India

GEOGRAPHY, CLIMATE AND POPULATION

Geography

India is located in southern Asia and has a total area of almost 3.3 million km^2 (Table 1), making it the largest peninsula in the world and the seventh largest country. It is bordered in the northwest by Pakistan, in the north by China, Nepal and Bhutan, and in the northeast by Myanmar and Bangladesh. In the south, some 7 600 km of coastline is on the Arabian Sea, Indian Ocean and Bay of Bengal. The peninsula can be divided into three main regions: peninsular India, located south of the Vindhya and Satpura mountain ranges; the plains of the Indus (northwest) and Ganges (north and northeast) rivers; and the mountainous terrain of the Himalayas. In addition, the Lakshadweep Islands in the Arabian Sea and the Andaman Islands and Nicobar Islands in the Bay of Bengal are part of the territory of India. For administrative purposes, India is divided into 28 states and seven union territories.

The total cultivable area is approximately 183 million ha, or over 55 percent of the total area of the country. In 2009, the total cultivated area was about 170 million, of which 158 million ha were annual crops and 12 million ha were permanent crops. Between the early 1960s and the late 1980s the cultivated area increased by 5 percent, since then there has been hardly any increase in the cultivated area. Crop yields, however, have increased significantly (food grain yields have more than tripled since 1950) as well as the cropping intensity, which increased from 111 percent in 1950 to 118 in 1970, 130 in 1990 and 135 in 2006.

Climate

India has a typical monsoon climate. In this region, surface winds undergo a complete reversal from January to July, and cause two types of monsoon. In winter, dry and cold air from land in the northern latitudes flows southwest (northeast monsoon), while in summer, warm and humid air originates over the ocean and flows in the opposite direction (southwest monsoon), accounting for some 70-95 percent of the annual rainfall. For most parts of India the rainfall occurs under the influence of the southwest monsoon between June and September. However, in the southern coastal areas near the east coast (Tamil Nadu and adjoining areas) much of the rainfall is influenced by the northeast monsoon during October and November.

The average annual rainfall over the country is around 1 170 mm, but varies significantly from place-to-place. In the northwest desert of Rajasthan, the average annual rainfall is lower than 150 mm/year. In the broad belt extending from Madhya Maharashtra to Tamil Nadu, through parts of Andhra Pradesh and Karnataka, the average annual rainfall is generally lower than 500 mm/year. At the other extreme, in a short period of a few months, more than 10 000 mm of rain falls on the Khasi hills in the northeast. On the west coast, in Assam, Meghalaya, Arunachal Pradesh (states located in the northeast) and in sub-Himalayan West Bengal the average annual rainfall is about 2 500 mm.

Except in the northwest of India, the inter-annual variability of rainfall is relatively low. The main areas affected by severe droughts are Rajasthan and Gujarat.

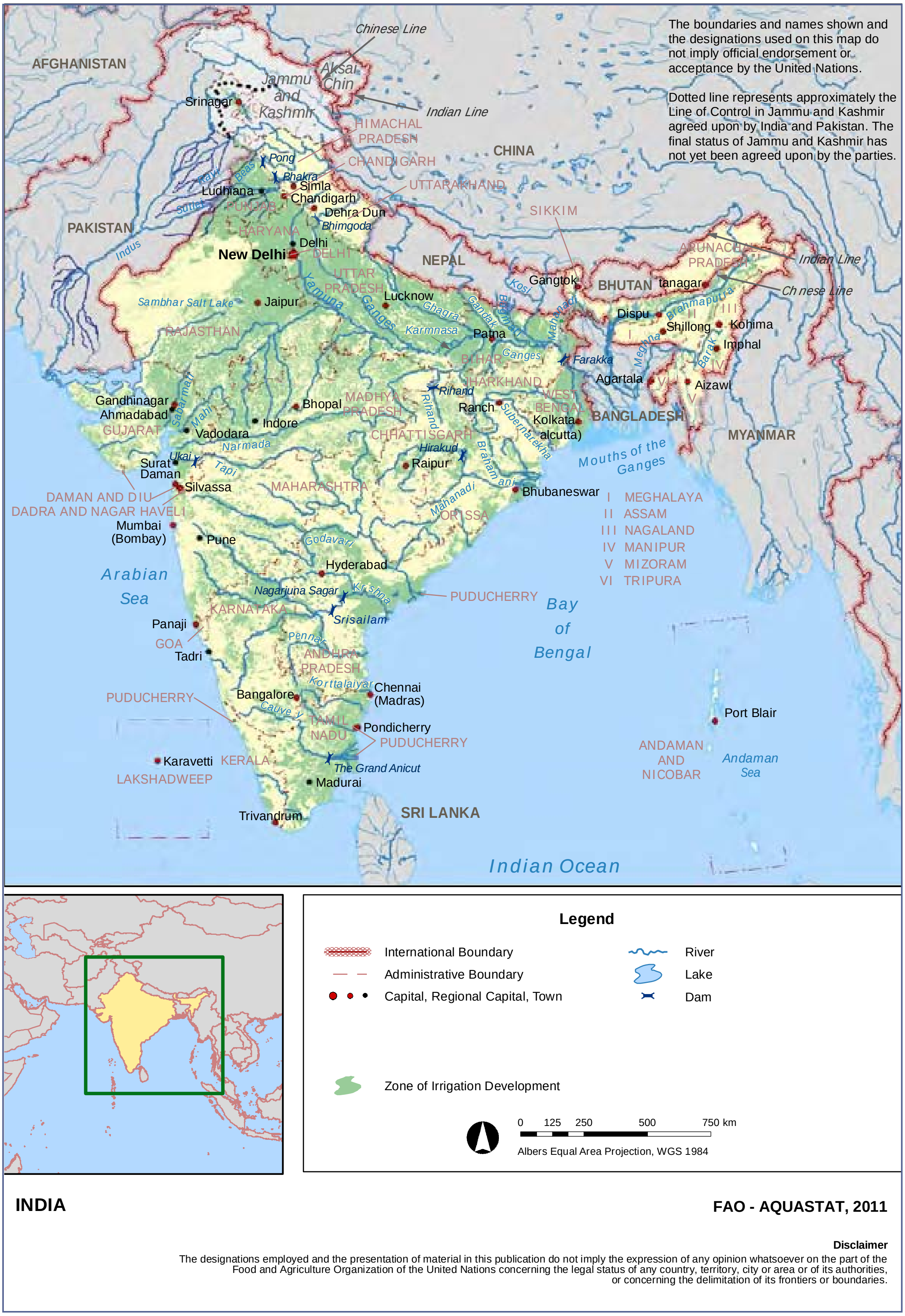
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.
AFGHANISTAN
PAKISTAN
CHINA
NEPAL
BHUTAN
BANGLADESH
MYANMAR
SRI LANKA
Chinese Line
Indian Line
Aksai Chin
Jammu and Kashmir
HIMACHAL PRADESH
CHANDIGARH
UTTARAKHAND
SIKKIM
PUNJAB
HARYANA
DELHI
UTTAR PRADESH
RAJASTHAN
GUJARAT
MADHYA PRADESH
BIHAR
JHARKHAND
WEST BENGAL
CHHATTISGARH
ORISSA
MAHARASHTRA
KARNATAKA
ANDHRA PRADESH
TAMIL NADU
KERALA
GOA
DAMAN AND DIU
DADRA AND NAGAR HAVELI
PUDUCHERRY
LAKSHADWEEP
ANDAMAN AND NICOBAR
I MEGHALAYA
II ASSAM
III NAGALAND
IV MANIPUR
V MIZORAM
VI TRIPURA
Srinagar
Simla
Chandigarh
Ludhiana
Dehra Dun
Delhi
New Delhi
Jaipur
Lucknow
Patna
Gangtok
Dispur
Shillong
Kohima
Imphal
Agartala
Aizawl
Ranchi
Kolkata (Calcutta)
Bhopal
Indore
Gandhinagar
Ahmadabad
Vadodara
Surat
Daman
Silvassa
Mumbai (Bombay)
Pune
Raipur
Bhubaneswar
Hyderabad
Panaji
Tadri
Bangalore
Chennai (Madras)
Pondicherry
Karavetti
Madurai
Trivandrum
Port Blair
Pong
Bhakra
Bhimgoda
Farakka
Rihand
Hirakud
Ukai
Nagarjuna Sagar
Srisailam
The Grand Anicut
Indus
Ravi
Beas
Sutlej
Yamuna
Ganges
Ghagra
Gandak
Kosi
Karmnasa
Mahanadi
Brahmaputra
Meghna
Barak
Narmada
Tapi
Mahi
Sabarmati
Godavari
Krishna
Pennar
Cauvery
Korttalaiyar
Subernarekha
Brahmani
Sambhar Salt Lake
Mouths of the Ganges
Arabian Sea
Bay of Bengal
Andaman Sea
Indian Ocean
Legend
International Boundary
Administrative Boundary
Capital, Regional Capital, Town
River
Lake
Dam
Zone of Irrigation Development
0 125 250 500 750 km
Albers Equal Area Projection, WGS 1984
INDIA
FAO - AQUASTAT, 2011
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TABLE 1
Basic statistics and population

Physical areas			
Area of the country	2009	328 726 000	ha
Cultivated area (arable land and area under permanent crops)	2009	169 623 000	ha
• as % of the total area of the country	2009	52	%
• arable land (annual crops + temp fallow + temp meadows)	2009	157 923 000	ha
• area under permanent crops	2009	11 700 000	ha
Population			
Total population	2009	1 207 740 000	inhabitants
• of which rural	2009	70	%
Population density	2009	367	inhabitants/km^2
Economically active population	2009	485 793 000	inhabitants
• as % of total population	2009	40	%
• female	2009	28	%
• male	2009	72	%
Population economically active in agriculture	2009	266 751 000	inhabitants
• as % of total economically active population	2009	55	%
• female	2009	32	%
• male	2009	68	%
Economy and development			
Gross Domestic Product (GDP) (current US$)	2009	1 310 171	million US$/yr
• value added in agriculture (% of GDP)	2009	17	%
• GDP per capita	2009	1 085	US$/yr
Human Development Index (highest = 1)	2010	0.519	
Access to improved drinking water sources			
Total population	2008	88	%
Urban population	2008	96	%
Rural population	2008	84	%

The year can be divided into four seasons, the:

- winter or northeast monsoon: January – February;
- hot season: March – May;
- summer or southwest monsoon: June – September; and
- post-monsoon season: October – December.

Temperature variations are also marked. During the post-monsoon and winter seasons, from November to February, the temperature decreases from south to north owing to the effect of continental winds over most of the country. From March to May, the temperature can increase to 40 °C in the northwest. With the advent of the southwest monsoon in June, there is a rapid fall in the maximum daily temperature, which then remains stable until November. The temperatures are suitable for year-round crop production throughout India, except at higher elevations in the Himalayas.

Population

In 2009, India was the second most populous country in the world, with an estimated total population of 1 208 million. In 2009, 849 million inhabitants (or 70 percent) were living in rural areas. The country's average population density then was an estimated 367 inhabitants/km^2, varying from fewer than 15 inhabitants/km^2 in the states of Arunachal Pradesh and

Himachal Pradesh to more than 9 300 inhabitants/km^2 in Delhi State. During the period 1999-2009 the average annual population growth rate was an estimated 1.5 percent.

In 2008, 88 percent of the population had access to improved water sources (96 and 84 percent in urban and rural areas respectively), but only 31 percent had access to improved sanitation (54 and 21 percent in urban and rural areas respectively).

ECONOMY, AGRICULTURE AND FOOD SECURITY

In 2009, the national gross domestic product (GDP) was US$1 310 171 million (Table 1). Agriculture accounted for 17 percent of GDP, while in 1999 it represented 25 percent. In 2009, the total economically active population was 486 million, or 40 percent of the total population. The economically active population in agriculture, then, was about 267 million, of which 32 percent were women. In 2004, about 238 million people comprising 21 percent of the total population were assessed to be below the poverty line.

The major cereals grown in India are rice, wheat, maize, bajra (spiked millet), barley, jowar (great millet), and ragi. The average yield of food grains (cereals and pulses) increased from 522 kg/ha in 1950 to 1 727 kg/ha in 2003-2004, meaning there was an average annual growth rate of 4.35 percent. Total food grain production in 2006-2007 was almost 212 million tonnes. The average operational farm size reduced from 1.57 ha in 1992 to 1.17 ha in 2002.

WATER RESOURCES AND USE

Water resources

India has an annual average precipitation of 1 170 mm and about 80 percent of the total area of the country experiences annual rainfall of 750 mm or more (Table 2). Owing to the large spatial and temporal variability in the rainfall, water resources distribution is highly skewed in space and time.

The two main sources of water in India are rainfall and glacial snowmelt in the Himalayas. Although snow and glaciers are poor producers of freshwater, they are good distributors as they yield at the time of need, in the hot season. Indeed, about 80 percent of the river flow occurs during the four to five months of the southwest monsoon season. Several important river systems originate in upstream countries and then flow to other countries: the Indus river originates in China and flows to Pakistan; the Ganges-Brahmaputra river system originates partly in China, Nepal and Bhutan, and flows to Bangladesh; some minor rivers drain into Myanmar and Bangladesh. However, no official records are available regarding the annual flows into or our of the country.

The rivers of India can be classified into four groups:

- The Himalayan rivers (Ganges, Brahmaputra, Indus) are formed by melting snow and glaciers as well as rainfall and, therefore, have a continuous flow throughout the year. As these regions receive very heavy rainfall during the monsoon period, the rivers swell and cause frequent floods.
- The rivers of the Deccan plateau (with larger rivers such as Mahanadi, Godavari, Krishna, Pennar and Cauvery draining into the bay of Bengal in the east, and Narmadi and Tapi draining into the Arabian sea in the west), making up most of the southern-central part of the country, are rainfed and fluctuate in volume, many of them being non-perennial.

TABLE 2
Water: sources and use

Renewable freshwater resources			
Precipitation (long-term average)	-	1 170	mm/yr
	-	3 846 000	million m^3/yr
Internal renewable water resources (long-term average)	-	1 446 000	million m^3/yr
Total actual renewable water resources	-	1 911 000	million m^3/yr
Dependency ratio	-	31	%
Total actual renewable water resources per inhabitant	2009	1 582	m^3/yr
Total dam capacity	2005	224 000	million m^3
Water withdrawal			
Total water withdrawal	2010	761 000	million m^3/yr
- irrigation + livestock	2010	688 000	million m^3/yr
- municipalities	2010	56 000	million m^3/yr
- industry	2010	17 000	million m^3/yr
• per inhabitant	2010	630	m^3/yr
Surface water and groundwater withdrawal	2010	761 000	million m^3/yr
• as % of total actual renewable water resources	2010	40	%
Non-conventional sources of water			
Produced wastewater	1996	25 410	million m^3/yr
Treated wastewater		-	million m^3/yr
Reused treated wastewater		-	million m^3/yr
Desalinated water produced	1996	0.55	million m^3/yr
Reused agricultural drainage water	2010	113 470	million m^3/yr

- The coastal rivers, especially on the west coast, south of the Tapi, are short with limited catchment areas, most of them being non-perennial.
- The rivers of the inland drainage basin in western Rajasthan in the northwestern part of the country, towards the border with Pakistan, are ephemeral and drain towards the salt lakes such as the Sambhar, or are lost in the sands.

For planning purposes, the country is divided into 20 river units, 14 of which are major river basins, while the remaining 99 river basins have been grouped into six river units, as presented in Table 3. The spatial imbalance of water resources distribution can be appreciated by the fact that the Ganges-Brahmaputra-Meghna basin, which covers 34 percent of the country's area, contributes about 59 percent of the water resources. The west flowing rivers towards the Indus cover 10 percent of the area and contribute 4 percent of the water resources. The remaining 56 percent of the area contributes 37 percent to the runoff.

The potential surface water resources is assessed as the natural runoff of the rivers. Looking at the Indus Water Treaty (1960) between India and Pakistan, however, these are an estimated 1 869.37 km^3, of which only 690.31 km^3 are considered usable or exploitable because of constraints related to topography, uneven distribution of the resource over space and time, geological factors and contemporary technological knowledge (Table 3).

Annual renewable groundwater resources are an estimated 432 km^3, of which around 90 percent or 390 km^3 are considered overlap between surface water and groundwater. Annual internal renewable surface water resources (IRSWR) have been estimated as 1 446.42 km^3, of which 1 404.42 km^3 surface water, 432 km^3 groundwater and 390 km^3 overlap. The IRSWR have been estimated by deducting the inflow from the total renewable surface water resources.

TABLE 3

Basin wise distribution of utilisable surface water resources (Source: Central Water Commission (1993), p 12, and Central Water Commission (1996), p 15)

	River basin unit	Location	Draining into	Catchment area (% of the country)	Average annual runoff (km^3)	Exploitable surface water (km^3)
1	Ganges	Northeast	Bangladesh	26.5	525.02	250.0
	Brahmaputra	Northeast	Bangladesh	6.0	537.24	24.0
	Meghna/Barak	Northeast	Bangladesh	1.5	48.36	
2	Minor rivers of the northeast	Extreme northeast	Myanmar	1.1	20.00	
			Bangladesh		11.00	
3	Subernarekha	Northeast	Bay of Bengal	0.9	12.37	6.8
4	Brahmani-Baitarani	Northeast	Bay of Bengal	1.6	28.48	18.3
5	Mahanadi	Central-east	Bay of Bengal	4.4	66.88	50.0
6	Godavari	Central	Bay of Bengal	9.7	110.54	76.3
7	Krishna	Central	Bay of Bengal	8.0	78.12	58.0
8	Pennar	Southeast	Bay of Bengal	1.7	6.32	6.9
9	Cauvery (1)	South	Bay of Bengal	2.5	21.36	19.0
10	East flowing rivers between Mahanadi and Pennar	Central-east	Bay of Bengal	2.7	22.52	13.1
11	East flowing rivers between Kanyakumari and Pennar	Southeast	Bay of Bengal	3.1	16.46	16.7
12	West flowing rivers from Tadri to Kanyakumari	Southwest	Arabian Sea	1.7	113.53	24.3
13	West flowing rivers from Tapi to Tadri	Central-west	Arabian Sea	1.7	87.41	11.9
14	Tapi	Central-west	Arabian Sea	2.0	14.88	14.5
15	Narmada (2)	Central-west	Arabian Sea	3.1	45.64	34.5
16	Mahi	Northwest	Arabian Sea	1.1	11.02	3.1
17	Sabarmati	Northwest	Arabian Sea	0.7	3.81	1.9
18	West flowing rivers of kutsh and Saurashtra	Northwest	Arabian Sea	10.0	15.10	15.0
19	Rajasthan inland basin	Northeast	-	0.0	Negligible	-
20	Indus Eastern tributaries (3a)	Northwest	Pakistan	10.0	11.10	46.0
	Indus Western tributaries (3b)				62.21	
	Total considering Indus Treaty			**100.0**	**1 869.37**	**690.3**

Notes: (1) The assessment for Cauvery was made by the Cauvery Fact Finding Committee in 1972 based on 38 years' flow data at Lowe Anicat on Coleroon. An area of 8000 km^2 in the delta is not accounted for in this assessment. (2) The potential of the Narmanda basin was determined on the basis of catchment area proportion from the potential assessed at Garudeshwar as given in the report on Normanda. Water disputes Tribunal Decision (1978). (3) Under the Indus Water Treaty (1960) between India and Pakistan the following is foreseen. (a) All waters of the eastern tributaries of the Indus originating in India (11.1 km^3) shall be available for unrestricted use by India (Sutlej, Beas, Ravi), except some domestic and non-consumptive use. (b) All waters of the western tributaries (Chenab, Jhelum) shall be available for unrestricted use by Pakistan, except for some domestic use, non-consumptive use, agricultural use, generation of hydroelectric power; total flow of western rivers is estimated at around 232.48 km^3 (flow from China to India is estimated at 181.62 km^3 and flow generated within India at 50.86 km^3), of which 170.27 km3 should then be reserved for Pakistan and therefore 62.21 is available for India.

Under the Indus Water Treaty (1960) between India and Pakistan, it was estimated that 73.31 km^3/year is available for India (Table 3). The following rules apply:

- *Eastern rivers:* All the waters of the eastern tributaries of the Indus river originating in India, i.e. the Sutlej, Beas and Ravi rivers taken together, shall be available for unrestricted use by India. Pakistan shall be under an obligation to let flow, and shall not permit any interference with, the waters (while flowing in Pakistan) of any tributary which, in its natural course, joins the Sutlej Main or Ravi Main before these rivers have finally crossed into Pakistan. This average annual flow in India before crossing the border is an estimated 11.1 km^3. All the waters, while flowing in Pakistan, of any tributary which in its natural course joins the Sutlej main or the Ravi main, after these rivers have crossed into Pakistan, shall be available for the unrestricted use of Pakistan.

- *Western rivers:* Pakistan shall receive for unrestricted use all those waters of the western rivers, i.e. Chenab and Jhelum, which India is under obligation to let flow, except for restricted uses, related to domestic use, non-consumptive use, agricultural use and generation of hydroelectric power of which the amounts are set out in the Treaty. Annual flow from China to India in the Indus basin is 181.62 km^3 and it is estimated that the flow generated within India is 50.86 km^3, resulting in a flow from India to Pakistan in this part of 232.48 km^3, of which 170.27 km^3 reserved for Pakistan and 62.21 km^3 available for India.

Besides this outflow to Pakistan from the Indus basin, 1 121.62 km^3 flows annually to Bangladesh (525.02 km^3 from the Ganges, 537.24 km^3 from the Brahmaputra, 48.36 km^3 from the Meghna and 11 km^3 from other rivers into southeast Bangladesh), and 20 km^3 flows to Myanmar.

In 1996, produced wastewater was an estimated 25.4 km^3. In 2004, wastewater production in urban centres (rural areas with larger population have not been accounted) was an estimated 10.585 km^3 and the treated wastewater was about 2.555 km^3.

No reliable statistics are available on the number or the status of desalination plants, or on their capacities or technologies adopted. Estimates indicate, however, that there are more than 1 000 membrane-based desalination plants of various capacities ranging from 20 m^3/day to 10 000 m^3/day. There are few thermal-based desalination plants. In 1996, some 550 000 m^3 of seawater were desalinated in the Lakshadweep Islands, mainly using electro dialysis and reverse osmosis (RO). Solar stills are also installed on the peninsula, as in Gujarat in the northwest. A 6 300 m^3/day desalination plant is being set up at Kalpakkam, Chennai with a capacity of 4 500 m^3 from multi stage flash (MSF) method, using low pressure steam from the Madras Atomic Power Station and 1 800 m^3/day from RO method. While the Plant using the RO method is under operation, the MSF-based plant is to be commissioned soon.

The total constructed water storage capacity, up to 2005, was 224 km^3. Another 76.26 km^3 are estimated to be possible from dams under construction and 107.54 from dams under consideration. Seven dams have a reservoir capacity that exceeds 8 km^3. They are the Nagarjuna Sagar dam on the Krishna river (11.56 km^3), the Rihand dam on the Rihand river (10.6 km^3), the Bhakra dam on the Sutlej river (9.62 km^3), the Srisailam dam on the Krishna river (8.72 km^3), the Hirakud dam on the Mahanadi river (8.1 km^3), the Pong (Beas) dam on the Beas river (8.57 km^3) and the Ukai dam on the Tapti river (8.5 km^3).

India controls the flow of the River Ganges using a dam completed in 1974 at Farraka, 18 km from the border with Bangladesh. The Farakka barrage is a low diversion structure and not classified as a large dam.

India is endowed with rich hydropower potential, ranking fifth in the world. The gross hydropower potential was an estimated 148 700 MW as installed capacity, or 84 000 MW at 60 percent power load factor, of which the Brahamaputra, Ganges and Indus basins contribute about 80 percent. Further, small, mini and micro hydropower schemes (with a capacity of less than 3 MW) have been assessed as having almost 6 782 MW of installed capacity.

International water issues

The earlier-mentioned dam at Farraka, 18 km from the border with Bangladesh, was a source of tension between the two countries, when Bangladesh asserted that the dam held back too much water during the dry season and released too much water during monsoon rains. A treaty was signed in December 1996, under which Bangladesh is ensured a fair share of the flow reaching the dam during the dry season.

The Indus Water Treaty (1960) between India and Pakistan, described earlier, helped to resolve the issues between these two countries; although during the last few years Pakistan has objected to India's development of hydropower projects on the western rivers, Chenab and Jhelum.

Similar arrangements exist between Nepal and India for the exploitation of the Kosi river (1954, 1966) and the Gandak river (1959).

Water use

It is estimated that in 2010 total water withdrawal was 761 km^3 of which 91 percent, or 688 km^3, are for irrigation. About 56 km^3 are for municipal and 17 km^3 for industrial use(Figure 1).

In 2010, primary surface water withdrawal accounted for 396 km^3, primary groundwater withdrawal accounted for 251 km^3, and reused agricultural drainage water accounted for 113 km^3. In 1996, some 550 000 m^3 of seawater were desalinated (Table 2 and Figure 2).

FIGURE 1
Water withdrawal by sector
Total 761 km³ in 2010

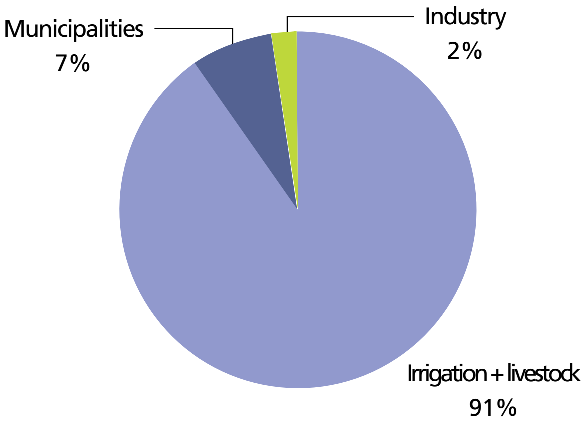
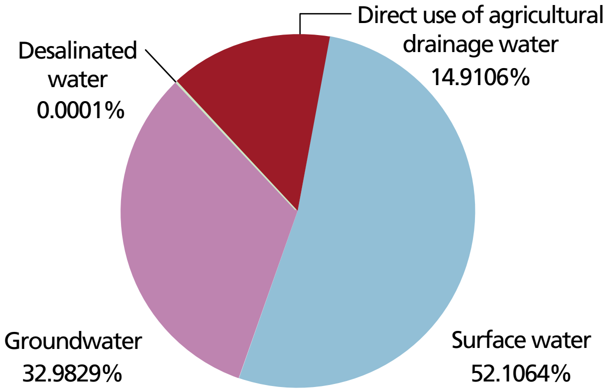


FIGURE 2
Water withdrawal by source
Total 761 km³ in 2010



In 1990, total water withdrawal was an estimated 500 km^3, of which 92 percent was for irrigation. Primary surface water withdrawal was 362 km^3, while the amount coming from primary groundwater was an estimated 190 km^3.

IRRIGATION AND DRAINAGE DEVELOPMENT

Evolution of irrigation development

The history of irrigation development in India can be traced back to prehistoric times. Ancient Indian scriptures referred to construction of wells, canals, tanks and dams and their efficient operation and maintenance. Irrigation to produce food grains is known to have been in existence for over 5 000 years (Framji, 1987). There is evidence of irrigation being practised since the establishment of settled agriculture during the Indus Valley Civilization (in 2500 Before the Common Era [BCE]). These irrigation technologies were in the form of small and minor works. Traces of irrigation structures dating back 3 700 years have been found in the state of Maharashtra. During the Mauryan era (2 600-2 200 years ago), it is reported that farmers had to pay taxes for irrigation water from neighbouring rivers.

The Grand Anicut (Canal) across the Cauvery river in Tamil Nadu was begun 1 800 years ago and its basic design is still used today. In 1800, some 800 000 ha were irrigated in India. Major irrigation canals were built following the major famines at the end of the nineteenth century and, in 1900, the Indian peninsula (including Bangladesh and Pakistan) had some 13 million ha under irrigation. In 1947, India had about 22 million ha under irrigation. High priority has been given to irrigation with nearly 10 percent of all planned outlays since 1950 being invested in irrigated agriculture. This has resulted in the development of, on average, 0.6-0.7 million ha new irrigated schemes every year.

The emphasis on irrigation development was initially on run-of-the-river schemes. Subsequently, the need was felt for storage projects for either single or multiple purposes. Irrigation schemes are grouped under three categories: major (>10 000 ha), medium (2 000-10 000 ha) and minor (<2 000 ha) schemes. Minor irrigation projects generally have both surface water and groundwater as sources, while major and medium projects exploit surface water resources. In 1993 around 65 percent were minor schemes. In new major irrigation works, social and environmental costs (resettlement of displaced people, loss of biodiversity in submerged areas, etc.) are more systematically considered than in the past.

While in 1993 the ultimate irrigation potential of India was an estimated 113.5 million ha, new estimates give a figure of 139.5 million ha, of which 58.1 million ha for major and medium irrigation schemes and 81.4 million ha for minor irrigation projects. Of the 81.4 million ha of minor irrigation potential, groundwater based potential is estimated to be 64.1 million ha and the surface water based potential is 17.3 million ha.

Total area equipped for irrigation was around 66.3 million ha in 2008 (Table 4). Irrigation is mainly concentrated in the north of the country along the Indus and Ganges rivers: Punjab, Rajasthan, Uttar Pradesh and Madhya Pradesh. A classification of irrigation by origin of water is in common use in India. It differentiates irrigation from canals (29 percent in 2001), most of which are government canals, tanks (4 percent), groundwater wells (63 percent), the majority being privately owned and managed, and other or undefined sources (4 percent) (Figure 3). In 1993 the area equipped for irrigation was about 50.1 million ha of which irrigation by canals accounted for 34 percent (97 percent are government canals), tanks 6.5 percent, groundwater 53 percent (generally privately owned and managed) and other or undefined sources (6.5 percent). This shows that the use of groundwater for irrigation has increased considerably.

Of the 19.75 million minor irrigation schemes, groundwater schemes account for 18.5 million and the rest are based on surface water resources. The surface flow schemes typically comprise tanks and storage developed by construction of check dams. Groundwater schemes are composed of dug wells, dug cum bore wells, borings, and both shallow and deep tubewells. There is considerable variation in the development of minor irrigation from state-to-state. The full potential of minor irrigation has been tapped in Uttar Pradesh, Punjab, Haryana, Rajasthan. In some of the Union Territories it is as low as 18 percent in Manipur and 20 percent in Madhya Pradesh. Minor irrigation schemes are generally in the private sector and very few (6 percent) are owned by public institutions.

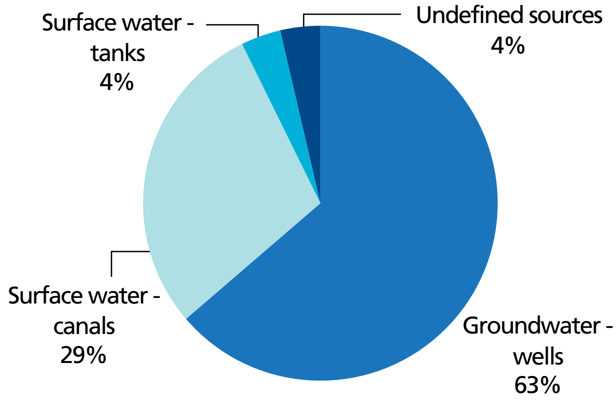
Over the past few decades, the main driving force behind the expansion of groundwater irrigation and improvement in agricultural productivity, was support to investment to provide electrical infrastructure and credit. Private groundwater irrigation, with shallow wells that serve 3-5 ha each, is considered to be the most cost-effective solution. Of the 18.50 million groundwater wells 16.43 million wells are in use (7.85 million dug wells, 8.10 million shallow tubewells and the rest deep tubewells). Development of groundwater resources varies from state-to-state. Groundwater is still available for exploitation in the eastern parts of the country, and in Madhya Pradesh, Chhattisgarh, specific pockets of Andhra Pradesh, Karnataka, Maharastra and Jammu and Kashmir. In Punjab, Haryana, Rajasthan, Gujrat and Tamil Nadu, exploitation exceeds the recharge to groundwater.

TABLE 4
Irrigation and drainage

Irrigation potential			139 500 000	ha
Irrigation				
1. Full control irrigation: equipped area		2008	66 334 000	ha
- surface irrigation		2004	61 937 988	ha
- sprinkler irrigation		2004	1 445 805	ha
- localized irrigation		2004	578 207	ha
• % of area irrigated from surface water		2001	37	%
• % of area irrigated from groundwater		2001	63	%
• % of area irrigated from mixed surface water and groundwater			-	%
• % of area irrigated from mixed non-conventional sources of water			-	%
• area equipped for full control irrigation actually irrigated		2008	62 286 000	ha
- as % of full control area equipped		2008	94	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)			-	ha
3. Spate irrigation			-	ha
Total area equipped for irrigation (1+2+3)		2008	66 334 000	**ha**
• as % of cultivated area		2008	39	%
• % of total area equipped for irrigation actually irrigated		2008	94	%
• average increase per year over the last 7 years		2001-2008	1.0	%
• power irrigated area as % of total area equipped		2001	83	%
4. Non-equipped cultivated wetlands and inland valley bottoms			-	ha
5. Non-equipped flood recession cropping area			-	ha
Total water-managed area (1+2+3+4+5)		2008	66 334 000	**ha**
• as % of cultivated area		2008	39	%
Full control irrigation schemes	**Criteria**			
Small-scale schemes	< 2 000 ha	1993	33 017 000	ha
Medium-scale schemes	included in large	1993		ha
Large-scale schemes	> 10 000 ha	1993	17 084 000	ha
Total number of households in irrigation		-	-	
Irrigated crops in full control irrigation schemes				
Total irrigated grain production			-	metric tons
• as % of total grain production			-	%
Harvested crops				
Total harvested irrigated cropped area		2004	76 820 000	ha
• Annual crops: total				ha
- Rice		2004	22 428 000	ha
- Maize		2004	1 411 000	ha
- Barley		2004	472 000	ha
- Wheat		2004	23 498 000	ha
- Sorghum		2004	699 000	ha
- Cereals not specified		2004	801 000	ha
- Pulses		2004	3 326 000	ha
- Cotton		2004	2 591 000	ha
- Groundnuts		2004	1 052 000	ha
- Sugarcane		2004	4 043 000	ha
- Tobacco		2004	215 000	ha
• Permanent crops:				ha
- Oil Palm		2004	5 442 000	ha
• Annual or permanent crops:				ha
- Fruits and vegetables		2004	4 590 000	ha
- Condiments and spices		2004	1 852 000	ha
- Other crops		2004	4 400 000	ha
Irrigated cropping intensity (on area actually irrigated)		2004	130	%
Drainage - Environment				
Total drained area		1991	5 800 000	ha
- part of the area equipped for irrigation drained			-	ha
- other drained area (non-irrigated)			-	ha
• drained area as % of cultivated area		1991	3.4	%
Flood-protected areas				ha
Area salinized by irrigation		1998	3 300 000	ha
Population affected by water-related diseases		1998	44 000 000	inhabitants

In many states, especially in the north (Uttar Pradesh, Punjab and Haryana), the conjunctive use of surface water and groundwater has been practiced using canal systems and tubewells or dug wells to increase the yield and general efficiency of the water system. Water from the tubewells, which are installed alongside existing canals, is added into the canals for use in the canal command areas. This practice helps prevent waterlogging, but requires that farmers adopt good management techniques.

FIGURE 3
Source of irrigation water on area equipped for full control irrigation
Total 61 907 846 ha in 2001

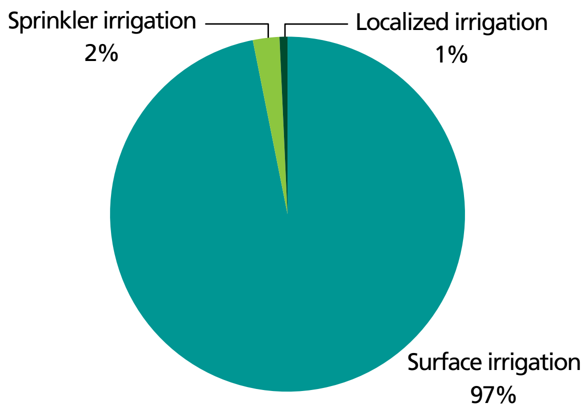


The irrigation component of the Bharat Nirman Programme of the Government of India, a business plan for rural infrastructure, started in 2005, envisages the development of an additional irrigation area of 10 million ha through various irrigation schemes. Currently, 166 major, 222 medium and 89 environmental resources management (ERM) projects are reported to be ongoing in various states. The Government of India provides support to State Governments through the Accelerated Irrigation Benefits Program (AIBP) and other schemes.

In recent years, the development of sprinkler and localized irrigation has been considerable, mainly the result of the pressing demand for water from other sectors, a fact that has encouraged governments and farmers to find water-saving techniques for agriculture. Sprinkler irrigation was not widely used in India before the 1980s; however between 1985 and 1996 more than 200 000 sprinkler sets were sold. In 2004 the area under sprinkler irrigation was an estimated 1.4 million ha, while in 1996 it was about 0.7 million ha.

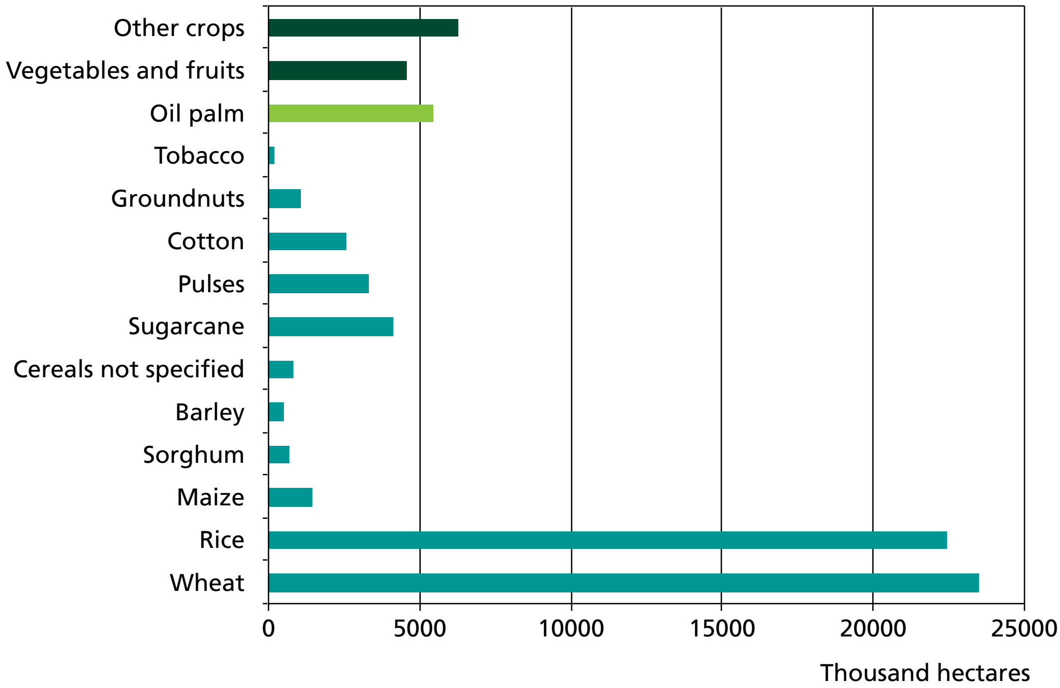
Localized irrigation is also expanding rapidly in India. This can be partly explained by the subsidies offered by the Government to adopt drip systems. From about 1 000 ha in 1985, the area under drip irrigation increased to 70 860 ha in 1991, mainly in Maharashtra, Andhra Pradesh and Karnataka. In 2004 the area under localized irrigation was about 578 207 ha (Figure 4). Drip-irrigated crops are mainly used in orchards, mainly grapes, bananas, pomegranates and mangoes. Localized irrigation is also used for sugarcane and coconut. In 2004 surface irrigation covered approximately 61.9 million ha. The approximate capital cost of sprinkler systems (excluding pump cost) ranges from US$345-450/ha. The approximate cost of localized irrigation is US$1 780-6 240/ha.

FIGURE 4
Irrigation techniques on area equipped for full control irrigation
Total 63 962 000 ha in 2004



Water-harvesting systems, comprising tanks and other water conservation works, are devised to capture, store and distribute water for irrigation, besides meeting the municipal needs of the population. According to the third minor irrigation census carried out in 2001 the number of tanks, storage and other water conservation works is 0.457 million.

FIGURE 5
Irrigated crops on area equipped for full control irrigation
Total harvested area 76 820 000 ha in 2004 (cropping intensity on actually irrigated area: 130%)



Role of irrigation in agricultural production, economy and society

Irrigation development has enabled diversification of cropping patterns with crops grown all year round. The expansion of irrigation has not only directly enabled yield increases, it has also facilitated high input, high-yielding agriculture involving the use of chemical fertilizers and high-yielding varieties of wheat rice and maize. The food grain production has increased from about 50 million tonnes in 1951 to 213 million tonnes in 2004. Although irrigated crop yields have increased considerably, they are still low compared to those of other countries. This is mainly because of poor water management in many surface irrigation schemes.

In 2004, the harvested irrigated crop area covered around 76.8 million ha, of which 31 percent wheat, 29 percent rice, 2 percent maize, 7 percent oil palm, 6 percent vegetables and fruits and 5 percent sugarcane (Table 4 and Figure 5). In 1993, the total harvested area was an estimated 66.1 million ha.

Status and evolution of drainage systems

In 1991, drainage works had been undertaken on about 5.8 million ha, which was 12 percent of the irrigated area. Investment in drainage has been widely neglected and, where such investment has been made, poor maintenance has caused many drainage systems to become silted up. On the eastern Ganges plain, investment in surface drainage would probably have a larger productive impact, and at a lower cost, than investment in surface irrigation. In 2010, only some irrigation systems, predominantly of south and western India, have well laid out drainage systems.

WATER MANAGEMENT, POLICIES AND LEGISLATION RELATED TO WATER USE IN AGRICULTURE

Institutions

Under the Indian Constitution, the states are responsible for water. Thus the federal states are primarily responsible for the planning, implementation, funding and management of water resources development. The responsibility in each state is borne by the Irrigation and Water Supply Department. The Inter-State Water Disputes Act of 1956 provides a framework for the resolution of possible conflicts.

At central level, which is responsible for water management in the union territories and in charge of developing guidelines and policy for all the states, three main institutions are involved in water resources management:

- The Ministry of Water Resources (MWR) is responsible for laying down policy guidelines and programmes for the development and regulation of the country's water resources. The ministry's technical arm, the Central Water Commission (CWC), provides general infrastructural, technical and research support for water resources development at state level. The CWC is also responsible for the assessment of water resources.
- The Planning Commission is responsible for the allocation of financial resources required for various programmes and schemes of water resources development to the states as well as to the MWR. It is also actively involved in policy formulation related to water resources development at the national level.
- The Ministry of Agriculture promotes irrigated agriculture through its Department of Agriculture and Cooperation.

Further, the Indian National Committee of Irrigation and Drainage (INCID) coordinates with the International Commission on Irrigation and Drainage (ICID) and promotes research in the relevant areas. The Central Pollution Control Board (CPCB) is in charge of water quality monitoring, and the preparation and implementation of action plans to solve pollution problems.

In 1996, the Central Groundwater Authority was established to regulate and control groundwater development to preserve and protect the resource.

Water management

Water resources planning and management should be seen in a context of food grain availability. From the mid-1960s onwards, food grain production increased in the 1950s and 1960s as a result of increases in the cultivated area, expansion in irrigated area and the use of high-yielding varieties (HYVs). Irrigation also helped reduce inter-annual fluctuations in agricultural output and India's vulnerability to drought. One of the goals of Indian policy is to find ways to maintain the level of food grain availability per inhabitant in a context of population increase. Total water demand is expected to equal water availability by 2025, but industrial and municipal water demand are expected to rise drastically at the expense of the agricultural sector, which will have to produce more with less water.

The centrally sponsored Command Area Development (CAD) Programme was launched in 1974-1975. The main objectives of the programme are to improve use of the area equipped for irrigation and optimize agricultural production and productivity from irrigated agriculture. The Programme involves the implementation of on-farm development works such as construction of field channels and field drains, reclamation of waterlogged areas, renovation and rehabilitation of minor irrigation tanks, correction of irrigation water distribution system deficiencies.

The programme also involves 'software' activities such as adaptive trials, demonstrations, training of farmers, evaluation studies, etc. One component of the programme is *Warabandi*, which is a rotation system for the distribution of irrigation water to ensure equitable and timely supply of water to all farm holdings in the command. An amount of Rs 35 280 million has been released to the states as central assistance under the programme from inception until the end of March 2008. Since the programme's inception, and up to the end of March 2007, 18.07 million ha had been covered. The CAD Programme was restructured in April 2004, the and renamed as the 'Command Area Development and Water Management (CADWM)' Programme.

The main systems of irrigation water management (distribution) schemes practised are:

- The *warabandi* system in semi-arid and arid northwest India, where irrigation water is strictly rationed in proportion to farm area and supplied on a predetermined rotational schedule. The distribution system is equipped with field channels and watercourses. Primarily designed to adapt to shortage in water supplies, farmers decide on crops according to the expected water supply.
- The *shejpali* system of western and parts of central and southern India, where farmers obtain official sanction for proposed cropping patterns and are then entitled to irrigation supplies according to crop needs. The distribution system is equipped with field channels and watercourses. These systems were designed when irrigation water was plentiful relative to demand.
- The localization system, in parts of southern India, focusses on locational control of cropping patterns. Low-lying areas are zoned for 'wet' crops (primarily rice and sugarcane), while higher areas are limited to 'irrigated dry' (ID) crops with restricted water supplies. The distribution system is equipped with watercourses and field channels. Such systems break down as head-end farmers in ID zones take up cultivation of high water requiring crops and draw more water than their allowed allocation quantity.
- The traditional field-to-field irrigation system is used mainly for rice in some areas of eastern India and some parts of south India. Continuous irrigation flows are provided, passing from field-to-field, generally without watercourses or field channels. Operating rules have often evolved and been agreed based on local tradition, and where water is abundant, yields can be good. However, crop choice and cropping patterns are limited.

A broad distinction can be made between supply-based systems (such as *warabandi*) that distribute water according to predetermined procedures and require farmers to respond accordingly for cropping patterns and areas, and demand-based systems (such as *shejpali*) that attempt to meet crop–water needs. In supply-based systems, the role of the irrigation department tends to be simpler than under demand-based systems, which require that the department responds to the changing needs of farmers with more complex and flexible infrastructure and more intensive management. The average overall water-use efficiency in canal irrigation systems is an estimated 38-40 percent.

The National Water Policy 2002 emphasises a participatory approach for water resources management. It has been recognized that participation of beneficiaries will help optimize the upkeep of the irrigation system and promote the efficient use of irrigation water. The participation of farmers in irrigation management is formulated based on the creation of water user associations (WUAs), which aim to:

1. promote and secure distribution of water among users;
2. ensure adequate maintenance of the irrigation systems;
3. improve efficiency and economic use of water;
4. optimize agricultural production;
5. protect the environment; and

6. ensure ecological balance by involving the farmers and inculcating a sense of ownership of the irrigation systems in accordance with the water budget and operational plan.

The WUAs are formed and work guided by the executive instructions and guidelines laid down by each state government. There is no central legislation or legal instrument in this regard. However, Andhra Pradesh is the only state that has passed legislation exclusively covering farmer participation in the management of irrigation systems. A total of 55 500 WUAs were constituted in India covering 10.23 million ha.

The National Groundwater Recharge Master Plan (NGRMP) provides a nationwide assessment of the groundwater recharge potential and outlines the guiding principles for an artificial groundwater recharge programme. The plan estimates that by using dedicated recharge structures in rural areas and rooftop water harvesting structures in urban areas a total of 36 km^3 can be added to groundwater recharge annually. The master plan follows two criteria for identifying recharge: availability of surplus water and availability of storage space in aquifers. Investments in the programme would, therefore, be driven by the potential available for groundwater recharge, and not by the need for recharge. Thus, the three states of Andhra Pradesh, Rajasthan, and Tamil Nadu, which together account for over half of India's threatened groundwater blocks, receive only 21 percent of funds, whereas the states of the Ganges-Brahmaputra basin, which face no groundwater over development problems, receive 43 percent of the funds. If implemented successfully, this recharge programme will be able to add a significant quantity of water to India's groundwater storage, but it will not provide much help in the areas that are most in need of help.

Finances

Currently, there is no uniform set of principles to fix the water rates. The water charges vary from state-to-state, project-to-project and crop-to-crop. The rates vary widely for the same crop in the same state depending on irrigation season, type of system, etc.

Water rates, being abysmally low, do not generate sufficient funds for the proper maintenance of irrigation systems, leading to poor quality of service. The state governments need to evolve a policy for periodical rationalization and revision of water rates, so that the revenue generated by the irrigation sector is able to meet the cost of O&M. However, in view of unreliable and poor quality of services, farmers are reluctant to pay increased water charges. They may not be averse to paying increased water charges if the quality of services is first improved.

It is imperative that the tariff structure is reviewed, and revised with simultaneous improvement in the quality of services provided, to restore efficiencies. Rationalization of water rates will also act as a deterrent to excessive and wasteful use of water. Shifting towards fixing the water rates based volume is desirable. This will encourage farmers to avoid over-irrigation and wasteful use of water, thereby increasing water-use efficiencies. A uniform formula of water pricing for the entire country would have no practical value. A recommendation may be considered of setting up an independent State Regulatory Authority to rationalize water rates in each state.

Policies and legislation

India adopted a National Water Policy in 1987, which was revised in 2002, for the planning and development of water resources to be governed at the national level. It emphasizes the need for river basin based planning of water use. Water allocation priority has been given to drinking water, followed by irrigation, hydropower, navigation and industrial or other uses. As water resources development is a state responsibility, all the states are required to develop their state water policy within the framework of the national water policy and, accordingly, set up a master plan for water resources development.

ENVIRONMENT AND HEALTH

Water quality is a major issue in India. Although in their upper reaches most rivers are of good quality, the importance of water use for cities, agriculture and industries, and the lack of wastewater treatment plants in the middle and lower reaches of most rivers cause a major degradation of surface water quality. Groundwater is also affected by municipal, industrial and agricultural pollutants. The over exploitation of groundwater can also lead to seawater intrusion. For example, there is an inland advance of the saline-freshwater interface in the Chingelput district of Tamil Nadu, where a well field along the Korttalaiyar River supplies water to the city of Madras.

In 1992, the Central Pollution Control Board completed water quality studies in all major river basins. The pollution control action plan of the Ganges River basin was formulated in 1984 and has been enforced by the Ganges Project Directorate, under the Central Ganges Authority, to oversee pollution control and the consequent cleaning of the Ganges River. The water quality in the middle stretch of the Ganges River, which had deteriorated to class C and D (the worst class is E, the best A), was restored to class B in 1990 after the implementation of the action plan. Similar programmes for other rivers have been developed, as well as a national river action plan to clean the heavily polluted stretches of the major rivers.

According to the National Commission on Floods, the area subject to flooding is an estimated 40 million ha (about 12 percent of the area of the country). About 80 percent of this area, or 32 million ha, could be provided with reasonable protection. Bihar is the worst flood hit state. Hardly a year passes without severe flood damages. With the onset of the monsoon, rivers come down from the Himalayan hills in Nepal with enormous force, leading the following rivers the Ghagra, Kamla, Kosi, Bagmati, Gandak, Ganges, Falgu, Karmnasa, Mahanadi to rise above the danger level. This results in severe floods in North Bihar.The Kosi River, popularly known as “the sorrow of Bihar”, has not yet matured enough to settle on a course, and has changed its course 15-16 times, the last time as recently as August 2008. About 2.8 million people were said to have been marooned by these floods in Bihar.

The total area subject to waterlogging was an estimated 8.5 million ha in 1985, including both rainfed and irrigated areas. This is thought to be a substantial underestimate as precise data are lacking. It is estimated that about 24 percent irrigated command areas of major and medium irrigation projects is subject to waterlogging. Measures to counter waterlogging and salinity are being taken by constructing field channels and drains, and by encouraging the combined use of surface water and groundwater. Furthermore, it is estimated that out of the total irrigated area about 3.3 million ha are affected by salinity.

Water-borne diseases have continued to increase over the years in spite of government efforts to combat them. States such as Punjab, Haryana, Andhra Pradesh and Uttar Pradesh are endemic for malaria as a result of the high water table, waterlogging and seepage in the canal catchment area. There are also numerous cases of filariasis. In 1998 the population affected by water-related diseases was 44 million inhabitants.

Climate change may alter the distribution and quality of India’s water resources. Some of the impacts include occurrence of more intense rains, changed spatial and temporal distribution of rainfall, higher runoff generation, low groundwater recharge, melting of glaciers, changes in evaporative demands and water use patterns in agricultural, domestic and industrial sectors, etc. These impacts lead to severe influences on the agricultural production and food security, ecology, biodiversity, river flows, floods, and droughts, water security, human and animal health and sea level rise.

PROSPECTS FOR AGRICULTURAL WATER MANAGEMENT

Water resource availability is replete with severe uncertainties. Frequent severe droughts and floods are not uncommon. There is a need to produce as much as 325-350 million tonnes of food grains by 2025 to meet the food, feed, fodder and fibre requirements of India. To meet this estimate of food grain requirement it is assumed that the overall irrigation efficiencies will be 50 percent for surface water systems and 72 percent for groundwater systems, compared to the present level of 35-40 percent, and that the national average food grain production yields are expected to increase to 3.5 tonnes/ha for irrigated areas and 1.25 tonnes/ha for rainfed areas, compared to the present levels of 2 tonnes/ha in irrigated areas and 1 tonne/ha in rainfed areas. In the wake of the development of large-scale irrigation facilities, there were several serious problems related to the degradation of soil, water, and environment, which threatened the sustainability of agricultural production. These include:

- land availability for agriculture is extremely limited;
- a total of 8.53 million ha is subject to waterlogging;
- land degradation of over 22.5 million ha is caused by floods, water and wind erosion;
- the per capita availability of water resource is expected to reduce to 1 335 m^3/year by 2025;
- no irrigation development has taken place in the Brahmaputra basin, which has 60 percent of India's water resources;
- agriculture in India will face stiff competition for water from other sectors. By 2025, agricultural water withdrawal is expected to fall to 70 percent of total withdrawal, against 90 percent at present;
- irrigation tanks have been neglected and most have become non-operational; and
- continued extensive pollution of water bodies, both from point and non-point sources, has deteriorated the quality of available water resources, further depleting usable water

The important issues that need to be addressed immediately, to overcome these constraints, and to achieve sustainable development and use of water resources to ensure the targeted food grain production of 325-350 million tonnes by 2025 the include:

- considering precipitation as the primary renewable water resource;
- undertaking effective steps for the speedy completion of ongoing major and medium irrigation projects where large investments have already been made without appreciable physical achievement. Rehabilitation and modernization of old irrigation works is of utmost priority;
- reorienting irrigated agriculture to produce more with less water;
- providing incentives to farmers that adopt water-saving devices and scientific irrigation scheduling;
- combatting waterlogging and salinity build up in irrigation command areas;
- combatting unsustainable use of groundwater;
- inducing scientific management of water resources in drought prone areas;
- directing all efforts towards ensuring access to safe drinking water for all;
- pricing irrigation water in a way that will cover at least the O&M charges of providing the service. The water rates shall be linked directly to the quality of service provided;
- increasing participatory irrigation management and transfer of the management of water distribution system to stakeholders, spreading water use literacy among stakeholders through training programmes, and providing water at cheaper bulk rates to WUAs;

- ensuring environmental protection of water resources by meeting environmental flow requirements, environmental management of river systems, and prevention of pollution to groundwater bodies and conservation of wetlands.

To intensify research and development (R&D) efforts to seek ways to improve water-use efficiency, both location specific field studies and analytical studies should be implemented to develop systematic decision support systems for planning and implementing real time operations in the irrigation systems. These measures would allow growing multiple crops under limited water supply, using modern tools such as medium range weather forecasts, and modern irrigation methods.

Efficient water management in agriculture could fulfil the future food needs of India because of several comparative advantages. The most common strengths and opportunities for increasing food grain production, through improved water management include:

- high average annual rainfall as compared to many other countries;
- irrigation infrastructure is the largest in the world;
- total cropped area is the second largest in the world;
- widely varied climatic zones –from temperate regions suitable for horticultural crops, flowers, to tropical regions suitable for cereals, oilseeds and pulses, with ample sunshine for over 11 months of the year;
- vast alluvial tracts of the entire Gangetic plains, the fertile deltaic regions of major rivers such as the Mahanadi, Godavari, Krishna, and Kaveri, which are endowed with rich water resources, possess excellent potential for food production;
- India has the world's third largest fertilizer industry;
- the large National Agricultural Research System (NARS) comprises 87 national institutes and research centres, 81 all-India coordinated research projects and 29 agricultural universities; and
- there is ample scope for realizing the full yield potentials for most crops.

Uncommon opportunities, which are high technology innovations that are likely to be developed in the future are:

- membrane technology for wastewater treatment and desalinization at low cost, thus increasing water availability to agriculture;
- biotechnology: low water requiring crops, high yielding plant varieties that are most environmental friendly, plants that are salt tolerant or drought tolerant, plants with pest resistance (reduces pesticide pollution), hyper toxin accumulating plants to remove soil toxins;
- microbial technologies for wastewater treatment for agricultural reuse;
- increase in yields of rainfed agriculture; and
- separating heavy metals and other toxins from soil and water.

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