Water resources of India—an overview

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1. Introduction

Specific physiographic, climatic and hydrologic characteristics along with economic and demographic features of a region determine the development of water resources. These are briefly described in the case of India as a prelude to the systems studies described later. A historical and quantitative perspective of developments is also given briefly. For details reference may be made to Rao (1976), Irrigation Commission Reports (1972), Chaturvedi (1976) and National Commission on Agriculture Reports (1976).

2. Physiographic features

The land mass which forms the subcontinent of India is a large peninsula, covering an area of 328 million hectares (mha), and supporting a population of 658 million (1981). It lies between $8^{\circ} 4'$ and $37^{\circ} 6'$ North latitude and $68^{\circ} 7'$ and $97^{\circ} 25'$ East longitude. With a land frontier of 15,200 km, much of which is bordered by very high mountains and a coastline 5,700 km long, it is the seventh largest country in the world. The location and the characteristics—a large peninsula with high mountains on the North—create a unique hydrologic-climatic environment.

Physiographically, India can be divided into seven divisions and twenty subdivisions (figure 1): (a) the Northern Mountains (b) the Great Plains (c) the Central Highlands (d) the Peninsular Plateau (e) the East Coast Belt (f) the West Coast Belt and (g) the Islands. We shall only confine ourselves to the coterminous subcontinent.

The northern Himalayan mountains stretch in a virtually unbroken chain, 2,500 km in length and 250 to 400 km in width, as a series of more or less parallel, though sometimes converging, ranges from the Indus in the west to the Brahmaputra in the east. In the north, there are three distinct ranges known as the Greater and the Middle Himalayas and the Lower Siwaliks. The average heights of these ranges are 6,000, 4,000 and 1,000 m respectively. They have some of the highest peaks of the world, and large areas above 5,000 m elevation are permanently snowclad. They contribute an annual snow melt of 5 million hectare metres (m ha m). They are geologically very young and, being formed of sedimentary rocks with steep slopes, contribute to high sediment charge to surface runoff. This is mitigated only by the fact that they are heavily covered with forests. As human and livestock populations grow, increasing soil erosion poses a serious problem.

Stretching at their feet and built up from the rivers flowing from the Himalayas, are the great Indo-Gangetic Plains. The alluvium forming the plains was laid down in

Figure 1. India physiographic map. International boundary—, regional boundary---.
(source: Chaturvedi 1976)

successive geological eras and have depths of thousands of metres. The plains, with an area of 652,000 km², account for about 25 % of the total land area of India. The surface of the great plains is at tide level near the sea but is well over 200 m above sea level in the Punjab plains.

Further south, are the Central Highlands, consisting of a compact block of mountains, hills and plateaus intersected by valleys and basins covered by forests, accounting for one-sixth of the total land area.

The triangular peninsula plateau, ranging in elevation from 300 to 900 m constitutes about 35 % of the land. The surface sometimes consists of extensive plains. It is well-drained by a number of rivers flowing from west to east.

Of the two coast belts, the eastern is wider with a width of 100–300 km with a number of river deltas. The western belt is only 10–25 km wide between the Western Ghats and the sea.

The land is served by a number of large rivers. They can be divided into two groups; *viz* the perennial rivers of the Himalayan region which are snow fed, and the peninsular rivers. The maximum monthly discharge variation of the former is of the order of 50:1 while that of the latter is of the order of 1000:1. These can also be classified in three groups in terms of their catchment areas, as discussed later.

India can be divided into 17 river basins as shown in figure 2. The Ganga basin is the

Figure 2. India—: river basins 1) Ganga, 2) Brahmaputra, 3) Barak & others 4) Between Ganga & Mahanadi (east-flow), 5) Mahanadi, 6) Between Mahanadi & Godavari (east-flow), 7) Indus, 8) Luni & others, 9) Sabarmati & Mahi, 10) Narmada, 11) Tapi, 12) Godavari, 13) Krishna, 14) Pennar & others, 15) Cauvery, 16) Below Cauvery (east-flow), 17) Below Tapi (west-flow). International boundary—, river basin boundary--- (source: Chaturvedi 1976)

Table 1. Salient water, land and population statistics

Sl. No.	River basin	Land				Water					
		Catchment area (inside India) m.ha	Culturable area (% of 1) %	Net sown area (% of 2) %	Cropping intensity (% of 4) %	Precipitation cm	Evaporation cm	Annual runoff mhm	Annual ground water recharge mhm	Utilizable	
										Surface runoff (% of 7) %	Utilizable ground water (% of 7) %
		1	2	3	4	5	6	7	8	9	10
1	Ganga	86.15	70.0	76.5	125	116	212	55.01	14.62	33.6	18.9
2	Brahmaputra	18.71	64.9	22.7	118	122	125	42.2	3.97	2.1	4.5
3	Barak and others	7.82	14.3	66.5	124	286	150	17.5	1.60	2.12	3.7
4	Between Ganga and Manahadi (East flow)	8.10	63.0	65.1	114	147	175	4.35	1.63	94.0	16.0
5	Mahanadi	14.16	56.5	70.3	125	146	200	7.07	2.13	93.7	15.0
6	Between Mahanadi and Godavari (East flow)	4.97	54.4	66.7	124	111	200	1.72	0.73	93.5	23.6
7	Indus	32.13	30.0	72.3	133	56	200	7.69	2.90	64.2	14.8
8	Luni and others	32.18	72.8	60.3	105	38	305	1.23	0.80	74.0	48.2
9	Sabarmati and Mahi	5.93	62.8	77.6	111.5	159	320	1.55	0.62	73.35	21.0
10	Narmada	9.88	59.8	76.2	106	121	245	4.01	1.24	73.0	17.8
11	Tapi	6.69	66.0	88.6	104	78	305	1.97	0.61	71.0	20.1
12	Godavari	31.28	60.5	76.5	107	110	235	11.54	3.31	73.8	17.2
13	Krishna	25.90	78.4	76.6	105	81	290	6.28	2.65	83.5	31.5
14	Pennar and others	14.49	65.0	59.5	116	82	230	2.53	1.82	73.3	41.5
15	Cauvery	8.79	66.0	64.5	115	99	225	1.86	1.23	96.4	26.0
16	Below Cauvery East flowing	3.51	75.0	62.8	111	91	270	0.95	0.54	36.9	12.2
17	West flowing below Tapi	11.21	56.0	69.0	119	279	200	2.79	2.01	13.2	5.0
	Total	321.87	59.7	67.7	115.4	124.8	228	188.8	42.41	35.4	13.8

Utilized % of utilizable			People			Unit figures			
Surface	Ground water	Total utilized % of utilizable	Population	% of total population	Density/Km ²	Culturable land/capita	Water/capita	Water/culturable land	% gross sown area irrigated
%	%	%	m	%	persons/km ²	ha	cu.m	cms	%
11	12	13	14	15	16	17	18	19	20
71.0	39.4	59.1	221.19	41.20	256	0.32	3140	116	28.3
70.0	1.1	23.6	17.65	3.28	94	0.69	25700	375	21.3
27.0	11.3	10.0	5.33	0.99	68	0.21	36000	171	13.0
15.18	3.1	13.3	13.70	2.55	169	0.37	4370	117.2	16.8
33.60	2.8	27.1	17.80	3.39	126	0.45	5160	115.1	18.3
54.60	5.0	45.0	9.44	1.76	190	0.29	2600	90.6	35.4
93.40	71.2	90.0	24.63	4.58	77	0.39	4300	110	50.6
41.70	41.8	42.1	21.82	4.25	68	1.08	930	8.64	8.23
50.2	31.5	40.0	10.38	1.96	184.5	0.76	4060	54.5	11.6
9.46	19.8	11.1	10.60	1.97	107	0.56	4950	89	4.48
37.0	40.0	37.4	9.14	1.76	137	0.49	2820	58.4	6.10
38.4	28.2	37.5	35.46	6.69	113	0.29	2600	90.6	13.0
90.5	36.9	77.3	38.50	7.16	149	0.53	2190	41.6	12.9
81.0	45.0	71.6	30.28	5.18	209	0.31	1435	46.3	37.6
86.9	52.0	80.0	21.60	4.02	246	0.27	1430	53.3	36.5
82.1	10.4	83.1	9.48	1.77	270	0.28	1570	56.6	42.10
44.15	7.7	34.6	40.55	7.55	362	0.16	5850	379.0	17.0
47.1	30.0	50.1	537.55	100.06	166.2	0.43	4280	116.0	20.6

largest, covering almost one-fourth of the total geographical area. It has considerable variations in physiography, climate and allied characteristics and is, therefore, subdivided into eight sub-basins. Some vital statistics, regarding water, land and people of the seventeen river basins are given in Table 1.

While our description of the system is primarily in terms of physical characteristics, the States are the administrative units and reference may have to be made to them. The country is divided into 22 states and 9 centrally administered union territories as shown in figure 3.

3. Climate and rainfall

The distinguishing characteristics of India are a tropical climate and the monsoons. Literally, the word monsoon means a wind system which undergoes a seasonal 180° reversal of direction. Many regions of the world experience the monsoons, but in India, two factors make them unique. One is the continuous and high mountain mass in the north which forms an effective barrier to the air movement across them and also contributes to the formation of a low pressure zone favourable to the monsoon across

Figure 3. India—political map (source: Chaturvedi 1976)

India. The second is the peninsular shape of the subcontinent with the close proximity of the land to the ocean, thereby providing a rich source of moisture. India has a diversity and variety of climate and an even greater variety of weather conditions. The climate varies from continental to oceanic, from extremes of heat to extremes of cold, from extreme aridity and negligible rainfall to excessive humidity and torrential rainfall. Thus, generalizations cannot be made, but for convenience, it is possible to demarcate five broad regions with more or less similar patterns of climate and weather: (a) north-west India comprising West Rajasthan, Punjab and Kashmir, (b) central India comprising East Rajasthan, Gujarat, the northern districts of Madhya Pradesh, Uttar Pradesh and Bihar (c) the plateau region (d) Eastern India comprising West Bengal, Orissa and Assam and (e) the peninsular coastal lands and plains.

The average temperature with seasonal patterns is shown in figure 4. During the winter season, from November to February, the temperature decreases from the south to the north from about 24–29°C in the south to about 5–18°C in the north. From March to May the temperature rises sharply in northern India and the maximum may be above 40°C. Evaporation closely follows the march of the monsoon (figure 5). The potential evapo-transpiration (PE) which may be assumed to be the same as the evaporation, ranges between 140 and 350 cm.

Rainfall is primarily dependent on the monsoons and to a certain extent on shallow cyclonic depressions and disturbances. Only a fraction of the more than 3.87×10^8 m ha m of atmosphere moisture moving over India reaches the ground as rain or snow. Evaporation from the oceans provides about 80 percent of this precipitation. The summer monsoon, coming from the southwest, bursts on the Malabar coast in the first week of June and establishes itself over most of the country by the end of the month. Coming from over the sea, it provides about 80–90% of the total annual rainfall. In view of the orographical features, the monsoons travel up *via* the Indus plain on the Arabian side and up the Gangetic plain on the Bay of Bengal side. The strength of the monsoon current increases from June to July, remains more or less steady in August and begins to weaken in north India in September, when there is a rapid decrease in rainfall towards the end of that month. Prior to the monsoons in the early part of the year, disturbances continue to enter India, bringing some rain to the north-west part of the country and a reasonable amount in West Bengal and Assam.

By the middle of October, the low pressure is transferred to the centre of the Bay of Bengal and the direction of the winds becomes north-easterly. They cause occasional showers on the mid east coast. Cyclonic storms from the Bay of Bengal, during October and November, are mainly responsible for the rainfall in the Deccan Plateau and Tamil Nadu. In the winter, from December to February, a shallow but extensive low pressure system moves across northern India from west to east. There is heavy precipitation in the form of snow in the higher ranges of the Himalayan system and moderate rain over the lower and outer ranges.

It has been estimated that during the four rainy months of June through September, the Arabian sea branch of the monsoon carries moisture amounting to about 770 m ha m and the Bay of Bengal branch about 340 m ha m of the monsoon moisture, 25 to 30% precipitating in the form of natural rainfall. During the remaining eight months also, there is a substantial amount of moisture over the country and it constitutes a precipitation of the order of 100 m ha m, a small portion of it being in the form of snowfall.

The annual rainfall and its seasonal distribution is shown in figure 6. It is upto 250 cm

Figure 4. India—temperature variation (source: Chaturvedi 1976)

along almost the entire West coast and Western ghats and over most of Assam and sub-Himalayan West Bengal. West of the isohyetal joining Porbandar to Delhi and thence to Ferozpur it diminishes rapidly from 50 cm to less than 15 cm at the extreme west. The peninsula has an elongated area of less than 60 cm of rainfall. The normal annual precipitation over the country of 119.4 cm (National Commission on Agriculture 1976) is slightly more than the global mean of 99.1 cm. The point to be noted is the extreme spatial and temporal variation. Cherrapunji in the extreme east records a rainfall of the order of 1142 cm in a year and as much as 104 cm in a day, which are some of the highest figures in the world. In the west, in the Rajasthan desert some of the driest spots on earth can be located.

Figure 5. India—pan evaporation contours (source: Chaturvedi 1976)

The extreme spatial variation is further demonstrated in terms of annual water surplus and deficits, shown in figures 7 and 8. The values are computed by subtracting values of potential evapotranspiration from the average precipitation and adding up the annual surplus or deficit separately. The figures show that on the whole there is a net deficit all over the country. Even in the monsoon months, when there is general surplus, some regions are eternally drought-stricken. The figures are only indicative, as even in areas of annual water surplus, there are often seasonal or short-term periods of deficiency. The variability of available water resources is extremely important as deficiencies during critical periods of crop growth can be disastrous. Besides the considerable geographical and seasonal variation, the rainfall even during the monsoon

Figure 6. India—Isohyetes (source: Chaturvedi 1976)

is most uncertain. There are alternating periods of heavy to moderate rains and partial and general breaks when there are no rains.

The annual variation is, however, much less. The annual coefficients of variations are shown in figure 9. These present the percent plus or minus variation from the mean for 70% of the year. It generally varies between 15 to 30 taking the year as a whole. Along the West Coast near Mangalore, the coefficient of variation is less than 15%. The isoline of 30% runs through Bengal, Orissa, the Bihar Plateau and Assam, the north-eastern part of Assam having less than 15% variability. Over Gujarat and Rajasthan this coefficient is higher than 40%.

Figure 7. India—water surplus regions (source: Chaturvedi 1976)

4. Hydrological cycle and water balance

A correct assessment of the surface runoff is not possible as yet, as long-term and reliable discharge measurements have not been carried out at sufficient locations. The earliest attempt at estimating these was based on an empirical correlation with rainfall and temperature. Later, studies were made by several agencies on the basis of actual measurements and empirical studies. The figures currently in common use are given in

Figure 8. India—water deficit regions (source: Chaturvedi 1976)

table 1. These give the total runoff. Mean monthly and maximum monthly runoffs of some major rivers at some measuring sites are shown in figure 10.

Natural runoff is the annual flow of water that would appear in surface streams if there were no upstream development. In areas of surface water-groundwater continuity, the natural runoff includes the perennial recharge yield of groundwater aquifers. According to the Irrigation Commission Reports (1972), some estimates are as follows.

The mean annual natural runoff which leads to surface flows and groundwater recharge is estimated to be 188·12 m ha m. Of this, 42·41 m ha m is estimated to be the

Figure 9. India—annual rainfall variation (source: Chaturvedi 1976)

mean annual groundwater recharge. The total surface flows which are considered to be utilisable are estimated to be 66.6 m ha m. In addition, 26.1 m ha m of groundwater is expected to be utilisable leading to a total utilisable resource of 92.7 m ha m. These figures are still tentative and approximate. There are vast disparities from river basin to river basin. For instance, the total utilisable water resource per unit of land is 116 cm in the Ganga basin, while the corresponding figure in the Cauvery basin is only 43.3 cm.

Assessment of groundwater is even more difficult and incomplete. Measurements of water balance, annual recharge and groundwater levels have to be made. The distribution of precipitation into surface runoff and groundwater recharge depends upon site conditions. The potential for groundwater is shown in figure 11 and the

Figure 10. India—maximum and monthly mean river discharges in cumecs (source: Chaturvedi 1976)

pertinent data on annual ground-water recharge is given in table 1. The figures although not accurate are the best estimate on the basis of currently available data. As estimated earlier, out of the total of 42.41 m ha m, 26.1 m ha m are considered utilisable. The availability is even more nonuniform spatially as brought out in figure 11, as about 70% of the land surface is covered by hard rocks. Besides the annual recharge, a vast amount of nonrenewable groundwater resources are available which could be mined. This, however, creates many problems. As the groundwater table is lowered, a new equilibrium between surface runoff and annual recharge is established and contri-

Figure 11. India—depth of aquifers and quality of groundwater (source: Chaturvedi 1976)

bution to surface runoff from groundwater will be reduced. There would be in-perpetuity costs of pumping from the reduced levels, and the resources developed would be nonrenewable.

Recently, water balance has again been estimated by the National Commission on Agriculture (1976). The water balance as estimated in 1975 and the likely position in the years 2000 and 2025 is shown in figure 12. The country's average annual rainfall is about 119.4 cm and the country's total average annual precipitation is estimated to be 394 m ha m. This may be rounded off to 400 m ha m including snowfall which is not yet

Figure 12. India—approximate distribution of average annual water resources as in 1974, 2000, and 2025 AD (m ha m). The numbers in brackets are those for the year 2000 (source: National Commission on Agriculture)

fully recorded. Out of the 400 m ha m, about 70 m ha m is estimated to be lost to the atmosphere by evaporation. Of the remaining 330 m ha m, about 115 m ha m becomes surface runoff and the remaining 215 m ha m soaks into the ground as soil moisture and groundwater recharge. Of this, about 45 m ha m regenerates as surface flows. An additional 20 m ha m is brought in by streams and rivers from catchments lying outside the country in Nepal and Tibet, and thus the total surface flows have been estimated to be 180 m ha m. Of the total surface water of 180 m ha m available in the country in an average year, about 15 m ha m is stored in various reservoirs and tanks of which about 5 m ha m is lost by evaporation. A considerable portion of the storage is in tanks constructed over long periods in the past. With future construction of projects, storage is ultimately expected to be about 35 m ha m and the loss about 10 m ha m. Of the 165 m ha m of water that flows in the river annually at present without any storage facility, the utilization through diversion works and direct pumping aggregates to 15 m ha m, which is more than that from the storage works. The remaining river flow of 150 m ha m goes to the sea and some adjoining countries. On full development, the use of water through diversion works or direct pumping is expected to increase to 45 m ha m. The balance of 105 m ha m would continue to flow to the sea and outside the country.

Of the 215 m ha m percolating into soil, about 50 m ha m, *i.e.* about 12.5% of the total precipitation is estimated to percolate as groundwater and the rest is retained in the soil as soil moisture. No significant change is expected in this according to present thinking and policy, although as we will argue later, the groundwater recharge has to be and can be substantially increased. Infiltration and contribution to groundwater also takes place from the irrigation works themselves. In the alluvial plain of north India, about 45% of the water that is let in at the head of an unlined canal system is lost from channels through seepage. Of the remaining 55% which reaches the field, another 30% is lost. Thus, it is estimated that only about 40% of the water let into an unlined canal system is actually utilised. It is estimated that at present about 5 m ha m is retained in the soil as soil-moisture and about 12 m ha m is added to the groundwater. On full development of irrigation in the country, the contribution to soil moisture and groundwater is expected to be about 15 m ha m and 25 m ha m respectively. Similarly, contribution to groundwater from streams is estimated to be 5 m ha m currently and is expected to be increased to 10 m ha m by developing schemes of induced groundwater. With the addition of 5 m ha m from flood flows and 12 m ha m from the irrigation system to the 50 m ha m from precipitation, the total groundwater, excluding soil moisture comes to 67 m ha m. It is estimated that at present, of the total groundwater amounting to 67 m ha m replenished on an average annually, 13 m ha m is extracted for various uses, about 45 m ha m regenerates into rivers and the remaining 9 m ha m is accounted for by evapotranspiration and raising of the water table. On the near full-development of water resources, the extraction is estimated to rise to 35 m ha m, evapotranspiration reduced to 5 m ha m, and the remaining 45 m ha m regenerates to rivers as at present.

Currently, the transpiration is estimated to be about 110 m ha m, 13 m ha m from irrigated crops, 42 m ha m from unirrigated crops, and 55 m ha m from forests and other vegetation. On full development, the total transpiration is estimated to become 125 m ha m, the component figures being 35, 35 and 55 m ha m, respectively.

Evaporation is a major item of the hydrological cycle. Of the total precipitation of 400 m ha m, 70 m ha m is lost directly. Of the 215 m ha m percolating into the soil,

another 10 m ha m is estimated to be non-beneficial evaporation. These figures are estimated to change only marginally with development.

In terms of estimated utilisable resources and their development, it is seen that 180 m ha m of surface flows (which includes 45 m ha m of contribution from groundwater) is available. After almost complete development, these figures are estimated to change to 185 m ha m, the groundwater contribution to surface runoff remaining the same. Currently, 13 m ha m of groundwater and 25 m ha m of surface water have been developed, totalling 38 m ha m. These figures are estimated to change to 35, 70 and 105 m ha m at almost full utilisation—almost a three-fold increase. It is estimated that currently 150 m ha m of natural runoff, mostly in the form of surface runoff is flowing to the sea or out of India. This figure is anticipated to change to 105 m ha m.

5. Floods

The extreme seasonal and spatial variability of water resources in India is dramatically yet catastrophically exemplified by the occurrence of droughts and floods in different parts of the country almost at the same time every monsoon. The damage by floods depends upon the use characteristics and land shapes of the flood plains. All river basins are prone to floods in view of the extreme variability of the monsoons but the Brahmaputra and the lower Ganga river basins are subject to serious floods every year. (National Commission on Floods, 1980).

A total area of 40 m ha is estimated to be prone to floods of which 32 m ha can be protected though by 1980 only 10 m ha had been protected. During the period 1970 to 1978, the flood affected area worked out to 11.9 m ha in respect of total area affected and 5.4 m ha for cropped area. The former constituted 3.9 % of the reporting area in the country while the cropped area affected constituted 7.8 % of the total net sown area. For major flood-prone states, relevant figures for the seventies are much higher *e.g.* 12 % and 10 % for Bihar, 10 % each for UP and 15 and 9 % for West Bengal.

Besides crop losses, floods cause considerable damage to houses and property as also loss of human and cattle lives. On an average 0.93 million houses were damaged every year during the last 25 years, and 1240 human lives and 77,000 head of cattle were lost. Railways, roads, communication lines, public utilities etc. also suffer considerable damage during high floods.

Average figures, however, conceal large year-to-year variations. For instance, in the case of the total area, while in 1965 only a million hectares were affected, the spread was many times more during the three years 1976 to 1978 being over 17 m ha. About 3,500 people lost their lives in 1968 as against only 34 in 1953. The picture would be similar in the case of other losses also. Besides the direct losses floods destabilize economic activity. For instance, the annual rate of agricultural activity during the period 1962–63 to 1970–73 was 1.94 % for the country as a whole. The rates recorded for most of the flood-prone districts of eastern UP was only in the range of 0.1 to 0.9 %.

6. Drought

Droughts are extended periods of subnormal precipitation. The effect of drought, however, depends on climate and man's adaptation to his environment. Thus in arid areas where man customarily depends on surface and ground water for irrigation and

supply, the lack of rainfall for a few months may not be noted, but in humid areas where man relies more on water from current rainfall, lack of rain for a few months could be disastrous.

Agricultural drought occurs when the soil moisture is so depleted that the normal yields are reduced resulting in substantial economic loss. Water supply drought, on the other hand, is related to general nonavailability of water. While the definition of drought is thus arbitrary we define drought areas as follows. We first define arid and semi-arid zones as those where the difference between precipitation received and potential evapotranspiration is, less than 33 cm, and between 33 and 66 cm, respectively. The drought areas are those which have an adverse water balance and 20 % probability of rainfall departure of more than 25 % from normal. If this probability is 40 % then the area is called a chronically affected drought area. The drought areas are shown in figure 13. In order that the area may tide over the drought, 30 % or more of the area should be irrigated. The total drought prone area comprises about 16 % of the total geographical area of the country and directly affects about 11 % of the population.

7. Water quality

Water quality is defined by a variety of physical and chemical parameters and pertains to suitability for a particular use. It is determined by the geological and hydrological influences present in a basin and also by such man-made influences as regulation of flow, discharge of waters and accelerated soil erosion. Studies of water quality in India are very scarce and we may analyse the basic factors to come to a general assessment.

Sedimentary rocks contribute much more suspended material than igneous rocks. Significant concentrations of dissolved materials, such as sodium, calcium, magnesium, chloride and sulphate ions are commonly associated with sedimentary rocks retaining brine from former marine environments. Areas of heavy precipitation and runoff, in otherwise similar situations, reduce dissolved chemical content but have little effect on sediment loads and concentrations. Groundwater is usually more mineralized than surface water owing to its longer and more intimate contact with weathered rocks and soils. The management of watershed land has profound effects on the quality, and considerable improvement could occur with the use of proper practices. By the above considerations, the quality of natural water can be judged from the geohydrological map of figure 11.

Pollution problems start when water is withdrawn from its natural place of occurrence, put to domestic, agricultural or industrial use, and this impaired water returned to a water course. With proposed large scale diversion of water for irrigation, and simultaneous increase in population and industrial activity, the problem is particularly serious, as discussed later.

8. Related land resources

The total geographical area of the country is 328 m ha. Of this, only 305.5 m ha are accounted for in land use statistics (1967–68). The difference of 22.5 m ha largely consists of mountains, deserts and forests in inaccessible areas. Regionwise details of land resources are given in table 1. The overall position is shown in table 2.

Figure 13. India—drought prone areas (source: Chaturvedi 1976)

According to the latest estimates (1972–73), the total arable area is estimated to be 175 m ha, of which 142 m ha would be under cultivation by the end of the Fourth Plan. The gross cropped area would be 169 m ha. According to present estimates 97 m ha of land or 55% of the gross cropped area can be ultimately irrigated both by surface and groundwater sources, their contribution being 72 and 25 m ha respectively. The concept of irrigation in these estimates, is, however, that of the marginal irrigation being provided as at present.

The percentage of the total land under cultivation in India is one of the highest in the world amongst the large countries. The percentage figures are: World 11·3; USSR 10·8; USA 16·2; China 11·5; India 49·7; Pakistan 30; Japan 15·5.

Table 2. Land resource statistics and projections (million hectares)

Classification	1970-71	2000	2025	% of total (2025)
Geographical area	328	328	328	100
Reporting area	305	318	318	96.95
Forests	66	70	70	21.34
Area under non-agricultural use	16	26	36	10.98
Barren and uncultured land (mountains, deserts and areas which can be brought under cultural use at high cost)	29	30	24	7.32
Miscellaneous trees, crops and groves not included in net sown area (thatching grass, casurina trees, bamboo bushes and other groves and trees for fuel etc.)	5	5	6	1.83
Culturable waste (not cultivated at present for the last 5 years or more)	16	9	4	1.22
Fallow lands other than current fallows (out of cultivation for 1 to 5 years)	9	5	3	0.91
Current fallows (not cultivated within one year for some reason)	11	8	5	1.52
Net area sown	140	150	155	47.26
Total cropped area	165	200	210	64.03

Source: National Commission on Agriculture, Part V, 1978.

9. Water resources development

Water resources development has received the highest importance in India right from prehistoric times down to the present. References to irrigation exist in folklore and ancient literature. Historical records bear testimony to the existence of a number of old works in different parts of the country. The characteristics of these were largely conditioned by the physiographic features of the area in which they were located. In the arid and semi-arid flat plains of North India, perennial rivers like the Indus and the Ganges made it relatively easy to direct flood flows through inundation channels. In the peninsula where the land is undulating but surface waters are not perennial, the practice of trapping stormwater in large tanks for domestic and agricultural purposes was widespread. In areas where a high groundwater table permitted lift irrigation, wells were common. These works were also of varied size. On the one hand, there were millions of small wells, on the other there were a few big canals, impressive for their times. The Grand Anicut near Tanjore built as far back as the 2nd century AD, irrigated 24,000 hectares in the beginning of the 19th century. The western and eastern Yamuna Canals and the Hasli Canal on the river Ravi were dug during the 14th to the 18th century, the latter irrigating 12,500 hectares in 1849.

Irrigation development under British rule began with the renovation, improvement and extension of existing works, like the ones mentioned above. When enough experience and confidence had been gained, new projects like the Upper Ganga canal, the Upper Bari Doab Canal, the Krishna Delta System and the Godavari Delta System were undertaken. These were major river diversion works, of the capacity of the order of 300 m³/s. Very often, these were undertaken to stabilize the irrigation in the wake of famines from political and financial considerations. All these works were constructed during the period 1836 to 1866, but then there was a slackening after this period for a couple of decades.

Attracted by the profitability of these schemes, two private companies planned grandiose schemes to construct transcountry link canals, but they failed. All that was achieved was a series of disconnected waterways. However, two decisions followed from these activities. It was decided that in future, irrigation development would be undertaken exclusively by the government. Second, in accordance with the policy of private companies, finances were developed by public loans and works were undertaken only if they promised a minimum net return.

Not much activity was witnessed in the second half of the 19th century. However, following the great famine of 1876–78, the Famine Commission of 1880 recommended emphasis on irrigation, though no action was taken. The two great famines of 1897–98 and 1899–1900 however led to the appointment of an Irrigation Commission in 1901. Policy recommendations about financial criteria were developed and several schemes were proposed for public irrigation works. Emphasis was also laid on development of private irrigation works like wells and tanks, through higher outlays on comparatively easier terms. Much activity ensued, particularly on productive works and particularly in the area of Punjab in the context of the colonization of First World War soldiers. By 1920–21, the total irrigated area in undivided India (India and Pakistan) was 22.6 m ha.

Much of the irrigation development upto 1930 was in terms of diversion canals. There was little development in groundwater or even wells. The area irrigated by wells in British India was 4.68 m ha in 1902–03 and only 4.73 m ha in 1925–26. In 1930, hydroelectric development was undertaken in Uttar Pradesh by tapping the falls in the Ganga Canal and tubewell construction was started.

By the time of Independence, about 28.2 m ha of land, almost 24 % of the cultivated land, was under irrigation. Source-wise, 54 % of the area was irrigated by canals (mostly Government-owned), 23 % by wells, 12 % by tanks and the remaining 11 % by miscellaneous sources. Much of the canal-irrigated area was, however, in what constitutes Pakistan now, and after independence, the irrigated area in India was reduced to 19.7 % of the net sown-area against the earlier figure of 24.1 % of undivided India.

Table 3. Irrigation potential (in m ha) (gross)

Period	Major and medium	Minor irrigation			Total irrigation	Percentage of ultimate potential
		Ground	Surface	Total		
1. Pre-Plan (1950–51)	9.70	6.50	6.40	12.90	22.60	19.9
2. End of 1st Plan (1956–58)	12.19	7.63	6.43	14.06	26.25	23.3
3. End of 2nd Plan (1960–61)	14.33	8.30	6.45	14.75	29.08	25.7
4. End of 3rd Plan (1965–66)	16.56	10.52	6.48	17.00	33.56	29.6
5. End of Annual Plans (1968–69)	18.10	12.50	6.50	19.00	37.10	32.7
6. End of 4th Plan (1973–74)	20.70	16.50	7.00	23.50	44.20	38.9
7. End of 5th Plan (1974–78)	24.77	19.80	7.50	27.30	52.25	46.0
8. Addl. target (1978–79)	26.12	20.85	7.75	28.60	54.90	48.4
9. Addl. target (1979–80)	27.22	22.10	8.00	30.10	57.50	50.7
10. Target 6th Plan (1980–85)	33.72	29.10	9.50	38.60	72.60	64.0
11. Ultimate feasible by conventional	58.60	40.00	15.00	55.00	113.50	100.0
12. Additional through national prospectives	25.00	10.00	—	10.00	148.00	—

Water resources development received the highest importance after Independence. Many impressive storage works, like the Bhakra Dam, the Rihand Dam, and the Earth and Rockfill Ramganga Dam to name a few, were constructed to augment irrigation facilities and hydropower generation. Equally important is the groundwater development particularly through private tubewells. This has unfortunately been limited to the arid areas of northwest India, particularly in Punjab.

The development of irrigation is shown in tables 3 and 4 and figure 14. Table 3 gives the development of irrigation source-wise and table 4 gives the net area sown, net area irrigated and the percentage of net area sown. The growth of irrigation is also shown in figure 14. The area irrigated crop-wise is given in table 5.

The achievements vary from State to State. Rainfall irrigation and sources of irrigation state-wise are given in figure 15.

Table 4. Development and future of irrigation in India

Year	Net area sown (m ha)	Net area irrigated (m ha)	% of net sown area irrigated
1950-51	110.75	20.85	17.56
1955-56	129.16	22.76	17.62
1960-61	133.20	24.66	18.51
1967-68	139.70	27.52	19.70
1973-74	142.71	32.60	22.85
1977-78	149.93	40.00	26.68
1982-83	155.17	52.40	33.77

Source: Irrigation Commission Report (1972); Sixth Five Year Plan. Figures for 1982-83 are estimates

Figure 14. India—development of irrigation (source: Singh 1980)

Figure 15. Rainfall, irrigation and sources of irrigation (source: Commerce Annual Number 1976)

Besides the quantitative increase, qualitative changes have also taken place. In addition to surface diversion works, several large dam and considerable groundwater development have also taken place. In addition, schemes of command area development for field-level distribution and application have been taken up.

10. Hydroelectric development

The hydropower potential of India is quite rich and is still largely untapped. The country's economically exploitable hydropower resources have been estimated at

Table 5. Irrigated area under principal crops

Crops	1970-71	1985	2000 AD
Rice	14.93	21.50	24.00
Wheat	9.84	14.00	14.90
Other cereals	3.80	5.76	6.99
Total cereals	28.57	41.26	45.89
Pulses	1.99	4.30	5.37
Total foodgrains	30.56	45.56	51.26
Oilseeds	1.02	2.80	5.10
Cotton	1.29	4.00	7.50
Sugarcane	1.90	3.25	5.00
Tobacco	0.10	0.25	0.40
Other crops	3.63	5.14	14.74
Total non-foodgrains	7.94	15.44	32.74
Total irrigated area	38.50	61.00	84.00

Table 6. Basin-wise abstract of hydropower potential and development in India (MW)

Name of river basin	Power potential*	Installed capacity	Effective capacity	Balance to be exploited
Indus	7,000	3,039	2,370	4,630
Ganga	5,000	1,899	1,127	3,873
Brahmaputra	12,000	276	152	11,848
Sabarmati	Nil	Nil	—	—
Mahi	100	Nil	—	100
Narmada	1,000	Nil	—	1,000
Tapi	300	300	115	185
Subarnarekha	100	130	26	74
Brahmani	1,000	Nil	Nil	1,000
Mahanadi	1,000	270	200	800
Godavari	6,000	1,355	662	5,338
Krishna	1,500	1,893	1,096	404
Pennar	Nil	Nil	—	—
Cauvery	1,000	940	586	414
Medium and Minor Basins	5,000	3,881	2,987	2,013

Source: Rao (1976)

* These are earlier figures. The present potential is estimated to be 75,400 W.

41,000 MW at about 60 % load factor of which only about 10 % is utilised at present (Sixth Five Year Plan 1980). In addition, the potential of Nepal is 85,000 MW of which none has been exploited. It is further considered that these estimates are on the low side and the actual potential may be almost twice as much. For instance according to a more recent estimate, the potential in India has been put at about 75,400 MW.

Figure 16. Hydropower potential and development in India (source: Rao 1976)

A basin-wise abstract of the hydropower potential and development in India is shown in table 6 and figure 16.

11. Conclusion

India is rich in natural resources, land and water, which however, have to be developed to improve their productivity. With the rising population and efforts on economic development, the problem is extremely important and urgent.

Development of water resources is central in this context as water is generally not available where and when required. India's arid-monsoon climate and geographical features lead to extreme seasonal and spatial variations. Efforts in this direction have been made since time immemorial, but as the overview shows, we have a long way to go.

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