market, brings in cash income from farming. This enables the households to purchase other essential commodities, which ensures better access to food supplies both in terms of quantity and variety.

To have a broad understanding of the food security impact of TP adoption, the data on the transaction of the essential commodities[9] are analysed for different categories of farming households. The results show that the percentage of households engaged in buying is the third lowest in the case of TP adopters (69 %), and the highest for rain-fed farmers (73 %). Also, the average number of commodities purchased is the highest for rain-fed farmers (6.57), and the smallest for TP adopters (6.17), though the difference is marginal. On the contrary, the percentage of households engaged in selling is the highest for TP adopters (19.8 % against 5 % for rain-fed farmers, 12.8 percent for tenda owners, 15.5 percent for water buyers, and 4.8 percent for landless sharecroppers), and the differences are wide. Further, the average number of commodities sold is the highest for TP adopters (1.8 against 0.45, 1.15, 1.4 and 0.4) and the differences are sharp. On the average, the number of commodities being transacted (either sold or bought) is, therefore, the largest for TP adopters (8.0 against 7.02, 7.38, 7.42 and 6.13) including kerosene, which every household purchases (Kumar 2000b).

The percentage of households engaged in the transaction (buying and selling) of all essential commodities is the highest in the case of TP adopters (88.4) as compared with that of the rain-fed farmers (78), *tenda* owners (82), water buyers (82.4) and landless sharecroppers (68). This means that the percentage of households which have access to all essential commodities is significantly higher for TP adopters than all their counterparts, especially rain-fed farmers and landless sharecroppers. An average TP adopter is able to access more of essential commodities than all his counterparts. The improvement in income levels has also influenced the type of food, as many adopter families started taking meat and eggs frequently, while it was a rare event prior to the adoption (Kumar 2000b).

[9]The commodities selected are rice, dal, egg, meat, edible oil, milk, vegetables and kerosene.

A comparative analyses of the quantum of the purchase and sale of different commodities showed that the average per capita transaction of six of the essential commodities (rice, meat, fish, milk, kerosene, and vegetables) was higher for TP adopters when compared with that of rain-fed farmers and landless sharecroppers. Further, the average per capita transaction of rice and vegetables is the highest for TP adopters and the average per capita transaction of fish, milk and kerosene is the second highest. This led to the conclusion that the TP adopter families enjoy greater access to food supplies in number of items and quantity than their counterparts having no irrigation facilities (Kumar 2000b).

Another aspect of household food security is the nutritional value of the food consumed. As Kumar (2000b) states "The introduction of TP has directly contributed to growth in vegetable production from farms. The green vegetables, which are also highly perishable, most often are harvested on alternate days. Farmers always keep a portion of the harvested vegetables for their domestic use. If the market price of the vegetable is too low, a good portion of the yield is kept for domestic consumption. Discussions with the women indicate that there has been a substantial increase in the intake of vegetables after the introduction of treadle pump technology. When they were purchasing vegetables from the market, the amount of intake was limited and very few varieties of vegetables, more specifically potato and onion, were used. Now, the families are able to take different varieties of green vegetables" (Kumar 2000b).

3.2 Technologies to increase crop per drop

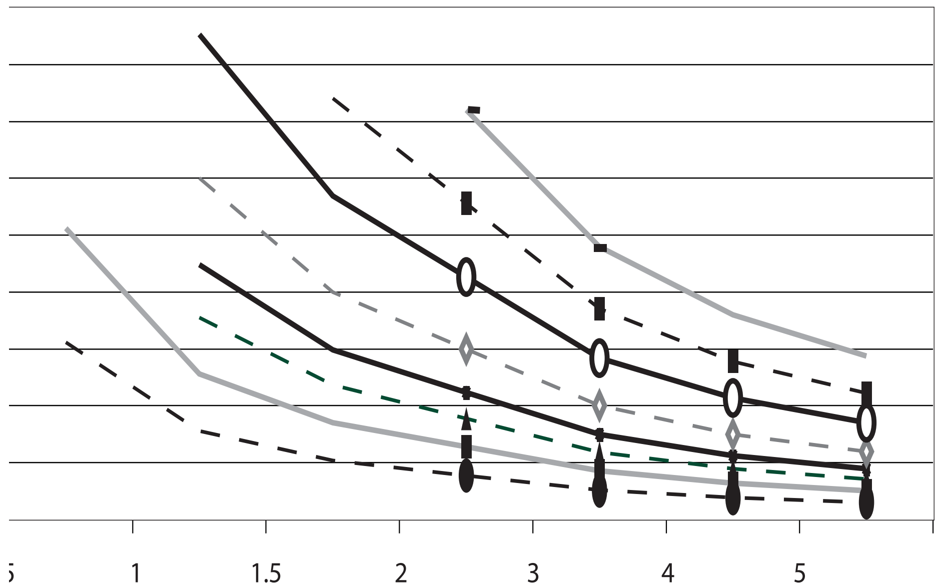
So far as harnessing more and more water from the natural systems is concerned, technologies have their limits. The next option available to enhance food production is to improve the efficiency of the use of water.

Worldwide, microirrigation technologies, conceptualised and developed in the early 1970s, are promoted to save water and get increased efficiency of water use in agriculture. There are several technologies, which help farmers save irrigation water (the water saving is up to 75 percent over flood irrigation) but also gives 20-30 percent higher yields apart from saving labour. While microirrigation systems have seen a relatively rapid adoption rate over the past one decade in India, the overall adoption level is still quite low. Drip and sprinkler irrigation systems cover less than 6 percent of the global irrigated area, and in India, they cover only 2,00,000 ha or less than half percent of the net irrigated area of the country. (Behr and Naik. nd. as cited in www.ideorg.org/techgallery-library/techinfor/china1.htm)).

But, these technologies have great bias. For farmers to take full advantage of them in terms of water saving, they should install them for large fields. However, this depends on the mode of charging for electricity in the farm sector. In areas (states) where power pricing is dependent on the pump horsepower, both the capital cost of the pumping per unit per unit area and the operating cost per unit area will be higher for resource poor farmers who adopt the system for smaller areas. The farmers who adopt the system for larger areas can bring down the cost per unit area significantly (figure 5: based on author's own calculations. Details are given in table 3 of Kumar 2002c). This is due to two reasons: the capacity of the pumping unit is not dependent on the area of coverage of the pressurised irrigation system, but the discharge of the pump; and the electricity charge is not dependent on the energy consumed which will be high for farmers who adopt the system in larger areas.

These systems involve high capital investments. Further, installing these systems for small fields would increase the cost per unit area. Also, the maintenance requirements of these irrigation systems

Figure 5. Estimated unit operating cost of microsprinklers for different discharges and areas under flat rate system.



are quite high. The drip system, the most water efficient of these technologies, is most suitable for horticultural plantations from the point of view of cost effectiveness. Thus, they are best suited to resource rich, large farmers, who can spare part of their land for horticultural crops, and wait for 3-4 years for returns.

Another important issue involved in the adoption of pressurised irrigation systems is the lack of enough economic incentives. In many Indian states where depletion problems are encountered, groundwater resources are abundant, only the power supply is limiting the farmers' access to groundwater. Examples are alluvial areas of north Gujarat, Punjab, western UP and Haryana where the groundwater supply potential is higher than what the available power supply could deliver.

The large static storage of the aquifers[10] permits the farmers to keep pumping water, even though it is at the cost of an excessive draw down. The factors like the overall physical availability of utilisable groundwater, and economically viable pumping depths do not have any influence on the pumping behaviour. This is owing to two major reasons. First, either the cost of electricity for pumping a unit volume of water is extremely low (under subsidised unit pricing system) or the marginal cost of energy for pumping is zero (under the flat rate system of pricing electricity). Second, there are no limits on the volumetric pumping by well owners, and well owners do not pay for water.

Since pressurised irrigation systems need extra power to run, the well output could drop with their installation. As the farmer is already utilising the power supply fully, the total water output from the well would drop. Though farmers could manipulate the well output by choosing a higher capacity pump, he will not do so due to the power tariff implications. Thus, the farmer will not be

[10]Western UP and Haryana are underlain by deep alluvial aquifers which have a vertical extent of nearly 2000 metres. Most parts of north Gujarat are underlain by a multi-aquifer system of alluvial nature, which has a vertical extent of up to 600 metres in many parts. Most of Punjab is underlain by the alluvial deposit of the Indus valley.

able to cash in on the benefit due to water saving in the form of an increased area under irrigation. Therefore, the only economic opportunity available with pressurised irrigation technologies is the yield increase. However, ability to secure higher yield through water saving devices depends heavily on the management practices, including agronomic practices.

Nevertheless, the situation would be drastically different in hard rock areas facing depletion problems. This is a situation where power supply is in abundance and groundwater is scarce. In these areas, currently, farmers are not able to utilise the power supply fully due to the shortage of water in wells. In such situations, pressurised irrigation systems could benefit the farmer by enabling him to run the pump for longer hours, maintain the same level of total well output and irrigate a larger area.

Water saving technologies have recently been developed to suit the requirements of many millions of the poor, small and marginal farmers in the country. They are the mini sprinkler systems and microtube drip systems being promoted by the international development enterprises. While minisprinklers require energised pump sets, microtube drips can work under a very low-pressure head, with as little as a bucket full of water. These systems are adaptable to postal stamp sized holdings. It enables the poorest farmers with very little access to irrigation water to grow crops and earn their livelihood. Such technologies can attract even the landless farmers, who can cultivate vegetables in their backyards. The investment is as low as Rs.15, 000 per acre, while the conventional sprinklers and drips cost around Rs.60, 000 and Rs.75, 000 per acre, respectively. These systems require much less maintenance when compared with the conventional pressurized irrigation systems. The ease of maintenance is more significant in the case of microtube drip systems. However, the adoption of these technologies by poor farmers would depend heavily on the supply of information, materials and services for installation.

There are several hilly regions in India where plantation crops such as tea, coffee, rubber, and horticultural crops are widely grown, such as western Ghats covering parts of Kerala and Tamil Nadu, the northeastern mountain regions covering parts of Assam, West Bengal, and Himachal Pradesh. In spite of the heavy rainfall received during the southwest monsoon and the southeast monsoon, crops in these regions require water during parts of winter and the entire summer season due to high evapo-transpiration and the poor natural storage of water. Conventional irrigation practices cannot be adopted due to the topographical constraints. Low cost pressurised irrigation technologies, more specifically minisprinklers (mainly for tea and coffee plantations), and microtube drip systems (for all types of orchards) would prove a boon in these regions.

4.0 NRM Technologies for Sustainable Agricultural Production

The ability to improve the water productivity and land use productivity depends on the way we manage the primary productivity of land (Kumar 2002a). There are several on-farm management practices the Indian farmers can adopt. Such practices are particularly important for the semiarid regions which have already taken to intensive farming with irrigation water, both from canals and aquifers, such as Punjab, western UP, Haryana, Gujarat, Rajasthan and Tamil Nadu.

These practices, if carried out consistently, can progressively reduce the water requirement of the existing crops, and improve primary productivity of the cultivated land. They are the increased use of organic manure with the gradual reduction of chemical fertilizers, vermin-culture, and agronomic practices such as mulching, crop rotation and the use of biopest control measures. Organic manure can help regain structure and texture of soils and enhance their moisture retention capacity along with improving soil nutrients. Use of farm management practices such as mulching can reduce the evaporation from soil surface, thereby increasing the efficiency of irrigation water utilization. A recent study of organic farming practices adopted by nearly 250 farmers in Gujarat showed that over a period of three years, the irrigation water requirement of the crops in the organically farmed field, had reduced by half (Kumar 2002a).

There are several scientific studies carried out in Gujarat, which show the yield and water productivity impacts of organic manures and mulching (Sadhu et al. 1996; Singh et al. 1990; Dudhat et al. 1996). In a study carried out on the effect of mulching on the yield and water productivity of the mustard crop in south Saurashtra, it was found that the pooled yield of seeds went up from 1004 to 1087 kg/ha and pooled stover yield went up from 2751 to 2962 kg/ha with the application of mulch at the rate of 10t/ha, over a two-year period. Further, the agronomic efficiency of water use also increased significantly from 4.56 kg/ha/mm to 5.43 kg/ha/mm (table 1; Sadhu et al. 1996). The study reported by Dudhat et al. (1996) showed the positive effect of organic manures such as Farm Yard Manure (FYM) and castor cake on grain and straw yields of wheat with a significant impact on B/C ratio. The yield of wheat went up from 4.30 t/ha to 4.683 t/ha with the application of FYM (15t/ha), and from 4.3 to 5.038 t/ha with castor cake (table 1, Dudhat et al. 1996). The B/C ratio was 1.94 with the combined dose of FYM and Full Recommended NP Dose(FRD) of fertilizers, against 1.72 with FRD of fertilizers (table 2, Dudhat et al. 1996).

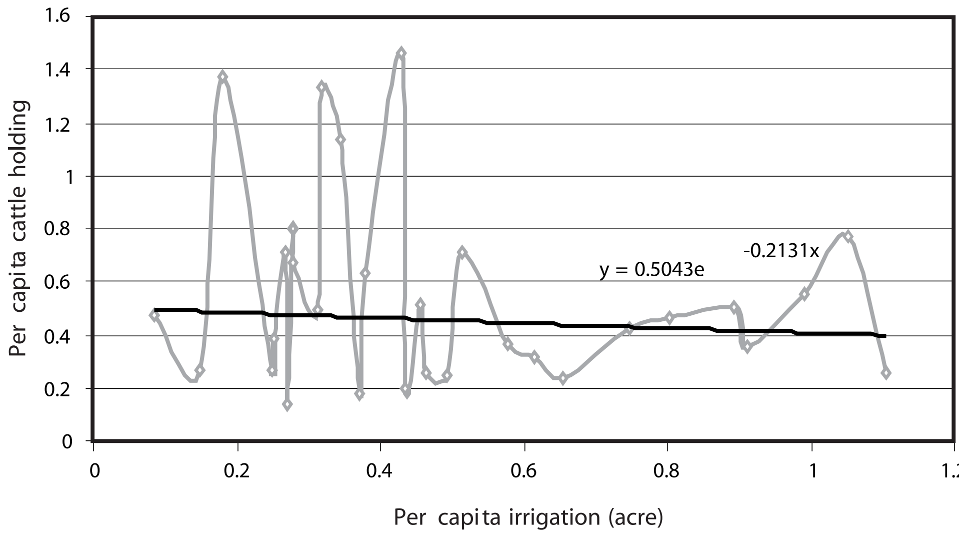
In a nutshell, in order to increase the water productivity in agriculture, the primary productivity of land needs to be increased. This requires nutrient management measures. The biomass inputs have to be proportionally increased to increase the efficiency of utilisation of irrigation water. In order to increase the overall productivity of land, the moisture retention capacity of soil needs to be enhanced along with increasing the biomass inputs. Thus, there is a need to manage land, water and biomass in an integrated manner (Kumar 2002a).

But, the Indian farmers would face several constraints in adopting more sustainable agriculture based on organic farming practices. They use cattle dung and straw for preparing FYM. However, the practice followed for this is highly unscientific and the efficiency of the utilisation of biomass is extremely low. This is the first constraint. Studies show that if scientific methods of composting are practised, the efficiency of producing FYM can be substantially increased.

The second constraint is the availability of biomass for the preparation of organic manure and mulching. Cattle dung is the major source of biomass. The other sources of biomass are crop residues, and trees. Farmers use cattle dung for preparing “dung cakes” apart from using it for compost making. They often use leaves and branches of trees planted on the farm-bunds for feeding cattle during drought years, apart from using them for compost making. On the other hand, crop residue is an important source of fodder and domestic fuel. The increase in the cattle holding per family can increase the availability of biomass. But that will increase the biomass requirement for fodder, which in turn would increase the water requirement for growing fodder. This means, the farmer should have a land holding of optimum size at his disposal to generate surplus biomass, which can be used as cattle feed and farm input, without using exogenous water inputs. For a farmer, the availability of surplus biomass for best farming heavily depends on how he is positioned with regard to cattle, namely the land holding, and his ability to invest for efficient compost making practices and find alternative sources of cooking fuel.

This means that small and marginal farmers are likely to face severe constraints in shifting to more sustainable ways of farming. The farmers having large holdings along with cattle are likely to experience relatively lower stress in managing their biomass needs. One main reason for this is that the size of the cattle holding is not proportional to the land holding size. The families having large holdings, and irrigation facilities try to minimize cattle holdings, while those with poor holdings and irrigation facilities utilize surplus family labour for rearing cattle. As a matter of fact, livestock keeping and dairy have become the most important source of livelihood for the small and marginal farmers of "water stressed" regions like Gujarat and Rajasthan where their ability to generate sufficient income from irrigated farming is declining. A study carried out in 30 villages in the Banaskantha District, which is in one of the most water scarce regions in India shows, according to the author's analysis, that the per capita cattle holding (milch) is inversely proportional to the per capita irrigation (see figure 6).

Figure 6: Irrigation vs cattle holding.



Note: 1 cow/buffalo = 1 cattle unit; 1 sheep/goat = 0.1 cattle unit.

The issue of biomass availability is pertinent in the Indian context as the small and marginal holdings account for the lion's share of the total operational holdings in India. According to 1990-91 Agricultural Census, 78.2 percent of the holdings belonged to small (18.8 %) and marginal (59.4 %) farmers, who controlled a total of only 29 percent of the area under cultivation. The number of small and marginal holdings in the country has been on the rise over the years, while the medium and large farmers have been on the decline.

The challenge is to produce surplus biomass that can be used as input for farming, without causing any increase in the dependence on exogenous water for producing it in the form of fodder and leafy material.

Rainwater is the only endogenous source of water. Many arid and semi arid regions of the country which receive low to medium rainfall, are characterized by high year to year variation in the monsoon rains, with years of high and low rainfalls. In high rainfall years, the number of rainy days is also high, and the farmers can take up the plantation of trees in common land as well as private land. The resistance of trees to moisture stresses is high, by virtue of which they would survive even during the years of low rainfall and during droughts. In the absence of moisture in the soil moisture zone of the sub-surface strata, the deep-rooted trees can suck the hygroscopic water in the vadose zone. Once matured, the trees will provide biomass throughout the year.

Farmers with relatively large holdings can adopt block plantation, and those with smaller holdings can take to peripheral plantation on private land. On-farm water conservation practices such as construction of "farm bunds" and "farm ponds" can also be adopted to ensure the availability of moisture and water, necessary for the growth of trees. Another way to produce surplus biomass is to go for rain-fed crops in large areas that would yield sufficient green fodder during *kharif* and dry fodder during other seasons, and also crop residues for mulching and compost making. However this is viable only in the case of farmers having large holdings.

Community plantation is another viable alternative. In case of common land, soil moisture conservation measures can be adopted. Indian villages have sufficient amount of wasteland under the control of the local government. These lands can be transferred to the village institutions, which are legally recognised, for taking up plantation and soil moisture conservation activities. These local institutions can take up the plantation of tree crops, grasses and some of the green fodder. They can evolve norms to ensure equitable distribution of the returns. If the farmers practice scientific methods of composting, the effective availability of biomass will increase. Adoption of biogas plants would reduce the pressure on crop residues and cattle dung for cooking fuel.

5.0 Institutional Changes for Changing the Trajectory of Water Use and Productivity in Agriculture

The strategy to increase agricultural production and economic outputs, without causing any increase in the overall demand for water, is to increase the economic efficiency of water use. Demand management strategies have two components: the transfer of water for economically more efficient uses; and the encouraging of the present efficient use of water. But to ensure food security at the house level, there should be greater equity in access to and control over water allocated for agriculture.

5.1 Promoting equity and productivity in water use

The growing competition and concomitant conflicts between different sectors are major issues that need to be addressed in water allocation. The fundamental challenges are the promotion of economically efficient uses, while adequately compensating the agriculturists for the losses they suffer due to the transfer of water to other efficient use sectors, and the equitable access to water from canals and groundwater within the agricultural sector. This is important for regions with good natural endowment of water like Bihar, Orissa, and eastern UP as well as those, which face physical shortage of water, and where demand exceeds supply like Gujarat.

Saleth and Dinar in their paper, *Water Challenge and Institutional Responses (A Cross Country Perspective)* say that concerns in the water sector, which once revolved around water development (and quantity), are now focussed on water allocation (and quality) (Saleth and Dinar 1999).

Markets and regulations can be sought as instruments for water allocation (Frederick 1993; Howe et al. 1986). Howe and co-authors suggest six criteria for comparing alternative institutional arrangements to allocate water: (a) flexibility in allocating supplies in response to both short-term and long-term changes; (b) security of tenure to encourage investment in and maintenance of water-use system while allowing for users to respond voluntarily to incentives to reallocate supplies; (c) whether or not the user is confronted with the real opportunity costs of the resource; (d) predictability of the outcome of the transfer; (e) equity impacts; and (f) whether or not the public values are adequately reflected in the process. Frederick (1993) adds low-transaction costs of moving water from one use to another to this list.

But, both markets and regulatory approaches are likely to fall short of satisfying all these criteria for efficient and effective water allocation (Frederick 1993). Let us take the case of maintaining in-stream flows in natural watercourses and rivers, which is an important demand management objective to be achieved through water transfers. This is a public good and the users of in-stream flows have no incentives to pay for the services it provides. As a result, markets are likely to fail in this sector. The enormous geographic and temporal diversity in water supply and demand situations suggest that no single institutional arrangement is likely to be preferred in all instances (Frederick 1993). Howe et al. (1986) have argued that markets meet all the criteria for effective water allocation better than any likely alternative in many situations. Saleth and Dinar (1999), based on their cross-country evaluation of the institutional responses in the water sector, show that "the old paradigm focused on centralized decision making, administrative regulation, and bureaucratic allocation is fast giving way to a focus on decentralized allocation, economic instruments, and stakeholder participation" (Saleth and Dinar 1999).

This argument, by and large, is valid in the Indian context. The spatial and temporal variation in water availability is very high in India, caused by heterogeneity in hydrology and geo-hydrology, and high inter-annual variability in rainfall. For instance, 62 percent of India's water resources are concentrated in the Indo-Gangetic basin (GOI 1999). There are significant variations in the per capita renewable freshwater availability across regions. The author's own estimate shows that it is as high as 1,210 m^3 per annum in erstwhile Bihar and 1,362 in UP where the withdrawals are very low, while it is as low as 427 m^3 per annum in north Gujarat where the annual water withdrawal is 448 m^3 per capita (Kumar and Singh 2001).

So is the variability in demand situation. Socially and economically in regions such as Bihar and Eastern Uttar Pradesh, irrigation demand is very low, though water resources are abundant, and problems of waterlogging due to rising groundwater levels caused by flooding and excessive irrigation from canals are encountered (Shah 2000). The demand for water for industrial and urban uses also remains very low in these regions. The demand management challenge here is to create increased demand for groundwater through market institutions, as investment in public tube wells has not been very effective.

However, demand for water is extremely high in arid and semiarid regions of Gujarat, Rajasthan, Tamil Nadu and Maharashtra where water resources are very scarce, and groundwater is the major source for all purposes. Pumping regulation in areas facing over-development problems through groundwater legislation, control of institutional financing for well development and the restriction of power connections for pumps have been by and large ineffective in these regions (Kumar 1995; Kumar 1999/2000; Janakarajan 2002). Further, long distances involved in the conveyance of water between regions of abundance and shortage, reduces the ability of the government to invest in public water systems for the supply of water in bulk as it has serious financial and environmental imperatives. Inadequate finance too restricts public investment in large-scale inter-basin transfer projects, as discussed earlier (Chaturvedi 1999).

The absence of well defined property right regimes is a major source of uncertainty about the negative environmental impacts of resource use, leading to inefficient and unsustainable use (Pearce and Warford 1993; Kay et al. 1997). This has been apparent in the case of both groundwater and canal water supplied for irrigation.

In the Indian context, many researchers in the recent past have suggested establishment of property rights as a means of building institutional capability to ensure equity in the allocation of and efficiency in the use of water across sectors (Singh 1995; Chaudhary 1996; Kumar 1997; Saleth 1996; Kumar et al. 1999; Kumar 1999/2000). But, again, if the rights are allocated only on water use, this can result in the expending of water without good use for it (Frederick 1993). Therefore, water rights have to be tradable (IRMA/UNICEF 2001; Kumar and Singh 2001). The establishment of privately-owned, tradable property rights is important for the creation of conditions for individuals to have opportunities and incentives to develop and use the resource efficiently, or transfer it for more efficient uses (Frederick 1993).

The volumetric use right of individuals or "entitlements" can be defined and established by the government agency concerned using a variety of social and economic parameters. A user who needs more water than the actual entitlement can purchase the water rights from another user by paying prices determined by the supply–demand interactions. The price of water will reflect the opportunity cost of its use. The markets and market determined prices could work in two ways: they make farmers shift to alternative uses that provide higher economic returns than the price of water; or continue the existing uses with more efficient practices or else resort to sell (Frederick 1993). Such transfers can promote access equity and efficiency in use (Kumar 1997; Kumar et al. 1999; Kumar 1999/2000).

Empirical evidence collected on the functioning of groundwater irrigation institutions in north Gujarat shows that under a system of fixed volumetric water use rights, farmers prefer to grow mustard, which is less water intensive, in a larger area than wheat, though the former has much lower land use productivity than the latter, but with the same water use productivity (Kumar 2000a).

Tradable private property rights need to be enforced for groundwater and water supplied from public reservoirs for irrigation. In the case of groundwater and canal water supplied for irrigation, as individuals enjoy access to the resource, private property rights for individual users are envisioned.

For markets to function efficiently, the full benefits and costs of transfer should be borne by the seller and the buyer. Generally, this is not possible due to the third party effects of water transfer. Allowing the user to transfer only the consumptive portion of the water he uses can reduce the third party effects in dry regions. The government will have to play a great role in reducing the third party effects of water transfers. Similarly, the government has to invest in protecting the ecological and environmental services that are affected by water transfers (Frederick 1993).

Fixing norms for the allocation of volumetric water rights across individual sectors, viz., agriculture, industry and domestic use, should involve considerations such as the physical sustainability of the water resource system and the environmental sustainability. The total water allocated from any region/basin, therefore, should not exceed the difference between the annual renewable freshwater and the ecological demand, or the utilizable freshwater whichever is less. Going by such norms, in the regions, where water resources are abundant by nature such as the eastern part of UP, Bihar, Orissa and West Bengal, the volumetric water rights of individual sectors and users, especially farmers would be very high.

In these regions, the potential for enhancing water productivity is low, though there are opportunities for increasing output through increased use of irrigation input. At the same time, land availability would continue to be an important factor in deciding returns from agriculture. The farmers will, therefore, have to choose crops, which are more water intensive and which would encourage intensive use of the same piece of land. In states such as UP and Bihar, land reforms could not have been implemented so far. Hence, water rights would not mean much for a large number of cultivators who have marginal holdings or no land. But, allocating and enforcing water rights would be easier in these regions than the land ownership rights as water is in surplus.

In such situations, the allocation norms in agriculture need to be carefully designed, if equal opportunities are to be given to all types of cultivators for improving their own farm economies. In water allocation, the food security needs of the families could be given priority rather than the farm size. This will result in disproportionate allocation of rights in favour of small and marginal farmers, and thus, we can delineate water rights from landownership rights, enabling the landless to get rights to use water. Since the chances of increasing water productivity through improvements in physical efficiency are low, the rich farmers would try to intensify land use to enhance land use productivity by going for highly water intensive, short duration crops. This would increase the water requirement.

Total productivity or production = water use productivity x volume of water use

This can induce interlocked land, pump and water markets, wherein the rich well owning farmers will offer pump services to farmers who do not have their own irrigation sources, and can, in return, use a portion of their water rights. This will force the rich well owners to charge less for their pump irrigation services they provide.

The rich will also enter into sharecropping arrangement with the landless. A good economic opportunity lies for landless, small and marginal farmers in transferring water in bulk to water scarce regions, or cities and industrial areas, which are concentrated points of great demand for water, as these farmers are likely to have excess water.

Physical conditions for the transfer of water from rich areas to water scarce areas exist in many regions. For instance, great opportunities exist for such transfer from south and central Gujarat to north Gujarat (Kumar and Singh 2001). There could as well be opportunities for the transfer of water from the areas of Punjab showing a rise in water levels to areas facing the crisis of overdraft. Once water rights are properly established, farmers will show the willingness to invest in infrastructure for the transfer of large quantities of water to the areas of high demand through group efforts.

In developing countries, effecting institutional reforms for water management, including well established water rights is going to be an ardous exercise, and the transaction cost is going to be enormous. However, the opportunity costs of not investing in institutional reforms in the water sector are going to be enormous due to the growing water scarcity, and can exceed the transaction cost (Saleth and Dinar 1999). Therefore, in water stressed regions, investment in creating institutions could be justified to a great extent. Further, it is a global phenomenon that when water becomes scarce, communities increasingly evolve and enforce social institutions.

Efficient water markets are likely to come up more in intensively irrigated (groundwater) areas due to three reasons: the extensive use of conduits for water conveyance which increases the transferability of water and reduces the third party effects; the ability to measure the rights purchased; and the relatively low distance of transfer which reduces the transaction cost.

Well established tradable property rights and well developed water markets can bring about significant improvements in the water productivity in agriculture, and the growth in agricultural outputs, thereby ensuring economic security.

One of the fears associated with the allocation of tradable water rights is the trade off between food security and economic efficiency: that it encourages farmers to increasingly allocate water for non-agricultural purposes such as industry, with adverse impacts on food grain production, though such a tendency is desirable in a drought year. Results from the study carried out by IFPRI on Maipo river basin show that net profits in irrigated agriculture increased substantially when compared with those in the case of proportional use rights without rights to trade water. Moreover, agricultural production did not decline significantly, when water was traded from agriculture. Farmers earned substantial benefits from selling their unused rights, during the months with little or no crop production (www. ifpri.cgiar.org/themes/mp10.htm).

Legally, well established water right systems exist in some parts of the developed countries even for groundwater. Examples are California and Kansas in the western United States. The Kansas state applies the prior appropriation doctrine "first in time is the first in right" to groundwater. The states in the western U.S. recognize rights to use water as property rights regarding much like land. Under *the Kansas Water Appropriation Act (1945),* from the effective date of law, any person seeking the rights to use water had to apply for a permit. The "junior water rights" were to give way to "senior water rights" in times of conflict. However, these water appropriation rights were not expressly stated as property rights, but were recognized as usufructuary rights. The Act is administered by the chief engineer of the Division of Water Resources in the State Board of Agriculture. But in 1957, the Kansas legislature amended the Act to re-define water rights as "real property rights".[11] However, these water rights differed from land ownership rights in the sense that water right is a usufruct— i.e., a right to use water and not absolute ownership.

Though several thousands of permits were granted under the Act, it led to the creation of several groundwater mining areas, which subsequently led the chief engineer to close many parts of Kansas to new appropriation permits. Recognising the problems, the Kansas legislature passed an enabling Act for the creation of Groundwater Management Districts (GMDs) for the purpose of conserving groundwater resources. However, it had the twin policies of preserving basic water law doctrine and establishing the rights of local water users to determine their destiny with regard to the use of groundwater. The GMD Act led to the creation of groundwater management districts covering one-fourth of the Kansas State. Though the GMDs also came out with several regulations relating to well spacing, the formula for safe yield and depletion etc., they were applicable to new permits only and by that time some areas were already over-appropriated. But, part of the GMD Act gave the chief engineer power after notice and hearing, to establish "intensive groundwater use control areas" (IGUCAs). Within the IGUCAs, the chief engineers would have extra-ordinary power for reducing the permissible withdrawal of groundwater by any one or more appropriators there. However, such intensive groundwater use control areas still account for only a small share of the Ogallala aquifer in the western US that experiences serious mining problems (Peck 2003). Peck (2003) opines that it will be difficult to establish water rights in areas where over-pumping is a problem, but property rights do not exist.

The western US examples with the established and well defined water rights, though, do not provide successful cases of checking or controlling groundwater mining problems.[12] One should keep in mind that the water right laws framed in 40's and 50's in that part of the world have not evolved in response to the problem of groundwater mining per se. They have evolved in response to a series of court cases to either protect the rights of prior appropriators or secure new rights, and at a time mining was not a social concern. In contrast to the western US, India does not have water rights defined, but almost every land owning farmer enjoys rights to access groundwater underlying his plot of land, and overdraft and mining are problems that concern society at large. It

[11]Henceforth, water rights were to be regarded as those concerning real estate with deeds for conveyance and mortgage for security interests, with rights treated as real estate for *ad valorem* taxation, and with the applicability of the Statute of Frauds requiring contracts for the sale of water rights to be in writing to be enforceable.

[12]A few exceptions are the Walnut Creek IGUCA and Rattlesnake Creek Management Programme. There was also a recent proposal to extend the life of Ogallala aquifer. The three main recommendations of the proposals was to delineate the aquifer into subunits to allow management decisions in areas of similar aquifer characteristics; to identify each aquifer subunit in decline or suspected decline by the GMDs and DWR and establish water use goals to extend and conserve the life of Ogallala aquifer; and to identify vulnerable subunits for action.

will be easier to define water rights as "property rights" and grant/allocate them in a manner that the total allocation does not go beyond the renewable recharge.

Over and above, the water rights law of Kansas and other parts of the western United States and the Groundwater Management Districts provide pointers to India for the possible legislative courses of action and institutional interventions. The concerns such as the long term sustainability of the resource base and safe yield could be taken into consideration in defining use goals for groundwater in a region while establishing a groundwater management regime. One important factor that renders the instituting of well defined property rights on water in India almost an impossible task is the presence of millions of tiny users within the jurisdiction of a state or hydrological entity (basin). This problem can be tackled by creating management regimes for small geographical units inside a large management area, which could be an aquifer or a river basin, and integrating them at the larger management unit level through vertical coordination and linkage.

5.2 Encouraging efficient use of water in agriculture

Irrigation is the largest user of water in India. Water conservation has three distinct components: a) the prevention of the loss of stored water; b) the prevention of the loss of water from the system during conveyance from supply source to the agricultural fields; and, c) the adoption of efficient water use technologies on farms. The scope of these three components needs to be analyzed.

In irrigation, storage losses are very high for surface reservoirs. The potential for saving this water is very high. Again, the conveyance or the network losses are very high for the surface irrigation systems in the country. It is believed to be in the order of 45-55 percent for many of the large surface irrigation systems with extensive distribution networks consisting of several hundred kilometres of unlined channels.

In India, the farm level efficiency in surface irrigation systems is very poor due to very high field evaporation, evapo-transpiration, percolation, and runoff losses due to flood irrigation and the poor on-farm water management practices being adopted by farmers. There is enough empirical evidence to substantiate this. For instance, it was found that 70 percent water loss in rice fields was due to percolation through the sandy loam soils of Delhi and only 480 mm out of 1200 mm of water was actually used consumptively by rice (Vamadevan & Destane 1968). But, the use of irrigation technologies such as drips (for row crops) and sprinklers (for field crops) that can result in significantly saving water used for irrigation is found only in just one percent of the total irrigated area.

There are no storage losses in groundwater irrigation. Conveyance losses are also very low due to the generally short conveyance systems used. The field efficiency is also generally higher due to the greater control over water and the manageable discharges. However, uncertainties about time and duration of power supply compel farmers to apply excess water when supply is available, leading to inefficient use.

5.2.1 Pricing of irrigation water

The fact that water is a scarce economic input should be a major consideration in determining the price of water used in irrigation (Kay et al. 1997). As a general principle, price of water for competitive use sectors such as irrigation and water intensive industry, should be guided by economic efficiency consideration. This means the pricing of water should be fixed in such a way that it discourages uses that are economically inefficient. In India, annual irrigation subsidies are estimated to be around 5,400 crore rupees (Wolf and Hubener 1999). However, irrigation water pricing is complex due to the concerns relating to public policy apart from those which are purely economic in nature (Rao 2000).

The financial health of irrigation agencies is another important concern, which may conflict with the social welfare concerns. After independence, the Indian governments saw irrigation as a welfare activity, and were reluctant to raise the irrigation fee charged from poor farmers. As irrigation services declined and agencies weakened, farmers became reluctant to pay the water charges.

India's food security policy, which has the objective of ensuring food grain availability at an affordable price, has been another compelling reason to provide subsidies for the agricultural inputs, namely, water for irrigation supplied from public systems, electricity used for groundwater pumping, and fertilizers. This is because the farmers are denied the option of fetching high prices for their grain through free trading due to the government restrictions on inter-state grain trading, and that the only way to make food production remunerative was through cutting down on the input costs (Goyal 2002).

The provision of input subsidies as such is not a bad idea in the agricultural sector. Several countries around the world still resort to subsidies to enable farmers to grow food at low cost (Kay et al. 1997; Rao 2000). For instance, according to the estimates compiled by the US bureau of reclamations, in 1986, 17 western states in the US received an irrigation subsidy of US$534 million, from the federal government, with an average of US$54 per acre of irrigated land. As Rao states, "To the extent that large subsidies can alter the potential efficiency patterns of water use, water subsidies can cause long term irreversible effects — environmental, physical, geographic, economic" (Rao 2000).

While, a properly formulated and targeted pricing policy can bring about the desired outcome of a subsidy, there are significant policy failures in the pricing of irrigation water, owing mainly to the inappropriate pricing structure.

Due to the incredibly low water rates for the crops, and the zero cost of marginal increase in irrigation water use, the farmers have a tendency to grow crops that are highly water intensive. In the canal-irrigated south and central Gujarat, out of the total 6,177 MCM of water used for agriculture, 4,614 MCM is used up by sugarcane and paddy alone (IRMA/UNICEF 2001). These crops yield very low returns per unit volume of water. Adoption of such crops leads to shrinkage in the command (Kumar and Singh 2001). Such system of pricing perpetuates inequity in access to water and the distribution of the subsidy benefits. The inappropriate pricing structure and the lack of agency capability to recover water charges and penalise free riders encourage wasteful practices.

In spite of the recommendations of the Second Irrigation Commission, state irrigation bureaucracies have failed to raise water charges that make economic sense. The failure has its roots in the absence of institutional capability to improve the quality of irrigation services and correctly monitor the water use, the lack of institutional arrangements at the lowest level to recover water charges from the individual farmers, and the failure to enforce penalties on free riders (Brewer et al. 1999).

An appropriate pricing structure with volumetric mode, followed by volumetric rationing could facilitate the introduction of conservation measures and efficient use practices in irrigation. A recent analysis for Gujarat shows that the negative impact of the rise in cost of irrigation water can be offset by the differential yield due to the increased reliability of irrigation water delivery (Kumar and Singh 2001). This leads us to the conclusion that the rates for canal water can be increased to substantially higher levels, provided the quality of irrigation water is enhanced.

But, the water pricing for irrigation can impact poor farmers adversely, if pitched at higher levels (Frederick 1993). One of the ways to reduce the negative impacts on access equity is to introduce progressive pricing system (Kay et al. 1997). The low levels of use can be priced low and higher levels of use, higher. In any case, the prices have to reflect the scarcity value of the resource. This can motivate the farmers to allocate water for the most efficient uses or to adopt efficient water use technologies for the existing use and sell the excess water at the market rates to those who need it. Though the rights of individual users are a function of overall water availability and will change with regard to rainfall and other climatic factors, they will be assured to meet the basic needs in all the years. But, pricing changes and rights reforms will have to be accompanied by the modernisation of irrigation schemes. It involves technological innovations in the infrastructure for greater control and measurement of water delivery, and institutional changes for greater involvement of user groups in irrigation management right from the main system. The cornerstone of the strategy is to improve the quality of irrigation.

5.2.2 Pricing of electricity in the farm sector

Most Indian states follow the flat rate system of pricing the electricity supplied for the farm sector based on the premise that the management costs of metering electricity are high. The flat rate system of pricing electricity encourages farmers to over-pump groundwater. It also leads to the disproportionate distribution of the benefits of subsidies in favour of farmers who enjoy greater access to groundwater, either because of the resource availability or because of the yield potentials of wells in particular geo-hydrologic environments (IRMA/UNICEF 2001).

Many researchers have suggested rational pricing of electricity as a potential fiscal tool for sustainable groundwater use in India (Moench 1995; Saleth 1997). Many argue that the flat rate based pricing structure in the farm sector encourages farmers to over-extract it, as the marginal cost of extraction is zero. However, empirical evidence does not seem to suggest any impact of the cost of extraction on the use of groundwater for irrigation in water scarcity areas (Kumar and Patel 1995), and in areas where water charges reflect the scarce value of the commodity (Mohanty and Ebrahim 1995). Diametrically opposite views about the impact of electricity pricing on the groundwater use also exist. For instance, Shah argues that flat rate pricing will induce a positive impact on access equity in groundwater (Shah 1993). Others have argued that power tariff fixing, based on diesel prices would have some positive impact on equity as well as efficiency (Saleth 1997).

Going by the conventional wisdom, if the pricing structure is designed in such a way that it reflects the actual volume of water and the unit of electricity consumed, with progressive increase in unit rates, it can induce incentives among farmers to use water more efficiently. But, such measures have not been attempted in any of the states where groundwater depletion problems actually exist, because of their social and political ramifications. The influential farm lobby is likely to protest against any move by the government to change the tariff structure, fearing that it would affect the prospects of irrigated farming adversely.

The studies on economic returns from farming in diesel and electric well commands show that diesel well commands yield higher returns, due to the greater control over irrigation water enjoyed by diesel well owners (Kumar and Patel 1995). The results thus indicate that returns from farming are more variable depending on the reliability of irrigation than its cost. This proves the important point that power tariffs can be raised to substantially high levels to achieve the efficient use of water, without causing negative impacts on the farmers.

An important argument against using power pricing as a policy instrument for regulating groundwater use is that the price levels at which the demand for electricity is elastic to tariff changes would be too high and would adversely impact on the economic returns from farming, making it unviable (de Fraiture and Perry 2002). Narayanamoorthy (1997) argues that the influence of power tariff on the consumption of electricity and water would be too less on the ground that it constitutes a meagre portion of the total cost of cultivation. Saleth states that power tariff policy alone cannot be an effective tool for achieving efficiency, equity and sustainability in groundwater use (Saleth 1997). But, recent research in north Gujarat, examining the water use and the productivity of groundwater buyers and sellers has shown that the net economic returns from irrigated farming corresponding to the price levels at which demand for groundwater becomes elastic depending on price changes (as indicated by the reduction in water use rate and the shift of crops to low water intensive ones) are positive. This is owing to the fact that with very high water rates, farmers use water efficiently and shift to crops that give high economic return for every unit of water used (Kumar 2003).

This, however, also substantiates the fact that the desired impacts of price changes can be brought about if we provide high quality power supply in rural areas and meter its use, levy the charges without default, prevent thefts, and penalise free riders (Kumar and Singh 2001). The private sector participation in power transmission and distribution will be an important part of the reform process.

Engaging user group organizations for the distribution and metering of electricity at the village level, and the bulk metering of electricity at the user group level could be another step (Kumar and Singh 2001; Panda 2002). The experience with vidyut sanghs, the rural electricity users' groups, set up in Orissa for the purpose of metering power consumption and the recovery of electricity payments, has been by far quite positive. It is shown that the introduction of unit rate increases and the recovery rates bring about more rational use of power in agriculture (Panda 2002).

Geo-hydrological environment will be an important factor, which would decide as to what level, the unit rates on electricity use in the farm sector could be raised with reference to the actual cost of production of energy, leaving aside the sociopolitical and institutional factors. This is because the actual consumption of electricity (in units) for pumping a unit volume of water would vary according to the geo-hydrological situation. In a deep water table area, the energy consumption per unit volume of water would be much higher than in an area where water table is shallow. The cost of irrigation would become a significant part of the total input cost in such cases. Therefore, the feasibility of charging the full cost of electricity would be extremely poor in deep pumping areas. Subsidies are imminent in deep water table areas. The analysis carried out for the white paper on water shows that in areas such as Mehsana in north Gujarat, many crops like wheat and bajra would be economically unviable, if the full cost of electricity is charged and hence, subsidised unit rates will have to be introduced (IRMA/UNICEF 2001). At the same time, the full cost of electricity would be chargeable in high water table areas. The following example would illustrate this.

In an area, where the depth to the water table is nearly 25 feet (7.5 metres), the energy consumption for lifting one cubic metre of water would be 0.027 KWhr, whereas it would be as high as 0.55 KWhr for an area where the depth is 500 feet (150 metres), if we assume 75 percent efficiency. The cost of irrigation would be nearly 11 paise per cubic metre of water in the first case and Rs.2.2 in the second case if we take the cost of generation and supply of electricity to be Rs.4. In the first instance, the electricity department could pitch the power prices at levels much higher than the generation cost, making profits, while in the second instance, the department could not recover more than 25 percent of the cost from the farmer, if we consider the rate at which water is sold in the deep pumping areas (Rs.1-1.5) as the reference.

6.0 Concluding Remarks

The promotion of low cost, and energy efficient water harnessing technologies such as treadle pumps, through the supply of information, materials and services can, not only change the trajectory of water resource development, but also enable poor farmers in the agriculturally backward eastern and northeastern parts of our country, access irrigation water. This will create millions of micro economies with sustainable utilisation of water resources in the water abundant regions. Low-cost water saving technologies will enable the poorest sections of the communities to practice irrigated agriculture with very limited water in water scarce regions.

The policies and programmes need to be designed and operationalized to encourage sustainable farming practices with increased use of bio-fertilisers. Subsidies can be introduced for small and marginal farmers to adopt biogas plants and scientific compost making. Community-based programmes for increased production of biomass from common property wastelands can also be introduced. Extension activities on efficient compost making practices, organic farming practices, biogas, and low-cost water saving technologies need to be taken up. The agricultural research should shift from a supply driven system to one that takes into account the demand side variables such as the local physical and socioeconomic conditions, in order to increase the scope of the research.

Institutional reforms in the water sector, effecting the establishment and enforcement of private and tradable water rights on groundwater and the water supplied from public reservoirs, can together bring about a significant increase in farm outputs with the reduction in the aggregate demand for water in agriculture. It will also bring about more equitable access to and control over the water available from canals, and also the groundwater, for producing food and ensuring household level food security. This has to be complimented by the volumetric pricing of can water, and the unit rate based pricing of electricity in the farm sector with due considerations on the energy requirement for pumping water. In order to realize the desired outcomes, demand management and efficiency through pricing changes, and also the quality of power supply and irrigation need to be enhanced.

Literature Cited

Ahluwalia, M. S. 1978. Poverty and Agricultural Performance in India. *Journal of Development Studies, Vol. 14*; p 298-323.

Ahluwalia, M. S. 2000. Economic Performance of States in Post Reform Period. *Economic and Political Weekly*. Special Article, May 6.

Banik, D. 1997. *Freedom from Famine: The Role of Political Freedom in Famine Prevention*. Centre for Development and the Environment, University of Oslo. Dissertations and Theses, No. 4/97.

Ballabh, V.; M. D. Kumar; and J. Talati. 1999. *Food Security and Water Management in India: Challenges for the First Quarter of 21st Century*. Paper presented at the National Symposium on Building and Managing Organisations for Rural Development held at Institute of Rural Management, Anand. December 13-14.

Behr, C. and G. Naik. nd. *Applying Micro-Irrigation in the Himalaya*: *A Case Study on IDE's Experience.* http://www.mtnforum.org/resource/library/behrx99a.htm.

Brewer, J.; S. Kolavalli; A.H. Kalro; G. Naik; S. Ramnarayan; K.V. Raju; and R. Shakthivadivel. 1999. *Irrigation Management Transfer in India: Policies, Processes and Performance*. New Delhi and Culcutta: Oxford & IBH.

Central Ground Water Board (CGWB). 1995. *Groundwater Resources of India.* Ministry of Water Resources. New Delhi: Government of India.

Central Water Commission (CWC). 1998. *Water and Related Statistics.* Ministry of Water Resources, New Delhi: Government of India, July.

Chaturvedi, M. C. 1999. Water Resources Development Plan for India: Some Policy Issues-Some Observations. *Integrated Water Resource Development: A Plan for Action*. Report of National Commission on Integrated Water Resources Development, New Delhi.

Chaturvedi, M. C. 2000. Water for Food and Rural Development, Developing Countries. *Water International*, 25 (1), p 40-53.

Chaudhari, S. 1997. To Sell A Resource. *Down to Earth,* February 15, 1997.

Datt, G. 1997. *Poverty in India and Indian States.* Washington D.C.: International Food Policy Research Institute.

Datt, G. 1999. Has Poverty Declined Since Economic Reforms? *Economic and Political Weekly*, Vol. 34; p 3516-3518, December 11.

Datye, K. R. 1997. *Banking on Biomass: A New Strategy for Sustainable Prosperity Based on Renewable Energy and Dispersed Industrialisation*. Ahmedabad: Centre for Environment Education.

De Fraiture, Charlotte and Chris Perry. 2002. *Why is Irrigation Demand Inelastic at Low Price Ranges?* Paper presented at Irrigation Water Policies: Micro and Macro considerations, jointly organized by World Bank and Government of Morocco, Adigar, Morocco. 15-17 June 2002.

Desai, B. M. and N. V. Namboodri. 1998. Policy Strategy and Instruments for Alleviating Rural Poverty. *Economic and Political Weekly,* Vol. 33; p2669-2674.

Dev, S. M. and R. Ajit. 1998. Rising Food Prices and Rural Poverty: Going Beyond Correlation,*Economic and Political Weekly*, Vol. 33; p 2529-2536.

De Vries, F. W. T. Penning; H. Acquay; D. Molden; S. J. Scherr; C. Valentine; and O. Cofie. 2002. *Integrated Land and Water Management for Food and Environmental Security*. Comprehensive Assessment Research Paper No. 01, Colombo, Sri Lanka: International Water Management Institute.

Dudhat, M. S.; D. D. Malavia; R. K. Madhukia; and V. D. Kanpara. 1996. Effect of Organic Manures and Chemical Fertilizers on Wheat and Their Residual Effect on Green Gram. *GAU Research Journal*, 22 (1); 4-8.

Evenson, R. E.; C. E. Pray; and M. W. Rosegrant. 1999. *Agricultural Research and Productivity Growth in India*. Research Report 109. International Food Policy Research Institute.

Food and Agriculture Organization (FAO). 1996. *Food Security Assessment* (Document WFS 96/Tech/7), Rome, p.16.

Frederick, K. D. 1993. *Balancing Water Demand with Supplies: The Role of Management in a World of Increasing Scarcity*. Technical Paper 189. Washington D. C: World Bank.

Gadgil, S.; Y. P. Abrol; and P.R. S. Rao. 1999. On Growth and Fluctuations of Indian Food Grain Production. *Current Science*, February 25.

Ghosh, M. 1996. Agricultural Development and Rural Poverty in India. *Indian Journal of Agricultural Economics, Vol. 51*; 374-380.

Glieck, P. H. 1997. Human Population and Water: Meeting Basic Needs in the 21st Century. In R. K. Pachauri R.K and Lubina F. Qureshi. eds. *Population, Environment and Development*. 357p.

Government of India (GOI). 1991. *Report of the Working Group on Waterlogging, Soil Salinity and Alkalinity.* Ministry of Water Resources. New Delhi: Government of India.

Government of India (GOI). 1999. Integrated Water Resource Development: A Plan for Action. *Report of the National Commission on Integrated Water Resources Development, Volume I.* Ministry of Water Resources.

Government of India (GOI). 2001. *National Human Development Report*. New Delhi: Government of India.

Government of India (GOI). 2002. *India's Planning Experience*. New Delhi: Planning Commission.

Goyal, P. 2002. Food Security in India, *The Hindu*, Jan 10.

Gulati, S. 2002. *Energy Implications of Groundwater Irrigation in Punjab*. Paper presented at the International Workshop "Forward Thinking Policies in Energy-Irrigation Nexus". 2-6 September 2002.

Hazzle, P. B. and S. Haggblade. 1991. Rural Urban Growth Linkages in India. *Indian Journal of Agricultural Economics*, Vol. 46; 515-529.

Howe, C. W.; D. R. Schurmeier; and W. D. Shaw, Jr. 1986. Innovative Approaches to Water Allocation: The Potential for Water Markets. *Water Resources Research*, 22 (4). 439-445, April.

Institute of Rural Management, Anand/ UNICEF. 2001. *White Paper on Water in Gujarat.* Report prepared for the Government of Gujarat.

Janaiah, A.; M. L. Bose; and A. G. Agarwal. 2000. Poverty and Income Distribution in Rainfed and Irrigated Ecosystems, Village Studies in Chahatisgarh. *Economic and Political Weekly*, 30 December 2000.

Janakarajan, S. 2002. *Wells and Illfare: An Overview of Groundwater Use and Abuse in Tamil Nadu, South India.* Paper presented at the Annual Partners' Meet of the IWMI-Tata Water Policy Research Programme. Anand. February 19 –20.

Katyal, J.C.1998. Paper Presented at Brainstorming on Scientists Perception for Agriculture - 2002. NBPGR Auditorium, New Delhi.

Kay, M.1997. *Water: Economics, Management and Demand*. London: E & FN Spon.

Kumar, M. D. and P. J. Patel. 1995. Depleting Buffer and Farmers Response: Study of Villages in Kheralu, Mehsana, Gujarat. In *Electricity Prices: A Tool for Groundwater Management in India?* ed.M.Moench. Monograph. Ahmedabad: VIKSAT-Natural Heritage Institute.

Kumar, M.D. 1995. *Over-exploitation and Approaches to Management; An Overview of Groundwater in Gujarat, Western India*. Paper presented at the 3rd South Asian NGO Summit, Kathmandu, Nepal. February 21-23.

Kumar, M. D. 1997. *Managing Common Pool Groundwater Resources: Identifying Management Regime*s. Monograph, Ahmedabad: VIKSAT.

Kumar, M.D.; Shashikant Chopde ; Srinivas Mudrakartha; and Anjal Prakash. 1999. Addressing Water Scarcity; Local Strategies for Water Supply and Conservation Management in Sabarmati Basin, Gujarat. In *Rethinking the Mosaic: Investigations into Local Water Management.* Eds.M. Moench, E. Caspari and A. Dixit. Kathmandu and Boulder: Nepal Water Conservation Foundation and Institute for Social and Environmental Transition.

Kumar, M. D. 1999/2000. Institutional Framework for Managing Groundwater: A Case Study of Community Organisations in Gujarat, India. *Water Policy,* 2(6).

Kumar, M. D. 2000a. Institutions for Efficient and Equitable Use of Groundwater: Irrigation Management Institutions and Water Markets in Gujarat, Western India. *Asia-Pacific Journal of Rural Development*, Vol. X (1), July.

Kumar, M. D. 2000b. *Irrigation with a Manual Pump: Impact of Treadle Pump on Farming Enterprise and Food Security in Coastal Orissa.* Working Paper 148. Anand: Institute of Rural Management.

Kumar, M. D. 2001. *Demand Management in the Face of Growing Scarcity and Conflicts Over Water Use in India: Future Option.* IRMA Working Paper 153. Anand.

Kumar, M. D. and V. Ballabh. 2000. *Water Management Problems and Challenges in India*: *An Analytical Review*. Working Paper 140. Anand : Institute of Rural Management.

Kumar, M. D.; O. P. Singh; and K. Singh 2001. *Groundwater Depletion and its Socioeconomic and Ecological Impacts in Sabarmati Basin,* Monograph. Anand: India Natural Resource Economics and Management Foundation.

Kumar, M. Dinesh and O. P. Singh. 2001. Market Instruments for Demand Management in the Face of Growing Scarcity and Overuse of Water in India. *Water Policy*. 5 (3). 86-102.

Kumar, M. D. 2002a. *Integrated Water Management in the Face of Growing Demand and Threatened Resource Base in North Gujarat: Constraints and Opportunities: A Pilot Project to protect North Gujarat's Groundwater Ecology and Agriculture Economy*. Paper presented at the annual partners' meet of the IWMI-Tata Water Policy Research Programme. Anand. February 19-20.

Kumar, M. D. 2002b. *Reconciling Water Use and Environment: Water Resource Management in Gujarat, Resource, Problems, Issues, Strategies and Framework for Action*. Report prepared for State Environmental Action Project Supported by the World Bank. Gujarat Ecology Commission.

Kumar, M. D. 2002c. *Micro Management of Groundwater in Banaskantha, North Gujarat: Issues, Prospects and Future Directions.* Paper presented at the IWMI-Tata Annual Partners' Meet. January 27-29, 2003.

Kumar, M. D. 2003. Impact of Electricity Prices and Water Allocation on Energy and Groundwater Demand Management: Analysis from Western India. *Energy Policy.* Accepted paper.

Leisinger, K. M. 1996. *Food Security for a Growing World Population*. Paper presented at the Saguf Symposium, "How will the Future World Feed Itself?" October 9-10.

Moench, M. 1995. *Electricity Pricing: A Tool for Groundwater Management in India?* Monograph, Ahmedabad: VIKSAT-Natural Heritage Institute.

Mohanty, S. and A.Ebrahim. 1995. Groundwater Management Perspectives for Junagadh District of Saurashtra. In *Electricity Prices: A Tool for Groundwater Management in India?* Monograph. M.Moench.ed.Ahmedabad: VIKSAT-Natural Heritage Institute.

Naraayanamoorthy, A. 1997. Impact of Electicity Tarriff Policies on the Use of Electricity and Grounwater: Arguments and Facts. *Artha Vijnana,* XXXIX (3) 323-340.

Palanisamy, K 1994. *Evolution of Agricultural and Urban Water Markets in Tamil Nadu, India. Arlington, Virginia*. Irrigation Support Project for Asia and the Near East (ISPAN), United States Agency for International Development.

Panda, H. 2002. *Energy-Irrigation Nexus: Orissa's Power Sector Reforms and Its Groundwater Economy*. Paper presented at the annual partners' meet of the IWMI-Tata Water Policy Research Programme, Anand. February 19-20.

Peck, J.C. 2003. *Property Rights in Groundwater—Lessons from Kansas Experience.* Paper presented at the 3rd World Water Forum, Osaka, Japan. 16-23 March 2003.

Pearce, D.W. and J. Warford. 1993. *World Without End: Economics, Environment and Sustainable Development.* New York: Oxford University Press.

Postel, S.1999. *Pillar of Sand: Can the Irrigation Miracle Last?* New York, USA: W.W. Mortan and Co.

Rao, P. K. 2000. A Tale of Two Developments of Irrigation: India and USA. *International Journal of Water*, 1 (1); 41-60.

Rao, C. H. H. 1994. *Agricultural Growth, Rural Poverty and Ecological Degradation in India*. New Delhi: Oxford University Press.

Ravallion, M. 1998. Reforms, Food Prices and Poverty in India. *Economic and Political Weekly*, *Vol. 33*; 29-30.

Sadhu, A.C.; D. D. Malavia; and R. K. Madhukia. 1996. Effect of Irrigation, Mulching and Fertility Levels on Mustard and Their Residual Effect on Succeeding Groundnut Crop. *GAU Research Journal*, 21 (2); 1-7.

Saleth, R.M. 1993. Water Rights System: Is it Feasible for India. *Journal of Indian School of Political Economy*. 5(3). 578 –594.

Saleth, R. M.1997. Power Tariff Policy for Groundwater Regulation: Efficiency, Equity and Sustainability. *Artha Vijnana*, XXXIX (3), September.

Saleth, R. M. and A.Dinar 1999. *Water Challenge and Institutional Responses (A Cross Country Perspective)*. Policy Research Working Paper Series 2045, Washington D.C.: World Bank.

Seckler, D.; U.Amarasinghe; D.Molden; R. de Silva; and R. Barker. 1998. *World Water Demand and Supply 1990-2025: Scenarios and Issues*. Research Report 19. Colombo, Sri Lanka: International Water Management Institute.

Shah, T. 1993. *Water Markets and Irrigation Development: Political Economy and Practical Policy*. Bombay: Oxford University Press.

Shah, T.; M. Alam; M. D. Kumar; R. K. Nagar; and M. Singh. 2000. *Pedaling Out of Poverty: Social Impact of a Manual Irrigation Technology in South Asia*. Research Report 45, Colombo, Sri Lanka: International Water Management Institute.

Shah, T. 2000. *Wells and Welfare in Ganga Basin: Public Policy and Private Initiative in Eastern Uttar Pradesh, India.* Research Report 54. Colombo, Sri Lanka: International Water Management Institute.

Singh, K.1995. Cooperative Property Rights as Instruments for Managing Grounwater. In *Groundwater Law: The Growing Debate*. Ed.M.Moench. Monograph. Ahmedabad: VIKSAT – Natural Heritage Institute.

Singh, B. P.; B. N. Singh; and A. Singh. 1996. Effect of Mulch and Irrigation on Yield of Indian Mustard on Dry Terraces in Alfisols. *Indian Journal of Agricultural Sciences*, 60 (7); 477-479.

Singh, Y. D. 2000. *State Environmental Action Plan Phase-1.* Report on Ranns and Desertification, submitted to Gujarat Ecology Commission, Government of Gujarat, Vadodara.

Tata Energy Research Institute (TERI) 1998. *Looking Back to Think Ahead: Growth with Resource Enhancement, Environment and Nature.* New Delhi: Tata Energy Research Institute. March.

Vamadevan, V.K. and N.G.Destane. 1968. *Suitability of Soils for Irrigated Rice.* IL RISO. Anno. XVII (3): 243-250.

Wolf P. and R. Hubener. 1999. Irrigation in the World – The Future will not be like the Past. *Natural Resources and Development,* Vol. 51. Tubingen :Institute of Scientific Co-operation.

World Bank/Government of India. 1998. Inter-Sectoral Water Allocation Planning and Management. *India Water Resource Management Sector Review, Volume I*-Main report. New Delhi: World Bank-Government of India.

World Resources Institute. 1995. *World Resources 1994-95: People and the Environment*. Report prepared by World Resource Institute in collaboration with United Nations Environment Programme and United Nations Development Programme. Bombay: Oxford University Press.

World Resources Institute. 1996/97. *World Resources. 1996-97*. New York, USA: Oxford University Press.

Xie, M.; U. Kuffner; and G. Le Moigne. 1993. *Using Water Efficiently: Technological Options*. Technical Paper 205. Washington D.C: World Bank.

Postal Address
P O Box 2075
Colombo
Sri Lanka

Location
127, Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Telephone
94-11-2787404, 2784080

Fax
94-11-2786854

E-mail
iwmi@cgiar.org

Website
www.iwmi.org

International Water Management Institute

FUTURE HARVEST
IWMI is a Future Harvest Center supported by the CGIAR