





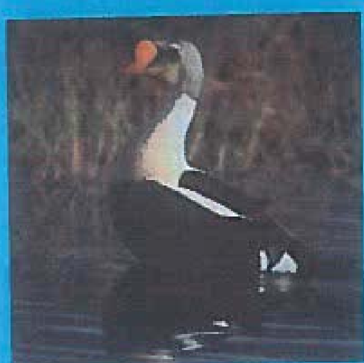
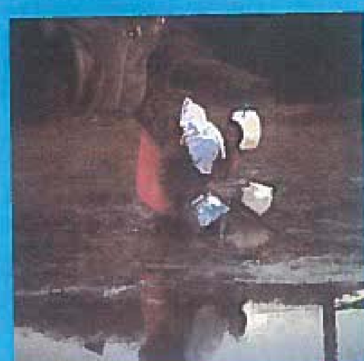


WATER RESOURCES MANAGEMENT

CROSSCUTTING ISSUES

Edited by

İ. H. Olcay Ünver

Rajiv K. Gupta

Water Resources Development, Vol. 18, No. 1, 25–45, 2002

Carfax Publishing
Taylor & Francis Group

Water and Energy Linkages for Groundwater Exploitation: A Case Study of Gujarat State, India

RAJIV K. GUPTA

South Eastern Anatolia Project (GAP)/United Nations Development Programme Sustainable Development Programme, South Eastern Anatolia Project Regional Development Administration (GAP–RDA), Prime Ministry, Republic of Turkey. E-mail: rgupta@gap.gov.tr

ABSTRACT *Water and energy, two important resources for human development, have inextricable inter-linkages between them. Their complementarity, a blessing otherwise, causes a vicious circle in a complex situation like the present case study of Gujarat state, India. This paper analyses the supply–demand situation of both sectors for a state that is primarily agrarian but also with a high industrial growth rate. Due to inequitable distribution of surface water, recurrent droughts and an ever-increasing demand trend, groundwater (a major source in the state) has been over-exploited in many parts, leading to 'water mining' with worsening water quality. With more than 40% energy consumed for extracting groundwater, this has had a serious impact on the energy balance. The paper brings forth the energy requirements to satisfy the water needs and the water requirements for the generation of energy. Finally, the feasible options available to meet the crisis, ranging from the development of mega projects like Sardar Sarovar and Kalpasar to micro water harvesting structures, water pricing and consumer training, etc., are reviewed.*

Introduction

Viewed in isolation, 'water' sustains human life and 'energy' develops it. But in reality, the experience has shown that for sustainable development, these two can no longer be viewed as mutually exclusive and their inter-linkages, however difficult they may be, need to be understood properly. While both water and energy can neither be produced nor destroyed, the dynamics of their transfer from one form to the other are significant. At times energy is needed to get the required water and the latter is required to meet the energy needs as well. Due to their complementary nature, scarcity of either of the two can be met with by the surplus of the other. However, in regions experiencing rapid development, such complementarity turns into competition between the two, posing a challenge for the planner and developer to select a suitable trade-off. This paper presents such a complex situation, analyses the supply–demand mechanism for water and energy sectors in the light of their inter-dependence and reviews the whole spectrum of available options to deal with the water–energy crisis in the state of Gujarat (India).

0790-0627 Print/1360-0648 On-line/02/010025-21 © 2002 Taylor & Francis Ltd
DOI: 10.1080/07900620220121639

Gujarat State

Constituted in 1960, the state of Gujarat, a major state in western India, has registered rapid industrial and economic growth. With less than 5% of the country's population, the state has achieved a growth rate of 6.55% in net state domestic product (NSDP), at constant prices, over the past 5 years, and ranks third in NSDP in the country after Maharashtra and Punjab (Gujarat Infrastructure Development Board (GIDB), 1999). Per capita income of the state is 35% higher than the national average with 34.5% of its population living in urban areas as compared to 25.7% for the country as a whole (1991 Census). The population growth rate has been 2.25%, with the current projected population around 50.6 million.

Water Availability in Gujarat

Gujarat has just 2.28% of India's water resources and 6.39% of the country's geographical area. This is again constrained by imbalances in intra-state distribution. The average per capita availability of water (876 m^3) reflects the situation of water scarcity in the state (as per the United Nations criteria of 1000 m^3), with 407 m^3 in the north Gujarat region and 1378 m^3 in south and central Gujarat. The state has an average annual rainfall of 80 cm with a high coefficient of variance over time and space, and as a result droughts are frequent.

On average, 3 years in a cycle of 10 years are drought years. Drinking water scarcity poses serious threats to the lives of humans and cattle. Government has to spend millions of dollars every year on temporary measures to supply drinking water, e.g. by road tankers, special water trains or even ships. Over-exploitation of groundwater is resulting in 'water mining' and serious water quality problems. The state, which is otherwise progressive and peace-loving, has recently witnessed 'water riots' due to severe water scarcity. Mass human and cattle migration in search of water is a common phenomenon in dry summer (Gupta, 2001). The water scarcity is seriously affecting flora and fauna in the world-famous Gir forests (harbouring Asiatic lions) and Nalsarovar (one of the country's largest bird sanctuaries).

Table 1 and Figure 1 reveal that 24% of the area of the state has around 77% of surface water resources, as against 23% in the rest of the area. Groundwater resources are also not evenly distributed. Therefore, the state has to depend on regional water transfer or groundwater extraction for all its water needs. The feasibility of the latter is constrained in the state by many factors which will be discussed later in the paper.

Sectoral Water Use Pattern

In Gujarat, agriculture and the domestic and industrial sectors consume 90%, 9% and 1% of water, respectively. In 1991, total groundwater utilization was 10 416 million cubic metres (MCM)/year as against total surface water utilization of 9019 MCM/year. The projected supply–demand scenario for 2010 indicates that, in spite of increased surface water utilization of up to 23 210 MCM/year, groundwater will continue to be a major source with annual utilization of around 20 940 MCM (Figure 2).

Until now, groundwater has been the main source. The scenario is likely to

Table 1. Intra-state distribution of water resources

Region	Area	Population (2001 Census)	Rivers	Perennial rivers	Utilizable surface water	Utilizable groundwater	Designed live storage (DLS)	Current[a] live storage as a percentage of respective DLS
State as a whole	196 024 (km^2)	50 596 992	185	8	31 480 MCM	12 848 MCM	14 995 MCM	2079 MCM
North Gujarat	19.63%	29.15%	6	0	8.68%	25.48%	12.28%	1.79%
South and central Gujarat	24.26%	41.28%	11	8	77.09%	35.28%	71.09%	98.21%
Saurashtra	32.82%	26.55%	71	0	12.42%	35.34%	14.86%	2.36%
Kutch	23.29%	3.02%	97	0	1.81%	3.9%	1.76%	0.61%

MCM, Million cubic metres.
[a] As of 23 February 2001.

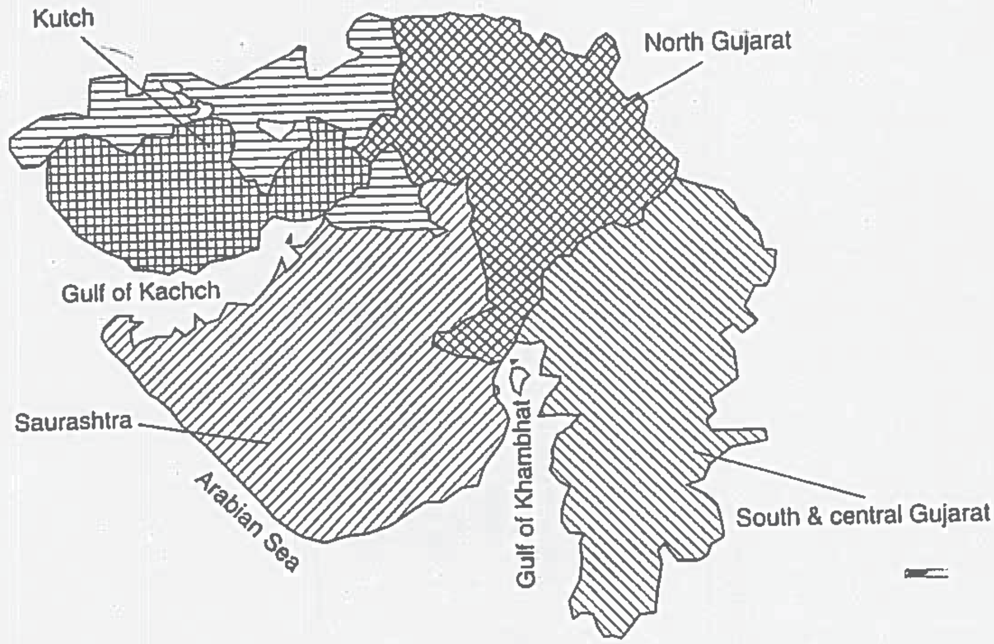

Figure 1. Intra-state distribution of water resources. *Note*: As on 23 February 2001.

change with rapid depletion of groundwater levels and consequently higher dependence on surface water and indirect sources in the coming years.

Water Demand Trends

Agriculture

In Gujarat, arable land is slightly more than 50% of the geographical area. Out of the gross cropped area, around 41% is under food grains, 18.3% under oilseed and 13.8% under cotton. The state ranks first among all the states in the country

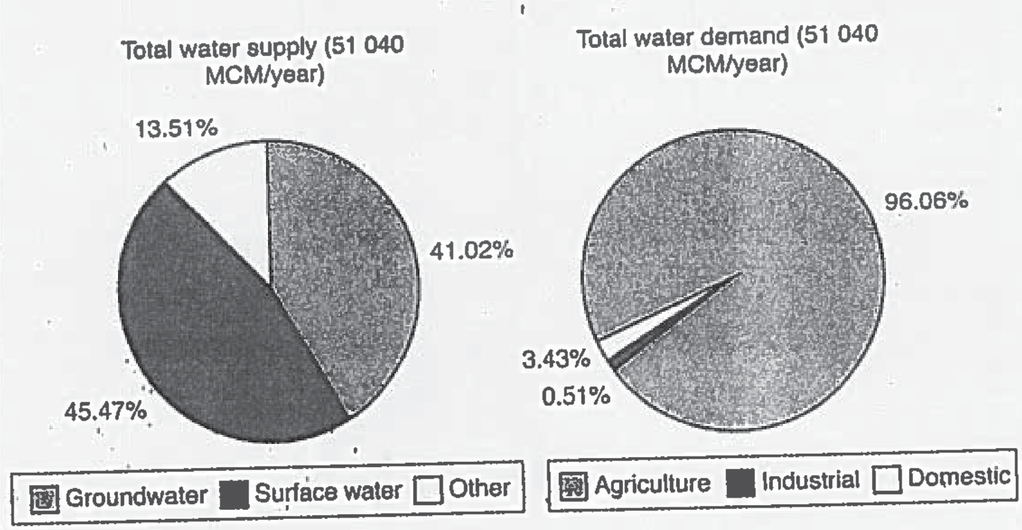

Figure 2. Water balance scenario in 2010.

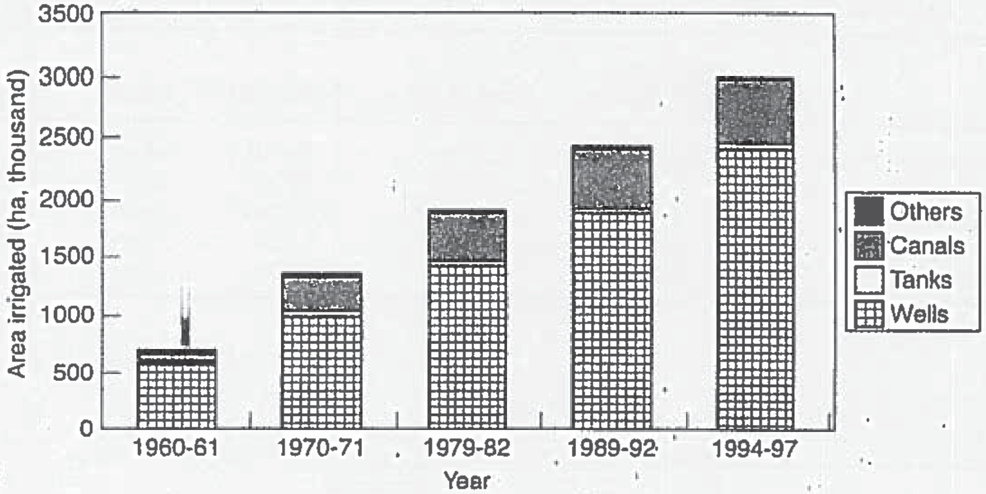

Figure 3. Sources of irrigation in Gujarat state.

in the productivity of castor, sesame, potatoes, onions and bananas and second in the productivity of groundnut, rapeseed, mustard, cotton, psyllium, tobacco and chikoo. Among the principal crops, Gujarat has a major share in India in bajra (12.89% area, 20.08% production), groundnuts (25.0% area, 24.99% production) and cotton (16.92% area, 21.99% production). However, it ranks low in its productivity of rice, wheat, maize and gram, etc. In 1998, total food grain production in the state was 5.7×10^6 t, i.e. approximately 340 g per capita per day. Thus, the state would need to raise food grain production to at least 6.95×10^6 t in 2021 to feed the projected population of 56.57 million at the present rate.

When the state was constituted in 1960, the net area irrigated was 682 900 ha, which had increased by almost 5 times by 1997. Groundwater has contributed to more than 80% of irrigation in the state (Figure 3). At the ultimate irrigation potential of 6.85 Mha, 43% of it will be from groundwater, 31% from surface water from the state basins and 26% from inter-state allocations (Agriculture and Cooperation Department, 2000).

There has been a consistently increasing trend of groundwater utilization for irrigation purposes, which is reflected in the spectacular increase in the number of irrigation wells and tube wells in different parts of the state (Figures 4 and 5). Along with other important agronomic considerations, increased groundwater utilization in Saurashtra region is reflected in the highest productivity of food grain in this area, despite the low dependability of rainfall (Table 2). In four major groundnut-producing districts (all in Saurashtra region), the actual yield of groundnuts has not been dependent on the rainfall pattern (Figure 6). For instance, in Junagadh district, rainfall in three consecutive years, 1996–98, was leaner than average but groundnut production exceeded the state average. This demonstrates the significance of irrigation through excessive exploitation of groundwater in these areas.

However, the state has had to pay heavily in terms of severe depletion of utilizable groundwater resources all over the state. Because of typical water-intensive crop varieties and less awareness/experience of the real value of water, the so-called water surplus regions of south and central Gujarat have also

Table 2. Regional area, production and yield of food grain (1998–99)

	South and central Gujarat	North Gujarat	Saurashtra	Kutch	Total
Food grain area (ha)	1 694 700	1 273 100	759 700	176 200	3 903 700
Percentage	43.41	32.61	19.46	4.52	100
Production (Mt)	2 396 200	1 752 700	1 308 100	109 800	5 566 800
Percentage	43.04	31.49	23.50	1.97	100
Yield (kg/ha)	1414	1377	1722	623	1426

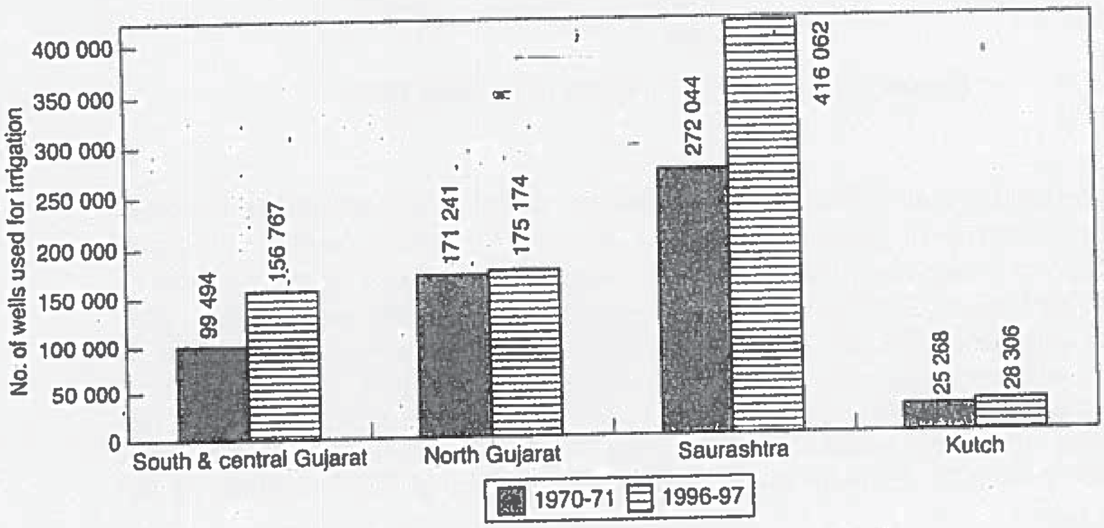

Figure 4. Number of wells used for irrigation.

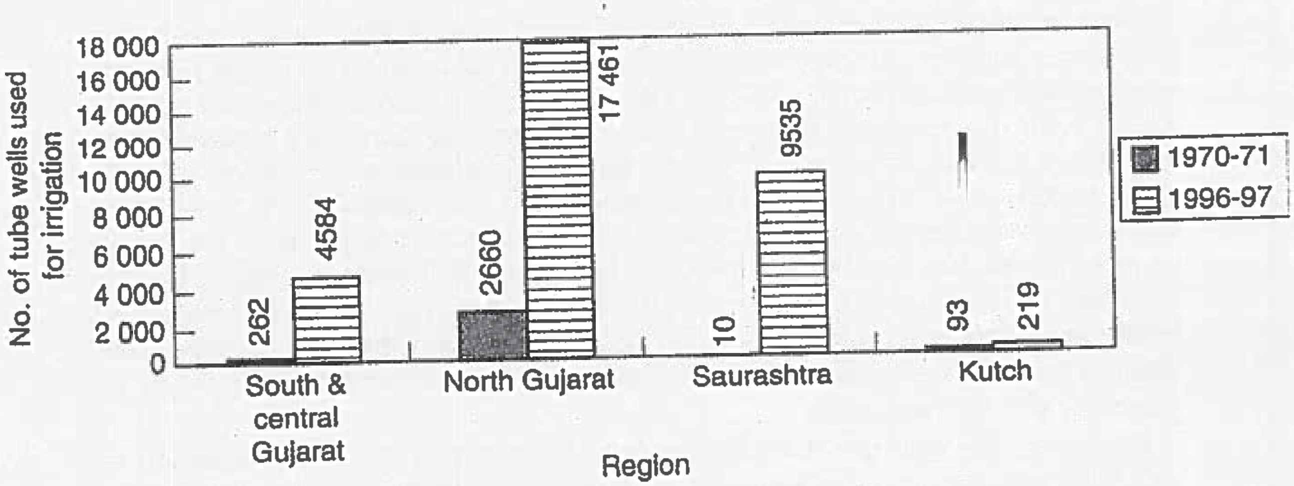

Figure 5. Number of tube wells used for irrigation.

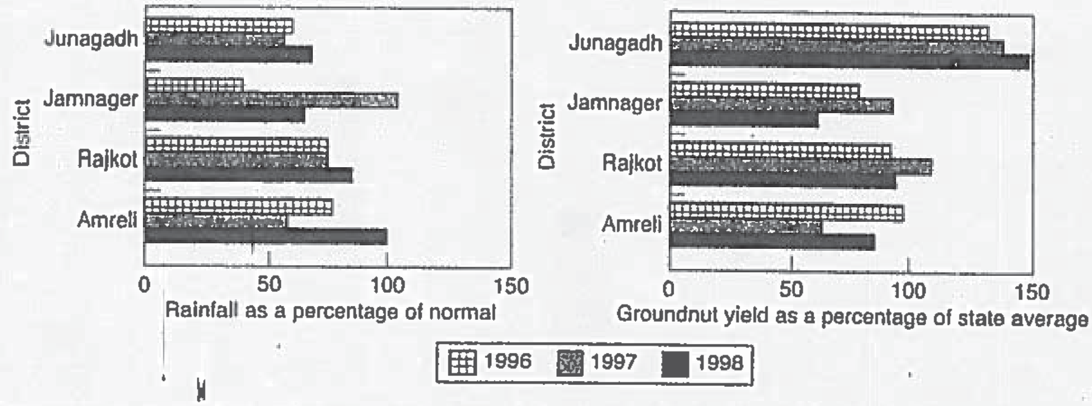

Figure 6. Rainfall pattern and groundnut productivity in selected districts of Saurashtra.

demonstrated the significance of irrigation through excessive exploitation of groundwater in these areas.

However, the state has had to pay heavily in terms of severe depletion of utilizable groundwater resources all over the state. Because of typical water-intensive crop varieties and less awareness/experience of the real value of water, the so-called water surplus regions of south and central Gujarat have also experienced a severe loss in utilizable groundwater as compared to water-scarce regions (Table 3).

In 1984, 88.5% subdivisions of the state had less than 70% groundwater development. In 1997 these white subdivisions were reduced to 51.9%, with a corresponding increase in over-exploited subdistricts from 0.55% in 1984 to 16.4% in 1999 (Figures 7 and 8). Continuous lowering of the groundwater table has resulted in an alarming increase in the number of defunct wells, 1.9 times over a period of 25 years (1970–71 to 1996–97). Regionally, it has been many times over in certain water-scarce regions (Figure 9).

This phenomenon is more pronounced in the water-scarce regions of north Gujarat and Saurashtra. Over-drafting of groundwater (as compared to the annual recharge) has caused serious water quality problems, and has also led to serious diseases such as fluorosis and kidney stones, etc. More than 25% of villages of the state suffer from water quality problems such as excessive fluoride, nitrate and salinity, north Gujarat being the worst sufferer with more than 38% villages affected (Figure 10).

Table 3. Absolute change in utilizable groundwater

	South and central Gujarat	North Gujarat	Saurashtra	Kutch	Total
Utilizable groundwater (MCM/year)					
1984	6783.95	4216.87	5682.07	682.51	17 365.4
1997	4533.11	3274.33	4539.23	501.60	12 848.27
Absolute percentage change (1984–97)	−33.18	−22.35	−20.11	−26.51	−26.01

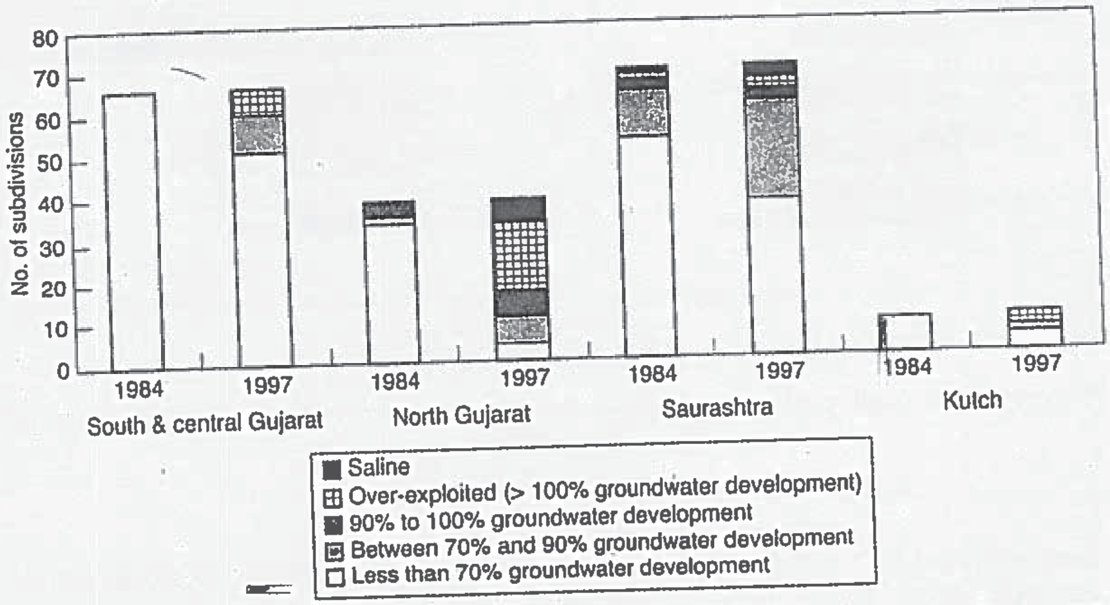

Figure 7. Subdivisional comparative level of groundwater development from 1984 to 1987. *Note*: The state is administratively divided into districts which are further subdivided into subdivisions (*talukas*).

Having a planned target growth rate of 6.04% (Agriculture and Cooperation Department, 2000) per year for the next 10 years, the agricultural water demands are bound to shoot up. With an estimated rate of demand of 7200–9300 m^3/ha, total demand at ultimate irrigation potential would be in the range of 46 728–60 357 MCM. Thus, by 2010, agricultural water demands may exceed the ultimate utilizable water resources (both surface water and groundwater) (Tahal Consulting Engineers Ltd, 1997).

Domestic

In the first population census (1961) after the state came into existence, total population of the state was 20.6 million, which has increased continuously in the subsequent censuses: 26.7 million in 1971; 41.3 million in 1991; and 50.6 million in 2001. Except in the decade 1981–91, its growth rate has been more than the country's average. Today, around 34.5% of the population live in cities and towns, a figure which was only 25.77% in 1961. Thus, the trend of urbanization is equally significant in the assessment of domestic water needs of the state, as is the rate of population growth.

Domestic water requirements of the state are projected to cross 4000 MCM/year by 2025 (Gujarat Drinking Water Infrastructure Board, 2001), suggesting a steep rise of 170% over just 25 years. The challenge is tougher than it appears, because of the issues related to water quality.

As of April 2001, 8508 villages (out of 18 028), five cities and 61 towns were facing acute water shortage, affecting around 30 million people. Due to inadequate rains the regional and local water supply schemes were adversely affected (Table 4). All possible options, ranging from pipeline projects to temporary water supply through tankers, special trains and ships and from tube

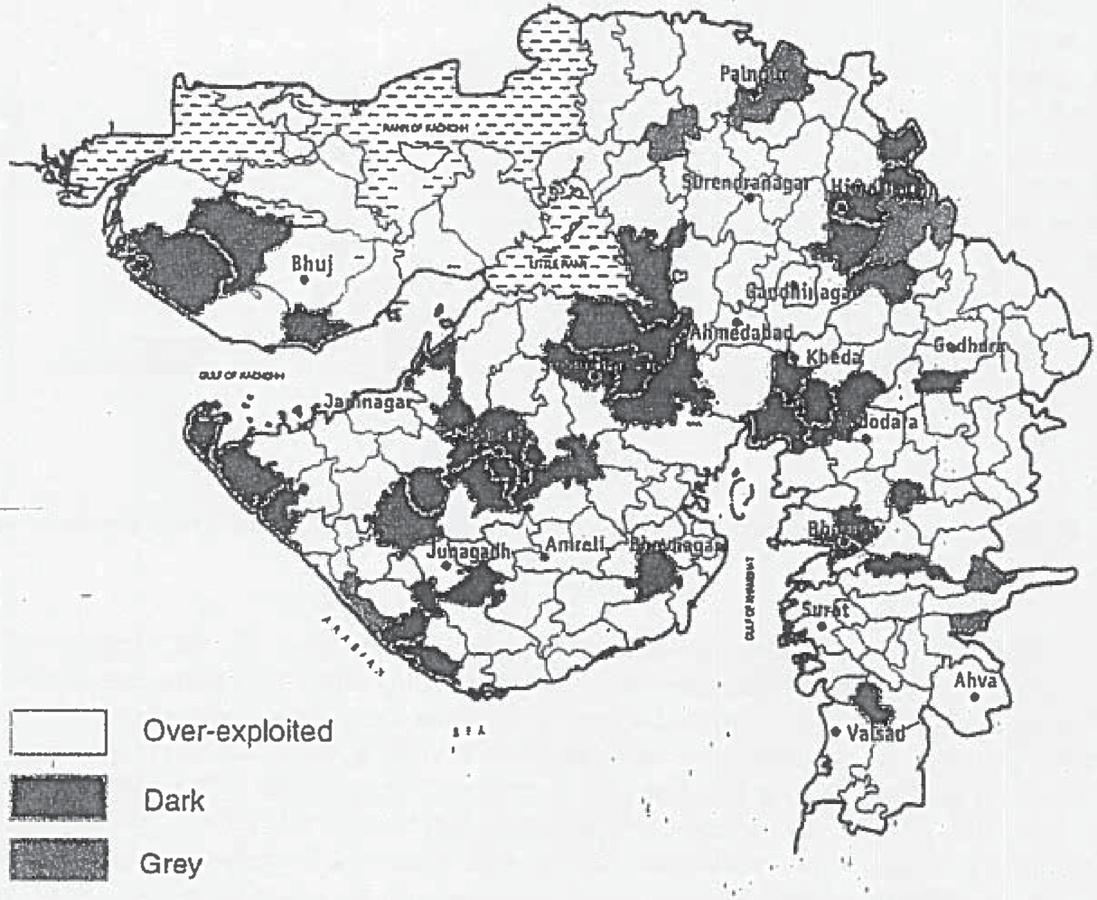

Figure 8. Level of groundwater development in different parts of the state. *Note*: Over-exploited subdivisions are those with groundwater development of more than 100% of their potential. Dark subdivisions are those with groundwater development between 90% and 100% of their potential and grey areas are the ones which are between 70% and 90% groundwater development.

wells to desalination plants, had been implemented by the state government. In 2001, 2784 villages of Saurashtra and Kutch, 213 villages of north Gujarat and even 146 villages of central Gujarat were supplied with drinking water through tankers. Women and children have to spend considerable time and energy bringing water from distant places (even 7–8 km in many cases). Lack of access to safe water, time lost in collecting available water, effects of head loading on women's and girl children's health and the burden of women's household responsibilities all have an adverse impact on their health and general family welfare, including their income-earning abilities (Self Employed Women's Association, 2001).

Industrial

In the last decade the industrial growth rate was 7.4%. The state accounts for 11% of the country's share in industrial output and has a predominant position in cotton textiles, organic, inorganic and heavy chemicals, agrochemicals, petroleum and petrochemicals, food processing and edible oils, paper, cement, steel

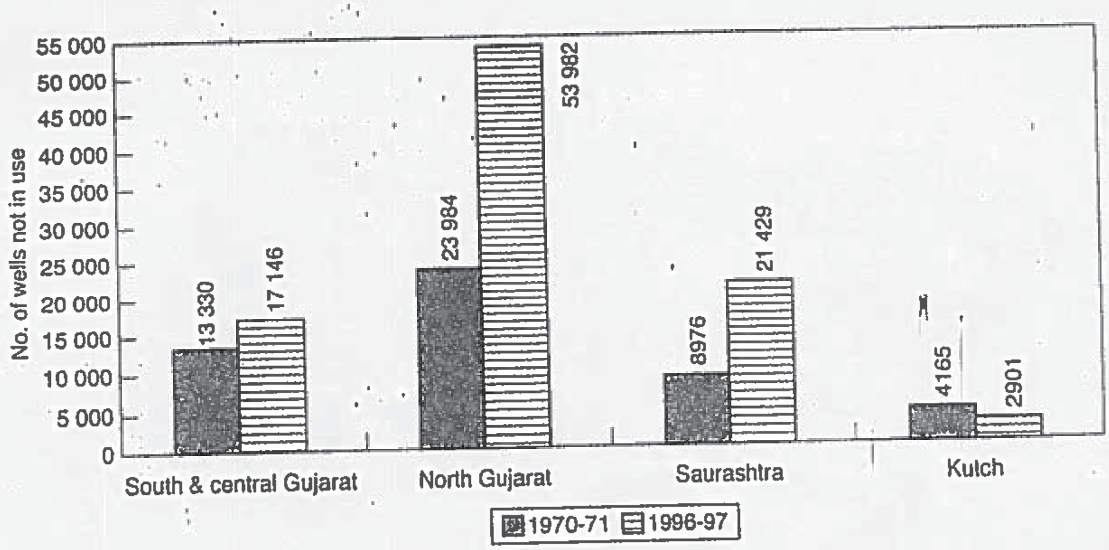

Figure 9. Number of defunct wells due to over-exploitation of groundwater.

re-rolling and machinery products. There are more than 230 000 registered small-scale industries and more than 1600 medium- and large-scale industries. Gujarat Industrial Development Corporation has developed 270 industrial estates in the state. Although the small-scale industrial growth has been spectacular in all regions during the last two decades, ranging from 4.55 times to 6.82 times, the growth in water-scarce regions (barring Ahmedabad, Rajkot and Mehsana) is not satisfactory considering their potential (Figure 11).

The availability of raw materials and physical and social infrastructure are the key elements attracting even water-intensive industries in water-scarce regions. Typical water requirements of various industries are compared in Figure 12. Many of these industries are meeting their water requirements by desalination and reverse osmosis, etc. at a cost of US$2/1000 l, which is very high for the Indian situation (Industrial Credit and Investment Corporation of India Ltd,

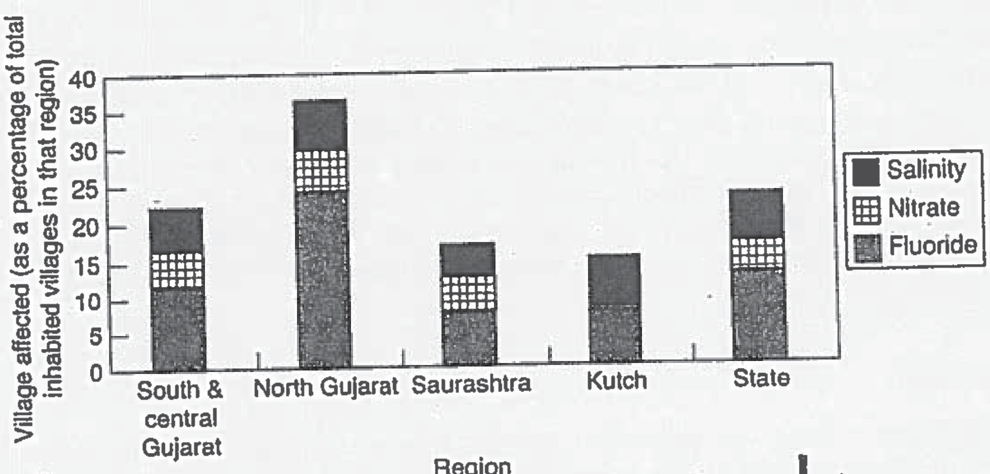

Figure 10. Water quality problems in different regions of the state.

Table 4. Effect of inadequate rains on water supply schemes

Serial number	Scheme	Number of villages/covered	Schemes adversely affected
A	Rural regional water supply schemes	404 schemes/4765 villages/habitations	190 schemes/800 villages/habitations
B	Individual piped water supply	7417 villages/habitations	3800 villages/habitations
C	Hand pumps	108 911 hand pumps	35% of hand pumps in tribal area 55% in Saurashtra area expected to get dry

1997). Keeping in view the present and future trends of industrialization, it is estimated that industrial water demand will rise from its current level of 153 MCM/year to about 281 MCM/year by 2021 (Tahal Consulting Engineers Ltd, 1997). This will further stress the available groundwater resource, unless a fresh surface water supply is planned.

Energy Profile of Gujarat

During the last couple of decades, the state has given a high priority to the development of the power sector. As a result, the annual per capita consumption of electricity in the state (848 units) is much higher than the average annual per capita consumption of the country (446 units) and has been increasing consistently (Figure 13). All the 17 940 feasible villages out of the total of 18 028 villages in the state have been electrified.

The state has increased its total installed capacity of power generation from a meagre 300 MW in 1960 to 8387 MW presently. Almost 90% of this comes from thermal power, i.e. it is coal-, gas- or naphtha-based. Hydropower generation is just 6.52% of the installed capacity (Figure 14) as against the national average of

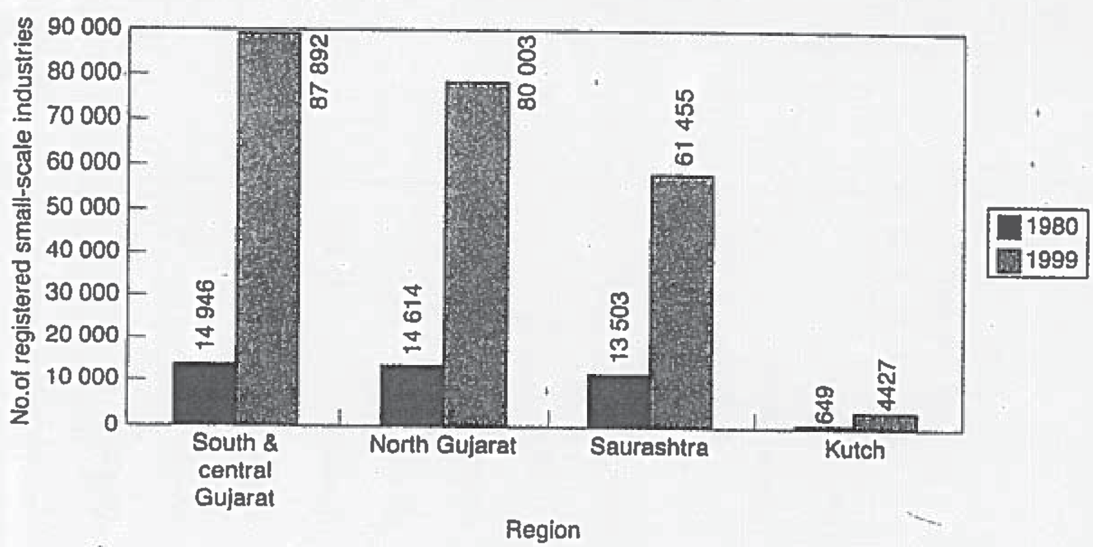

Figure 11. Small-scale industrial growth (1980–99).

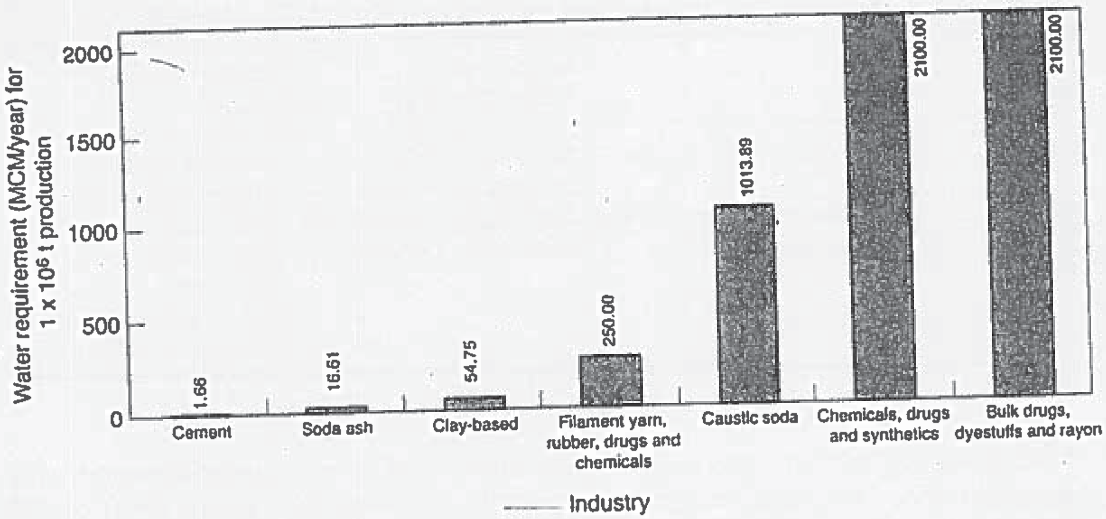

Figure 12. Industrial water requirements.

24%. Only 54.06% of the installed capacity is from the power stations of the Gujarat State Electricity Board, whereas the remaining 3853 MW lies with the private and federal government sectors (Figure 14).

Gujarat state is connected to the neighbouring states of Maharashtra, Madhya Pradesh and Goa via the Western Grid, one of the five power grids of the country. Since both Maharashtra and Gujarat are highly industrialized and developed, their cumulative peak demands make this grid more critical. Against an average rate of a 9% increase per year in the installed power generation capacity, Gujarat state is having 11% increase in demand per year; thus the gap between demand and supply is widening. Projections of supply–demand indicate that in the next 10 years, the installed capacity will have to be doubled to meet the prospective demand (GIDB, 1999). The state government has planned to invest around US$12 billion to implement the power projects in such a way that it will have a surplus of around 879 MW in 2010 (GIDB, 1999).

Power generation in the state is mostly constrained by the long-distance

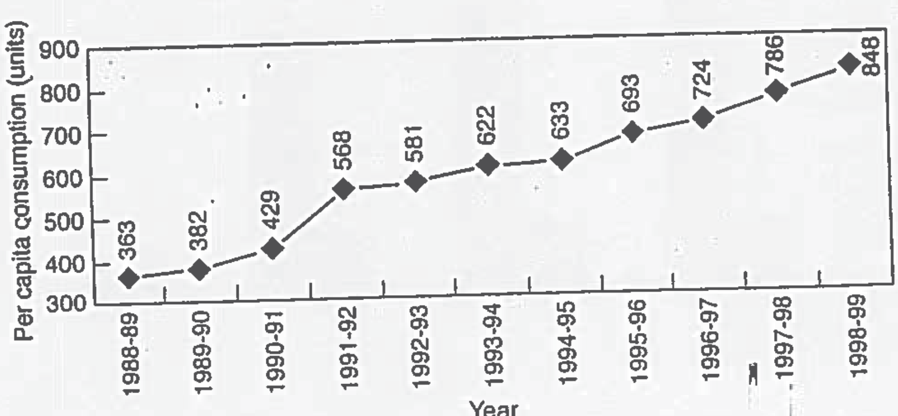

Figure 13. Trend of energy consumption in the state.

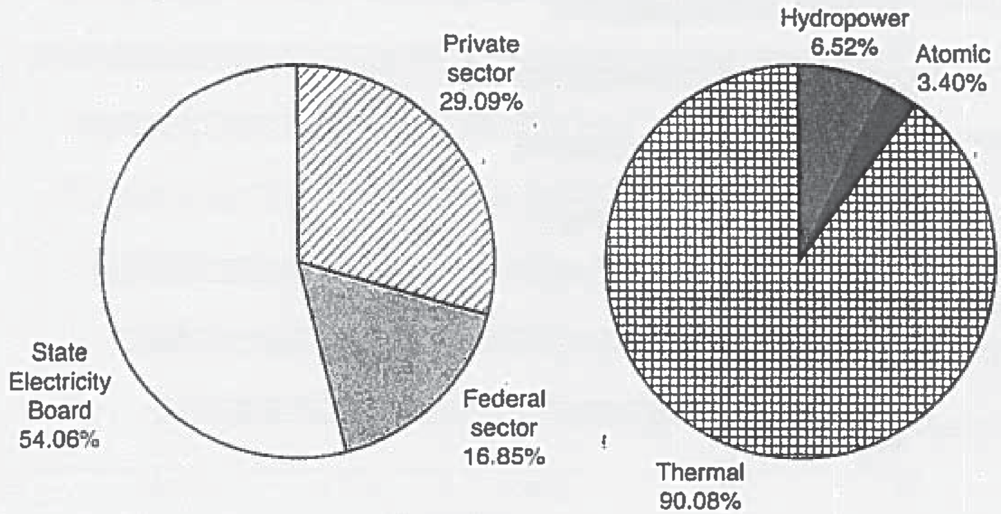

Figure 14. Energy profile of Gujarat state (total installed capacity: 8387 MW).

conveyance (1200–1700 km) of coal, its quality and pricing (Figure 15). Therefore, it is projected that domestic coal will become a relatively less important source of power generation in the state and that imported coal, naphtha and liquified natural gas will contribute almost 50% of power generation in the state by 2010 (GIDB, 1999). The share of electricity units purchased by the State Electricity Board has increased from around 25% of its generated units in 1992–93 to around 42% of the generated units in 1998–99 (Figure 16). The shortfall in supply is being managed by demand management, i.e. staggering industrial demand and grouping agricultural load by day and night.

The generation of non-conventional types of energy is not very significant. Attempts are being made to tap potential sources of energy, such as solar, wind and tide energy, etc., but their contribution still remains insignificant.

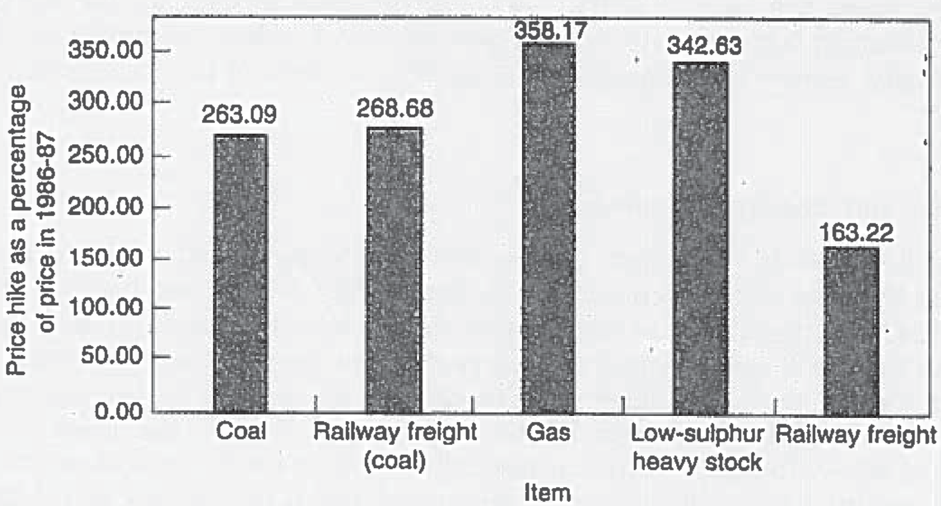

Figure 15. Price hike in raw materials for thermal power generation (during the period from 1986–87 to 2000).

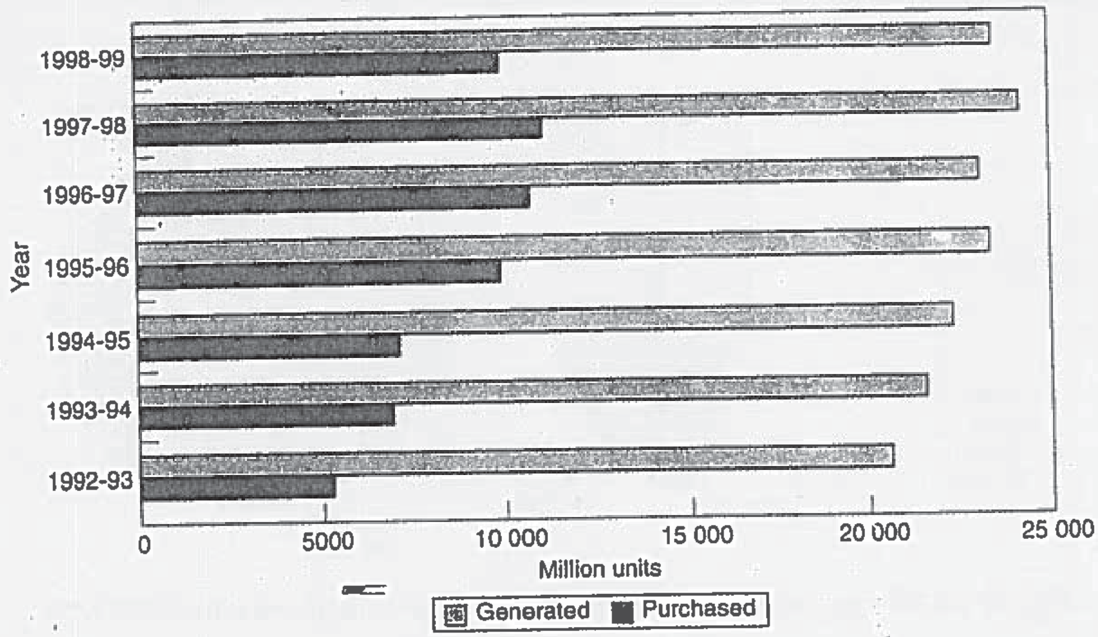

Figure 16. Details of power generation *vis-à-vis* purchase.

Energy Demand Trend: Past, Present and Future

While, on the one hand, energy generation from water or related sources is far below the corresponding world and national averages, the energy consumed for making the water available for various purposes, such as irrigation, drinking and domestic use, etc., has been the highest among all the competing consumers. Almost half of the energy produced by the state during the last 5 years has been consumed by the agricultural and public water works sectors (Figure 17). Energy consumed for agriculture purposes in the state is around 40%, which is significantly higher than the national average of about 30% (Agriculture and Cooperation Department, 2000). Analysing the energy consumption details for the period 1995–96 to 1999–2000, it can be seen that due to consecutive drought years, there has been a striking increase in consumption by the agricultural sector during last couple of years. Consequently, this has drastically reduced the industrial energy consumption from 43.62% in 1997–98 to just 30.24% in 1999–2000.

Water and Energy Inter-linkages

Inter-linkages of water and energy are never experienced or even thought of when both the resources are available abundantly. Only when the scarcity of one stresses the availability of other, as in the present case study, does considering these inter-linkages becomes necessary. Lack of access to surface water coupled with the inherent advantages of groundwater, e.g. ease of control and reliability, has led to relentless groundwater exploitation, which has been mentioned elsewhere. Although the role of groundwater as a buffer against erratic rainfall and resulting droughts cannot be under-estimated, the absence of regulation on groundwater extraction has caused a severe decline in water levels. Such *water mining* also necessitates over-use of energy at a high opportunity cost.

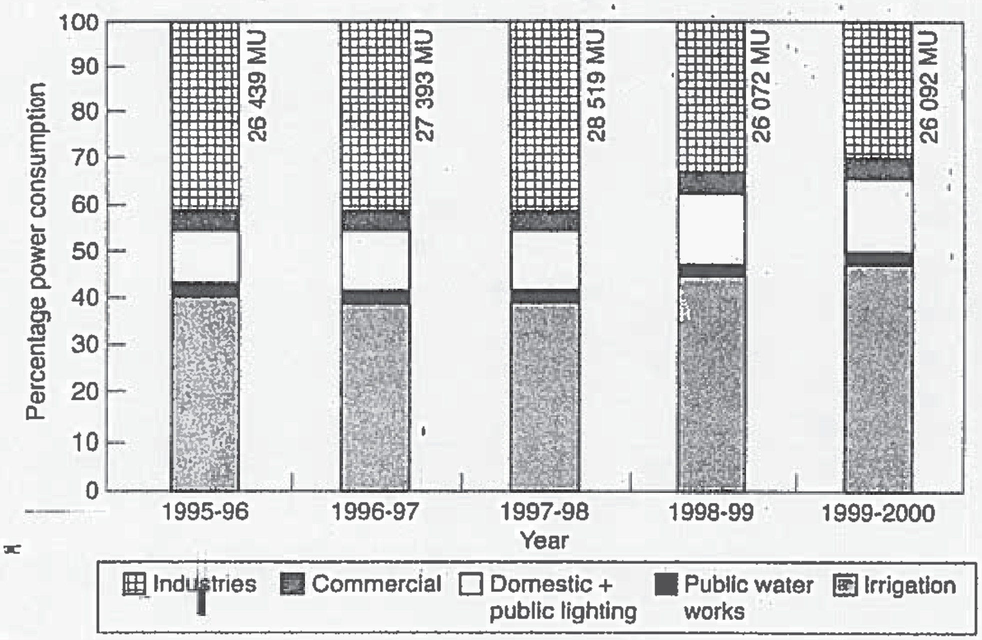

Figure 17. Energy consumption mix for Gujarat state. MU, Million units.

Attempts to harness the groundwater using a variety of man- and animal-driven water-lifting devices from shallow, open wells have become part of history and they are no longer viable options for pumping the water, which is more than 330 metres deep in many parts of the state. The treadle pump, popularly known for its ability to 'pedal out of poverty', can lift water up to a maximum height of 7 m (International Water Management Institute, 2001) and hence capital-intensive and energy-intensive pumps have practically no alternative. In water-scarce regions of the state, the number of electric and diesel pumps is significantly higher than in the water-surplus regions of south and central Gujarat (Table 5). Because of the prevailing water-mining conditions in north Gujarat, even diesel pumps are not useful for drawing groundwater. With the decline in the r table, the horsepower required to lift water using a centrifugal pump increases exponentially (Figure 18).

The 1997–98 data of energy consumption indicate that in water-scarce regions of the state, the energy consumption for agriculture purposes is quite high as compared to the water-surplus regions of the state (Figure 19). Temporal variations also show that in water-stress (deficit-rainfall) years, energy consumption for agriculture remained higher than that of normal years (Figure 20). If

Table 5. Trends of groundwater exploitation

	South and central Gujarat	North Gujarat	Saurashtra	Kutch	Total
Electric pumps per 1000 people	7.70	19.50	27.70	21.45	16.63
Diesel pumps per 1000 people	2.28	3.59	17.72	11.22	7.02

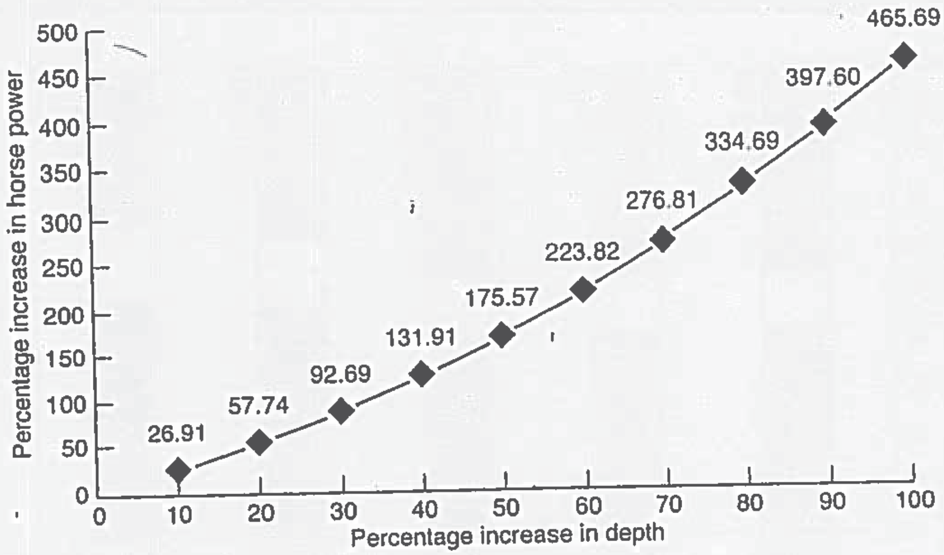

Figure 18. Characteristic curve for a centrifugal pump.

assured surface water supply is made available, this energy could well be saved and used for other productive purposes. While this is true, waterlogging arising due to over-irrigation by surface water would also be avoided, which otherwise could add to energy needs (for augmentation tube wells).

For the urbanized state of Gujarat, energy is critically needed also to maintain the domestic water supply. In the most populous city of the state, Ahmedabad (3.5 million population), more than 100 MU of electricity are consumed annually by the domestic water supply. Ahmedabad Municipal Corporation has spent more than US$16 million during last 2 years (1998–2000) for this purpose. Rajkot, another major city of the drought-prone region of Saurashtra, has been increasingly spending more on electricity consumption for water supply (Figure 21). In just 5 years' time, the electricity bill for water supply has increased fourfold in Rajkot city.

Thus recurrent monsoon failures, the constant lowering of the groundwater

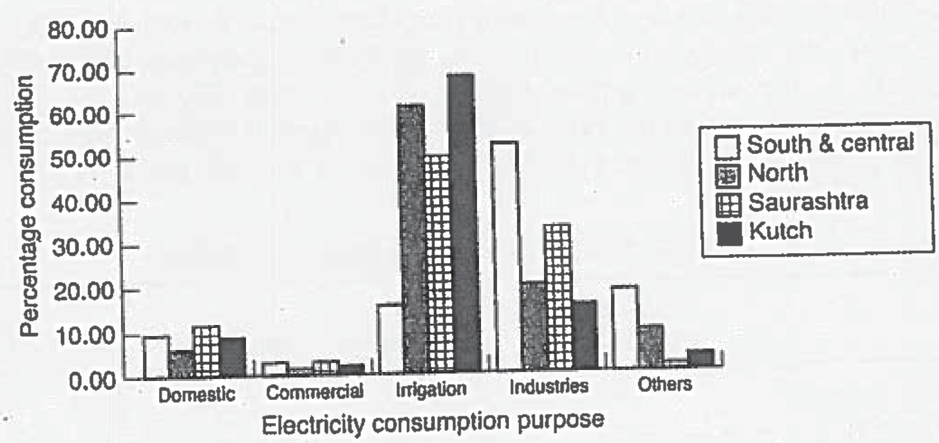

Figure 19. Energy consumption mix in different regions of the state (1997–98).

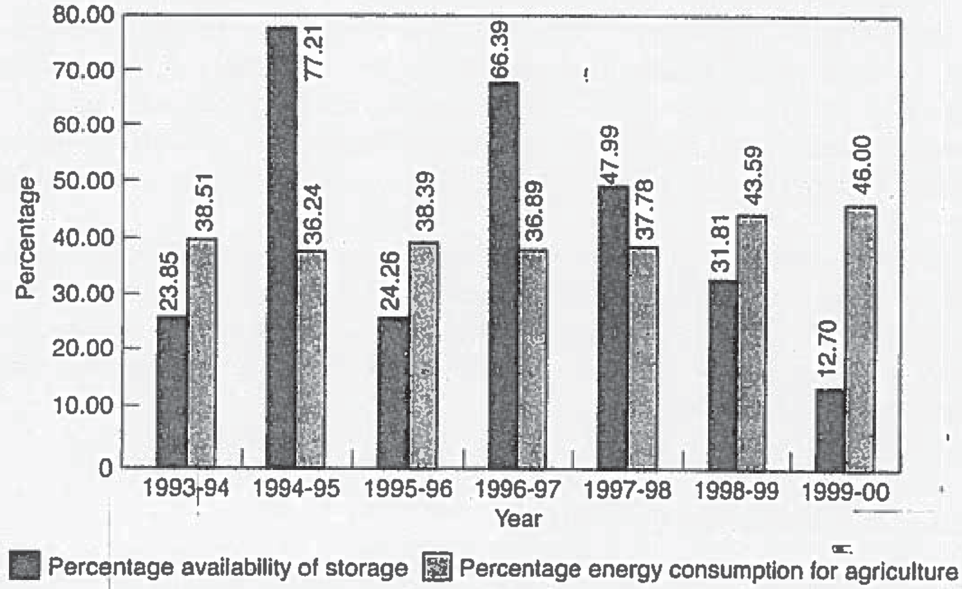

Figure 20. Water storage in reservoirs and energy consumed for agriculture.

table and the consequent reduction in the total utilizable groundwater resources, increasing numbers of electrified wells and increasing energy demands for satisfying water needs—all have been upsetting the supply–demand balance of the energy sector.

This vicious circle does not end there. The generation of electricity also requires water. For a 1 MW coal-based thermal power plant, a water supply of 6.5 m^3/h is needed. At this rate the thermal power stations of the state cumulatively consume more than 165 MCM of water annually. The degrading quality of fossil fuels and stringent pollution control requirements will increase this water demand in future. Thus, saving water leads to savings in energy, conse-

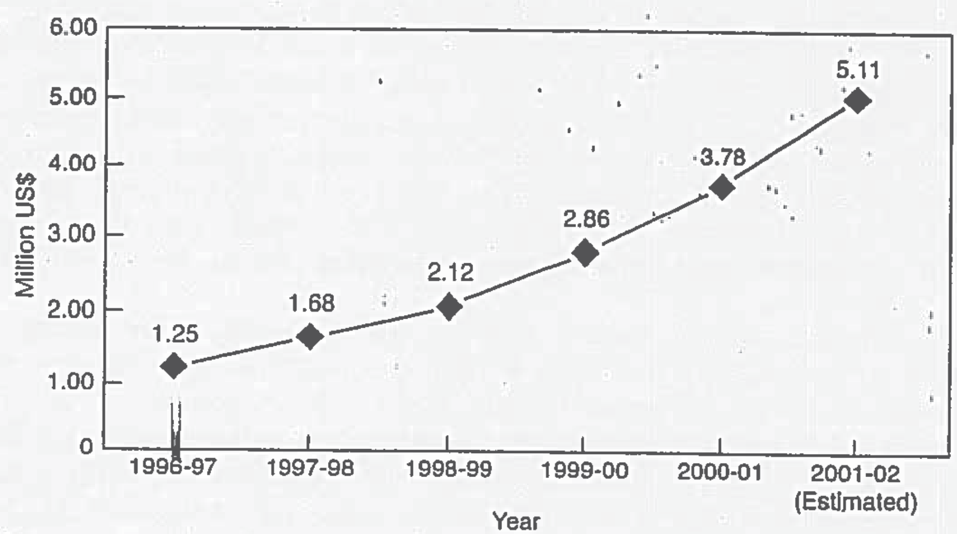

Figure 21. Electricity expenditure for water supply in Rajkot city.

quent savings in water and again in energy and so on (rippling effect); and vice versa is also true. Experience with the two major hydropower projects in Gujarat, i.e. Ukai and Kadana, indicates that on average about 8.45 m^3 of water is utilized for the generation of one unit of electricity (Vyas, 2001). Of course, this water can sometimes be reused for irrigation, domestic or industrial purposes. However, it underlines a major inter-linkage between the water and energy sectors.

Under the current conditions of water and energy availability and consumption in the state, conservation and efficiency in the use of water or energy will definitely have a positive impact on the other. Resolving the present crisis probably requires approaches based on the explicit recognition of the complementarity of available options.

Spectrum of Crisis-solving Efforts

The emergent situation of groundwater availability and utilization is seriously affecting the energy consumption pattern in the state. The multi-pronged efforts required to solve this typical water–energy crisis vary significantly in concept, scale and cost-effectiveness, etc. A few amongst these are as follows:

Regional Transfer of Narmada Water and Hydropower Generation by the Sardar Sarovar Project

Termed as one of the 'modern eight wonders of the world abuilding' (*Time*, 1994), the Sardar Sarovar project, a multi-state, multi-purpose river valley project on the Narmada River, will provide 11.1 billion cubic metres water annually for irrigating 1.9 Mha land and supply drinking water to 8215 villages and 135 urban centres (around 30 million population). Sixty-eight per cent of irrigation benefits and 95% of drinking water supply will go to the water-scarce regions of Saurashtra, Kutch and north Gujarat, which will have two inter-related effects. On the one hand, this assured surface water supply will reduce the pressure on groundwater, and on the other hand the return flow from irrigation will help recharge the groundwater. Energy saving (of around 1350 MW) due to this reduced groundwater extraction would be a bonus in addition to the hydropower generation of 1 billion units per year with the installed capacity of 1450 MW. In order to have this 2800 MW at the delivery point, a thermal power project of 6000 MW is required (Vyas, 2001), which would need around 228 MCM of water per year. This saved water will virtually save the energy that would be required to pump it, and such energy saving further would save water, and so on.

The state has already begun receiving the Narmada water at the rate of around 1000 cusecs by pumping it from the reservoir (only as a temporary measure) to solve the present acute water crisis, since about 15% of the concreting is yet to be completed in the main dam. Although this discharge is one-fortieth of the design discharge, it has been quenching the thirst of millions. Consequently, live storage available in the reservoirs of water-scarce regions, which is presently reserved for domestic use only, could be released for irrigation, further reducing dependence on groundwater extraction.

Conceptualization and Development of Kalpasar Project[1].

The state, constrained by its dependence on monsoon vagaries, has also undertaken detailed feasibility studies of another ambitious project, called Kalpasar. This envisages the construction of a 64.16 km long main reservoir wall stretched across the Gulf of Khambhat, impounding the water of five major rivers flowing into the gulf. Annually 1400 MCM of fresh water is expected to be available from this gigantic project for domestic and industrial use and 1.054 Mha land will be irrigated, in addition to renewable tidal power generation of up to 5880 MW. Apart from other inherent advantages that the initial studies have shown, this project has a significant potential to solve the water–energy crisis prevailing in the state.

Rainwater Harvesting and Aquifer Recharging

As a complementary measure to mitigate water scarcity, rainwater harvesting through microstructures such as check dams, percolation tanks and retention basins, etc. has a definite role to play. In Gujarat, such water-harvesting structures are constructed under a micro watershed development programme by agricultural, rural and water resource development schemes of the state government with popular participation. So far, a total of 22 697 such structures have been constructed to harvest 1047.62 MCM of water and 2250 works are in progress, which will store approximately 100.32 MCM of water. In spite of their limitations in terms of dependence on the vagaries of nature, carry-over storage, hydrogeological factors and high evaporation due to shallow storage depths, etc., these water-harvesting measures help build up the groundwater reserves through recharge and save the energy required for pumping. But regular failure of the monsoon restricts the effectiveness of these schemes.

Planning for Efficient Irrigated Agriculture

Given the status of water scarcity and the fact that agriculture is going to remain the major water consumer in the state, water use efficiency (more crop per drop—the blue revolution) acquires vital importance. Planning for less-water-demanding crops, rotation of crops to optimally utilize the soil moisture, improved land levelling and irrigation methods to achieve better uniformity in application of water, etc. are the steps that need immediate attention. Sustainability of irrigated agriculture needs to be ensured by proper long-term planning for conjunctive use of water for irrigation to avoid waterlogging as well as water-mining conditions (Joshi, 1998). Innovative irrigation methods, such as drips and sprinklers, etc., are slowly gaining popularity in the state despite high capital investments and external energy requirements. In order to reduce the conveyance losses, the existing canal networks of the state are being modernized (i.e. lining of canals, dredging of weed growth, better geometrical control and improved operation techniques, etc.).

Policy Options for Preventive Measures

In the present situation, preventive measures are required to be taken for public policy, such as:

- legislative prohibition/control on groundwater exploitation, at least in over-exploited and grey areas;

- enforcement of mandatory recycling of industrial water use;
- public–private participation in urban water supply;
- participatory irrigation management (involving farmers in canal operation and maintenance);
- provision of soft finance for water-efficient equipments/machines;
- promoting research for less-water-intensive crops as well as industrial processes.

Pricing of Water and Energy

Ensuring efficient consumer use of any commodity requires appropriate pricing. The rates of irrigation water supply in the state have been amongst the lowest in the country. The farmers are charged on a crop acreage basis and the recently revised rates per hectare for the entire season vary from US$1.5 to US$40 for different crops (Narmada, Water Resources and Water Supply Department, 1999). Irrigation water supplied by pumping at the cost of government is also charged only at the rate of Rs 1.20 (around US$0.03)/10 000 l. Although the revenue generated from irrigation water is negligible as compared to the actual costs incurred, to improve the water use efficiency, government has recently decided to increase these rates every year (by 15% for all other crops and 25% for paddy and sugar cane). However, this is still less than the amount paid by a farmer for just one watering from a private tube well source.

As regards the energy consumed for various uses, the recently revised tariffs are Rs 1680 (~US$37)/year/horsepower of the pump. For metered electricity connection used for irrigation, Gujarat Electricity Regulatory Commission has hiked the per unit (kwh) rate to Rs 0.50 (around US$0.01). For public water works, the rate per unit varies from Rs 2.30 to Rs 3.40 (around US$0.08)/unit. Thus, the electricity charges are highly subsidized in Gujarat and hence the state has to bear a burden of more than US$0.5 billion a year (Gujarat Electricity Board, 2000). With the World Trade Organization obligations to reduce the aggregate measurement of support and direct production subsidies, the state has to reduce subsidies and shift to metered billing in both water and energy sectors.

Consumer Education and Training

Ultimately, the message of efficient use has to percolate down to the end users. Often farmers have a tendency to irrigate their fields with excess water, unmindful of its adverse impact on the crop yield and soil conditions. A large volume of water is also wasted in the domestic sector (e.g. in malfunctioning of water flushes, water tapes, leaking pipes and over-use, etc.). Similarly, in the energy sector, an energy audit can help solve the crisis to a great extent. Farmers' education for using solar energy to run their drips or sprinklers is also desirable.

Conclusion

Considering the cause and effect relationship between water and energy in the state of Gujarat, immediate measures for reducing dependence on groundwater over-exploitation and the harnessing of available surface water resources (otherwise going waste in the sea) are required to be undertaken with a great deal of grit and political will. The state has already entered a vicious circle of water–energy–water crisis in which the imbalance in one sector disturbs the balance in the other sector. However, explicit recognition of their inter-linkages can certainly help solve the problem, since conservation and efficient use of one will lead to augmentation of the other. As the detailed analysis presented in the paper has shown, early completion of the Sardar Sarovar project, the planned development of Kalpasar project, regulating the groundwater use by making public policy provisions and tapping the untapped hydropower potential of the state can be considered as the main crisis-solving measures to be complemented by rainwater harvesting, artificial recharge, recycling of water for industrial use, conservation and efficient use of water and energy, etc.

Note

1. Kalpasar, in local language, means a lake that fulfils all wishes.

References

Agriculture and Cooperation Department (2000) *Gujarat Agrovision, 2010: A Working Document* (Gandhi Nagar, Government of Gujarat).

Directorate of Agriculture, Gujarat State (2000) *Districtwise Area, Production and Yield per Hectare of Important Food and Non-food Crops in Gujarat State* (Gandhi Nagar, Government of Gujarat).

Directorate of Economics and Statistics *Socio-economic Review, Gujarat State (1999–2000)*, Budget Publication No. 30 (Gandhi Nagar, Government of Gujarat).

Gujarat Drinking Water Infrastructure Board (2001) *Drinking Water Scarcity (2000–2001)* (Gandhi Nagar, Government of Gujarat).

Gujarat Electricity Board (www.gseb.com).

Gujarat Electricity Board (2000) *GEB News*, November (Vadodara).

GIDB (1999) *Gujarat Infrastructure Agenda, Vision 2010, Vol. I: Summary and Recommendations* (Gandhi Nagar, Government of Gujarat).

Gupta, R.K. (2001) Human rights dimension of regional water transfer: experience of the Sardar Sarovar project, *International Journal of Water Resources Development*, 17, pp. 125–147.

Hirway, I. & Patel, M. (2000) *High on Economic Growth, Low on Water Resources: Understanding the Dynamics of Water Crisis in Gujarat, India* (Ahmedabad, Centre for Development Alternatives).

Industrial Credit and Investment Corporation of India Ltd (1997) *Final Report on Structuring Commercial Sale of Water to Bulk Users*, unpublished, SENNL, Gandhi Nagar.

International Water Management Institute (2001) *Pedaling out of Poverty* (www.iwmi.org).

Joshi, M.B. (1998) Environmentally sustainable conjunctive water management: a computer aided approach, *Proceedings of the Seminar on Environmental Management of Water Resources and Power Projects*, Central Board of Irrigation and Power, 6–8 September, Indore, India.

Modi & Sheth (1983) *Hydraulics and Fluid Mechanics* (Delhi, Standard Book House).

Narmada, Water Resources and Water Supply Department (1999) *Report of the Committee on Estimation of Groundwater Resource and Irrigation Potential in Gujarat State (GWRE—1997)* (Gandhi Nagar, Government of Gujarat).

Narmada, Water Resources and Water Supply Department (2001) *Drinking Water Scarcity 2000–2001* (Gandhi Nagar, Government of Gujarat).

Patel, P. & Ragavan, R. (2000) Sustainable environmental outcomes from water related energy projects, *International Journal of Water Resources Development*, 16, pp. 511–524.

Self Employed Women's Association (2001) *Women, Water and Work: SEWA's Millennium Campaign (2000)*, Report of the Self Employed Women's Association (Ahmedabad).

Tahal Consulting Engineers Ltd (1997) *International Journal of Water Resources Planning for the State of Gujarat: Final Report, Vol. I*, unpublished (Gandhi Nagar, Government of Gujarat).

Time (1994) Eight modern wonders abuilding, 24 January, p. 9.

Varma, C.V.J. (2000) Role of dams and hydropower, *India Power*, 7.

Vyas, J.N. (2001) Water and energy for development in Gujarat with special focus on the Sardar Sarovar project, *International Journal of Water Resources Development*, 17, pp. 37–54.