16 Water

Gouranga Kar

Abstract

Water forms the backbone for all future endeavors to achieve food security for ever-increasing population of our country. In the present context, upscaling agricultural economic growth to more than 4% annually is the main challenge. Taking water technologies for better water management from lab to land is a formidable task to be addressed. Modernization/automation of irrigation systems, precision irrigation, land reforms, corporate farming, cooperative farming, water and energy pricing, crop insurance, institutional mechanism for better governance, and water rights are some of the key issues for better water management in agriculture. The projected food requirement demands a pronounced role for research, development, and training in the water and agriculture sector. It is evident that the water availability for agriculture is declining, and to enhance agricultural production, more water is needed. Therefore, concerted and holistic efforts are required in increasing the overall water use efficiency at system level which would be achieved through various measures like timely execution of projects, minimizing the losses, better operational efficiency through stakeholders' participation, implementation of on-farm water management technologies, conjunctive use of water, and changes in irrigation policy. The need of the day is to economize water in agriculture, bring more area under irrigation, and increase the yield per unit area and unit quantum of water through multiple use of water, conjunctive use, recycling of poor quality/waste water, pressurized irrigation system, crop diversification, and other water-saving agricultural methods.

G. Kar (✉)
Central Research Institute on Jute and Allied Fibre, Barrackpore, West Bengal, India

P. K. Ghosh et al. (eds.), *Trajectory of 75 years of Indian Agriculture after Independence*, https://doi.org/10.1007/978-981-19-7997-2_16

Keywords

Water resources · Agricultural water management · Irrigation use efficiency · Water productivity

16.1 Water Resource Scenario of India

The main water resource of India consists of the precipitation on the Indian territory which is estimated to be around 4000 km^3/year and transboundary flows received in rivers and aquifers from the upper riparian countries which are around 500 km^3. Out of the total precipitation including snowfall, the availability from surface water and replenishable groundwater is estimated as 1869 km^3. Due to various constraints of topography, uneven distribution of resource over space and time, it has been estimated that only about 1123 km^3 including 690 km^3 from surface water and 433 km^3 from groundwater resources can be put to beneficial use. The water resources of the country at a glance are given in Table 16.1. Water resources of major river basins of the country are given in Table 16.2. Indian precipitation has high spatial and temporal variability. Precipitation over a large part of India is concentrated in the monsoon season during June to September/October. Precipitation varies from 100 mm in the western parts of Rajasthan to over 11,000 mm at Cherrapunji in Meghalaya. Water resources of major river basins of the country are given in Table 16.2.

The spectacular growth in food production in India (from merely 50.8 million tons in 1950–1951 to an estimated production of more than 300 million tons in 2021–2022) is mainly attributed to three major factors, namely, development of high-yielding varieties, expansion in irrigated area, and fertilizer use. Though agriculture sector is the largest consumer of water (82.8%), the requirement of water from other sectors like domestic and industrial needs is increasing due to escalating population, urbanization, and industrialization (Table 16.3).

The Ministry of Water Resources (MoWR) has projected that in 2025 the total demand of water will be 1093 billion cubic meter (BCM), the bulk of which

Table 16.1 Water resources of India

Estimated annual precipitation (including snowfall)	4000 km^3
Runoff received from upper riparian countries	500 km^3
Average annual natural flow in rivers and aquifers	1869 km^3
Estimated utilizable water	1123 km^3
(a) Surface	690 km^3
(b) Ground	433 km^3
Water demand utilization (for year 2000)	634 km^3
(a) Domestic	42 km^3
(b) Irrigation	541 km^3
(c) Industry, energy, and others	51 km^3

Source: Water Resources at a Glance. Central Water Commission (2021), GoI

Table 16.2 Water resources of major river basins of the country

S. no.	River basin	Catchment area (km^2)	Average water resource potential (BCM)	Utilizable surface water resources (BCM)
1	Indus (up to border)	317,708	45.53	46
2	(a) Ganga	838,803	509.52	250
	(b) Brahmaputra	193,252	527.28	24
	(c) Barak and others	86,335	86.67	–
3	Godavari	312,150	117.74	76.3
4	Krishna	259,439	89.04	58
5	Cauvery	85,167	27.67	19
6	Subarnarekha	26,804	15.05	6.8
7	Brahmani and Baitami	53,902	35.65	18.3
8	Mahanadi	144,905	73	50
9	Pennar	54,905	11.02	6.9
10	Mahi	39,566	14.96	3.1
11	Sabarmati	31,901	12.96	1.9
12	Narmada	96,659.79	58.21	34.5
13	Tapi	65,805.80	26.24	14.5
14	West-flowing rivers from Tapi to Tadri	58,360	118.35	11.9
15	West-flowing rivers from Tadri to Kannyakumari	54,231	119.06	24.3
16	East-flowing rivers between Mahanadi and Pennar	82,073	26.41	13.1
17	East-flowing rivers between Pennar and Kanyakumari	101,657	26.74	16.5
18	West-flowing rivers of Kutch and Saurashtra including Luni	192,112	26.93	15
19	Area of inland drainage in Rajasthan	144,835.90	Negi.	N.A
20	Minor river draining into Myanmar (Burma) and Bangladesh	31,382	31.17	N.A.
	Total	3,271,953	1999.2	690.1

Source: Water Resources at a Glance. Central Water Commission (2021), GoI

(910 BCM) will be consumed by irrigation and the country will face the stiff competition for water from different sectors (Table 16.4). The National Commission on Integrated Water Resources (NCIWRD) projected much lower water demand of 784–843 BCM under different scenarios than MoWR. Further, the average consumption per person per year for all users is around 680 m^3, but it is projected to increase. There is continuous decline in per capita water resources of the country from 5176 m^3 in 1951 to 4732 m^3 in 1955, 2209 m^3 in 1991, 1820 m^3 in 2001, and

Table 16.3 Water requirement or demand estimation by uses (in BCM) projections as per standing subcommittee of MoWR, RD, and GR

Sector	2025	2050
Irrigation	910	1072
Domestic	73	102
Industrial	23	63
Energy	15	130
Other	72	80
Total	1093	1447

Source: Standing Subcommittee of MoWR, RD, and GR Report-Basin Planning Directorate, CWC, XI Plan Document; Report of the Standing Subcommittee on "Assessment of Availability and Requirement of Water for Diverse Uses 2000"

Table 16.4 Sector-wise projected demand of water in 2025 (billion cubic meter)

Sector	Ministry of water resources	National Commission for Integrated Water Resources Development (NCIWRD)	
		Low	High
Irrigation	910	561	611
Drinking water	73	55	62
Industry	23	67	67
Energy	15	31	33
Other	72	70	70
Total	1093	784	843

Source: Water Resources at a Glance. Central Water Commission (2021)

Table 16.5 Categorization of river basins by water stress

Water availability (m^3/year/capita)	Category
≥1700 both in 2025 and 2050	Safe
≥1700 both in 2025 but <1700 in 2050	Moderately stressed
<1700 both in 2025 and 2050	Critically stressed
<1700 in 2025 and <1000 in 2050	Moderately scarce
<1000 in 2025 and <1000 in 2050	Critically scarce

Source: Water Resources Sector Report, NITI, DMEO, NITI Aayog 2021, GoI

1703.6 m^3 in 2005. The per capita water availability has been reported to be 1656 m^3 in 2007 implying that the entire country is now classified as "water-stressed" (Table 16.5). Indian population is expected to rise to around 1640 million by 2050. As a result, by 2050, the per capita water availability will further decline to 1140 m^3/year. For adequate living standards as in western and industrialized countries, a renewable water supply of at least 2000 m^3 per person per year is necessary (Postel 1992). A country will be water-stressed if water availability is only 1000–2000 m^3 per person per year, while the country is called "water-scarce" if the value comes below 500 m^3 per person per year (Bouwer 2000). With the decline in per capita water availability to 1140 m^3/person/year by 2050, the country will enter into the "water-stressed" category (Kumar and Kar 2013).

16.2 Plan-Wise Gross and Net Irrigated Area

An overlook of different 5-year plan (FYPs) depicts that the net sown area in first FYP was 125.95 Mha which has increased to 139.6 Mha in fourth FYP and is almost constant thereafter (Table 16.6). There is a consistent growth (0.58% per year) in gross sown area from 140 Mha in first FYP to 189.84 Mha in tenth FYP. The increase in gross sown area was a result of improvement in cropping intensity from 111.17% in first FYP to 136.05% in tenth FYP. The major reason for increase in cropping intensity was due to assured supply of irrigation water through different irrigation projects. This is reflected through significant increment in the net as well gross irrigated area of the country with the growth of 2.08% and 2.52% per annum, respectively, during 1950–2007. Over different FYPs, increase in net irrigated area and gross irrigated area led to higher share in gross and net sown areas. Reports indicate that around 42% of gross as well as net sown area was irrigated. Cropping intensity, irrigation intensity, share of net, and gross irrigated area witnessed increasing trend in all regions of the country over different FYPs reflecting an improvement in status of agriculture. State-wise irrigation potential created in major, medium, and minor irrigation is depicted in Table 16.7.

16.3 Water Productivity

Water productivity (WP, expressed in kg of dry matter per m^3 of water) can be defined in different ways (Molden et al. 2001). The numerator may refer to dry matter (DM), e.g., total DM or yield DM. Among different states, crop water productivity varies from 1.01 kg/m^3, the highest being in Punjab to 0.21 kg/m^3, the lowest in Odisha (Table 16.8). These differences are mainly due to varying cropping and land-use patterns, yield levels, and consumptive water use (CWU). Punjab, Haryana, and Uttar Pradesh (UP) in the Indo-Gangetic Basin (IGB) have the highest water productivity. Although irrigation contributes a major part of CWU in AP and TN, its contribution is low in West Bengal and Kerala. Maharashtra, Madhya Pradesh (MP), Karnataka, and Gujarat, with a mixture of cropping patterns (more than 50% of the area under maize and other coarse cereals and pulses), have lower WP. In Maharashtra and Karnataka, irrigation covers only 15 and 23% of area, respectively, and contributes 17 and 28% of the CWU. Irrigation in MP and Gujarat covers 29% of the grain area but contributes 52 and 41% of the CWU. Orissa, Chhattisgarh, and Jharkhand have the lowest water productivities and share 12.8% of the total CWU but contribute only 6.3% of the grain production. Rainfed rice dominates cropping patterns in these states.

Table 16.6 Details of plan-wise position of irrigation potential created and utilized (in Mha)

Plan		Potential created					Potential utilized				
		Major and medium	Minor			Total	Major and medium	Minor			Total
			S.W.	G.W.	Total			S.W.	G.W.	Total	
Up to 1951 (pre-plan)	Cumulative	9.7	6.4	6.5	12.9	22.6	9.7	6.4	6.5	12.9	22.6
I plan (1951–1956)	During	2.5	0.03	1.13	1.16	3.66	1.28	0.03	1.13	1.16	2.44
	Cumulative	12.2	6.43	7.63	14.06	26.26	10.98	6.43	7.63	14.06	25.04
II plan (1956–1961)	During	2.13	0.02	0.67	0.69	2.82	2.07	0.02	0.67	0.69	2.76
	Cumulative	14.33	6.45	8.3	14.75	29.08	13.05	6.45	8.3	14.75	27.8
III plan (1961–1966)	During	2.24	0.03	2.22	2.25	4.49	2.12	3.03	2.22	2.25	4.37
	Cumulative	16.57	6.48	10.52	17	33.57	15.17	6.48	10.52	17	32.17
Annual plans (1966–1969)	During	1.53	0.02	1.98	2	3.53	1.58	0.02	1.98	2	3.58
	Cumulative	18.1	6.5	12.5	19	37.1	16.75	6.5	12.5	19	35.75
IV plan (1969–1974)	During	2.6	0.5	4	4.5	7.1	1.64	0.5	4	4.5	6.14
	Cumulative	20.7	7	16.5	23.5	44.2	18.39	7	16.5	23.5	41.89
V plan (1974–1978)	During	4.02	0.5	3.3	3.8	7.82	2.7	0.5	3.3	3.8	6.5
	Cumulative	24.72	7.5	19.8	27.3	52.02	21.09	7.5	19.8	27.3	48.39
Annual plans (1978–1980)	During	1.89	0.5	2.2	2.7	4–59	1.48	0.5	2.2	2.7	4.18
	Cumulative	26.61	8	22	30	56.61	22.57	8	22	30	52.57
VI plan (1980–1985)	During	1.09	1.7	5.82	7.52	8.61	0.93	1.01	4.24	5.25	6.18
	Cumulative	27.7	9.7	27.82	37.52	65.22	23.5	9.01	26.24	35.25	58.75
VII plan (1985–1990)	During	2.22	1.29	7.8	9.09	11.31	1.9	0.96	6.91	7.87	9.77
	Cumulative	29.92	10.9	35.62	46.52	76.44	25.4	9.97	33.15	43.12	68.52
Annual plans (1990–1992)	During	0.82	0.47	3.27	3.74	4.56	0.85	0.32	3.1	3.42	4.27
	Cumulative	30.74	11.46	38.89	50.35	81.09	26.25	10.29	36.25	46.54	72.79
VIII plan (1992–1997)	During	2.21	1.05	1.91	2.96	5.17	2.13	0.78	1.45	2.23	4.36
	Cumulative	32.95	12.51	40.8	53.31	86.26	28.38	11.07	37.7	48.77	77.15

IX plan (1997–2002)	During	4.1	1.09	2.5	3.59	7.69	2.57	0.37	0.85	1.22	3.79
	Cumulative	37.05	13.6	43.3	56.9	93.95	30.95	11.44	38.55	49.99	80.94
X plan (2002–2007)	During	4.59	N.A.	N.A.	3.2	7.79	2.73	N.A.	N.A.	1.49	4.22
	Cumulative	41.64	N.A.	N.A.	60.1	101.74	33.68	N.A.	N.A.	51.48	85.16
XI plan (2007–2012)	During	6.34	N.A.	N.A.	5.45	11.79	1.33	N.A.	N.A.	1.43	2.76
	Cumulative	47.97	N.A.	N.A.	65.56	113.53	35.01	N.A.	N.A.	52.91	87.92

S.W. surface water, *G.W.* groundwater.
Source: Water Resources at a Glance. Central Water Commission (2021), GoI

Table 16.7 Irrigation potential created in major, medium, and minor irrigation

	State	UIP of MMI projects	UIP of minor projects	Total UIP	IPC up to XI plan		
					MMI	Minor	Total
S. no.	A	B	C	D	E	F	G = E + F
1.	Andhra Pradesh	5000.00	6260.00	11,260.00	4803.73	3340.550	8144.28
	Telangana						
2.	Arunachal Pradesh	0.00	168.00	168.00	1.20	132.248	133.448
3.	Assam	970.00	1900.00	2870.00	455.96	1016.820	1472.783
4.	Bihar	5223.50	5663.50	10,887.00	3054.46	5924.780	8979.240
5.	Chhattisgarh	1146.93	571.00	1717.93	1269.32	842.295	2111.610
6.	Goa	62.00	54.00	116.00	55.55	25.927	81.478
7.	Gujarat	3000.00	3103.00	6103.00	3679.09	2071.970	5751.060
8.	Haryana	3000.00	1512.00	4512.00	2206.29	1637.670	3843.960
9.	Himachal Pradesh	50.00	303.00	353.00	30.45	186.217	216.667
10.	Jammu Kashmir	250.00	1183.50	1433.50	325.61	745.661	1071.270
11.	Jharkhand	1276.50	1108.00	2384.50	530.71	534.200	1064.905
12.	Karnataka	2500.00	3474.00	5974.00	2965.83	1704.170	4670.00
13.	Kerala	1000.00	1679.00	2679.00	715.69	763.650	1479.340
14.	Madhya Pradesh	4853.07	11,361.00	16,214.07	2506.43	2534.340	5040.772
15.	Maharashtra	4100.00	4852.00	8952.00	4128.71	3185.600	7314.310
16.	Manipur	135.00	469.00	604.00	158.50	120.690	279.190
17.	Meghalaya	20.00	148.00	168.00	–	77.770	77.770
18.	Mizoram	0.00	70.00	70.00	–	51.740	51.740
19.	Nagaland	10.00	75.00	85.00	–	124.510	124.510
20.	Odisha	3600.00	5203.00	8803.00	2147.36	1887.430	4034.790
21.	Punjab	3000.00	2967.00	5967.00	2684.39	3497.710	6182.100
22.	Rajasthan	2750.00	2378.00	5128.00	3167.13	2487.760	5654.890

23.	Sikkim	20.00	50.00	70.00	–	42.740	42.740
24.	Tamil Nadu	1500.00	4032.00	5532.00	1578.27	2331.990	3910.260
25.	Tripura	100.00	181.00	281.00	29.25	161.863	191.113
26.	Uttar Pradesh	12,154.00	17,481.00	29,635.00	9288.09	25,320.130	34,608.220
27.	Uttarakhand	346.00	518.00	864.00	288.98	585.347	874.327
28.	West Bengal	2300.00	4618.00	6918.00	1901.41	4159.680	6061.090
	Union Territories	98.00	46.00	144.00	0.00	61.935	61.935
	All India total	58,465	81,428	139,893	47,972.41	65,557.393	113,529.798

UIP ultimate irrigation potential, *MMI* major and medium irrigation
Source: Water Resources at a Glance. Central Water Commission (2021), GoI

Table 16.8 Variation in water productivity among various Indian states

Sl. no.	States	Total (irrigated + rainfed)				
		Area (Mha)	Production (M Mt)	Yield (t/ha)	CWU (mm)	WP (kg/m^3)
1.	Uttar Pradesh	20.3	43.4	2.13	351	0.61
2.	Madhya Pradesh	11.2	11.1	0.99	278	0.36
3.	West Bengal	6.6	15.2	2.31	447	0.52
4.	Bihar	7.1	12.1	1.71	373	0.46
5.	Rajasthan	11.7	11.7	1.00	220	0.46
6.	Punjab	6.3	25.5	4.07	404	1.01
7.	Haryana	4.3	13.4	3.13	363	0.86
8.	Uttaranchal	1.0	1.7	1.75	298	0.59
9.	J&K	0.9	1.2	1.38	271	0.51
10.	Himachal Pradesh	0.8	1.5	1.78	245	0.73
	India	123	205.4	1.66	344	0.48

Source: Amarasinghe and Sharma (2008)

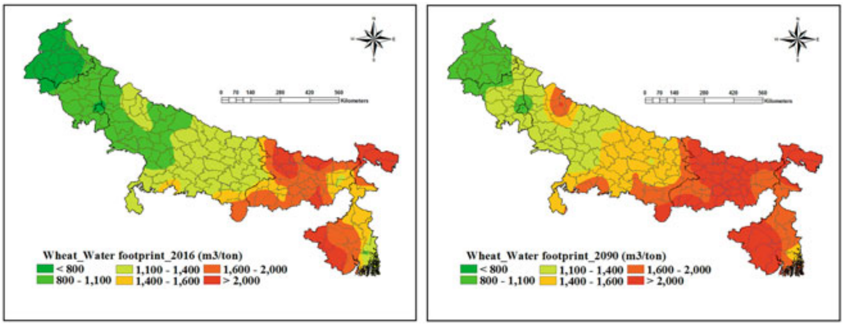

Fig. 16.1 Impact of climate change (RCP 4.5) on water footprints of wheat in Indo-Gangetic region. (Source: Kar et al. 2019)

16.4 Water Footprint

The increased temperature leads to increase in potential evapotranspiration which will result in more water demand for irrigation and ultimately lowering of ground-water table at some places. It has been estimated that the water footprint in wheat under Indo-Gangetic plains is 800–1700 m^3/ton during 2016, which will be around 1100–2000 m^3/ton in 2090 (Fig. 16.1). Decrease in rice yield by 20% due to water shortage has been predicted in India. There will be short-term increased availability of water in the rivers and their tributaries due to melting of glaciers in the Himalayas.

16.5 Suitable Agro-techniques and Water Management Practices to Enhance Water Productivity, Water Use, and Irrigation Efficiency

Strategies to enhance water use efficiency and irrigation efficiency include improved irrigation system management to provide more reliable water supply to farmers through storage and improved operation of reservoirs, better distribution of water with improved control structures, as well as more responsive management. More reliable water supply allows farmers to invest in better on-farm water management such as better land leveling, zero tillage, or pressurized irrigation. Improved management usually requires improved institutions as well as improved technologies. Irrigation efficiency mainly depends on water loss in conveyance system including distribution system and in the field. Loss of water in conveyance system is mainly due to seepage and evaporation. Evaporation loss takes place from the exposed water surface.

Some of the strategies needed to improve water and irrigation use efficiency under rainfed and irrigated agriculture are discussed below:

16.6 Rainwater Harvesting and Management

Rainfed farming supports the livelihood of millions of farmers and households even after realizing the complete irrigation potential. Under the changed climate scenario for effectiveness of rainwater harvesting, emphasis should be given on the following issues:

- Best designs for different rainfall zones and soil types.
- Optimum size of farm pond given the catchment area available under different farming situations.
- How can the capital cost of farm ponds be reduced through convergence of other developmental programs?
- What are the innovations in checking evaporative losses, cost-effective sealants, and water-lifting devices for conveyance?
- What are the best options in terms of crop choices to realize the best returns from stored water?
- How to resolve the issue of sharing water in case of smallholders where catchment and command area belong to different farmers?
- What are the on-site and off-site benefits including environmental payoffs due to rainwater harvesting?
- What are the indigenous techniques of rainwater harvesting which can help farm pond technology become more cost-effective?
- Potential of water harvesting through farm ponds in adaptation and mitigation of climate change.

16.7 Watershed Plus

The current watershed technologies should be further upgraded to diversify and enhance productivity, income, employment, and environmental service under the changed climate scenario. This should include value addition, new variety commodities, horticulture, livestock rearing, and aquaculture with greater emphasis on high and low rainfall regions. Soil and water conservation, efficient inputs, practices, seeds, enterprising by landless, equity, and convergence are the uppermost consideration of technology generation. Market- and agro-industry-driven employment generation, empowerment of local communities, panchayats, and women should be essential ingredients of all inclusive development process.

Convergence of diverse resources of various ministries like MGNREGA, eco-afforestation, million wells, and watershed allocation should generate critical mass and adequate synergies. Private-public-social capital linkage should target internalization of wastelands of private, panchayats, and public departments. Recharging of aquifers in forest and gully lands by runoff from agricultural fields, wasteland, urban areas, metaled roads, flyover, etc. is essential. Contamination of groundwater recharging through shafts, abandoned bore wells, open wells, etc. is a larger technological challenge. This technological demand presumes latest art of modeling contamination, bioremediation, and convergence of nontraditional sectors, departments, agencies, and resources.

16.8 Multiple Use of Water for Realizing Higher Water Productivity

Per capita availability of land, water, and other natural resources is already low and declining further. Multiple use of water through agricultural diversification which has several components like poultry, duckery, fisheries, apiculture, etc. along with diversified crop production or value-added products has proved to be an effective means in mitigating drought and eliminating poverty as it provides high income, regular employment, and balanced and quality food, even with less water. As the agricultural diversification comprises of several farm enterprises in addition to diversified crops, it provides opportunity to farmers to have a "basket of complementary options" for reducing the weather risks involved in single commodity-based agriculture. Water productivity can be improved by five to seven times by integrated planning through multiple use of water. In pond-based integrated farming, culturing of fish can be done in dug-out pond, and vegetables and horticulture can be grown on raised embankment. To enhance the productivity and profitability from harvested water, it has to be utilized for both consumptive and nonconsumptive purposes. Freshwater Indian major fish species (Catla, Rohu, Mrigal) of 3–4 units size at 10,000/ha can be released into the pond during August. The stored water of the pond can be utilized for providing supplemental irrigations to grow *rabi* crops like groundnut, sesamum, mustard, sunflower, and vegetables (cucumber, watermelon, okra, and ridge gourd). The vegetables like tomato, cauliflower, brinjal, and bottle gourd can be grown on the pond bund with the help of harvested water. Short-duration fruit crops like papaya and banana can be grown on the pond bund. After adoption of pond-based farming system, farmers' net returns were found to be higher by three to four times than that of earlier in a study at Balasore, Odisha.

16.9 Crop Diversification with In Situ Rainwater Management

Crop diversification with less water-requiring crops through intercropping/mixed cropping/sequential cropping will be useful for climate change mitigation. By introducing legumes in rice-wheat cropping system, natural resources can be conserved, and soil fertility can be increased. Crop diversification in rainfed rice field was implemented in Odisha on large scale with maize (cv. Navjyot), pigeon pea (cv. UPAS-120), groundnut (cv. Smriti), black gram (cv. T9), and cowpea (cv. Pusa Kamal), and their productivity and water use efficiency were compared with that of sole rice (cv. Vandana). Partial substitution of rice through rice-based intercropping, viz., rice + pigeon pea (4:1), rice + groundnut (4:1), and rice + black gram (4:1), was also practiced with proper weed management. Complete substitutions of rice through legume-based intercropping, viz., groundnut + pigeon pea (4:1), groundnut + green gram (4:1), groundnut + black gram (4:1), groundnut + cowpea (4:1), were also implemented. Study revealed that adoption of crop diversification enhanced water productivity and water use efficiency by two to three times (Kar et al. 2003). Crop diversification (sole cropping/intercropping) with maize, groundnut, black gram, green gram, cowpea, pigeon pea, etc. ensured higher net economic return in rainfed upland rice field even in rainfall deficit years when net return from sole rice was nil or negative.

16.10 Irrigation Scheduling Based on Scientific Approach

Irrigation scheduling is an approach of deciding the quantity and timing of irrigation. It helps the irrigator to decide on when and how much water to apply for minimizing crop yields and efficiency of water use. The basic objective of irrigation scheduling is to make available the correct amount of water for the biological processes of plants at appropriate time by applying water needed to replenish the soil moisture to the desired level. A phenological-based irrigation scheduling in maize was followed as per description in Table 16.9, and water productivities were compared. A comparison of crop water productivity (CWP) between treatments receiving irrigation at flowering and milk ripening and grain filling stages and not receiving irrigations at these stages with the same amount of irrigation (I_4 and I_5) showed that water was more efficiently utilized when irrigation was not skipped at flowering and milk ripening and grain-filling stages (Table 16.10). With the same amount of irrigation (300 mm) in I_4 and I_5, less crop yield was obtained in I_4 because irrigation was skipped at flowering stage of the crop under this treatment. Better water utilization efficiency and higher CWP in treatment I_5 were obtained which might be associated

Table 16.9 Irrigation treatment for field experiments

Stages	Description	Irrigation (mm) treatments					
		I_1	I_2	I_3	I_4	I_5	I_6
Stage 0	Period of germination of seed in the soil	X	X	X	X	X	X
Stage 1	Emergence of coleoptile from the soil and seedling growth up to three leaves unfolded	X	X	X	60	60	60
Stage 2	Stem elongation (1): internodes below fifth, sixth, and seventh leaves have begun to elongate	60	60	60	X	X	X
Stage 3	Stem elongation (2): 8–11 leaves unfolded, stem elongation rapidly, internodes below fifth and sixth leaves fully elongated	X	X	X	60	60	60
Stage 4	Stem elongation (3): 12–15 or more leaves unfolded, stem still elongates, emergence of tassel from the whorl	60	X	60	60	60	60
Stage 5	Flowering (start of pollen shedding, 50% pollen shedding, 50% silking, end of flowering)	X	60	60	X	60	60
Stage 6	Water ripe stage of caryopsis, start of silk drying	X	60	60	60	60	60
Stage 7	Milk ripening stage (milk to solid conversion of endosperm, but whole kernel content is still milky liquid)	X	X	X	60	X	60
Stage 8	Dry ripe stage (kernel is no longer milky, reached physiological maturity)	X	X	X	X	X	X
Stage 9	Ripeness	X	X	X	X	X	X
	Total irrigation during crop growth (mm)	120	180	240	300	300	360

I_1, I_2, I_3, I_4, I_5, and I_6 are irrigation treatments, *X* no irrigations were applied
Source: Kar and Kumar (2015)

with adequate water applied during flowering stage. This result implies that the crop growth stage at which deficit irrigations are imposed on the crop is also a determining factor to achieve higher CWP.

16.11 Pressurized Irrigation System

Conventional flood method of irrigation has low water use efficiency due to loss of water during conveyance and distribution. During the last few decades in Indian agriculture, pressurized irrigation systems are being promoted, which include both drip and sprinkler methods of irrigation. Since these methods need water under pressure, they are classified as pressurized irrigation systems. Pressurized irrigation system is a well-established efficient method for saving water and increasing water

Table 16.10 Water productivity of maize under different irrigation and nitrogen levels (pooled data of 2 years)

Irrigation treatments	GY (kg/ha)	NR (Rs./ha)	IWA (mm)	ER (mm) + SPC (mm)	SCWU (mm)	WP_{CWU} (kg/m^3)	WP_{NR} (Rs./m^3)
I. Irrigation treatments							
I_1	^{E}2129	11,661	120	131	251	^{D}0.849	^{D}4.65
I_2	^{D}2490	14,910	180	127	307	^{D}0.811	^{C}4.86
I_3	^{C}3553	21,977	240	118	358	^{B}0.993	^{A}6.14
I_4	^{B}3785	24,065	300	112	412	^{C}0.918	^{B}5.84
I_5	^{A}4534	25,806	300	105	405	^{A}1.120	^{A}6.37
I_6	^{A}4675	27,075	360	99	459	^{B}1.019	^{B}5.90
II. Nitrogen treatments							
N_1	^{D}2295	13,155	300	114.8	365	^{D}0.629	^{C}3.61
N_2	^{C}2714	20,526	300	116.8	366	^{C}0.742	^{B}5.61
N_3	^{B}3319	19,871	300	115.6	366	^{B}0.908	^{B}5.44
N_4	^{A}4385	29,465	300	114.5	365	^{A}1.203	^{A}8.08
N_5	^{A}4525	25,725	300	115.5	365	^{A}1.239	^{A}7.04

GY grain yield, *NR* net returns, *IWA* irrigation water applied, *ER* effective rainfall, *SPC* soil profile contribution, *SCWU* seasonal crop water productivity, *WPcwu* water productivity in terms of crop water use, WP_{NR} water productivity in terms of net return in rupees, WP_{NR} water productivity in terms of net return

I_1, I_2, I_3, I_4, I_5, and I_6 are irrigation treatments (in this table), and N_1, N_2, N_3, N_4, and N_5 are nitrogen treatments (nitrogen at 30, 60, 90, 120, and 150 kg N/ha)

Table 16.11 Irrigation efficiencies in pressurized irrigation system

Factors	Sprinkler irrigation system	Drip irrigation system	Surface irrigation system
Overall irrigation efficiency (%)	50–60	80–90	30–35
Application efficiency (%)	70–80	90	60–70
Water savings (%)	30	60–70	NA

Source: Kumar and Kar (2013)

use efficiency as compared to the conventional surface method of irrigation (Table 16.11).

16.12 Drip Irrigation

Drip irrigation is an efficient method of micro-irrigation since it applies water directly into the crop root zone to meet the crop water requirement. It permits application of pesticides, fertilizers, and other soluble chemicals through fertigation.

The system applies water at low rate and under pressure to keep the soil moisture within the desired range for plant growth. The system has overall application efficiency around 90% as compared to 25–30% for surface irrigation.

16.13 Sprinkler Irrigation System

The role of the sprinkler irrigation system has been universally acknowledged in achieving high water use efficiency, in improving crop productivity and quality of produce, and in saving of irrigation water and labor costs. The sprinkler irrigation system simulates the water application as that of rainfall. The overall efficiency of sprinkler method is as high as 65% as compared to 25–30% of surface method or irrigation. The system has an advantage for the close growing crops in supplying the required quantity of water. This saves the irrigation water and helps in uniform application of water in the field. To adopt sprinkler system, a farmer has to incur an average cost of Rs. 15,000/hectare. Classification of this irrigation system has been done based on arrangement of spraying water or on the basis of their portability. In India, the rotating head portable systems are most commonly being used by the farmers.

16.14 Improving Water Use Efficiency of Canal Command

Considerable amount of water is lost in canal command through evaporation, seepage, and percolation. In no irrigation project in India, the total losses in the canal distribution system and field have been less than 50% of the head discharge. A review of 90 irrigation projects of the world indicated generally low irrigation efficiencies, with only 20–40% of water diverted from the reservoir being effectively used by the crop, while in India the irrigation efficiency is around 10–20%. The losses of irrigation water are unlined canal distribution system in North India (Table 16.12). In any irrigation project, the total losses in the canal distribution system and field have not been less than 50% of head discharge.

Table 16.12 Losses of irrigation water in unlined canal distribution systems and in the field

	% of supplies at canal head		
Source of loss	Seepage	Evaporation	Total
Main canals and branches	13.6	3.4	17.0
Distributaries (10% of supply at distributor)	6.4	1.6	8.0
Field water courses (27% of supply at outlet head)	16.0	4.0	20.0
Losses from field during application (30% of supply reaching the head)	13.2	3.3	16.5
Total	49.2	12.3	61.5

Source: Kumar and Kar (2013)

Studies conducted in Nagarjuna Sagar Project have revealed that only 40–60% of water released from the reservoir reaches the field and only 20–40% is used by the crops. The main components of water losses in an irrigation system are (a) water losses in storage (10–20%), (b) water losses in conveyance systems (25–40%), (c) water losses in operation (10–30%), and (d) water losses in application (45–70%). To increase the overall irrigation efficiency of 40–50% for a project, improved irrigation and drainage practices should be adopted based on scientific land water management principles. The methods to reduce conveyance losses include lining the bed and sides of the canal, eradication of weeds, and reduction of wastage from escapes and tail ends. The use of plastic films as lining material also has tremendous scope in India.

16.15 Water-Saving Technologies in Canal Command

Irrigated agriculture can be made vibrant by increasing farm productivity in the country through scientific and efficient management of canal systems, and water production can be enhanced through adoption of water-saving technologies. Rotational irrigation is often recommended to irrigate a large area with limited water supply and to ensure better equity among water users. Rotational irrigation is the application of required amount of water to fields at regular intervals. The field may often be without standing water between irrigations, but ideally the soil does not dry enough for moisture stress to develop. A major advantage of rotational irrigation is possibly the more effective use of rainfall. Plant height, tiller number, leaf area index, dry matter production, and grain yield generally decrease as the irrigation interval increases from 4 to 10 days (Table 16.13). The results of experiments conducted by WALAMTARI on rice in Andhra Pradesh under Sriram Sagar Project in sandy loam soils are given in Table 16.14.

16.16 Reuse of Irrigation Water

About 30% of water applied to the field is lost as surface or subsurface flow reaches drains. The water lost through the drains can be stored at suitable sites and pumped back for irrigation by giving due consideration of water quality-related issues.

Table 16.13 Effects of rotational irrigation in IR 20 rice variety

Irrigation interval (days)	Plant height (cm)	Tillers (no. of hill)	LAI	Total dry matter (g/hill)	Yield (t/ha)
4	102	18	6.5	53	7.2
6	97	18	54	47	7.1
8	98	17	5.2	49	6.8
10	92	12	4.2	37	5.6

Source: Reddy and Reddy (2009)

Table 16.14 Savings in water due to rotational irrigation for rice crop

Irrigation interval (days)	Quantity of water applied (mm)	Yield of rice (kg/ha)	Reduction of yield (%)	Water saved (%)
1	1717	6324	–	–
2	1117	6056	4.42	34
3	1027	5924	6.75	40
4	913	5720	10.55	46
5	877	5646	12.00	48

Source: Reddy and Reddy (2009)

16.17 Better Operation Planning

Irrigation system operation is the process of releasing, conveying, and diverting water in the canal systems to ensure predetermined flows at prescribed times for specified duration at all designated points of delivery. The operation plan considers the water available in the reservoir at the beginning of each crop season and spells out the starting date of release of water; the mode of supplies, i.e., whether intermittent and continuous; the detailed schedule of releases; and the closing date of release of water. The operation plan is prepared with active participation and involvement of farmer's representatives so that it may be implemented without any resistance from the farmers. This will reduce wastage and better utilization of irrigation water will be ensured.

16.18 Systematic Canal Operation

The object of systematic canal operation is to ensure equitable distribution of available flows at the heads of all offtakes on a distributory. A schedule of canal operation has to be prepared in advance. For instance, a distributory may be divided into seven reaches each covering one or more offtakes whose total discharge is about a seventh of the designed discharge of the distributory. One-seventh of the total discharge can be saved on each day by closing the offtake in each reach of 24 hours in succession in a week. This water can be made available to tailenders and thus it will help saving water.

16.19 Response to Rainfall in Canal Operations

Canal operations should respond meticulously to rainfall in the command area for efficient use of storage water in the reservoir. The demand of crops for water is met in the wet season by both rainfall in the command area and water stored in the reservoir. Water requirement of crops is worked out using one of the empirical methods suggested by FAO, Rome. Commonly used method is Penman-Monteith method. While assessing the water requirements of crops during the wet season for preparing the operation plan, effective rainfall worked out from the data of average rainfall over a period during the past 20 years is deducted from the water requirements of crops worked out by the Penman-Monteith method or any other empirical method. But in real-time situations, the pattern and amount of rainfall vary influencing the scheduled deliveries. When rainfall is in excess, the scheduled irrigations are skipped, and when rainfall is deficient, unscheduled deliveries have to be made. This will ensure maximum utilization of rainfall as well as protecting the crops from water stress or from excess water. Irrigation deliveries are based mainly on the status of water balance in the cropped fields. The water balance in paddy fields is on the basis of ponding depth, while for light-irrigated crops, it is on the basis of water storage in the root zone. The allowable depletion of soil water storage is limited by readily available soil moisture capacity. Response to rainfall for paddy depends on adopted ponding depth, while for light-irrigated crops, response is related to the depletion level of readily available soil water from the root zone. The mode of irrigation supplies differ during various stages of crop growth and development, as water requirements of crops vary at vegetative and reproductive stages.

16.20 Precision Land Leveling

Declining irrigation water availability, sustainable crop production to meet increasing food demand necessitates adoption of advanced technologies for better water management. Land leveling at farmers' field enables efficient water utilization of scarce water resources through elimination of unnecessary depression and elevated contours. Laser leveling is a laser-guided precision leveling technique used to achieve very fine leveled land with desired grade on agriculture field. It is becoming popular in almost entire state of Punjab. Precision land leveling must be treated as a promising technology for improving crop yields, enhancing input use efficiency, and ensuring long-term sustainability of the resources based on intensively cultivated areas. Keeping in view the benefits of laser leveling, a study was conducted to evaluate the performance laser leveler at farmers' field and to estimate the savings in water resources at different level of adoption. Water saving in different crops at different level of laser leveler is presented in Table 16.15.

16.21 Groundwater Recharge

Groundwater played a major role in achieving green revolution and contributes to 60% of the gross irrigated area of the country. Overexploitation of groundwater has reached critical level in Haryana, Punjab, Rajasthan, and Tamil Nadu. The Punjab-Haryana region could lose its production potential in a few decades if current pattern of groundwater extraction and pollution, soil salinization, and rice wheat cropping system persists. Necessary steps must be taken immediately for groundwater

Table 16.15 Water saving in different crops at different level of laser leveler

Crop	Water saved (%)	Water required (cm)	Water saved (cm)	Area (ha)	Water saved (ha-m) at different level of irrigation				
					10	25	50	75	100
Maize	27.1	35	9.5	152,560	1447	3618	7235	10,853	14,470
Wheat	26.0	35	9.1	3,469,520	31,573	78,932	157,863	236,795	315,726
Cotton	27.25	20	5.5	541,060	2949	7372	14,744	22,116	29,488
Paddy	26.33	160	42.1	2,625,204	110,595	276,486	552,973	829,459	1,105,946
Total	26.25	81.3	21.3	6,788,344	146,563	366,408	732,816	1,099,224	1,465,631

Source: Annual Report (2009)

recharge in these areas. Rainwater harvesting has considerable potential for recharging depleted groundwater aquifers meeting irrigation demand. If water cannot be stored above the ground, it should be stored underground via artificial groundwater recharge, considering that 98% of Earth's freshwater resources are stored in underground and there is enough space for more storage.

16.22 Conjunctive Use of Surface Water and Groundwater

Conjunctive use of multiple water resources should be practiced to mitigate the effect of the shortage in canal water supplies subjected to variation in depth round the year, increase the availability of existing water supplies, alleviate the problems of high water table and salinity, and facilitate the utilization of saline groundwaters which, otherwise, cannot be used without appropriate dilution. Strengthening of knowledge based on geology and aquifer characteristics, hydrology of surface, and groundwater facilities is required to develop appropriate conjunctive use system.

16.23 Management of Poor Quality Groundwater

Groundwater in arid regions is largely saline and is sodic in nature under semiarid areas. The use of poor-quality water for irrigation deteriorates the soil health owing to salinity, sodicity, and toxic effects. In addition to reduced productivity, it deteriorates the quality of produce and also limits the choice of cultivable crops. In saline groundwater areas, where canal water availability is limited, conjunctive use of canal water and saline groundwater is recommended. Dilution or mining of available poor-quality water with good water should be done in such proportion that resultant EC is acceptable for the range of crops to be grown in a given area.

Some of the management options to manage the saline groundwater are selection of semi-tolerant crops, salinity-tolerant cultivars, proper selection of crop sequences, avoiding saline water use during initial growth stages, addition of farm yard manure and organic matter, application of additional dose of nitrogen, etc. Some important points to be noted for management of conjunctive use practices are analysis of saline water to evaluate its use potential, selection of crops/varieties, presowing irrigation with good quality water so that germination and seedling emergence are not affected, adequate leaching of salts, change of cropped area, and adoption of improved cultural and nutrient management practices.

Management technology options for use of sodic groundwater include selection of crops, conjunctive use of canal water, river water management and leaching strategies to maintain a high level of soil moisture and low level of salts, exchangeable sodium in the rhizosphere, use of land management practices to increase the uniformity of water distribution, infiltration and salt leaching besides the optimal use of chemical amendments like agricultural grade gypsum and acidic pyrites at proper time, and mode of their application with judicious use of organic materials and chemical fertilizers.

16.24 Mitigating Groundwater Pollution

The choice of appropriate cropping systems and management practices helps in minimizing nitrate leaching besides improving N-use efficiency. Legume intercropping in cereals grown with wider row spacing reduces nitrate leaching. Parallel multiple cropping (a system of growing two dissimilar growth habit crops with minimum competition) of sugarcane and black gram and that of pigeon pea and maize resulted in low NO_3-N content in soil profile as compared to sole cropping.

As a crop management strategy for minimizing NO_3-N leaching, delaying large N applications until the crop can utilize it, avoiding irrigation when large amounts of NO_3-N are present in the root zone and split application, etc. have also been recommended. There is a specific need to create awareness among people about the presence of fluoride in groundwater, its action on body tissues, and available remedial technologies. Various artificial recharge techniques including Aquifer Storage Recovery (ASR) technique may be applied to improve the water quality by dilution. The ASR technique is a viable or cost-effective option for storing large volumes of freshwater. Looking at the success achieved through ASR in many countries, there is a case to plan trial of this technology at suitable locations in the country. Besides this, the concept of mixing two different aquifers/sources of water can also be tried to overcome the fluoride problem (Bajwa et al. 1993).

Investigations of geochemistry are very essential to understand the occurrence and mobilization of arsenic in the aquifer system. Thus, there is urgency for an integrated study on geological, hydrological, and geochemical characterization of the multilevel aquifer system to predict the origin, occurrence, and mobility of arsenic in groundwater. There is a priority to arrive at suitable and economically viable alternatives to maintain sustainable drinking water supply. The traditional system of using surface runoff water can be augmented by system for reducing dependence groundwater extraction.

16.25 Farmers' Participation for Managing Irrigation Water

The effective water management is critically linked with the performance of local-level water institutions. The innovation of Water User Associations (WUA)/Pani Panchayat institution has diverted larger flow of information as well as initiative from government irrigation departments toward it. The transfer of irrigation management responsibility from the government irrigation authority to local body depends on allocative and investment decisions by the farmers' group/organization. There has to be a paradigm shift giving the irrigators (farmers) real decision-making power in managing the irrigation system as a whole system. Watershed management is by nature beyond the work of individuals, and thus collective effort by all farmers concerned is required for successful management. Replication of successful samples and community-led success stories is likely to lead to most sustainable results. The objectives of farmers' groups cannot be realized overnight and it takes time. Therefore, it is of paramount importance to keep it functional and effective for a long time.

It should become a part of the tradition of the village over time, as is the case with the already existing traditional village organizations.

16.26 Water Management in Waterlogged Areas

The saucer-shaped land forms, high rainfall (average 1500 mm) due to southwest monsoon (June–September), poor drainage condition, and slow disposal of accumulated water in the plains to the ocean make the coastal region susceptible to waterlogging and flood-prone, and the area remains submerged for about 5–-6 months (July–November) under water depths varying from 0.75 to 2.0 m. Alternatively, the winter and summer rainfall (November–May) is meager and erratic. As a result, after December, the land becomes dry, and available soil moisture in the land is not sufficient to meet evapotranspiration loss of any crops. Thus, coastal waterlogged areas are subjected to receive both extreme events. In one season, the area is underproductive due to excess water; in other season, agriculture is not possible because of the lack of soil moisture. Due to constant waterlogging of 0.5- to 2.0-m depths, the normal rice fails to grow in seasonal flood0prone areas. Improved deep waterlogging rice cultivars like 'Hangseswari' and 'Saraswati' were introduced with improved sowing methods (line sowing with 20 cm distance, row to row, and fertilizer dose of 20:20:20) in the seasonal waterlogged areas (Kar et al. 2010).These varieties can produce up to 2.8 t/ha grain yield in *kharif* season in deep waterlogged situation if flood commences after second week of August.

The suitable water harvesting structure depending upon the maximum depth of waterlogging was designed and constructed by taking 25–30% of the total field in representative waterlogging areas of Puri District. Waterlogging-tolerant rice varieties were grown surrounding the structure during *kharif* season. The water inside the structure was utilized for fish rearing, and the bund was utilized to grow vegetable short-duration fruit and vegetable crops initially and to grow firewood plants at later stages. The harvest was also utilized to grow high-yielding medium duration rice (cv. 'Lalat,' 'Konark') and vegetable crops during *rabi* season. Through this approach, farm returns enhanced up to about 1.0 lakh/hectare from waterlogged area which remained unproductive earlier. The cropping intensity of farmers was increased between 150 and 250%. Water chestnut and medicinal plant (*Acorus calamus*) were introduced in seasonal flood-prone areas, and package of practices for their cultivation was standardized. From water chestnut and calamus cultivars, Rs. 19,000/ha and Rs. 35,000/ha net returns were obtained, respectively.

16.27 Indigenous Technical Knowledge (ITK) for Water Resource Management

Our agriculture has a lot of inherited sustainable practices passed from one generation to another generation. The present and future generations must be aware of the ancient technologies practiced by our ancestors to build future research strategy.

With the success of Green Revolution, India has progressed in every field of agriculture and allied studies. But due to the indiscriminate use of chemicals, intensive cropping system with intensive input use on a long-term basis has been a major constraint to maintain sustainability. Our agroecosystem is threatened due to irrational use of chemicals in the form of pesticide, fertilizer, and herbicide. Soil health is getting deteriorated, water and air sources are getting polluted. and there is an increasing erosion of plant and animal genetic resources. Therefore, sustainability is the need of the hour.

The indigenous technical knowledge (ITK) provides an insight into the sustainable agriculture, since these innovations have been passed from one generation to another as a family technology. Various ITKs have been followed by our ancestors, but unfortunately these small local systems are dying out. Chadwick et al. (1998) explored ITK of water harvesting and artificial recharge and found that the most important strategy is with the Maldharis. The local people have traditionally managed to safeguard their livelihood through rainwater harvesting. The techniques developed by them harvest sporadic floodwater, which ensures that their drinking needs are fulfilled even during water-scarce years. Their extensive knowledge of water harvesting based on the local ecosystem and of the complex water harvesting system subsequently developed by them is based on their knowledge, culture, and experience. Though the area is flat, some depressions, known locally as tanks or jells, of various sizes exist and act as storage areas for flood water. The water lasts several months before drying up.

The local nomads found that after infiltration of water in the soil, the freshwater gets stored at shallow depths in a layer "floating" above salty groundwater. The dug shallow wells in this zone are called "virda" reaching down as far as the freshwater. Each virda is used until the water begins to get salty at which point the virda is filled with grasses and silt from the next virda and left to replenish. Other methods include the development of a series of tanks sunk parallel with the slope. These progressively fill during the rainy season with each feeding to one larger deeper tank. Similarly, sprinkling of thin slurry from cow dung over drought-affected paddy so as to increase the water retention properties of the soil is also a common practice. In the field of local Aus rice, at an early stage, the use of a hand hoe followed by laddering is undertaken. This process thins out unwanted seedlings and weeds and aids mulching.

16.28 Government Initiative/Policies for Higher Irrigation and Water Use Efficiency

Government has given considerable importance to the development of command area under canals. Earlier during 1950–1951, the canal-irrigated area was 8.3 million ha which is now 17 million ha. Wells and tube wells accounted for 29% total irrigated area in 1951, and they had a share of 64% of the total irrigated area in 2010–2011. It is worth mentioning that the Government of India has taken many initiatives in the past. Between 1991 and 2007, India invested (approx.) ~ USD 4000 million in public canal systems. Yet the canal-irrigated area decreased by 38 lakh hectares during that period, as infrastructure is old, water supply is unreliable, and further there are no incentives.

Similarly, even after 50–90% subsidy for the micro-irrigation, it covers less than 5% of India's cultivated area. The government schemes have succeeded in some states although faltered in others. Electric-powered groundwater exploitation has thus emerged as a unique confluence of physical, policy, and political factors that have trapped many states in a vicious spiral of declining groundwater, deteriorating water quality, stagnant crop productivity, deteriorating power service delivery, and poor financial health of power generation companies. Most state governments provide subsidized or free electricity to farmers which results in overuse of water and declining groundwater tables. It has been reported that Indian farmers use two to four times more water to produce a unit of major food crop than in China or Brazil. Of this maximum, 45% is shared by tube wells followed by canals and wells. In this context, the Indian government has tried to inculcate new policies and schemes to improve agricultural productivity while simultaneously increasing water use efficiency. The Indian government introduces schemes as commendable effort to increase irrigated area. One example is the launching of (approx.) ~ USD 7.5 billion "Pradhan Mantri Krishi Sinchai Yojana (PMKSY)." This scheme provides a sound framework for the expansion and effective water use in irrigation. This scheme can be enhanced by restoring Mahatma Gandhi National Rural Employment Guarantee Act.

16.29 Water Rights and Water Pricing

Water rights: In India, water rights are related with the ownership of land. That essentially means that the landowners have rights to extract water through wells on their lands. Also, they are encouraged to collect rainwater on their land.

Water pricing: Pricing water and water-related services adequately can boost people to invest more in water-related infrastructure and value watershed services rather than wasting them. In most states, there is no payment of water fees or any other charge. Even in many states, electricity is provided free to pump water if water is to be used for irrigation purposes. The distorted water pricing is resulting in overexploitation of the natural resources which may have long-term implication such as salination, thus rendering good agricultural land unfit for growing crops and presence of heavy metals. The state governments avoid withdrawing these provisions as farmers may consider high water pricing as depriving of their entitlement, which could in turn lead to conflict and may also result in increase in food prices.

16.30 Water Resources of North Eastern Hill (NEH) Region

The northeastern region of India comprising eight states, viz., Meghalaya, Nagaland, Sikkim, Tripura, Assam, Manipur, Mizoram, and Arunachal Pradesh, with 39 million population has a total geographical area of 262,180 km^2 (nearly 8% of the total area of India). The per capita availability in Brahmaputra Basin is more than 14,000 m^3 compared to only about 120 m^3 in Kutch area of Gujarat. The total annual water resources of the country have been estimated at 1953 km^3. The utilizable resource has been estimated as 690 km^3 surface and 450 km^3 groundwater equalizing a total of 1140 km^3. The annual demand for irrigation water in India and Northeast region during the year 2020 was 460 and 20 km^3 and for 2025 estimated at 810 and 32 km^3, respectively (Satapathy and Sharma 2006). The average annual precipitation in the country is about 4000 km^3, a part of it goes as runoff, a part of it lost as evapotranspiration, and the remaining goes to recharge groundwater. The NE region has a surface water and groundwater potential of 1487.2 and 25.3 km^3 (Table 16.16), respectively (Borthakur et al. 1989). Out of irrigation potential of 36,810 km^2, only 5120 km^2 or 15.3% of the potential has been exploited in NE region (Satpathy and Sharma, 2006). Out of total irrigated area, 69.8% is in Assam alone. Manipur has 25.5% of the net sown area, compared to 13.8% in Meghalaya. Present cropping intensity of 135% of the region would go up to 200% if full irrigation potential is utilized.

16.31 Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)

Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) was launched during the year 2015–2016, with an aim to enhance physical access of water on farm and expand cultivable area under assured irrigation, improve on-farm water use efficiency, introduce sustainable water conservation practices, etc. PMKSY has various components, viz., Accelerated Irrigation Benefits Programme (AIBP);

Table 16.16 Inland water resource potential in NE states (000 ha) and utilizable groundwater resource for irrigation (m ha m)

State	River length and canals (km)	Reservoirs	Tanks/ ponds	Lakes	Groundwater resource (m ha m)
Arunachal Pradesh	2500	0.38	1.00	2.50	0.1223
Assam	4850	36.04	16.47	83.84	1.8421
Manipur	3360	0.10	5.00	4.00	0.2681
Meghalaya	5600	1.17	1.82	0.21	0.1042
Mizoram	1748	–	1.60	–	–
Nagaland	1600	9.50	4.94	0.21	0.0615
Tripura	1200	4.50	9.60	0.50	0.2135
Total	19,468	51.69	40.44	91.26	

Source: Satapathy and Sharma (2006)

PMKSY-Har Khet Ko Pani (HKKP) including Command Area Development and Water Management (CADWM), Surface-Minor Irrigation (SMI), and Repair, Renovation and Restoration (RRR) of Water Bodies [implemented by DoWR, RD & GR, MoJS]; PMKSY-Per Drop More Crop (PDMC) [implemented by the Department of Agriculture, Cooperation and Farmers' Welfare]; and PMKSY-Watershed Development Component(WDC) [implemented by the Department of Land Resources]. The PMKSY-PDMC focuses on water use efficiency at farm level through precision/ micro-irrigation. Surface Minor Irrigation (SMI) schemes with irrigation potential less than 2000 ha were included under Accelerated Irrigation Benefits Programme (AIBP) for providing central assistance (CA) since 1999–2000 for Special Category States. Subsequently, the Scheme extended to area covering DPAP, tribal, DDP, flood-prone, left-wing extremist, and Kalahandi Balangir Koraput (KBK) region of Odisha. The scheme of SMI is now a part of PMKSY (HKKP).

16.32 Salient Features of the National Water Policy (2012)

The National Water Policy (2012) has been formulated for planning, development, and management of water resources. Some of the salient points regarding National Water Policy (2012) are given below:

- Planning, development, and management of water resources need to be governed by common integrated perspective considering local, regional, state, and national context, having an environmentally sound basis, and keeping in view the human, social, and economic needs.
- Principle of equity and social justice must inform use and allocation of water. Water needs to be managed as a common pool community resource held by the state under public trust doctrine to achieve food security, support livelihood, and ensure equitable and sustainable development for all. Water is essential for sustenance of the ecosystem, and therefore, minimum ecological needs should be given due consideration.
- Safe water for drinking and sanitation should be considered as preemptive needs, followed by high-priority allocation for other basic domestic needs (including needs of animals), achieving food security, and supporting sustenance agriculture and minimum ecosystem needs.
- Available water, after meeting the above needs, should be allocated in a manner to promote its conservation and efficient use. Given the limits on enhancing the availability of utilizable water resources and increased variability in supplies due to climate change, meeting the future needs will depend more on demand management, and hence, this needs to be given priority, especially through (a) evolving an agricultural system which economizes on water use and maximizes value from water and (b) bringing in maximum efficiency the use of water and avoiding wastages.
- Water quality and quantity are interlinked and need to be managed in an integrated manner, consistent with broader environmental management

approaches inter alia including the use of economic incentives and penalties to reduce pollution and wastage.

- The impact of climate change on water resource availability must be factored into water management-related decisions. Water-using activities need to be regulated keeping in mind the local geoclimatic and hydrological situation.
- There is a need to evolve a National Framework Law as an umbrella statement of general principles governing the exercise of legislative and/or executive (or devolved) powers by the center, the states, and the local governing bodies. This should lead the way for essential legislation on water governance in every State of the Union and devolution of necessary authority to the lower tiers of government to deal with the local water situation.
- There is a need for comprehensive legislation for optimum development of interstate rivers and river valleys to facilitate interstate coordination ensuring scientific planning of land and water resources taking basin/subbasin as a unit with unified perspectives of water in all its forms (including precipitation, soil moisture, groundwater, and surface water) and ensuring holistic and balanced development of both catchment and command areas.
- Such legislation needs, inter alia, to deal with and enable the establishment of basin authorities, comprising party states, with appropriate powers to plan, manage, and regulate the utilization of water resource in the basins.
- The center, the states, and the local bodies (governance institutions) must ensure access to a minimum quantity of potable water for essential health and hygiene to all its citizens, available within easy reach of the household.

16.33 Future Irrigation Water Resources

The ultimate irrigation potential is estimated to be 139 Mha. For meeting the future food grain demand of 494 million tons in 2050, it is required to bring 146 Mha under irrigation which is quite high compared to the present gross irrigated area of 89.55 Mha. Thus, it is difficult to achieve the requirement of 146 Mha of irrigated area considering the area that would continue to remain rainfed. Alternatively, it is essential to increase the crop productivity from present 2.3 t/ha to 4 t/ha under irrigated conditions and from less than 1 t/ha to 1.5 t/ha for rainfed area. Most of the irrigation projects are operating at a dismally low efficiency of 35%. Besides, there is an increase in waterlogged and saline areas due to erratic rainfall distribution. With increasing pressure on land and water, immediate action is needed to increase irrigation efficiency to 60% for surface water and 75–80% for groundwater. It has been predicted that with almost no increase in the net sown area in the near future, the cropping intensity needs to be increased from 132% to 145% by 2025 to step up the gross cultivated area from 194 Mha to 210 Mha.

Likewise, about 80 Mha would continue to remain as rainfed, and very less area is expected to switch from rainfed to irrigated due to erratic rain distribution. Management of declining water resources in a sustainable manner for enhancing their productivity needs to be addressed in the agricultural water management research and development of the country. The need of the day is to economize water in agriculture, bring more area under irrigation, and increase the yield per unit area and unit quantum of water through multiple use of water, conjunctive use, recycling of poor quality/waste water, pressurized irrigation system, crop diversification, and other water-saving agricultural methods.

16.34 Conclusions

Water forms the backbone for all the future endeavors to achieve the vision of food security. In the present context, upscaling agricultural economic growth to more than 4% annually is the main challenge. Taking water technologies for better water management from lab to land is a formidable task to be addressed. Modernization/automation of irrigation systems, precision irrigation, land reforms, corporate farming, cooperative farming, water and energy pricing, crop insurance, institutional mechanism for better governance, and water rights are some of the key issues for better water management in agriculture. The projected food requirement demands a pronounced role for research, development, and training in the water and agriculture sector. It is evident that the water availability for agriculture is declining and to enhance agricultural production, more water is needed. Therefore, concerted and holistic efforts are required in increasing the overall water use efficiency at system level which would be achieved through various measures like timely execution of projects, minimizing the losses, better operational efficiency through stakeholders' participation, implementation of on-farm water management technologies, conjunctive use of water, and changes in irrigation policy. Simultaneously, the efforts of research and development institutions are required in the development of water management technologies, suitable database development, economic studies of various irrigation systems, policy guidelines for on-farm water management, and adoption of participatory irrigation management. Serious efforts from developmental agencies as well as research institutes are required to develop a suitable water perspective plan for various regions in the country for its implementation.

References

Amarasinghe UA, Sharma B (2008) Spatial variation of crop water productivity of india and potential for improvements. Draft report prepared for the IWMI-CPWF project 'Strategic Analysis of India's River Linking Project'

Annual Report (2009) All India coordinated research project on water management

Bajwa MS, Singh B, Singh P (1993) Nitrate pollution of groundwater under different systems of land management in the Punjab. In: Proceedings of first agricultural science congress. National Academy of Agricultural Sciences, New Delhi, pp 223–230

Borthakur HP, Bora CK, Phukan U, Bhattacharya BK, Bowmie BC, Khound HP (1989) Agro-climatic regional planning of the eastern himalayan region—profile and strategy. Assam Agricultural University, Jorhat

Bouwer H (2000) Integrated water management: emerging issues and challenges. Agric Water Manag 45:217–228

Chadwick M, Soussan J, Mallick D, Alam S (1998) Understanding indigenous knowledge: its role and potential in water resource management in Bangladesh. LEEDs and BCAS, pp 13–15

Kar G, Kumar A (2015) Effect of phenology based irrigation scheduling and nitrogen on light interception, water productivity and energy balance of maize (*Zea mays* L.). J Indian Soc Soil Sci 63(1):39–52

Kar G, Singh R, Verma HN (2003) Crop diversification in rainfed rice area of eastern India to increase productivity and rainwater use efficiency. Research Bulletin 13/2003. Water Technology Centre for Eastern Region, Bhubaneswar, p 51

Kar G, Sahoo N, Ashwani K (2010) Deep water rice and pond based farming for higher productivity of waterlogged areas. Research Bulletin No 48. Water Technology Centre for Eastern Region, Bhubaneswar, pp 1–32

Kar G, Mohanty S, Anand PSB, Panda DK, Raviraj A, Rank RD, Singh PK (2019) National innovations for climate resilient agriculture, annual report, 2018–19. Indian Institute of Water Management, Bhubaneswar, pp 14–18

Kumar A, Kar G (2013) Sustainable agricultural water management strategies for higher water use efficiency. J Sustainable Planet 4(1):47–60

Molden D, Murray-Rust H, Sakthivadivel R, Makin I (2001) A water productivity framework for understanding and action. Workshop on Water productivity. Wadduwa, Sri Lanka, 12–13 November, 2001

Postel S (1992) Last oasis: facing water scarcity. Worldwatch Institute, Washington DC

Reddy GHS, Reddy TY (2009) Efficient use of irrigation water. Kalyani Publishers, New Delhi

Satapathy KK, Sharma UC (2006) Water and water resources management. In: Sharma UC, Datta M, Samra JS (eds) Soils & their management in North East India. ICAR Research Complex for NEH Region, Umiam

Water Resources at a Glance. Central Water Commission (2021) GoI, Central Water Commission, Sewa Bhawan, R.K. Puram, New Delhi