CHAPTER 1

INTRODUCTION TO WATER RESOURCES

Water is a unique and widely distributed resource for sustenance of life and humanity on earth and plays a very vital role in the economic development of any country or a region related to irrigation, agriculture, industrial development and drinking water needs. It is a finite resource in the global scenario and undergoes a cyclic phenomenon characterizing continuous exchange of processes from the surface of the earth (evaporation and evapotranspiration) and back to the surface in the form of precipitation under the influence of solar radiation and seasonal climatic changes. The water cycle provides us with a magnificent phenomenon of transforming and converting all types of waters on the earth's surface into fresh waters and brings them back in the form of precipitation. The precipitation though finite in its totality has wide space-time variations in different continents of the world. The global climatic phenomenon popularly known as 'EL Nino'-a quasi periodic climatic pattern which is largely a function of heat energies/solar radiations and trade winds across Pacific could create abnormal climatic variations in the southern continents of the world such as droughts and floods which are common and frequent in many parts of the world. The water utilization from precipitation levels in the early decades of human population has been insignificant, but with increasing population growth, mounting agricultural practices and large scale industrial activities over the last few decades, the demands for water has become multifold bringing the water potentials in several regions of the world to critical or near critical situations, and at the same time increasing the levels of contamination/pollution to alarming situation. In addition, the increased *'green house gases'* and the related anthropogenic impacts are set to cause *'global warming'* and *'sea level rise'* events and could result in disastrous situations in future in relation to precipitation levels, floods, and droughts in several parts of the world including India. Coastal systems with diversified ecosystems and environments, wetlands and deltas with potential surface and subsurface fresh water systems bear the brunt of these global processes and will have significant impacts on the production levels related to water resources and agricultural practices. Assessment of freshwater resources, development of appropriate methodologies and sustainable solutions, land-water interactions, and environmental protection strategies are of paramount importance apart from other resource potentials like minerals, soil nutrients, timber, fisheries and fauna & flora. Over exploitation, misuse of water resources, rapid industrialization and urbanization processes are posing serious threats for sustainable development, environmental protection and food security problems in most coastal regions of the world including India. An overall global and national perspectives related to water resources are briefly described below, before targeting in detail the Indian coastal delta ground water systems, fresh water resource potentials, saline-fresh water interrelationships, Quality trends and management strategies.

Several countries in the world and the United Nations agencies like UNDP, WHO, UNICEF, WMO, UNESCO & UNEP have taken several initiatives and coordinated action plans/ programs related to the availability of fresh water resources in different continents and the constraints involved in the development of this scarce resource. The International Conference on Water and Environment at Dublin (ICWE, 1992) and the United Nations Conference on Environment and Development at Rio de Janeiro (UNCED, 1992) stressed the need for world wide reforms towards sustainable food production and efficient management of water resources and water conservation methods/practices. The salient and guiding principles of Dublin and that of Rio de Janeiro (Agenda 21) conferences are briefed below:

Guiding principles of Dublin conference (ICWE, 1992)

- "Fresh water is a finite and vulnerable resource essential to sustain life, development and environment". Since water sustains life, effective management of water resources and holistic approaches linking social and economic development with natural ecosystems are of high priority.
- "Water development and Management should be based on a participatory approach involving users, planners and policy makers at all levels". The participatory approach involves raising awareness of the importance of water among policy makers and the general public. It means that the decisions are taken at the lowest appropriate levels with full public consultation and involvement of users in the planning and implementation of water projects.
- "Women play a central point in the provisions, management and safeguarding water" This pivotal role of women as providers and users of water and guardians of the living environment has seldom been reflected in the institutional arrangements for the development and management of water resources. Acceptance and implementation of this principle requires positive polices to address women and their specific needs and equip and empower women to participate at all levels in water resources programs including decision making processes.
- "Water has an economic value in all its competing uses and should be recognised as an economic good". It is vital to recognise first the basic right of all human beings to have access to clean water and sanitation at an affordable price. Earlier failures to recognise the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use and encourage conservation and protection practices of water resources.

Guiding principles: The Rio de Janeiro, Agenda 21 conference (UNCED, 1992)

- Establishing a new and equitable global partnership through creation of new levels of cooperation among states, key sector societies and people.
- Holistic management of fresh water and integration of several water plans and programs, with in the frame work of national, economic and social policies.

The above conferences have arrived at a number of recommendations based on the above guiding principles and discussions such as (i) Alleviation and poverty and disease (ii) Water conservation and reuse (iii) Sustainable urban development (iv) Agriculture production and rural water supply (v) Protection of aquatic ecosystems (vi) Resolution of water conflicts (vii) Protection of environments and the development of knowledge base and capacity building. Subsequently there are several forums on International needs to focus attention on food security, water resources and environmental programmes such as: (i) First world forum at Marrakech, 1997 (ii) Second world forum at Hague, 2000 (iii) Third world forum at Kyoto, 2003 (iv) Fourth world forum at Mexico, 2006 (v) Fifth world forum at Istanbul, 2009 and several world forums planned for future in the years to come. All these International gatherings and deliberations will go a long way to put the water resources programmes in proper perspective to derive the expected goals and fruits to all levels of society.

1.1 GLOBAL WATER RESOURCES

Water occurs widely throughout the globe and exists in three states: liquid, solid and vapour. A major chunk of water in liquid state is found in oceans, seas, lakes, rivers and groundwater and in the crustal layers of the earth down to 2000 meters. The solid form appears as ice and snow mostly in the Polar and Alpine Himalayan regions. A certain amount of water is found in the air as water vapour, water droplets and ice crystals and also in the biosphere. The different attributes of water, the hydrological and nutrient cycles, and the constraints involved in water budgeting etc are critically reviewed and discussed by Narasimhan, T. (2005).

Assessment of total water resources is rather a very complicated problem in view of its dynamic nature and the changes involved from liquid stage to gaseous stage and back again to liquid stage. Pioneering attempts to estimate the world water resources are made by Lvovitch, M.I. (1973); Korzun, V.I. (1978); Baumgartner, F.; Reichel, E. (1975) and more recently by Shiklomanov, I.A. (1997 & 98). The estimated global water resources are of the order of 1386 Million km³ of which 97.50% occurs as oceanic saline waters and the rest 2.5% as fresh water. A major portion of this fresh water (68.90%) is locked up in the form of ice caps, glaciers, permafrost and snow in the Arctic, Antarctic and Mountainous regions of the world. Then about 29.90% of the fresh water component occurs as groundwater. About 0.30% exists in lakes, river systems and about 0.90% in the soil moisture and swamps. The distributional pattern of different components of water is shown in Fig.1.1.

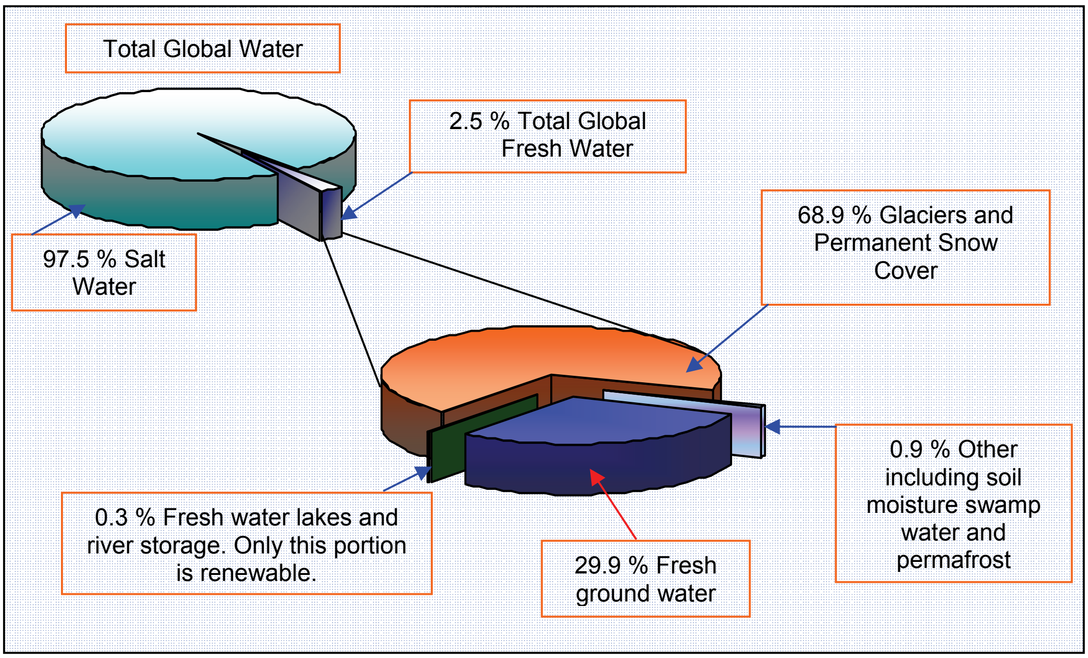


Fig. 1.1 Global water resources

(Source: Shiklomanov, I.A., 1998)

The above system approximately characterises the global storage potentials of fresh and saline waters and are subjected to cyclic changes over short and long periods of time. The volume of water stored in the hydrosphere vary depending upon the cyclic changes in the oceans, land and atmosphere. This exchange is called turnover of the water in terms of volume in the global hydrological cycle. The global water cycle involves basically evaporation of water from earth's surface into the atmosphere and returning back to earth in the form of precipitation which is the major source of rivers, lakes, glaciers and groundwaters as schematized in Fig. 1.2.

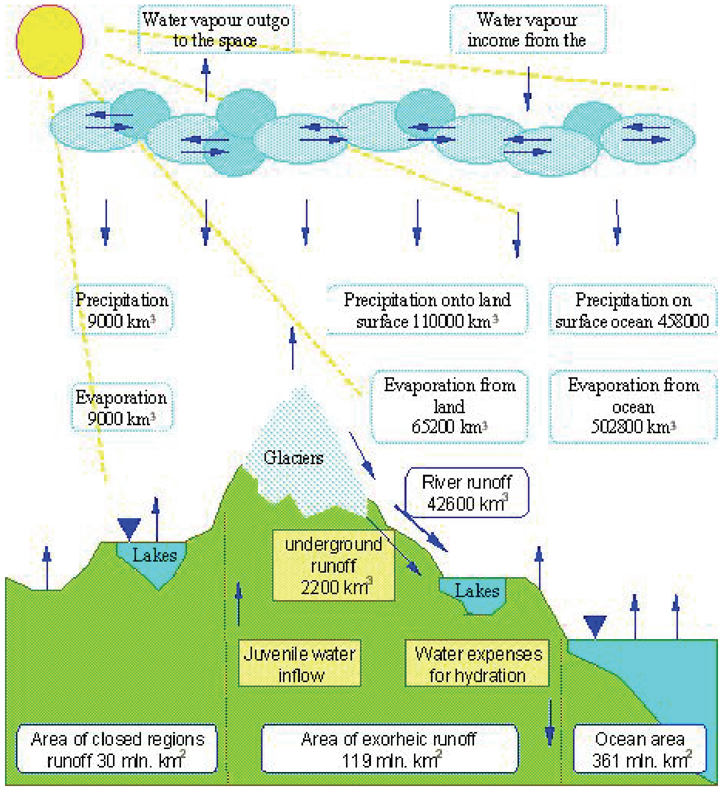


Fig. 1.2 Global water cycle

(Source: Shiklomanov, I.A; 1998)

A portion of the atmospheric precipitation evaporates, some part goes into river systems flow and some flow infiltrates into the soil cover and recharges the groundwater system. The quantitative estimates of different components of global hydrological cycle are reflected in fig. 1.2. The turn over of water on the earth over one hydrological cycle is estimated as 577000 km³ of water. The water that evaporates from oceanic surface is of the order of 502, 800 km³ and from the land surface is of the order of 74,200 km³. The amount of water that falls as atmospheric precipitation is of the order of 458,000 km³ on the ocean and about 119,000 km³ on the land. The difference between precipitation and evaporation from the land surface is 44,800 km³/year (119,000-74,200) which represents the total runoff component through the earth's river systems including groundwater runoff (42,700 km³/year, river runoff component + 2,100 km³/year groundwater runoff component) Shiklomanov, I.A., (1998).

Assessment of water resources in general involves two components: static storage and dynamic storage (renewal resources): Static storage by convention means renewal turnover time of over several decades and centuries like ocean bodies, glaciers, large lakes and deep groundwater bodies, where as the dynamic storage is one where the renewal turnover time is only one year or one hydrological cycle like major and minor river systems and near surface realms of groundwater. The river runoff of renewable water resources is the most important component of the hydrological cycle and has pronounced impact on the economy and ecology of any region. Assessments of precipitation levels, river runoff therefore are very important to understand the resource potentials in a region or a basin. A wide network of observational stations throughout the globe are in operation and several numerical model studies are in progress to assess these components for long term and short term perspectives. The world meteorological organization operates nearly 64,000 stations for river runoff measurements throughout the world. The renewable water resources and percapita availability of water have been estimated continental wise using about 2500 stations and are presented below in the Table 1.1.

Table 1.1 Distribution of renewable water resources in different continents and per capita availability

Continent	Area (Million km^2)	Population (millions)	Water resources, (km^3/year)				Per Capita water Availability 1000 m^3/year	
			Average	Max	Min	Cv	per 1 km^2	Per capita
Europe	10.46	685	2900	3410	2254	0.08	277	4.23
North America	24.3	453	7890	8917	6895	0.06	324	17.4
Africa	30.1	708	4050	5082	3073	0.10	134	5.72
Asia	43.5	3445	13510	15008	11800	0.06	311	3.92
South America	17.9	315	12030	14350	10320	0.07	672	38.2
Australia and Oceania	8.95	28.7	2404	2880	1891	0.10	269	83.7
The World	135	5633	42785	44751	39775	0.02	317	7.60

(Source: Shiklomanov, I.A., 1998)

The above table demonstrates that the maximum volume of water is available in Asia and South America and the minimum resources are in Europe and Australia. The mean value of renewable global water resources is estimated as 42,700 km^3 per year with large space-time variations. The largest volume of water resources are those of Asia and South America (13,000 and 12000 km^3 per year respectively) and the smallest resources are found in Europe and Australia + Oceania (2900 and 2400 km^3 per year respectively).

The rapid population growth rate between 1970 and 1994 has resulted in the per capita reduction from 12.9 to 7.0 thousand m^3/year/person. The greatest reduction appears to have taken place in Africa (2.8 times) followed by Asia (2.0 times) and South America (1.7 times). The studies on river run off over different continents have shown wide variations from the mean values and are cyclic in nature. The current estimations show that the major part of runoff in Europe takes place between April to July (46%); in Asia between June to September (54%), in Africa between September to December (44%), in South America between April to July (45%) and in Australia/Oceana between January to April (40%). The average runoff during the wet seasons for different continents is estimated to be of the order of 45% of the total renewable water resources. It is further estimated that a major chunk of river runoff (52%) takes place through major rivers like Amazon (Brazil), Ganges-Brahmaputra (India), Congo (Central Africa), Yangtze (China) and Orinoco (Venezuela). A graphical sketch presented in Fig. 1.3 shows long term run off patterns where annual volume exceeds 100 km^3 per year. The river runoff also includes the groundwater runoff component, whose quantified estimations over all the continents is not exactly available, but approximately pegged at 5% of the total river runoff (Shiklomanov, I.A., 1998).

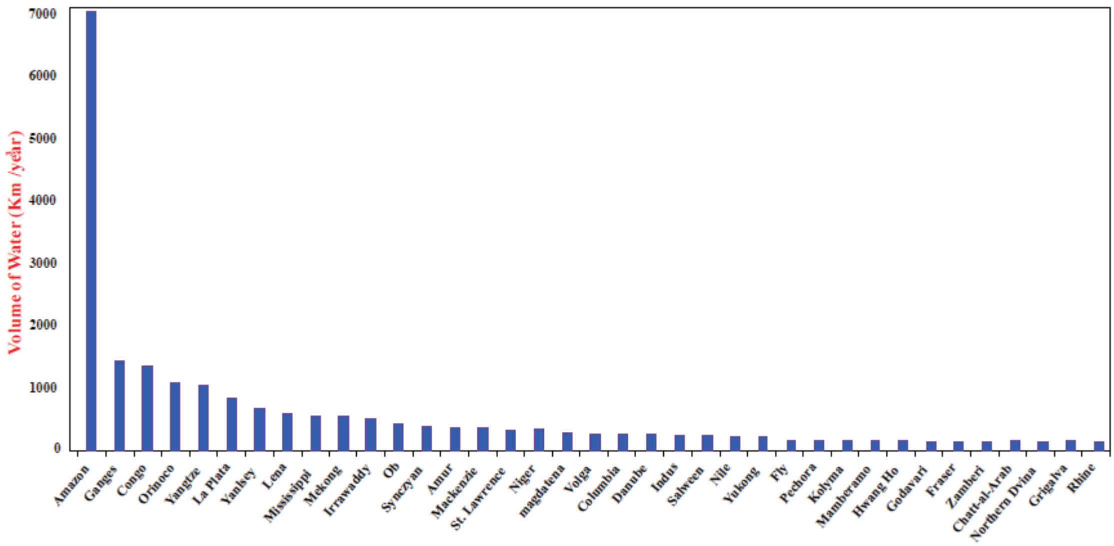


Fig. 1.3 Annual runoff patterns for different major river basins in the world

(Source: Shiklomanov I.A., 1998)

1.2 WATER RESOURCES (NATIONAL)

India is bestowed with complex physiographic and climatic distribution system with a number of major, medium and minor river systems. The average precipitation level is of the order of 1200 mm. The total precipitation in terms of volume over India is estimated to be of the order of 4000 BM^3. Against this total, the average annual runoff is estimated to be of the order of 1869 BM^3 and rest 2131 BM^3 returns back to atmosphere through evaporation (C.W.C., 2005). A brief description of different physiographic and climatic regions, precipitation levels and water resource potentials are described below, in the following paragraphs.

1.2.1 Physiographic regions

India with a geographical area of 3.29×10^6 km² has a wide range of physiographic and climatic situations. Physiographically India could be divided into seven broad well defined regions:

(i) The high altitude Himalayan Mountain ranges in the north where Indus, Ganges and Brahmaputra take their origin.

(ii) The Indo-Gangetic plains traversed by Ganges and Brahmaputra

(iii) The Central high lands starting from Aravallis in the west to steep escarpments and high altitude hill regions in the east.

(iv) The peninsular plateaus with Western Ghats on the west, the Eastern Ghats on the east and the Deccan plateau in the central region.

(v) The east coastal plains with a number of major, medium and minor east flowing rivers discharging into Bay of Bengal. By and large all the major delta systems fall in this region and join Bay of Bengal with good alluvial stretches and with widths varying from 100-140 kms, but sometimes gets narrowed down to 5-10 kms along the rocky shorelines.

(vi) The west coastal plains with a number of medium and minor westerly flowing rivers, discharging their sediments and waters into Arabian sea with relatively narrow widths of alluvial sediments, and with widths varying from 10 kms to 30 kms and sometimes shorelines abutting against elevated rocks and cliffs.

(vii) The Andaman-Nicobar islands in the Bay of Bengal and Lakshadweep islands in the Arabian Sea.

1.2.2 Climatic zones

The Physiography of India plays a very important role to characterize the climate variations. The Himalayas in the north, Indian ocean in the south, the Arabian sea and the Bay of Bengal on either sides of the peninsular coastal regions and the plateau regions play an important role on the climatic variations of India. India could be broadly classified into six climatic zones as shown in Fig.1.4 and as described briefly below.

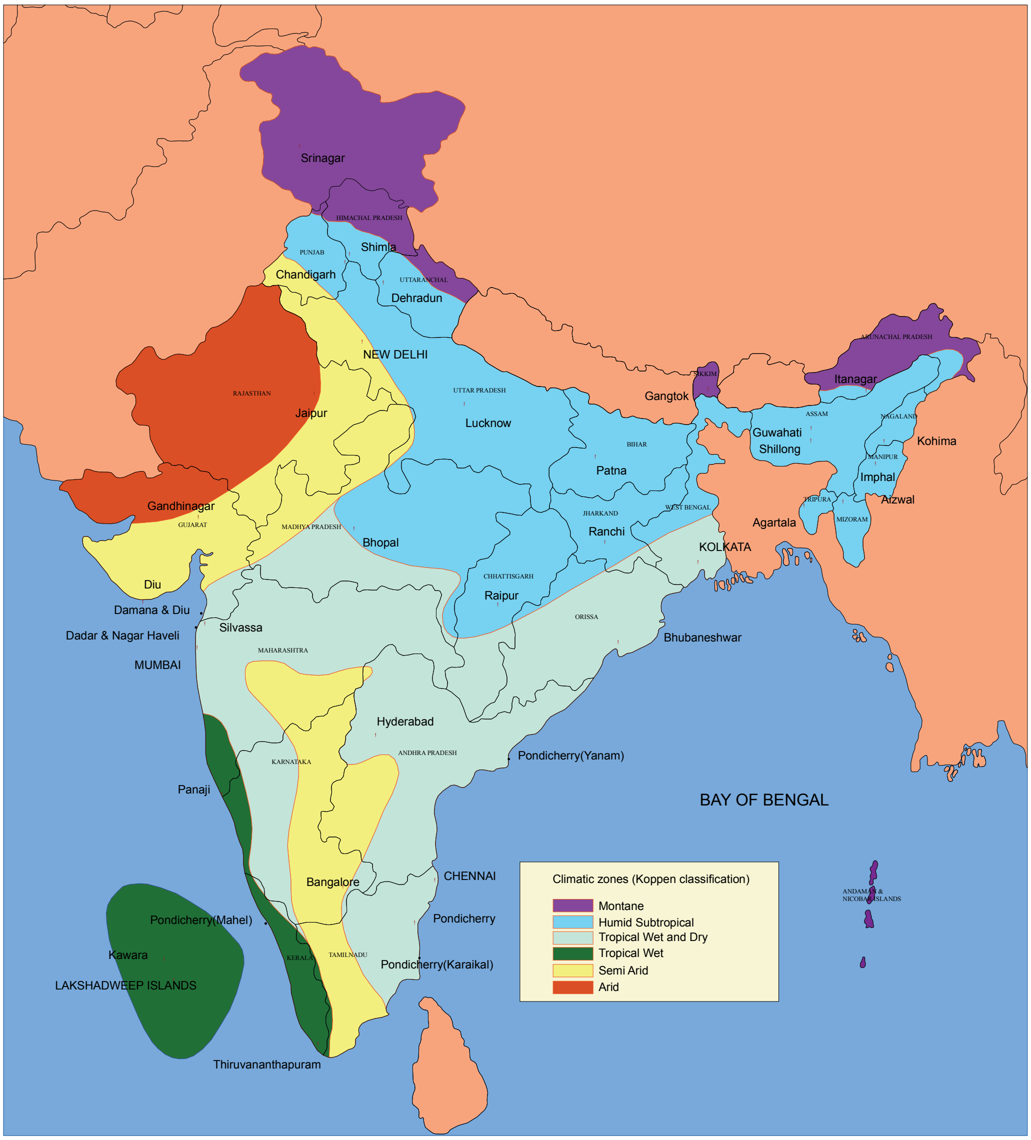


Fig. 1.4 Climatic zones of India

(a) ***Alpine Himalayas Zone:*** The High altitude Himalayan region is characterized by high diurnal temperatures, sharp temperature inversions and high rain fall variabilities. The states of Jammu & Kashmir, Himachal Pradesh, Uttarkhand experiences this type of climate.

(b) ***Humid Subtropical Zone:*** The Himalayan foot hill region and a major portion of Gangetic alluvial plains come under this category. The east Rajasthan region, Uttar Pradesh, Bihar and Northern part of West Bengal and Assam experiences this type of climate. The summers in general are hot and winters are moderately cold.

(c) ***Arid regions:*** The Western Rajasthan with scanty rainfall conditions comes into this category. This region is characteristic of very hot summers sometimes attaining as much as 50 ºC and cold winters sometimes almost touching freezing point.

(d) ***Semi arid region:*** This is transitional climate falling between tropical desert (arid) climate and humid sub-tropical climate with annual rainfall slightly more than the arid desert region of Rajasthan. Parts of Punjab, Haryana and Gujarat experiences this type of climate.

(e) ***Tropical wet and dry climate:*** Most plateau regions of Peninsular India enjoys this climate with summer temperatures touching 45 ºC and experiences good rainfall during June to September with an annual rainfall ranging between 750 mm to 1500 mm or even more. The coastal regions in general are wet and central high land regions are dry.

(f) ***Tropical wet:*** Part of west coastal region of Peninsular India reaching summer temperatures of the order varying between 35-40 ºC. Experiences high rainfalls ranging between 1500 mm to 2500 mm and sometimes even more.

1.2.3 Precipitation levels

The precipitation including snowfall is the source of all water potentials on the earth's surface. The average annual precipitation over India is estimated to be of the order of 4000 BCM of which a part goes as evapo-transpiration and a part goes as recharge to groundwater and the rest appears as surface runoff. Most of the rainfall over India is contributed by south west monsoon (June to September) and a limited contribution by north east monsoon (October to November). The long term average annual precipitation for the country is about 1869 mm with high levels of fluctuations and variabilities. The highest rainfall with about 11690 mm is recorded near Chirapunji in Meghalaya in the north east and the lowest of the order of 150 mm is recorded near Jaisalmer in Western Rajasthan. Rainfall varies between 2000 mm to 4000 mm along the north eastern and along the western ghat regions of India. The annual average rainfall over the foot hill regions of Himalayas and along the Indo-Gangetic plains varies from 1500mm in the east to 500 mm in the west. The northern half of peninsular India and the central high land region registers an average annual rainfall varying between 1500 mm on the east to about 500 mm on the west. The southern Indian peninsula registers an average annual rainfall varying from 100 mm to 750 mm from east to west. The western regions of Rajasthan receives vary scarce rainfall averaging about 150 mm or sometimes less. The distributional trends of normal annual rainfall over India are shown in the Fig 1.5 and the longtime rainfall trends for the period 1870 to 2010 are shown in Fig.1.6 based on all India weighted mean values over a homogeneous rainfall data set of about 306 rainguage stations covering India.

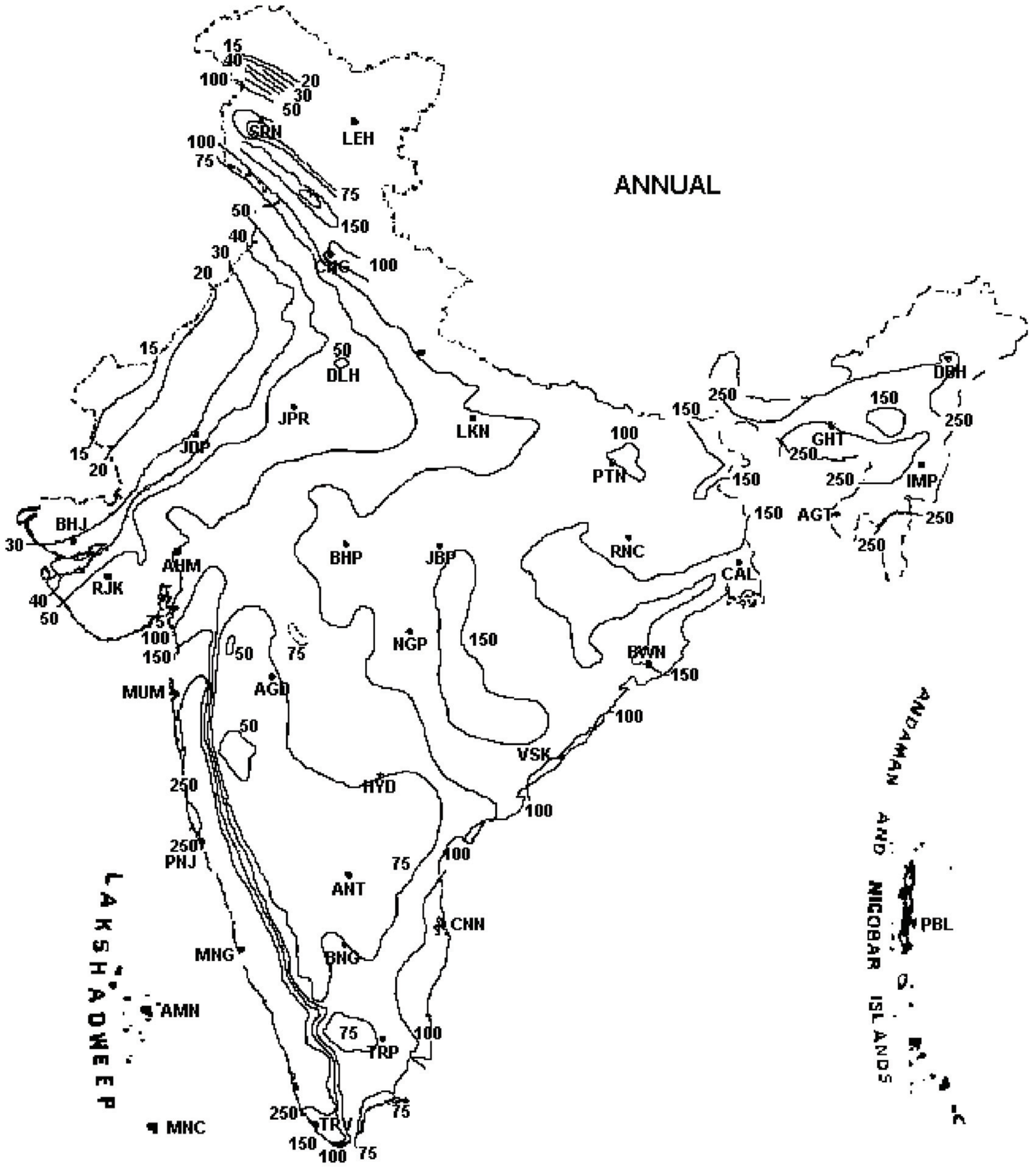


Fig. 1.5 Distribution of normal and annual precipitation levels of India (IMD, 2004)

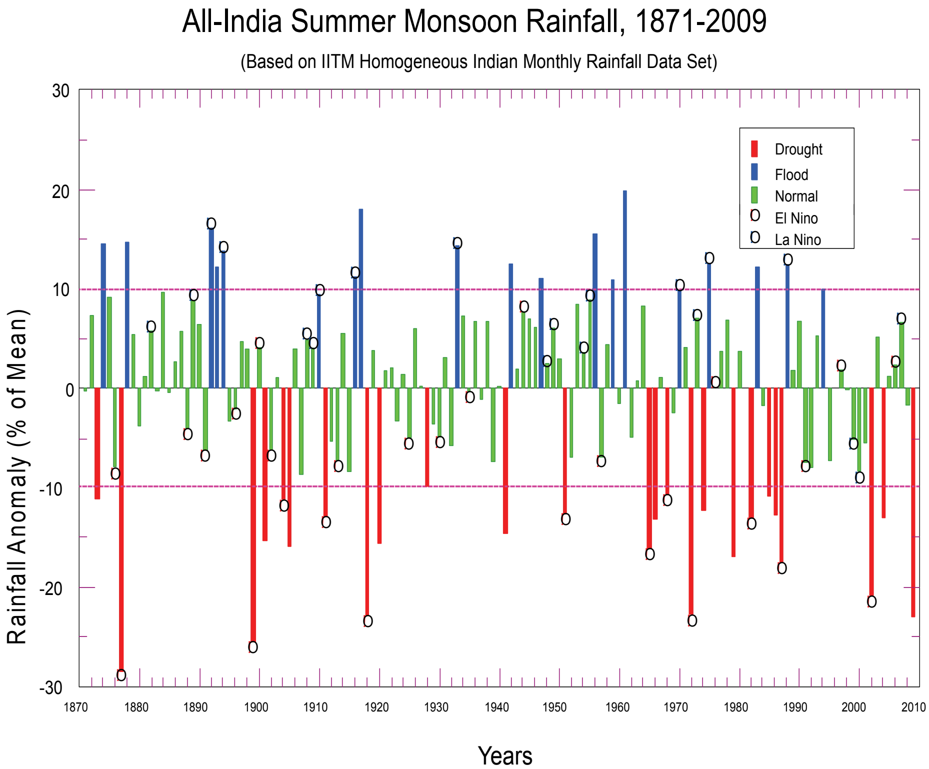


Fig. 1.6 All-India summer monsoon rainfall anomalies (1870-2010)

(Source: IMD, 2011)

A long time rainfall anomalies expressed in terms of percentage mean over the period 1870 to 2010 as described by IMD are presented in fig. 1.6. The series reveals several interesting aspects of decadal variations in terms of floods and droughts. There are about 19 flood years and 23 drought years identified over the period.

Flood years 1874, 1878, 1892, 1893, 1894, 1910, 1916, 1917, 1933, 1942, 1947, 1956, 1959, 1961, 1970, 1975 ,1983, 1988, 1994.

Drought years 1873, 1877, 1899, 1901, 1904, 1905, 1911, 1918, 1920, 1941, 1951, 1966, 1968, 1972, 1974, 1979, 1982, 1985, 1986, 1987, 2002, 2004 and 2009.

The Indian monsoon has a direct link with the Southern Oscillation Index (SOI). Weak Indian monsoons in the country are associated with a large negative SOI and occurrence of *EL Nino*, whereas, strong monsoons have been linked to large positive SOIs and absence of *EL Nino* events. In addition several global and regional parameters have also been found to contribute to the Interannual variabilities of monsoon rainfall.

1.2.4 Water resources potentials

Water resources of a country or a region play a major and crucial role in the overall economic development including agriculture production, irrigation potentials, drinking water needs and industrial productivity. India with a geographical area of 3.29 million km^2 contains 17% of the population, 2.45% of land resources and 4% of fresh water resources of the world. The southwest monsoon contributes to over 80% of the total rainfall input and the rest through northeast monsoon and other sporadic rains. The water resource potentials of India which occurs as natural run off in the rivers are estimated around 1869 BCM, which includes 432 BCM replenishable groundwater resources. It is also further estimated out of the above availabilities only about 1086 BCM could actually be put to use with 690 BCM from surface water and 396 BCM from groundwater (CWC, 2005 & CGWB, 2005).

India is a vast country with excellent net work of river systems and with potential subsurface groundwater systems. There are about 14 major river basins (catchment areas greater than 20,000 sq.kms) with total catchment area of 2,579,108 sq.kms and about 44 medium river basins with a catchment area of 239,302 sq.kms (catchment areas between 20,000 sq.kms and 2000 sq.kms). The major river basins form 85% of the total drainage area and together with medium river basins form about 91% of the total drainage area. In addition there are several minor rivers in the catchment areas less than 2000 sq.kms and whose total length stretches are mostly restricted to the coastal regions and desert regions. The Ganga-Brahmaputra has the largest catchment area with 110 Million hectares accounting to 43% of the catchment areas of all major rivers of the country, followed by Indus (32.10 M.Ha), Godavari (31.3 M.Ha), Krishna (25.9 M.Ha) and Mahandi (14.2 M.Ha) etc. and several others. The total annual flow of all the rivers in the country is estimated as 1869 BCM (Central Water Commission, 2005) and the replenishable groundwater recharge of the order of 432 BCM (Central Groundwater Board, 2005). The basin wise details for all the river systems with details on catchment areas, average annual potential, utilizable surface water resources and replenishable groundwater flows are presented in Table 1.2.

Table 1.2 Water resource potentials of the river basins of India (surface and groundwater)

S.No.	Name of the River Basin	Catchment Area(km^2)	Average annual potential in river (BCM)	Utilisable Surface flow (BCM)	Repleni-shable Ground flow (BCM)
1.	Indus (up to border)	321289	73.31	46.0	26.49
2.	(a) Ganga	861404	525.02	250.0	170.99
	(b) Brahmaputra Barak & Others	194413	585.60	24.0	26.55
3.	Godavari	41723	110.54	76.3	40.65
4.	Krishna	258948	78.12	58.0	26.41
5.	Cauvery	81155	21.36	6.8	12.30
6.	Pennar	55213	6.32	6.9	4.93
7.	East Flowing Rivers Between Mahanadi & Pennar	866643	22.52	13.1	18.84
8.	East Flowing Rivers Between Pennar & Kanyakumari	1100139	16.46	16.7	18.22
9.	Mahanadi	141589	66.88	50.0	16.46
10.	Brahmani & Baitarni	51822	28.48	18.3	4.05
11.	Subernarekha	29196	12.37	6.87	1.82
12.	Sabarmati	21674	3.81	1.9	
13.	Mahi	34842	11.02	3.1	8.52
14.	West Flowing Rivers of Kutch, Sabarmati including Luni	321851	15.10	15.0	11.23
15.	Narmada	98796	45.64	34.5	10.83
16.	Tapi	65145	14.88	14.5	8.27
17.	West Flowing Rivers from Tapi to Tadri	44940	87.41	11.9	

Table 1.2 ***Contd…***

S.No.	Name of the River Basin	Catchment Area(km^2)	Average annual potential in river (BCM)	Utilisable Surface flow (BCM)	Repleni-shable Ground flow (BCM)
18.	West Flowing Rivers from Tadri to Kanyakumari	56177	113.53	24.3	17.69
19.	Minor River Basin Drainage into Bangladesh & Burma	36302	31.00		
	TOTAL:		**1869.37**	**690.3**	**431.42**

(Source: Ministry of Water Resources, 1999)

The utilizable water resource is the quantum of water that could be withdrawn in a given basin/area over a period of one hydrological cycle. The total utilizable water resource of the country is estimated as 1086 km^3 with surface water component as 690 km^3 and the groundwater component as 396 km^3. The present utilization trends of both surface and groundwater are of the order of 690 km^3. This is likely to go up to 1073 km^3 by the year 2050. This means that the water resource potentials of the country would reach a critical position by around 2050 and water conservation methods will play a very dominant role to preserve and protect the available water resources.

1.2.5 Water requirements, population rise and water scarcity trends

The water requirements in India are closely linked with the population growth rate, increasing tends of irrigation and agricultural outputs, industrial and energy outputs and drinking water needs. The population of India as on March, 2001 stood at 1.027 billion and is likely to shoot up to 1.308 billion by 2025 and 1.463 billion by 2050 (Fig. 1.7). The population growth rates since 1951 and the per capita availability of water are shown in Table 1.3 (Ramesh Kumar Gupta, 2008).

Table 1.3 Population and per capita availability of water resources

Year	Population (million)	Per capita
1951	361	5177
1961	439	4257
1971	548	3410
1981	683	2736
1991	846	2209
2001	1027	1819
2050	1463	1277

(Source: CWC, 2005)

The per capita availability of water at the beginning of the last century was of the order of 8192 M^3/year and was reduced to 5177 M^3/year by the year 1951. This exponential population growth then after was further brought down to 2209 M^3/year by the year 1991 and to 1819 M^3/year by the year 2001 and is expected to go down to 1277 M^3/year by 2050. These trends are shown graphically in Fig 1.8 with indications of stressed and scarcity boundary lines.

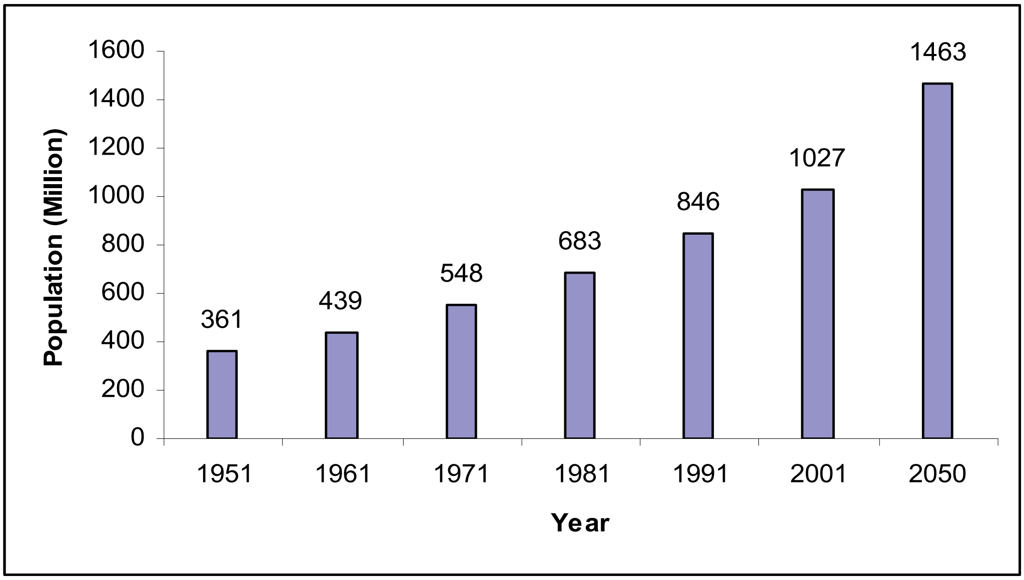


Fig. 1.7 Population growth levels

(Source: Ramesh Kumar Gupta, 2008)

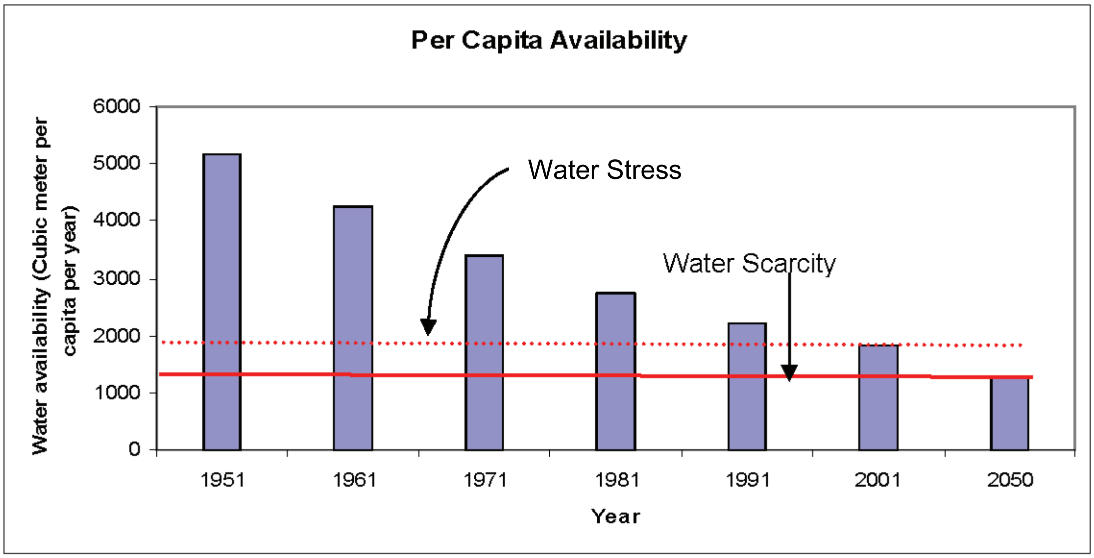


Fig. 1.8 Per capita availability/water stress/water scarcity trends

(Source: Ramesh Kumar Gupta, 2008)

The trends indicate by and large the country is already in a water stressed situation in respect of water resources consumption and would reach near to the scarcity line by 2025 and reach critical situation by 2050. These trends reflect on the need to plan carefully to optimize the utilization of consumption rates and also adopt suitable methodologies to create additional water resources.

The total requirement of water to produce required food grains based on the projected population is of the order of 557 BCM for 2010, 611 BCM for 2025 and 807 BCM for 2050 through surface water. Similarly the projected contribution from groundwater resources is 218 BCM for 2010, 245BCM for

2025 and 344 BCM for 2050. The requirements in the domestic sector would be 43 BCM, 62 BCM and 111 BCM for the year 2010, 2025 and 2050 respectively and from groundwater 19, 26 and 45 BCMs respectively for the above years. In addition there will be demands from industrial, power and environmental maintenance sectors also. All these statistics indicate both surface and groundwater utilizable resources would reach a critical stage by 2050 and demands a very careful management and conservation practices which are required to be initiated and adopted from now on.

1.2.6 Irrigation and agriculture growth rates

Irrigation and Agriculture is the prime concern of the nation and about 85% of the available water potential is diverted to irrigation and agriculture sector and the rest towards domestic, industry and energy needs. There has been a very systematic and sustained growth of irrigation potentials since the beginning of five year plan period from 1951 onwards. The ultimate irrigation potential of the country was estimated as 140 M.Ha from Major, Medium and Minor irrigation systems. The irrigation potential created at the end of 1951 is 16% of the ultimate irrigation of 140 M.Ha, and by the end of 2005 the created irrigated potential has reached upto 71%. The irrigation potential created had increased from 22.6 M.Ha in 1951 to about 93.90 M.Ha at the end of the 9th Plan period 97-2002. The Plan wise position of irrigation potential created and utilized is given in the Table.1.4.

Table 1.4 Plan-wise position of irrigation potential created and utilized (In million hectares.)

Plan	Potential created			Potential utilized		
	Major & Medium	Minor S.W & G.W Total	Total	Major & Medium	Minor S.W & G.W Total	Total
1951-56	12.20	14.06	26.26	10.98	14.06	25.04
1956-61	14.33	14.75	29.08	13.05	14.75	27.80
1961-66	16.57	17.00	33.57	15.17	17.00	32.17
1966-69	18.10	19.00	37.10	16.75	19.00	35.75
1969-74	20.70	23.50	44.20	18.69	23.50	42.19
1974-78	24.72	27.30	52.02	21.16	27.30	48.46
178-80	26.61	30.00	56.61	22.64	30.00	52.64
1980-85	27.70	37.52	65.22	23.57	35.25	58.82
1985-90	29.92	46.61	76.53	25.47	43.12	68.59
1990-92	30.74	50.35	81.09	26.32	46.54	72.86
1992-97	32.96	53.31	86.26	28.44	47.83	76.27
1997-2002	37.05	56.90	93.95	31.01	49.05	80.06

(Source: CWC, 2005)

The basic responsibilities for the creation of irrigation & potentials and agriculture products etc. exists with the respective state governments. A sustained and coordinated action programs are therefore required to be launched to meet the emerging future demands. The National Water Policy launched in 1987 and subsequently modified in the year 2002 provides a direction for optimum development of water resources while protecting the environment etc. Some of the salient points included in the policy are briefed below:

- Water is a prime natural resource, a basic human need, a prime natural asset and is a part of the global ecological system. It is to be planned, developed, conserved and managed on an integrated way with sound environmental principles.

- A well developed information system with a net work of data banks and data bases for all water related systems at state/central level needs to be introduced for appropriate resource planning systems analyses and augmentation of water resources.
- All water resources development and management programmes should be planned taking sub-basin/basin as a hydrological unit and evolve integrated action plans. Watershed management programme should consider soil conservation, catchment area treatment, afforestation and check dams construction.
- All existing institutions at various levels under the water resources sector will have to be re-oriented and strengthened wherever necessary taking into consideration the emerging technologies and practices.
- Planning and operation of systems should broadly consider the following aspects: (a) Drinking water; (b) Irrigation; (c) Hydropower; (d) Ecology; (e) Agro industries and non-agricultural industries and f) Navigation and other uses.
- All water resources development projects should be planned and developed as mutlipurpose projects involving drinking water needs, ecological and environmental balances, economics and sustainabilities.
- Groundwater resource assessments should be organized with sound scientific basis involving quantity and quality of water. All exploitation endeavours should be based on input/output analyses. Over exploitation of groundwater resources should as far as possible be avoided and conjunctive utilization of surface and groundwater resources should be planned.
- All irrigation projects/development practices should take into account the cost-benefit analyses and adopt methods for optimization of resources, reclamation of water logged and saline affected areas. Rehabilitation practices should be adopted wherever required particularly in major river valley projects.
- Adequate emphasis needs to be given towards physical and financial sustainability while creating additional water resource potentials by way of fixing water cess so as to cover operational maintenance and capital costs.
- Water utilization and management programmes, should incorporate participatory approach of various governmental institutions, users and stake holders. Efforts should be made to involve women water users associations and local bodies like panchayats and municipalities etc in different stages and project formulation, development and operational maintenance etc.
- Private sector participation should be encouraged wherever feasible and encourage innovative ideas, generate financial resources and help introducing corporate management practices.
- Water qualities of both surface and groundwaters should be regularly maintained and introduce appropriate neutralization methods wherever water qualities deteriorate beyond their threshold limits and introduce necessary legislation practices wherever required.
- The entire water resources domain of the country should be classified into different zones in terms of quantity and quality and update the data base and measures from time to time.
- Water conservation methods should be adopted invariably at all levels of water utilization practices, introduce techniques related to desilting of canals and tanks, recycling of waste water, adaptation of drip and sprinkler irrigation systems wherever feasible.
- Adequate cushioning for floods should be provided in the water storage areas, while physical flood projection works like embankments and dykes are required to be continued. Flood forecasting and warning measures should be modernized and minimize the loss of life and roperty as and when floods recur.
- Erosion impacts both in the coastal and river shore areas should be minimized by appropriate cost-effective measures. Indiscriminate exploitation of coastal resources should be regulated.

All coastal states should prepare comprehensive coastal zone management plans for sustainable development.

- Soil moisture conservation measures should be practiced in the vulnerable drought prone areas. Development of groundwater through appropriate water harvesting, recharge systematic monitoring, identification of bottlenecks and adopting remedial measures should form important activity of both surface and groundwater projects.
- Water sharing/distribution in different states should be guided by national perspectives and availabilities of water resources in a basin/river system. The inter-state water disputes act of 1956 should be renewed periodically and emerging disputes be referred to tribunals.
- There should be a paradigm shift from the emphasis on creation and expansion of water resources infrastructure facilities to the improvement of performance and maintenance of the existing water resources facilities and accordingly reprioritise the activities and financial budgets. Safety measures and modernisation practices for all existing structures should be undertaken and keep them in good health, through appropriate organization practices involving experts in different fields.
- All the latest available techniques and methods in the water related fields should be adopted for an effective management and utilization of available water resources. Training practices should form an integral part of all water resources developmental programs.

Agriculture

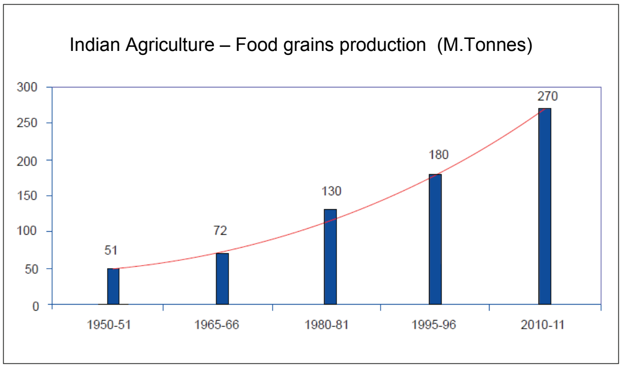
Agriculture is of fundamental importance to the Indian economy contributing to about 20-21% of gross domestic product (GDP) and generates two thirds of the employment potential. Assured irrigation water supply is most important for food security. The total food grain production which was only 51 million tons at the time of commencement of the first five year plan has gone upto 213.45 million tons by 2005 and projected to go up to 250 million tons by 2010. Thanks to the green revolution inducted in the country coupled with induction of high yielding varieties. Uttar Pradesh, Haryana, Madhya Pradesh, Rajasthan and Bihar account for 95% of wheat production in the country while West Bengal, Uttar Pradesh, Andhra Pradesh, Tamilnadu, Bihar, Punjab, Orissa, Madhya Pradesh, Assam and Karnataka account for more than 90% of rice production by 2010. The coarse cereals and pulses production are mostly from states like Maharashtra, Karnataka, U.P, Rajasthan, Madhya Pradesh, Andhra Pradesh, Gujarat and Bihar contributing to about 90% of production in the country. Similarly these states have contributed abundantly for all agro-based products like sugarcane, cotton, oil seeds, and horticulture based products like vegetables, fruits and animal based production like milk, fish and eggs etc. The production rates of all these items are incorporated in table 1.5 and also are shown graphically in Fig. 1.9.

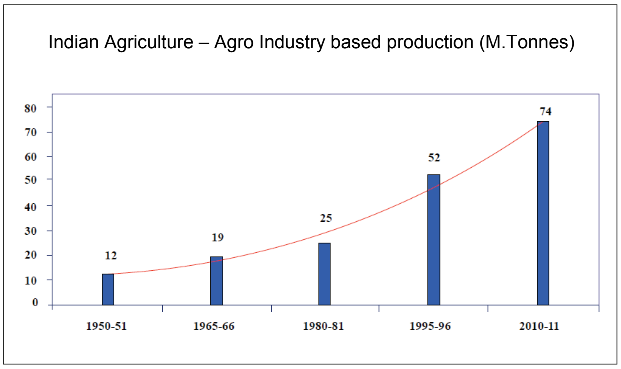
Table 1.5 Agriculture growth development

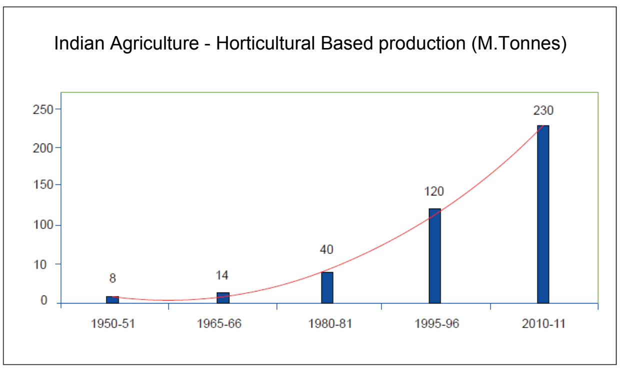
S.No.	Agricultural Products	1950-51 (M.Tons)	1964-65 (M.Tons)	1980-81 (M.Tons)	1995-96 (M.Tons)	2010-11 (M.Tons)
1.	Food Grains (Wheat, Rice, Coarse Cereals & Pulses)	51	72	130	180	270
2.	Agro based products (Sugarcane, Cotton, Oil Seeds)	12	19	25	52	74
3.	Horticulture based products (Vegetables, Fruits)	8	14	40	120	230
4.	Animal based products (Milk, Fish, Eggs)	19	22	38	80	149
	Total (Agri-Products)	90	127	233	432	703

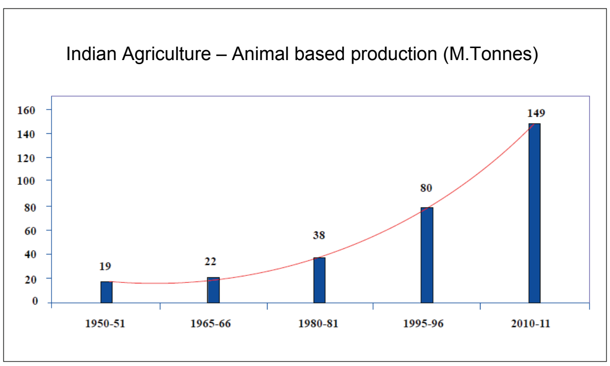
(Source: Goel, A.K., 2008)

Population growth rate will be far the most important parameter for the demands of irrigation and agricultural potentials. If the country's population has to be stabilized around 1.55 billion by around 2050, we have to plan to increase the overall food grains and related products from the present level of 430 million tons to more than double the amount by 2050. To achieve these objectives the current irrigation potentials of the order of 97 million tons will have to be substantially increased.









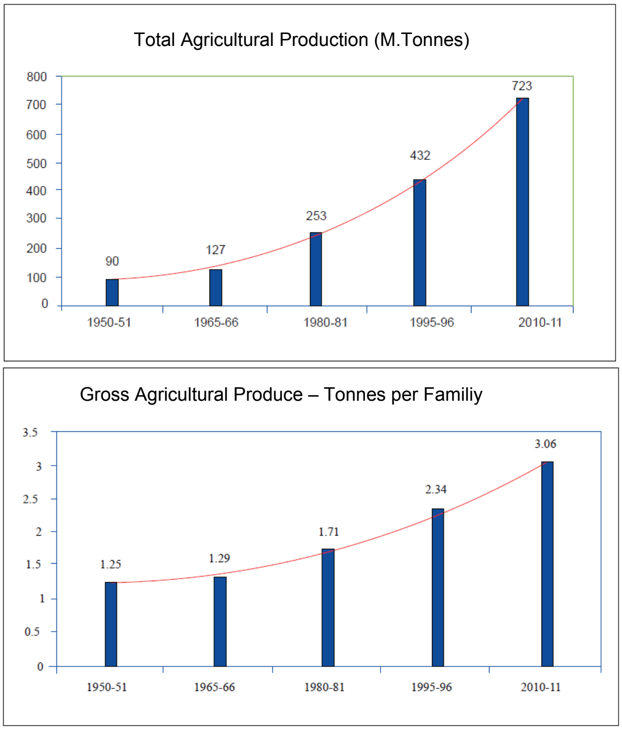


Fig. 1.9 Agriculture, Agro based products, Horticulture and Animal based products growth levels

(Source: Goel A.K, 2008)

The basic responsibilities for the creation of irrigation and agricultural potentials exist with the respective state governments. A sustained and coordinated action plans are required to be launched. A national water policy was launched in the year 1987 and was reviewed and updated in the year 2002, which provides directions for optimum development water resources and adopt necessary strategies/methodologies etc. Some of the salient points were included in the earlier paragraphs.

1.3 COASTAL SYSTEMS (WORLD SCENARIO)

Coastal Systems/Areas are the most dynamic systems interfacing the continents and oceanic basins and support some of the important, diverse productive habitats in the world. These are the areas where fresh water from the continents mix with the saline water from the oceans and make the environment very fragile and sensitive covering approximately 15% of the land surface of the earth and with over 1.6 million kms length (Burke, L., et al 2001). There are no rigid definitions and spatial boundaries to the coastal systems/areas. A distinction perhaps could be made between the terms '*coastal zone*' and '*coastal systems/area*'. The term '*coastal zone*' could be referred to a relatively narrow zone immediately adjacent to the coast line on either sides covering shallow parts of the oceanic basins and the low lying terrestrial regions of the continents where intense land-sea interactions take place and the term *coastal system/area* could be applied more broadly to the inland areas where oceanic and continental influences take place. These include beaches and dune systems, backwaters and lagoons, saline marshes, tidal flats, estuaries, deltas and the adjoining sedimentary environments.

Small, C. and Nicholls, R.J. (2003) characterizes the *coastal zone* or a *costal system* as an area running up to 100 kms from the coast line or 50 meters elevation whichever is closer to the coastal line with an outward extension of 50 meters depth level into the sea. LOICZ (Land-Ocean Interaction with Coastal Zone) a core project of the International Geosphere – Biosphere program defines the coastal zone as an area extending from the coastal plains to the outer edge of the continental shelf approximately matching the region that has been alternately flooded and exposed during the sea level fluctuations of geological past. The coastal regions are very crucial for social needs and economic development. They tend to be more densely populated than inland areas due to several economic reasons such as development of ports, shipping, fisheries, tourism, urbanization processes, coal, oil and gas field exploration and development, mining and refineries etc. It has been estimated that by the year 2025 about 75% of the world population would be living within 50 kms stretch of the coast line. This trend is more pronounced amongst the developing countries and as a consequence coastal systems/regions with degradation levels will be more conspicuous and could result in significant risks of life, property and severe health hazards. Some of the generalized characteristics of the coastal zone are mentioned below (HartWig Kremer and Criss Crossland, 2002).

- Comprises <20% of the Earths surface.
- Contains >50% of human population.
- Locating 70% of urban cities with >1.6 million inhabitants
- Yields 90% of the global fisheries.
- Produces about 25% of global biological productivity.
- Act as major sinks for sediments.
- Act as major sites for nutrients-sediment bio-geochemical processes.
- Act as a heterogeneous domain, dynamic process in space and time
- High gradients, high variabilities and high diversities.

1.3.1 Coastal features and ecosystems

Though our awareness in respect of coastal morphology, ecological dynamics of wet lands such as mangroves, tidal flats, coral reefs, sea grass systems, beaches and dunes, estuaries and deltas have increased over the past several years, the impact processes both natural and anthropogenic are still at the beginning of our understanding. Coastal systems, both terrestrial and offshore are not only the most productive but are also the most threatened systems of the world. They serve as huge productive centers and account for 35% of the global primary productivity, 90-95% of the world's marine fish, 80% of the global carbonate production, 50% of the global denitrification and 90% of the global sedimentary mineralization (UNEP, 1992). These systems are undergoing rapid physical, chemical and biological transformations over the last several years resulting in coastal degradations including severe erosion, losses in fishery resources, timber, fuel wood, oil and natural gas and beach sand minerals, agriculture and forestry, increasing pollution loads, tidal impacts and saline water intrusion processes in the near surface and deep groundwater systems. Effective measures to address these deteriorating levels world over have been very poor and ineffective. It would be the endeavour of this book to review all aspects of the subsurface groundwater systems, their resource potentials, environment and required management strategies, while taking into account the surficial impacts and their manifestations of the inland coastal ecosystems. Some of the major ecosystems confronting these coast lines are (i) Sand and gravel beaches, (ii) Estuaries, marshes, lagoons and backwaters (iii) Mangroves, (iv) Coral reefs and atolls and (v) Coastal deltas. A brief description of each of these ecosystems are briefly mentioned below.

(i) ***Sandy beaches, barriers and dunes:*** Sand beaches function as wave energy sinks and barrier beaches act as natural break waters. Coastal dunes form natural buffers and sand repositories. Majority of the coastal beaches/dunes are shaped primarily by wave and tidal processes and riverine and long shore current impacts and wind energies. Coarse sand, gravel and cobble beaches occur in tectonically active and high wave dynamic areas and fine sand and muddy beaches occur in low energy wave dynamic areas. It is estimated that over the last 100 years that about 70% of the world shorelines are retreating, 20-30% are stable and about 10% of them are advancing (Bird, E.C.F., 1993). These situations probably will alter with rising temperatures and related sea level changes in the years to come. Beaches, barriers and dunes serve as ecological protectors, but are subjected to quick dynamic erosional and depositional events depending upon the wave dynamics, currents and winds.

(ii) ***Estuaries, marshes, lagoons and backwaters:*** These ecosystems lie very close to the coast and face from time to time the ocean, atmospheric and continental dynamics, and at the same time highly productive and critical for the sustenance of coastal economy. Estuaries, marshy lands and lagoons play important role in maintaining hydrological balances, filtering water from pollutants entering into the environmental realms and provide good habitat for birds, fish, molluscs, crustaceans and other kinds of ecological sensitive fauna and flora (Beck, M.W., et al, 2001). It is estimated that world wide there are about 1200 estuaries and lagoons accounting to 80% of the worlds fresh water discharge (Alder, J., 2003). These systems often are subjected to anthropogenic impacts from humanity, industries and several pollution loads from urban and industrial centers which generally grow around these ecosystems. Efficient management and protective measures therefore are very important and necessary.

(iii) ***Mangroves:*** Mangroves are the shrubs and trees, grown very luxuriantly in the tidal flat areas and around the estuarine shorelines of the tropical and subtropical regions. These are considered as most productive bio-diverse wetland ecosystems of the earth and are estimated to cover about 16 to 18 million hectares in the Globe (Valiela, I., et al 2001; Spalding, M.D., et al 1997). These plants can survive in varying fresh water to saline conditions with different strengths and act as important guards and protectors of fauna and flora in the regions. Mangroves in general are classified into three major zones based on the physical and morphological characters of the regions (Ewel, K.C., et al 1998). (i) Tide dominated fringing mangroves (ii) River dominated mangroves and (iii) Interior basin mangroves. The fringe mangroves provide protection from cyclones and storm surges, floods and soil erosion and allow sustenance of animal habitat and nurseries. The riverine mangroves also by and large provide the same type of protective features. The interior basin mangroves in addition to the above act as nutrient sinks improve water qualities and allow growth of good plant products. These ecosystems are highly valued commodities for several coastal population groups for their living and growth. Mangroves have an important ecological and socioeconomic function in relation to sea food production, source of wood products and also act as nutrient sinks and shore line protection, (Ronnback, P., 1999), but then mangroves have become targets for degradation for several decades in terms of deforestation processes, agriculture conversions and climate change.

(iv) ***Coral reefs and Atolls:*** Coral reefs are shallow water tropical marine ecosystems characterized by a remarkably high biomass production and a rich faunal and floral diversity probably unequalled by any other habitat and harbour more than 25% of the known marine fish in the world. Corals can flourish only in relatively shallow marine waters, exposed to sunlight with optimum temperatures varying between 23 ^oC - 25 ^oC and free from suspended sediments. The reefs are formed by calcareous skeletons, a type of soft bodied radially symmetrical marine invertebrate. In general reefs are divided into three major types (i) Fringing reefs: reefs that grow close to the shore and extend into the sea like a submerged platform (ii) Barrier reefs: reefs separated from the land by wide expanses of water, but follow the coastline (iii) Atolls: reefs built up in circular fashions surrounding lagoons. The total extant of living coral reefs in the world has been estimated at about 284,300 km^2 (Spalding, M.D., et al, 2001). A major population of these are located in South East Asia. They serve important functions such as atoll island foundations, coastal protection structures and sources for beach sand. These systems are very valuable to continental pollution, coastal construction and industrial activities and climate change impacts. It is estimated that over the last few decades, about 20% of the coral reefs were destroyed and another 20% were degraded world over (Wilkinson, C., 2004).

(v) ***Coastal Deltas:*** Coastal river deltas are among the most valuable, heavily populated and vulnerable coastal systems in the world. These are also the systems where intense agricultural practices are taking place through good network of canal irrigation systems and several thousands of filter points tapping the fresh groundwater resources. The term delta was first applied by Greek historian Herodotus approximately 450 BC to the triangular alluvial deposits at the mouth of Nile river. Deltas develop where rivers deposit more sediment at the shore than can be carried away by waves. Delta plain land forms span most areas of the coastal regions and include distributory channels, river mouth bars, bays, tidal flats and ridges, beaches and dunes, swamps, marshes and estuaries. Coleman, J.M. (1976) while reviewing the processes responsible for most world delta regions indicated a number of parameters that go into the delta formation and processes such as climate, water and sediment discharges and their variabilities, river mouth processes, near shore wave power, tides, near shore currents, shelf slopes and tectonics and basin geometry. The delta basins could be classified basically into three categories, namely, river dominated deltas, wave dominated deltas and tide dominated deltas depending upon the energy levels. The deltas, estuaries and offshore island ecosystems are most vulnerable to climate change and sea level rise (IPCC, 2001). Some of the major delta systems of the world which come under the influence of climate change and sea level rise are Mississippi (USA); Amazon (South America); Rhine delta (Germany); Niger delta (Africa); Nile delta (Egypt), Indus (Pakistan); Ganges (India – Bangladesh), Mekong (Vietnam); Yangtze (China) and also several medium level delta systems in several coastal countries of the world.

1.3.2 Values and benefits of coastal zone

Some of the important values and benefits in the coastal zone are mentioned below as described by Hartwig Kremar and Chris Crossland, 2002.

Resources-Natural	Products (Natural and Human derived)	Amenities and services: (Natural & Human derived)
Water resources (Surface & Groundwater)	Agriculture & Food	Transport
Forests & Timber	Woolen industry and	Tourism
Arabia land and Food	Fisheries	Recreation & culture
Ores and Minerals	Oil, Gas & Minerals	Biodiversities
Ecosystems & Biodiversities	Habitation	Biodiversities and ecosystems services

1.3.3 Natural and Anthropogenic pressures in coastal systems

Natural impacts

- *Climate changes/shifts:* Climate changes/shifts and their intensities influence largely the thermohaline circulation pattern, the ENSO (Elnino Southern Oscillation) in Pacific and Atlantic oceans. These changes will have their impacts on our coastal ecosystems, bio-diversities, coastal hydrological processes and the CO_2 concentrations across the globe.

- *Sea level:* The IPCC estimated that the global average surface temperature has increased by 0.6 ^{o}C in the 20th century and is projected to rise by about 2.5 ^{o}C over the next 100 years. The IPCC estimates indicate that the sea level has risen by 1.0-2.5 mm a year over the last century and projects to increase to over 10-88 cm over the next 100 years.
- Several coastal ecosystems will be totally washed away and degrade and a few may survive depending upon the inland nutrients and strength they receive.
- Several coastal regions will undergo severe erosional processes, severe storm surge events and flooding etc. The tectonic subsidence that could take place in several coastal regions could trigger the subsidence rates further and facilitate large chunks of sea inundations in the low lying coastal areas.
- The atmospheric green house gases have increased considerably over the last 100 years. These will have impacts on coastal and shallow marine biological processes and their productivities, and degradation levels of all costal ecosystems and shallow coral reefs.

Anthropogenic impacts

- The population pressures in the coastal regions are increasing at an alarming rate. Most of the major cities around the world are located in the coastal areas. The influx of population in the coastal zone is of the order of 50-70% of the world population with wide variations among different coastal countries and cities. Nutrient loading into ocean basins is a key factor related to catchment area, run off and population built up.
- Agriculture and irrigation practices, conversion of forests and grass lands into agriculture based lands, intensification of fertilizer applications are some of the anthropogenic factors involved in coastal ecosystem patterns.
- Deforestation practices mounting year after year, diminishing watershed protections, increasing erosional processes and water quality deteriorations affecting the coastal ecosystems. There has been in recent years a spurt in the construction of major and minor dams in many parts of the world, affecting the river flow and sediment loads and nutrient influxes, which could bring in considerable change in the eco balance systems and increase saline water intrusion processes underground, reduce surface and groundwater discharges and biodiversities in the coastal areas.
- Urbanisation and industrial development processes, leading to nutrient and contaminant wastes, atmospheric levels, sewages, oils and oil wastes etc. are some of the important and globally significant issues affecting the coastal systems.
- Shoreline development reclamation & transportation projects like flood mitigation, barrages and dykes, ports and harbours development, dredging processes etc have affects on water qualities, biodiversities, fisheries and coastal sediment processes etc. which are globally wide spread events.
- Sand mining for minerals, oil and gas extraction and development programs will have substantial impacts on bathymetric changes, groundwater flows, shoreline stabilities, erosional processes and land subsidences.
- Fisheries is a major industry in the global coastal environment. An estimated 90% of the world fish catch comes from the coastal zone. In addition aquaculture expansion programmes are making considerable impacts on the physio chemical changes of the coastal zone.
- Integrated multidisciplinary approaches involving scientific and economic disciplines are required to be planed at macro and micro levels in different coastal countries and in the island areas.

Systematic and Holistic approaches involving studies on catchment areas of river systems, deltas, outflows, ocean dynamics and ecosystems are the need of the hour. Improved numerical and conceptual models and approaches are required to be adopted with real time analyses.

1.3.4 Global climate change impacts

The global importance of the coastal systems/area in terms of ecological and socio-economic values is well recognized and several International organizations including IPCC (Inter governmental Panel on Climate Change) have encouraged several actions and drew up programmes for appropriate management strategies. The IPCC has so far released four assessment reports since 1990 to 2007. The fifth assessment report is to be released during 2014. All these assessment reports in general cover different aspects related to scientific, technical and socio-economic information and inputs related to adaptation and mitigation strategies of climate change. The IPCC (1990) in its first assessment report, estimated that if green house gas emissions continue to grow, the global mean temperatures will increase by 0.2 ^{o}C - 0.5 ^{o}C per decade over the next century. One of the most important impacts of this global temperature change for the coastal zone is "*Accelerated Sea Level Rise (ASLR)*". The IPCC working group projected a global sea level rise ranging between 30 cm to 110 cm by the year 2100 due to thermal expansion of the ocean and melting of glacier mounds. As a consequence of this situation the coastal regions will have to face serious impacts in terms of population and resource potential losses, degradation of coastal ecosystems and increase in the levels of erosional processes etc. The climate change could also bring in variations in the intensities and patterns of extreme weather events like tropical cyclones, intense precipitation levels, storm surges and floods. In line with these findings and emerging situations, the IPCC has operationalised *a Coastal Zone Management sub group* (CZM). The initial findings of this group are summarized in the following statement *"In many parts of the world the natural systems that provide protection against the sea are being degraded by several unsustainable developmental activities such as sand and coral mining, mangrove cuttings and deforestation processes, damming the continuing river flows and wet land fillings etc. These issues are not being discussed substantially world over and the impacts on environmental degradations are increasing year after year".* The importance of these findings are explicitly reflected in chapter-17 of agenda 21 of the UN Conference on Environmental Development (UNCED) held at RIO in the year 1992. In response to the decisions in the conference, a world coastal conference (WCC93) was held at Netherlands with the following objectives:

(i) All nations with low lying coastal areas to come forward and share expertise to understand and solve their coastal management problems.
(ii) All nations prepare 'Coastal Zone Management Plans' with available tools and techniques.
(iii) All nations to participate and exchange information on climate change, impacts and adaptabilities and related programmes.
(iv) All nations to stimulate discussions and co-ordinate activities with all national and international organizations and implement coastal zone management programmes.

The WCC workshop further recognized and identified that "*Integrated Coastal Zone Management*" (ICZM) as the most appropriate process to address all short term and long term coastal management strategies including problems related to population rise, health hazards, habitat loss, coastal ecosystem degradations, beach erosion intensities, degradation of water quality changes in hydrological cycles, depletion of water resources intensities, saline water intrusion processes and adaptation to sea level rise events and other related impacts of global climate change(WCC, 1993). In addition the conference had identified the following salient points in its statement to be implemented by all coastal states by the year 2000 and also adopted an agenda for action.

- There is an urgent need for coastal states to strengthen their capabilities for ICZM, working towards the development of appropriate strategies and programmes by the year 2000.

- ICZM is the most appropriate process to anticipate and respond to long-term concerns and needs while addressing present day challenges and opportunities.
- ICZM involves the comprehensive assessment, setting of objectives, planning and management of coastal systems and resources, taking into account traditional, cultural and historical perspectives and conflicting interests and uses; it is a continuous and evolutionary process for achieving sustainable development.
- Coastal states that are in the process of defining and implementing a national programme for ICZM have encountered obstacles that constrain the effective development of national programmes. These include: limited understanding and experience in ICZM; limited understanding of coastal and marine resources; fragmented institutional arrangements; single-sector oriented bureaucracies; competing interests and lack of priorities; inadequate legislation and/or lack of enforcement; land-tenure regimes and other social factors; and lack of information and resources.
- Coastal states are urged to identify their priorites for ICZM, to identify their most pressing needs to improve their capabilities for ICZM, to undertake national measures to increase their capabilities, and to identify their special needs for assistance.
- Effective ICZM can be achieved by coordination between national, regional and international organizations and institutions. This will help to avoid unnecessary duplication and to develop the concepts, tools and networks needed to facilitate the development and implementation of national programmes. Support for ICZM capacity building could be in the following areas: information; education and training; concepts and tools; research, monitoring and evaluation; and funding.

Agenda for Action

- ***Raise awareness:*** Educate policy makers and decision makers about the urgency and the benefits of ICZM.
- ***Define the process:*** Clarify the process of ICZM and its elements, and identify the obstacles to its progress.
- ***Strengthen the national responses:*** Identify coastal states priorities for ICZM, improve their capabilities, and start implementing ICZM programmes.
- ***Strengthen the international responses:*** Strengthen international support for ICZM capacity building, including financial support for programme development, particularly in developing countries. This can be achieved through global, regional or blateral cooperation to assist and support national initiatives. Activities should include the organization of networks and clearinghouses to exchange and share ICZM knowledge, experiences, concepts, tools, education and training, and research programmes.

1.4 COASTAL SYSTEMS (NATIONAL SCENARIO)

India has an extensive coastline of about 7500 kms including those of offshore islands Andaman and Nicobar islands in the east and Lakshadweep islands in the west. The west coast in general has a wider continental shelf region (340 kms in the north and 60 kms in the south) and narrow alluvial coastal margins. The east coast on the other hand has wider alluvial margins and narrow continental shelf region with an average width of 38 kms. The coastal features include well developed beaches, and dune systems, rocky and cliffed shore lines; offshore bars; barriers and spits; tidal mud flats; marshy lands; with potential growth for mangroves; lagoons and backwaters; coral reefs and atolls and estuaries and delta systems (Ahmad, E., 1972).

1.4.1 Coastal features and ecosystems

The west coast is predominantly a coast with several river mouth estuaries, backwaters and lagoons with associated spits and barriers, narrow beaches/shore line/cliffed shorelines and offshore islands. The east coast is essentially a deltaic coast with wide spread beaches, large river mouth areas with estuarine conditions and well developed mangrove systems, lagoons, deltas and offshore islands. The Indian main land as per the naval hydrographic charts contain about 43% sandy beaches, 11% rocky coast with cliffs and 46% mud flats and marshy areas (Sanil Kumar, et al 2006). *Mangroves and estuaries* are the dominating ecological units along the Indian coast. Mangroves covers approximately an area of 6740 km^2 and estuaries cover over an area of 2.7×10^4 km^2. The estuaries are the mouth regions of the vast network of river systems joining the seas or along the coastlines and support rich biodiversities, nutrients and huge stocks of marine brackish water fish and aquaculture. The mangroves and estuaries form very important ecological assets and economic resource systems of the coastal regions and survive several environmental threats and hostile conditions, act as protective barriers from erosional processes, provide nursery grounds for a number of important fish like prawns and crabs etc and act as storehouses for several organic and inorganic nutrients. Well developed and prominent mangroves along the east coast of India are found in the delta distributary regions of Ganges in West Bengal (Sunderbans); Mahanadi – Brahmini – Baitarni delta – estuary regions of Orissa (Bhitarnika); Godavari delta-estuary region in Andhra Pradesh (Coringa); Krishna delta estuary region in Andhra Pradesh (Gollamattapaya and Nadimeru distributaries) and Cauvery delta estuary in Tamil Nadu (Pichavaram and Muthupet mangroves). In the west coast prominent mangrove systems are seen along the Gulf of Kutch and Khambat region of Gujarat. The offshore island in the Bay of Bengal contain a very prominent and well developed dense mangrove systems near the tidal creeks, bays and lagoons of Andaman and Nicobar islands. (Estuaries of India, ENVIS publication series 1/2002 and Mangroves of India, ENVIS publication series 2/2002). As per the records available it appears that over 40% of the mangrove systems along the Indian coast over the last one century have been either degraded or lost. The trends of degradation of mangroves over the last one decade are reflected in the following Table 1.6.

Table 1.6 Area distribution of mangroves in India (thousand ha)

State/Union territory	Government of India, 1987	Government of India, 1997
West Bengal (Sunderbans)	420	212.3
Andaman and Nicobar Islands	119	96.6
Maharashtra	33	12.4
Gujarat	26	99.1
Andhra Pradesh	20	38.3
Tamil Nadu	15	2.1
Orissa	15	21.1
Karnataka	6	0.3
Goa	20	0.5
Kerala	Sparse	Nil
Total	674	482.7

Lagoons and backwaters

Lagoons and backwaters occupy good stretches along the east and west coasts of India, act as good ecological centers, rich with flora and fauna and also act as sinks for nutrients. The coastal lagoons are shallow water bodies invariably separated from the ocean through a barrier but connected to the ocean at one or two inlet points. These lagoons in general are found in the low lying coastal regions and are normally align themselves parallel to the coast. They are often highly productive aquaculture systems, but at the same time strongly influenced by anthropogenic events and human activities. Some of the important lakes/lagoons along the east coast of India are (i) Chilka lagoon, Orissa (ii) Kolleru lake, Andhra Pradesh (iii) Pulicat lagoon, Andhra Pradesh (iv) Muthupet & Gulf of Mannar lagoons, Tamil Nadu. Some of the important lakes/lagoons in the west coast are (i) Vembanad lagoon (Kerala), (ii) Astamundi Lagoon, backwaters (Kerala), (iii) ETG Kulam lagoon (Kerala), (iv) Several lagoons along Maharashtra coast including Mumabi and (v) Several small lagoons in offshore islands of Lakshadweep Island.

Coral reefs and Atolls

Coral reefs in India are extensively developed and they represent both semi and sub-tropical climate types essentially along the offshore islands of Bay of Bengal and Arabian sea. Their distribution however is restricted to six regions. viz; Gulf of Kutch, Lakshadweep islands, Gulf of Mannar, Palk bay and Andaman and Nicobar islands. These reefs appear to have been building up since Tertiary times. Majority of the reefs in Lakshadweep islands appear as '*Atolls*' and the rest of the reefs both in the west and east coasts appear as '*reef*' structures with of course certain physical and structural variations. The reefs in the Gulf of Mannar, Palk bay and Andaman and Nicobar islands appear as fringing type of reefs. Platform types of reefs are seen in the Gulf of Kutch region.

Deltas

The east coast of India is predominantly a deltaic depositional coast with major river systems building their deltas like Ganges (West Bengal); Mahanadi-Brahmini-Baitarni and Subarnarekha (Orissa), Godavari-Krishna and Pennar (Andhra Pradesh) and Cauvery, Palar, Ponnaiyar and Vaighai (Tamil Nadu). The west coast of India is totally devoid of delta systems excepting Narmada and Tapti (estuarine deltas) in the North Western part of the Gujarat Coast. In addition there are a number of medium and minor rivers both along east and west coasts, and many of them are estuary delta systems bordering the Bay of Bengal and Arabian seas (Ahmad, E., 1972, Vaidyanadan, R., 1991 and Singh, I.B. and Seeta Rama swamy, A., 2006). There are 14 major rivers, 44 medium rivers and several minor rivers along east and west coasts of India making the coastal areas rich with soil and water resources and at the same time nutrient rich. All the major rivers by and large have large delta systems and the medium rivers have relatively either small deltas or estuary mouths. The delta systems of the Indian coasts are active resource centers for agriculture, industries and fisheries etc. Invariably all the coastal delta areas have good net work of canal systems and intense agricultural and irrigation practices. Population build up is increasing year after year with increasing levels of anthropogenic and pollution impacts. These rivers carry large sediment influx into the sea and get redistributed along and their associated environments such as levees, sand bars and spits, beaches and dunes etc., with rich soil patterns. A large proportion of food production comes from these delta tracks, and are active centers for fish and agriculture forming industries. These have also become active industrial centers and also centers for oil and gas explorations and development and as a result pollution levels are increasing year after year with possible threats of land subsidence and other environmental hazards (natural and anthropogenic).

1.4.2 Environmental impacts and vulnerabilities

India has been identified as one of the important countries in the world vulnerable to the impacts of global warming and *Accelerated Sea Level Rise* events (UNEP, 1989). The high degree of vulnerability of Indian coastal regions could be mainly attributed to (i) Extensive low lying coastal areas, particularly the east coast deltaic plains which are prone for saline water inundations and cyclonic threats (ii) Increasing levels of population growth, with over 30% population living in the coastal regions (iii) Large commercial exploitation of resources more than their optimum levels. A large chunk of population are directly dependent on resources like mangrove vegetations and timber wood cutting, agriculture, fisheries and aquaculture programmes (iv) Frequent occurrences of cyclones and storms. The cyclones, storms and depressions are more common along the east coast of India than in the west coast. Storm surges are generated by the winds and the atmospheric changes associated with the cyclones resulting in severe erosion of beaches and changes in the beach cycles. The tropical cyclones and surges are more common in the low latitude land locked locations in the Bay of Bengal. (v) The increase in the sea surface temperatures due to climate change could lead to increase in the frequencies and intensities of cyclones and storm surges along the Indian coasts and could bring in greater disasters in future such as loss of life and property, loss of cultivable land due to inundation of saline water, saline water intrusion and contamination of fresh water aquifers underground in the deltaic and outfall areas (vi) Exploration and exploitation of oil and gas resources. The developmental activities in the onshore and offshore regions are multiplied several folds in view of high potential oil and gas fields viz., Bombay High off shore region, Krishna-Godavari onshore and offshore regions, Cauvery delta and Mahanadi delta offshore regions etc. These activities have resulted in the oil spill contamination and waste disposals etc. (vii) Land subsidence and sea level rise: The deep seated basin structures with faulted boundaries and their reactivations could bring in land subsidence in certain regions of the coast. These events could further trigger the sea level rise and erosional impacts along the coasts. Several parts of west and east coasts of late have become targets of heavy erosion. Heavy erosional impacts are seen along the coastal regions of Kerala (480 kms), Maharashtra (263 kms), Karnataka (250 kms), Orissa (108 kms), Tamil Nadu (36 kms), West Bengal (49 kms), Gujarat (36 kms), and Andhra Pradesh (9 kms), (Sanil Kumar, V., et al 2006).

1.4.3 Coastal Zone Management/Integrated Coastal Zone Management (CZM/ICZM), National Initiatives

CZM'S and ICZM'S are two different spheres of activities dealing with coastal management systems but at the same time they are synonymous to each other. CRZ'S deal with bureaucratic norms regulations to protect the coastal resources and ecosystems where as ICZM'S deal with scientific, socioeconomic studies, capacity building, systems analysis and monitoring. Infact an intensive ICZM activity should precede implementation of CRZ'S to have a better regulatory measures. The Indian coast with a length of about 7500 kms contains valuable natural resources in terms of minerals, fisheries, soil nutrients, diversified fauna and flora and has a unique landscape attracting tourism and harbour buildings etc. In order to protect these vast resources from the onslaughts of anthropogenic and natural hazard impacts the government of India issued a notification called *"Coastal Regulation Zone act (CRZ)"* in the year 1991 under the environmental protection act 1986. The notification declares the coastal stretches of seas, bays estuaries, creeks, rivers and backwaters which are under the influence of tidal action (landward side) up to 500 meters from the High Tide Line (HTL) and the land between Low Tide Line (LTL) as *"Coastal Protection Zone (CPZ)"* . The notification further says that the coastal zones are being classified as Category I (CRZ-I),Category II (CRZ-II), Category III (CRZ-III) and Category IV (CRZ-IV) and the norms prescribed in respect of this zones are outlined below.

CRZ-I

- Ecologically sensitive areas(national/marine parks, sanctuaries, reserve forests, wild life habitats, mangroves, coral reefs, areas close to breeding and spawning grounds of fish and other marine life, areas of outstanding natural beauty/historical/heritage, areas rich in genetic diversity.
- Those falling between HTL and LTL.
- Those areas likely to be inundated due to sea level rise due to global warming and such other areas as may be declared by the concerned authority (Central/State/UT).

CRZ-II

- The areas that have already been developed up to or close to the shoreline as *'Developed area'* which falls within the limits of municipalities or in other legally designated urban areas which are already substantially developed with provisions of drainage and approach roads and other infrastructure facilities such as water supply systems and sewerage lines.

CRZ-III

- The areas that are relatively undisturbed which do not belong to either CRZ I & II. These include coastal zone in the rural areas (developed and undeveloped) and also areas within municipal limits or in other legally designated urban areas which are not substantially developed.

CRZ-IV

- Coastal stretches in the Andaman & Nicobar Islands, Lakshadweep and small islands except those designated as CRZ-I, CRZ-II, and CRZ-III.

Norms for Development and construction activities in CRZs

- The notification specifies norms and imposes certain restrictions for construction activities in different categories of CRZ areas such as covered area limits, heights and number of floors in a building etc. Specific guidelines have also been issued for development of hotels and beach resorts etc. in CRZ-III and restrict installation of effluent treatment plants and sand mining from the dune belts of CRZ areas.

Regulatory activities

- Clearances can be given for activities within CRZ areas if it requires water front and foreshore facilities subject to the clearance from the Ministry of environment and forests, Govt. of India. These include ports, harbours, light houses, spill ways, storage places for liquefied natural gas and the re-gasification facilities for transportation of raw materials for thermal plants, intake of cooling water and discharge of waste water.
- Buildings are permitted in CRZ-II areas subject to the provisions mentioned in the notification and existing local town and planning regulations including the existing norms of Floor Space Index/Floor Area Ratio.
- The area up to 200 meters from HTL in CRZ-III area is to be treated as "*No Development Zone*". However developments related to agriculture, gardens, pastures, parks, play grounds, forestry and salt manufacturing units from sea are permitted with the approval of Ministry.
- Construction of dwelling limits between 200-500 meters of HTL is permitted as they are within the ambit of traditional and customary usages of fishing villages, with certain restrictions as

notified. The total number of dwelling limits shall not be more than twice the number of existing units, covered area and shall not exceed 33% of the plot size, height shall be restricted to 9 meters and construction shall not be more than 2 floors including ground floor.

- Special provisions have been made for offshore islands such as Andaman, Nicobar and Lakshadweep islands. No new construction of buildings shall be permitted within 200 meters of HTL in Andaman-Nicobar islands. In the case of Lakshadweep, permission to construct building shall be decided based on the size of island and the distance from HTL. However in both the cases the rise of buildings are restricted to two floors only. Corals and sand from the beaches cannot be used for constructional purposes.

Prohibited Activities

- The notification prohibits setting up of new industries, expansion of existing areas and untreated wastes and effluents from coastal cities/towns and industries.
- It prohibits manufacture, storage or disposal of hazardous substances excepting transfer from ships to ports and vice-versa.
- It prohibits dumping of fly ash or any other waste from thermal power stations, mining of sands and other geological material except 'rare earth minerals' not available out side the CRZ areas. It also restricts groundwater withdrawal within 200 meters of HTL, and attempts to alter morphological configuration of dune sands and related coastal features, and setting up fish processing limits including warehousing and excluding hatchery and natural fish drying. Special provisions have been made in the notification for protection of ecologically sensitive areas such as national parks, marine parks etc.

Coastal Zone Management plans (CZM)

- As per the provisions contained in CRZ notification 1996, 13 coastal states and union territories are required to prepare Coastal Zone Management Plans (CZMPs) for identifying and classifying the CRZ-I within their respective territories as per the guidelines/notification and submit to the Government within one year stipulated time from the date of issue of the notification.
- In addition national level and state level coastal zone authorities are to be constituted as per the directives of Apex court dated November 26th 1998, delegating powers to adopt required strategies for the protection of coastal environments. The national level authority will provide all the required guidance, review modifications if any from the respective state/union territory governments and make necessary amendments whereever necessary and formulate specific management plans. (please look for details in the notification on Coastal Regulation Zone (CRZ) 1991 and subsequent amendments; Ministry of Environment and Forests; Govt. of India).

New CRZ notification 2011

In view of the several representations, complaints, modifications etc required to be made in all CRZs the Govt. of India issued a new CRZ notifications dated 6th January 2011, the details of which are published in the Gazette of India extraordinary, Part-II, Section 3, Sub-section (ii). The CRZ notification of 2011 uses essentially the 1991 notification as its base and codifies certain modifications in all CRZs. Similar to the 1991 notification the 2011 notification also classifies the 0-500 m coastal strip into four categories: CRZ-I (Ecologically sensitive areas); CRZ-II (Built up areas); CRZ-III (Rural areas) and CRZ-IV (Territorial waters and tidal influenced water bodies). In addition a separate notification for the protection of islands has also been issued. It also codifies 25 amendments to the earlier notification to ensure livelihood, security to the fishing communities and other local communities living in the coastal areas and also to conserve and protect the coastal stretches and promote development in a sustainable manner. The CRZ also includes, for the first time, the water and bed areas between the low tide line (LTL) to the territorial water limit (12 nautical miles) in case of the sea, as well as the water and the bed area of tidal influenced water bodies such as creeks, rivers and estuaries. Some other important features of this new notification are as follows:

- It introduces a concept of a "hazard line" to be demarcated taking into account tides, wave, sea level rise and shoreline changes and can expand wherever the hazard line falls beyond the 500 m line. Demarcation of such a hazard line will help to protect life and property of coastal communities and infrastructure developed.
- The notification also introduces two categories of "areas requiring special consideration"
  (i) Special dispensations are provided for greater Mumbai, Goa and the backwater islands of Kerala.
  (ii) It provides for notifying critical vulnerable coastal areas (CVCA) including the sunderbans mangroves and other ecologically important areas, through a process of consultation with local communities.
- The notification also takes into cognizance, the problem of erosion due to human interventions and proposes to classify the coastline into "high erosion", "medium erosion" and "low or stable stretches". Ports and harbour projects excepting the projects related to strategic and defense purposes will not be permissible in the high erosion areas while comprehensive environmental impact assessment (EIA) reports with cumulative studies will be required for projects in stretches classified as low and medium erosions.
- As reflected in the 1991 notification, the state governments/union territories are required to develop coastal zone management authorities which are given the primary responsibility for monitoring and enforcement. Further to assist in these tasks the respective state governments/UTs are required to constitute district level committees under the chairmanship of the district magistrate with at least three representatives of local traditional coastal communities.
- Time bound procedures for obtaining clearances of projects have been specified. Project authorities are required to submit half yearly compliance reports which are to be made available to the public and also display in the websites. (For details one can go through the website relating to CRZ notification dated 6th January 2011, and also publication in the Gazette of India extraordinary, Part-II, section 3, sub section(ii)).

Integrated coastal zone management

- The Integrated coastal zone management is a dynamic process which coordinates the activities related to environmental, social, cultural and insituational resources for sustainable development and solutions. The need to develop ICZMs for different countries/states have been emphasized by IPPC, 1990 and WCC, 1993 which have been discussed in the earlier paragraphs. These ICZM programs however have not been developed in the country in a systematic way in fact the ICZMs should have been systematized in the country simultaneously when the CRZMs were intitiated, which would have facilitated development of appropriate expert systems and insituational frames to deal with the activities related to CRZs in the country.

Government of India of late have cleared a major project on the Integrated coastal zone management in an effort to study the 7500 kms coast line. The objective of the Integrated Coastal Zone Management (ICZM) project is to assist Government of India (GOI) towards development and implementation of comprehensive coastal zone management approach in the country, and to pilot an integrated coastal zone management approaches in states of Gujarat, Orissa and West Bengal. There are four components involved in the project. The first component is National ICZM capacity building. This component includes mapping, delineation and demarcation of the hazard lines and delineation of coastal sediment cells all along the mainland coast of India. The second component involves piloting an ICZM approach in Gujarat. This component will support capacity building at the state level agencies and institutions, including preparation of an ICZM plan for the coastal sediment cell that includes the Gulf of Kutch and pilot investments. The third component involves piloting ICZM approach in Orissa. This component will include capacity building at the state level agencies and institutions, including preparation of an ICZM plan for the coastal sediment cells that includes the stretches of Paradip-Dhamra and Gopalpur-Chilika. The fourth component involves development of an ICZM approach in West Bengal on similar lines as that of Gujarat and Orissa. The ICZM programmes in other states are expected to be taken up in the second phase subsequently.

1.5 COASTAL SYSTEMS (RESOURCES)

The Indian coastal regions contain productive ecosystems such as mangroves, fisheries and aquaculture centers, rich soil systems, huge net work of canal systems with good irrigation potentials and agricultural practices, the surface and groundwater resources and several mineral deposits, oil and gas fields and lignite coal fields.

1.5.1 Water resources

Coastal systems constitute important resource belts for agriculture, irrigation, fisheries and are rich with biodiversities and nutrient soil profiles. Fresh water (surface and groundwater) plays a very important role in protecting these resources. Fourteen major rivers, forty four medium rivers and about one hundred and fifty odd small and minor rivulets join the sea on either sides of the peninsular coast, discharging fresh water of the order of 15,78,244 MCM into the sea. All the major rivers and a few medium rivers have built up good delta systems at present and also in the geological past, and are responsible for building up multiple water bearing strata in different sedimentary environmental systems along the coast. The multiple aquifer systems which were deposited under fluviatile and marine environments hold rich potentials of fresh and brackish groundwater resources which act as vital resource belts for agriculture, irrigation and several other industrial and drinking water needs and also for sustenance of flora and fauna in different coastal environments and echo systems. The deltas and sometimes estuaries are the store houses for these rich water belts and serve as potential irrigation belts for agriculture with intense canal network using surface water and high density development of dug wells, dug cum bore wells and shallow and deep tube wells. All the delta systems along the east coast have relatively high thicknesses of alluvial belts with thicknesses varying from 0-60 meters and sometimes even more. These alluvial systems constitute aquifers with rich permeabilities and high yields, where thousands of filter points, shallow tubewells are in operation supporting huge irrigation potentials. Similarly the sedimentries which are deposited in Tertiary/Mesozoic periods also serve as huge repositories for fresh groundwater systems and support irrigation potentials through shallow and deep tube wells. The Tertiary aquifers with fresh water are most prevalent in the coastal regions of Tamil Nadu, Andhra Pradesh, Orissa, West Bengal and Gujarat while some of these aquifer systems have become either brackish or saline. The irrigation potentials and availabilities of fresh waters for the coastal districts of India are briefly presented in Table 1.7 and are graphically shown in Fig. 1.10.

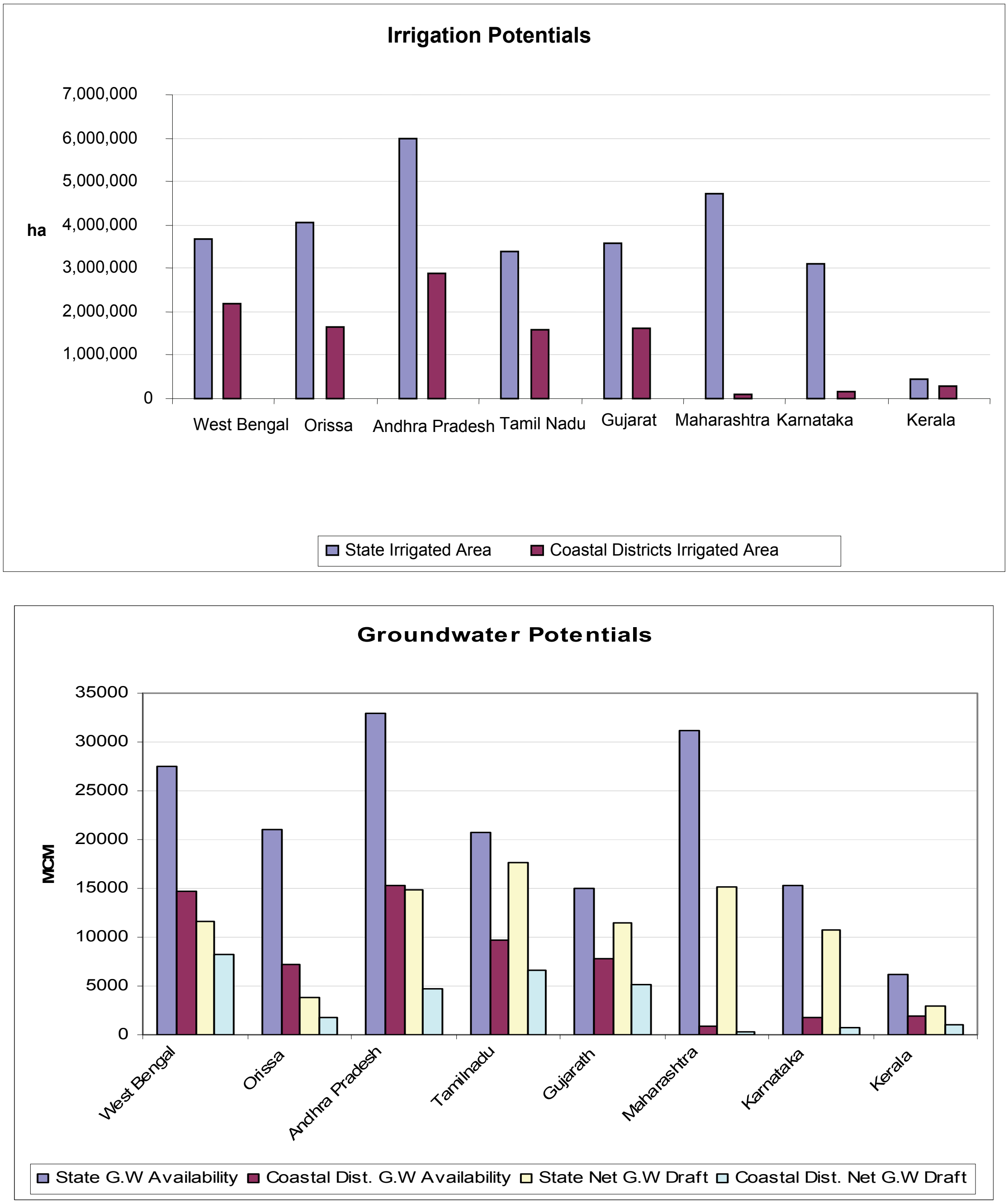


Fig. 1.10 Irrigation/groundwater potentials in coastal states/districts

Table 1.7 A Comparative Analysis of Irrigation potentials/Groundwater availabilities/draft situation in the coastal districts

S.No	State	Coastal districts	Total Irrigated Area in the state (ha)	Total Irrigated area in the coastal districts (ha)	%	Total groundwater resource availability (MCM)	Total groundwater resource availability in the coastal districts (MCM)	%	Total Draft (MCM)	Total draft in the coastal districts (MCM)	%
1	West Bengal	Midnapore, North 24 Paraganas, South 24 Paraganas, Howrah, Hugli Murshidabad, Nadia, Bhardman	3,661,000	2,188,718	59.8	27458.13	14725	53.6	11647.38	8254	70.9
2	Orissa	Bhadrak, Baleswar, Cuttuck, Ganjam, Jagatsinghpur, Khorda, Kendrapara, Puri	4040022	1644811	40.7	21009.28	7206	34.3	3847.67	1715	44.6
3	Andhra Pradesh	East Godavari, West Godavari, Krishna, Guntur, Nellore, Prakasam, Srikakulam, Vishakapatnam, Vizayanagaram	5996466	2883790	48.1	32946.36	15284.64	46.4	14901.33	4768.27	32.0
4	Tamilnadu	Cuddalore, Kanchipuram, Kanyakumari, Nagapattinam, Pudukkottai, Ramanathapuram, Sivaganga, Tirunelveli, Thanjavur, Thoothukudi, Thiruvallur, Villupuram,	3396700	1584437	46.6	20763.38	9711	46.8	17653.4	6683	37.9

Table 1.7 *Contd…*

S.No	State	Coastal districts	Total Irrigated Area in the state (ha)	Total Irrigated area in the coastal districts (ha)	%	Total groundwater resource availability (MCM)	Total groundwater resource availability in the coastal districts (MCM)	%	Total Draft (MCM)	Total draft in the coastal districts (MCM)	%
5	Gujarat	Ahmedabad, Amreli, Bharuch, Jamnagar, Junagadh, Kutch, Rajkot, Surat, Vadodara, Valsad	3572000	1605104	44.9	15020.39	7811	52.0	11485.72	5161	44.9
6	Maharashtra	Mumbai, Rajgad, Ratnagiri, Sindhudurg, Thane	4705000	100985	2.1	31214.04	847	2.7	15085.13	273	1.8
7	Karnataka	Dakshina Kannada, Udipi, Uttara Kannada	3089000	155395	5.0	15296.6	1736	11.3	10713.12	687	6.4
8	Kerala	Alappuzha, Ernakulam, Kollam, Kannur, Kasaragod, Kozhikode, Malappuram, Thirussur, Thiruvananthapuram	432000	279866	64.8	6229.55	1871	30.0	2920.01	956	32.7

1.5.2 Soil resources

Soils are thin top layers of earth's crust in different basins/water sheds and contain mixtures of minute particles, minerals, organic matter and bacteria. These are basically generated through weathering processes of provenance rocks and could be seen as *in situ* layers and sometimes transported and deposited in the vicinities of valleys, flood plains and related depositional areas, with varied thicknesses ranging from few centimeters to several tens of meters over a period of time depending upon the weathering and sedimentation processes involved. Soil profiles and platforms are essential base strata for good growth of plantations, cultivation and agricultural practices etc. The compositional soil characters depend upon its constituents like organic matter, soil organisms & bacteria, soil porosity and moisture levels and inorganic matter and soil pH and fertility. Soils could be broadly grouped into two categories namely acidic and alkaline/saline. The Acidic soils have pH in their aqueous solutions less than 7, open textures and massive structures with low Ca and Mg constituents and insignificant soluble salts. The alkaline soils are formed under high pH with significant amounts of sodium in combination with carbonates and chlorides. There are six major groups of soils in the coastal regions of India (Pofali, R.M., et al 1991).

Red soils: Red colour is due to various oxides of iron and are poor in N, P, K and with pH values ranging between 7 to 7.5. They are light in texture with good porosity and moisture levels. They occur widely in the coastal regions of Kerala, Maharashtra and certain inter deltaic regions of Tamilnadu, Andhra Pradesh, Orissa and Bengal coasts. These soils have been classified as Alfisols.

Lateritic soils: Dark brick red in colour with pH values ranging between 5 and 6. These soils form in the hilly regions and are subjected to high rainfall and weathering conditions. Eastern ghats and Western ghats contain this type soils at many places. These are classified as Ultisols and Oxisols.

Alluvial soils: These soils are sandy loam to clay loam with light grey to dark grey colour loose in structure and are good fertile soils. The pH values vary between 7 to 8. These soils are widely distributed over coastal delta plains of India and act as rich agriculture belts. These alluvial soils are classified as 'Entisols, Inceptisols and Alfisols'.

Black cotton Soilss: These are dark grey to black in colour with high clay content with pH values between 7 to 9. They have poor drainage and high base exchange conditions and contain Ca and K dominantly. They occur widely in the deltaic tracks of east coast and river mouth areas of Maharastra and Gujarat in the west coast. These are classified as 'Entisols, Inceptisols and Vertisols.

Peaty and Marshy Soils: These are well developed under humid conditions with high accumulation of organic matter. The soils get submerged in water during monsoon times and get exposed to atmosphere during non-monsoon times. These soils are black in colour with high acidic conditions and with pH values ranging from 3-3.5. These soils are commonly seen in the river mouth fringe areas of both east and west coasts.

Saline-Sodic Soils: These soils are dark grey in colour, high pH values and contain excess natural salts dominated by chlorides and sulphates and affects plant growth. These occur widely in saline affected regions of east and west coasts of India. These are classified as Aridsols, Entisols and Vertisols.

1.5.3 Mineral resources

The Indian coastal regions are endowed with rich placer mineral deposits, oil and gas fields both in the onshore and offshore delta frames, Tertiary lignite beds, placer deposits like ilmenite, rutile, zircon, monazite, garnet, sillimanite, glass sands and patches of gold and diamonds are reported to occur along the east and west coasts of India (Victor Rajamanickam, G., 2000; Subrahmanyam, A.V., et al., 2005). These placers basically are derived from the provenance rocks like granites, gneisses and schists of east and west coasts of India, transported by rivers/streams etc. and are subjected to wave actions and currents of the sea coast and get deposited along the coastal stretches, such as continental shelf regions, beach and dune sands, and along the areas adjoining the lagoons and estuaries. Some of the prominent and abundant placer deposits along the Indian coasts are briefed here. Ilmenite ($FeTiO_3$), Rutile (TiO_2), Zircon ($Zrsio_4$), Garnet and Monazite are the common heavy minerals distributed widely along the coasts of Kerala, Tamilnadu and Andhra and Orissa. The estimated deposits of these minerals in the country as a whole are: Ilmenite (278 million tons), Rutile (18 million tons), Zircon (18 million tons), Monazite (7 million tons) and Garnet (80 million tons) and Sillimanite (84 million tons) (Singh, A.P. and Gupta, P.K., 2003). In addition large quantities of glass sands and scattered quantities of gold coastal placers are reported from the coastal regions. The coastal placers being dynamic, the exact estimates of these deposits are subjective in nature but presumably about 30 to 40% of these overall estimates could come from placers of east and west coasts of India. The importance of these minerals are on the rise world over in view of their strategic importance in various industries like refractories, nuclear power plants, and gemstones.

The coastal deltas, on shore and offshore areas are the sites for potential occurrences of petroleum and gas fields. The Bombay high offshore region and the Krishna-Godavari onshore and offshore areas contain huge deposits of oil and gas. According to the Ministry of Petroleum and Natural gas, the estimated resources of the hydrocarbon potential (crude oil and gas) in the Bombay high area of west coast of India are of the order of 731.34 million tons. Another potential area along the east coast of India is Krishna Godavari basin. The estimated hydro carbon reserves in the K-G basin are of the order of 726 million tons. This shows both Bombay high structure on the continental shelf region of west coast and the onshore and offshore areas of Krishna–Godavari basin by and large contain rich potentials of hydrocarbons. The oil and gas commission have drilled several wells in the other coastal offshore areas along the east coast of India, but are of little importance when compared to overall production of oil and gas in the country.

The Lignite (Tertiaries) coal is known to occur in several coastal regions, but the most potential lignite field is Neyveli Lignite field in South Arcot region of Tamil Nadu. The estimated resources are of the order of 3840.36 million tons. These rich lignite belts occur as in the bedded formations in Tertiaries, spread over an area of 260 km^2 with thicknesses varying between 3 to 24 meters. In addition occurrences of tertiary lignites are reported with thin layers in coastal regions of Kerala, Orissa, and Gujarat but are not of much economic significance.