Chapter 4

Climate

INTRODUCTION

The climate of India is essentially sub-tropical monsoonic. The word 'monsoon' has been derived from the Arabic word ***'mausim'*** which means 'season'. Originally, the word 'monsoon' was used by Arab navigators several centuries ago, to describe a system of seasonal reversal of winds along the shores of the Indian Ocean, especially over the Arabian Sea, in which the winds blow from the south-west to north-east during the summer season and from the north-east to south-west during the winter season. In other words, monsoons are periodic (seasonal) winds in which there is a complete reversal of the wind direction after every six months.

In the opinion of Chang-Chia-Cheng: "Monsoon is a flow pattern of the general atmospheric circulation over a wide geographical area, in which there are clearly dominant winds in one direction in every part of the region concerned, but in which this prevailing direction of wind is reversed or almost reversed from winter to summer, and from summer to winter."

Monsoons are especially prominent within the tropics on the eastern sides of the great landmass, but in Asia, it also occurs outside the tropics in China, Korea, and Japan, and may be observed up to 60° north. South-East Asia, especially the subcontinent of India, however, is a typical example of a monsoon region. Other areas which experience similar but less pronounced seasonal changes of wind direction include south-eastern USA, the Caribbean Islands, Madagascar, East Africa, the Guinea coast of West Africa, South-east Asia, Philippines, south-eastern China, South Korea, and North Australia (**Fig. 4.1**).

INDIAN MONSOON

Monsoons are a complex meteorological phenomenon. Experts of meteorology have developed a number of concepts about the origin of monsoons. Some of the important concepts about the origin of monsoons have been given as under.

The Thermal Concept of Halley (1686)

Halley, a noted astronomer, hypothesised that the primary cause of the annual cycle of the Indian monsoon circulation was the differential heating effects of the land and the sea. According to this

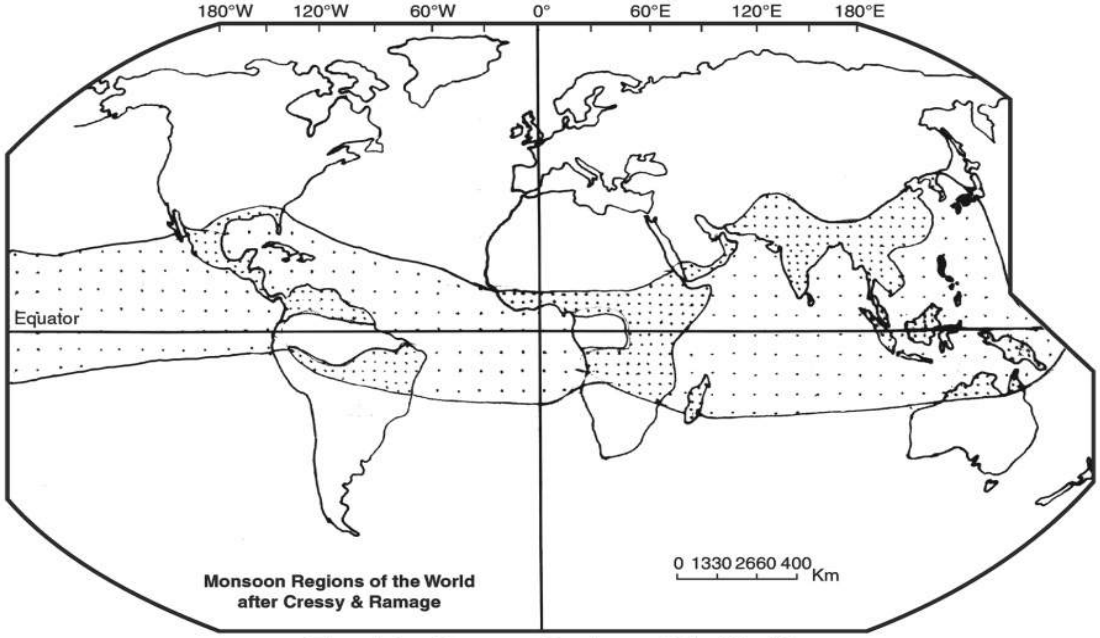


Fig. 4.1 Monsoon Regions of the World

concept *monsoons are the extended land breeze and sea breeze on a large scale, produced by the differential heating of continents and ocean basins* (**Fig. 4.2**). During the summer season in the Northern Hemisphere, when the Sun's rays are vertical over the Tropic of Cancer, the huge landmass of Asia heats quickly and develops a strong low pressure centre near Lake Baikal (Siberia) and Peshawar (Pakistan). This thermal low extends up to 700 mb. Moreover, the pole-ward shift of the Inter-Tropical Convergence Zone (ITCZ) to a position over southern Asia reinforces the thermally induced low pressure centre. In comparison to this, the pressure over the adjacent water of the Indian and the Pacific Oceans is relatively high. Under these conditions, a sea-to-land pressure gradient develops. Consequently, the surface air flow is from the high pressure over the oceans towards the low pressure areas over the heated landmass. Under the extreme low pressure condition on land, the wind from the southern part of the Indian Ocean (south of Equator) is attracted towards the subcontinent of

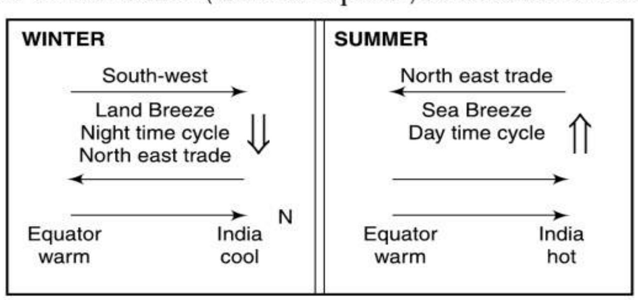


Fig. 4.2 Land Breeze and Sea Breeze: Monsoon Cycle

India. The air coming from oceans towards land is warm and moist. When land barriers like mountain ranges and plateaus come in the way of the moisture-laden winds, they ascend and result into saturation, condensation, and precipitation (**Fig.4.3**).

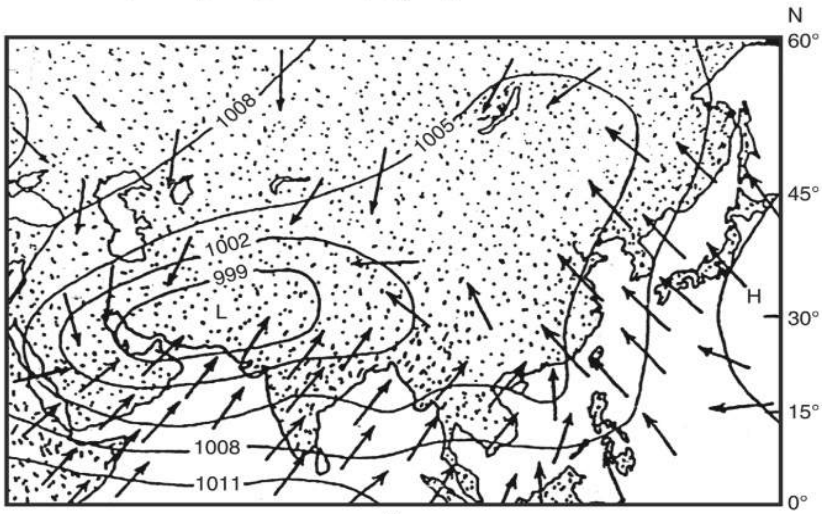


Fig. 4.3 The Summer Monsoon

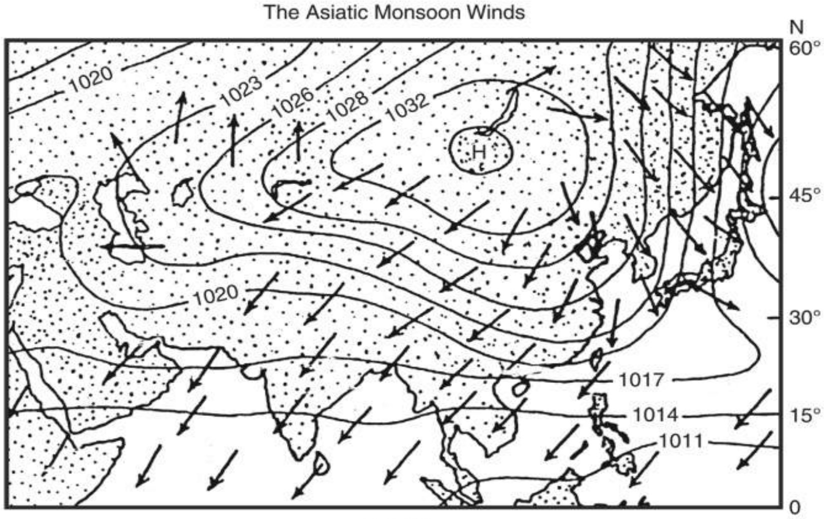
Contrary to this, in the Northern Hemisphere during winter season, there develops high pressure areas near Baikal Lake (Siberia), and Peshawar (Pakistan). As compared to these high pressures, the Indian Ocean and the Pacific Ocean (south of Japan) remain relatively warm, having low pressure areas. Consequently, there is an outflow of air from the high pressure of the land to the low pressure areas of the oceans. The air blowing from high pressure areas of land towards the sea is cold and dry. This cold and dry air is incapable of giving precipitation unless it comes into contact with some water body (ocean/sea) (**Fig. 4.4**)

The thermal concept about the origin of monsoon has, however, not been accepted universally as it fails to explain the intricacies of monsoon. Besides differential heating, the origin and development of monsoon are also influenced by the shape of the continents, orography, and the conditions of air circulation in the upper troposphere. The Halley's concept has been criticised on more than one count as follows:

1. The low pressure areas that develop over the continents during the summer season in the Northern Hemisphere are not stationary. These low pressure areas change their position (location) suddenly. This sudden change in the low pressure areas are not exclusively related to low thermal conditions. The low pressure areas stabilises in June in the north-eastern parts of the subcontinent. In fact, they represent the cyclonic lows associated with the dynamic factors, and therefore, these low pressure areas cannot be termed as only thermally induced.
2. Had the monsoon been thermally induced, there would be anti-monsoon circulation in the upper air of the troposphere, which is lacking.
3. Although high temperature and the consequent low pressure takes the north-west in its grip from the middle of April, no rain starts in northern India till the middle of June.

4. The modern researches in meteorology have shown that the monsoon rainfall is not wholly orographic. They are an amalgamation of convectional, orographic and cyclonic rainfall.
5. Instead of two broad seasons (winter and summer) the monsoon climate has more seasons (four in India), due to the highly variable characteristics of temperature and precipitation.
6. Halley did not take into consideration the Coriolis effect of rotation of the earth on its axis. On a rotating earth, the wind has a tendency to move towards its right in the Northern Hemisphere and towards its left in the Southern Hemisphere.
7. The role of latent heat passing into the atmosphere through water vapour was also not considered by Halley; water vapour also plays an important role in the origin and development of monsoons.

The Asiatic Monsoon Winds



January

Fig. 4.4 The Winter Monsoon

The Dynamic Concept by Flohn

The dynamic concept about the origin of monsoons was put forward by Flohn in 1951. According to this concept, monsoon is the result of seasonal migration of planetary winds and pressure belts**.** The Inter-Tropical Convergence Zone (ITCZ) is formed due to the convergence of north-east and south-east trade winds near the equator. The northern and the southern boundaries of the ITCZ are called NITC (Northern Inter-Tropical Convergence) and SITC (Southern Inter-Tropical Convergence) respectively. There is a belt of doldrums within the Inter-Tropical Convergence, characterised by equatorial westerlies. At the time of the summer solstice (21st June), when the Sun's rays are vertical over the Tropic of Cancer, the NITC is extended up to 30° N latitude, covering South and south-east Asia. Thus, equatorial westerlies are established over these areas. The equatorial westerlies become south-west or summer monsoons. On a rotating earth, the trade winds of the Southern Hemisphere after crossing the equator turn towards their right (Coriolis effect) (**Fig. 4.5**). The NITC is associated with numerous atmospheric storms (cyclones) which yield heavy rainfall during wet monsoon months (July to September). Similarly, the north-east or winter monsoon

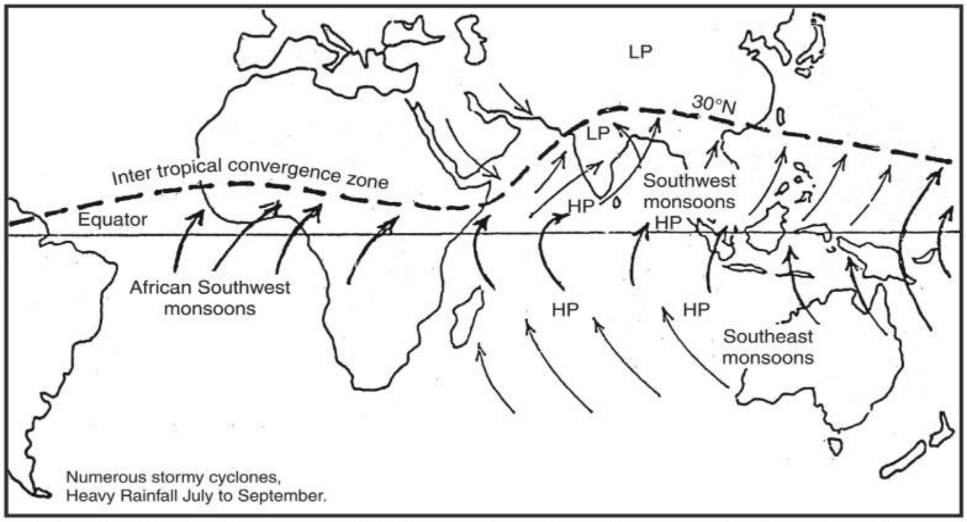


Fig. 4.5 South–West Monsoon (*Patterns of Surface Monsoon Winds in July (Summer)*)

does not originate only due to low pressure in the Southern Hemisphere during winter solstice (when the Sun's rays are vertical over the Tropic of Capricorn). In fact, the north-east monsoons are north-east trade winds which are re-established over south-east Asia due to southward shifting of pressure and wind belts. It is obvious that due to southward movement of the Sun at the time of winter solstice, the NITC is withdrawn from over south and south-east Asia, and north-east trade winds occupy their normal position. These north-east trades, thus, become winter monsoons. The north-east monsoons having their origin on land are generally dry and devoid of rains (**Fig. 4.6**).

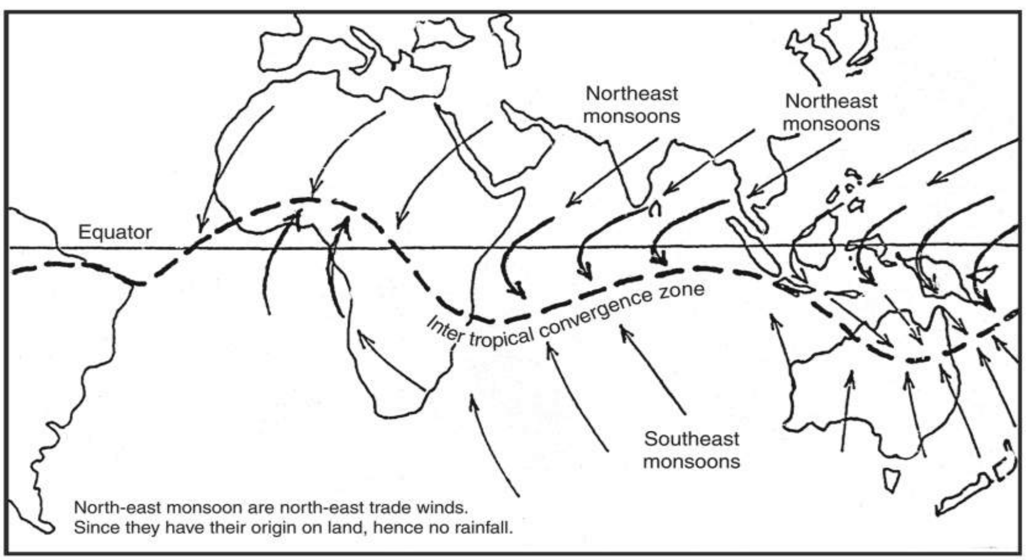


Fig. 4.6 North–East Monsoon (*Patterns of Surface Monsoon Winds in January (Winter)*)

In brief, according to Flohn, the existence of monsoons in Asia, especially in the subcontinent of India, is not due to temperature contrasts between land and sea, but mainly due to the annual migration of thermally produced planetary winds and pressure belts. Despite the relative shifting of Inter-Tropical Convergence (thermal equator) and pressure belts, Flohn seems to have ignored the upper atmospheric circulation (jet streams) and the southern oscillation, which make the Asiatic monsoon a fairly complex system. He also could not explain the causes of early arrival of Indian monsoons in the states of north-east India. The dynamic concept, therefore, was also not taken as the sole explanation of the origin of monsoons.

Recent Concepts about the Origin of Indian Monsoons

During the last five decades, the upper atmospheric circulation has been studied significantly, as a result of which meteorologists have raised certain doubts about the validity of the classical concept of the origin of Indian monsoon. It is now believed that the differential heating of land and sea cannot produce the monsoon circulation. More recent theories have laid greater emphasis on the circulation in atmosphere over the subcontinent and the adjoining areas. Apart from the upper atmospheric circulation, recent concepts rely heavily on the role of the Tibetan Plateau, jet streams, and the El-Nino (Southern Oscillation).

The data gathered by meteorologists after the Second World War have revealed that the origin and mechanism of monsoons are related to the following phenomena:

(i) The role of the Himalayas and Tibetan Plateau as a physical barrier and a source of high-level heat.
(ii) The circulation of upper air jet streams in the troposphere.
(iii) The existence of upper air circum-polar whirl over north and south poles in the troposphere.
(iv) The differential heating and cooling of the huge landmass of Asia and the Indian and the Pacific Oceans.
(v) The occurrence of El-Nino in the South Pacific and Indian Oceans.

INDIAN MONSOONS AND THE TIBET PLATEAU

In 1973, the Monsoon Expedition (Monex) was organised as a joint venture of the Soviet Union and India. Under this expedition, four Russian and two Indian ships equipped with modern scientific instruments were pressed into service in the Indian Ocean and the Arabian Sea to investigate the phenomenon of Indian monsoons. The period of investigation extended from the month of May to July, 1973. On the basis of the data obtained, the Soviet meteorologists arrived at the conclusion that the Tibet Plateau plays a crucial role in initiating the monsoon circulation over the Indian subcontinent. In 1958, Dr. P. Koteswaram, the Director General of the Indian Meteorological Observatories, while participating in the international symposium on 'The Monsoons of the World' had expressed views that the summer-time heating of the Plateau of Tibet was the most important factor in the causation and maintenance of monsoonal circulation. The Indian as well as the Soviet scientists were unanimous in their views on this point.

The plateau of Tibet is 600 km wide in the west and 1000 km in the east. Its length from west to east is about 2000 km. The average height of the plateau is about 4000 m. Thus, it is an enormous block of high ground acting as a formidable barrier. Due to its enormous height it receives 2°C to 3°C more insolation than the neighbouring areas. It is also one of the most important geographical controls on the general atmospheric circulation in the region. The Plateau of Tibet affects the atmosphere in two ways, acting separately or in combination: (i) as a physical barrier, and (ii) as a high-level heat source. The meridional cross-section of the Indian summer monsoon and its relationship with the Tibetan-Himalayan massif has been shown in **Fig. 4.7 and Fig. 4.8.**

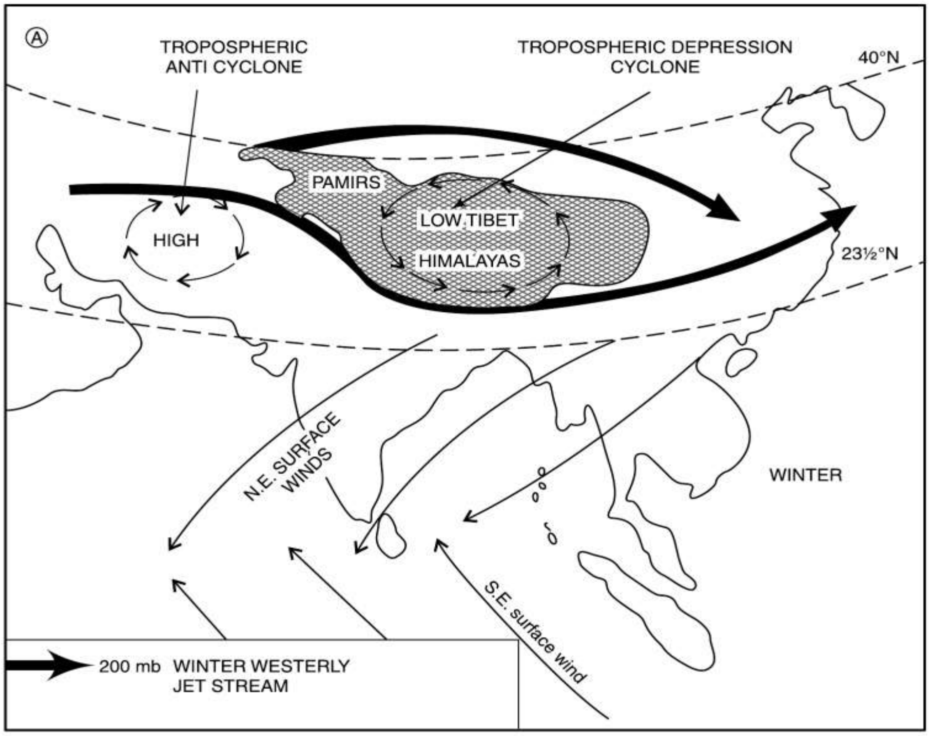


Fig. 4.7 Cross Section of the Indian Summer Monsoon

According to Maung Tun Yin, the Tibetan Plateau acts as a physical barrier. At the beginning of June, the subtropical jet stream disappears completely over northern India (**Fig. 4.8**). At this time, the jet stream shifts to the north of the Himalayas and Tibet, and takes up a position at about 40° N. Yin considers that there is a correspondence between the shifting of the jet and the slowing down of the westerlies over the whole of Eurasia. In fact, the plateau of Tibet becomes very cold in winter, and proves to be the most important factor in causing the advance of the jet far to the south in the middle of October. Thus, he opines that the abrupt onset of summer monsoon at the beginning of June is prompted by the hydro-dynamic effect of the Himalayas and not by the thermally induced low pressure centre over northwest India. In the middle of October, the plateau proves to be the most important factor in causing the advance of the jet south of the Himalayas or bifurcate it into two parts (**Fig. 4.7**).

The summer-time heating of the Tibetan Plateau makes it a high-level heat source. This 'Heat Engine' produces a thermal anticyclone over this region. A warm core anticyclone (high pressure) is formed over this plateau during the summer monsoon period. The formation of this anticyclone takes place in the middle part of the troposphere at 500 mb level. It is the result of a process called

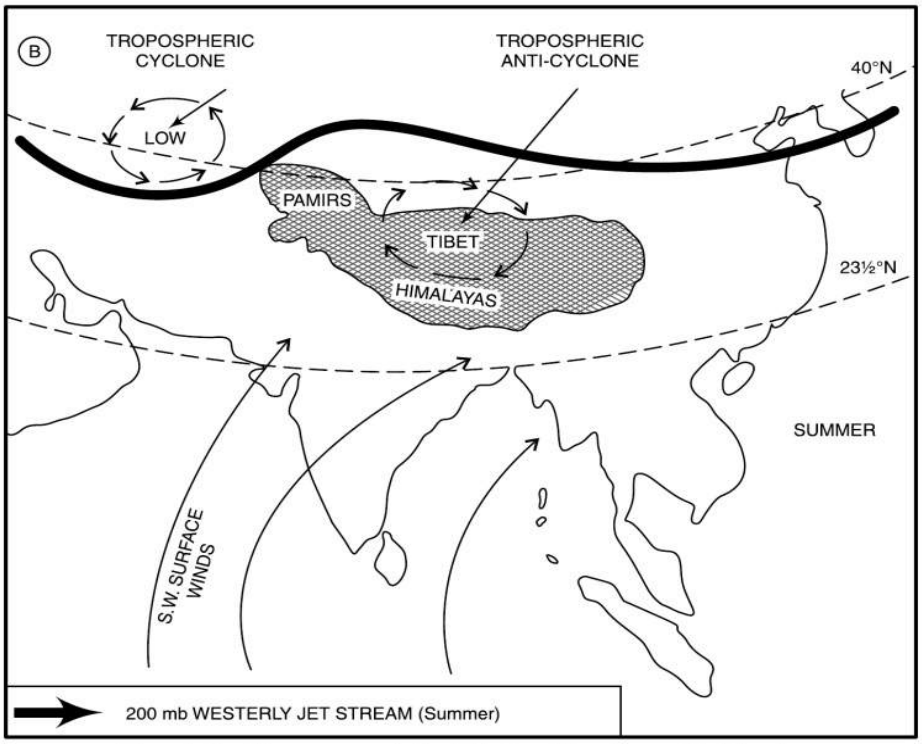


Fig. 4.8 Monsoon and the Tibetan-Himalayan Highlands

anti-cyclogenesis. The anticyclone at 500 mb at Tibet weakens the western sub-tropical jet-stream south of Himalayas, but produces tropical easterly jet on the southern side of the anticyclone. This tropical easterly jet stream first develops in longitudes east of India and then extends westwards across India and the Arabian Sea to eastern Africa. Blowing along Kolkata-Banglore axis the air under this jet descends over the Indian ocean and intensifies its high pressure cell, so as to finally move as south-west monsoon. The data collected under Monex support that higher the inensity of the tropical easterly jet greater would be potency of the high pressure cell over the Indian Ocean and stronger would be impact of south-west monsoon. Fig. 4.9 shows the meridional cross section

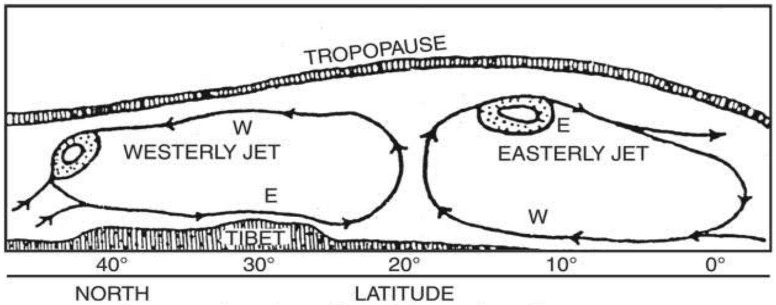


Fig. 4.9 Meridional Profile of the Indian Summer Monsoon

of the westerly and easterly jet-streams and their relationship with the Tibetan Plateau. However, on the southern side of this upper air anticyclone, the direction of air flow is from east to west. In fact, these easterly winds blowing in the mid-troposphere are known as tropical easterly jets. **Fig. 4.9** shows the meridional cross section of the Indian summer monsoon and its relationship with the Tibetan-Himalayan Highlands.

JET STREAM AND INDIAN MONSOONS

Jet stream is the most prominent movement in upper level westerly wind flows; irregular, concentrated, meandering bands of geo-strophic wind, travelling at speeds of 300 to 400 kmph. The jet streams are high altitude (9000–12000 m) westerly winds between middle latitudes (summer 35°N–45°N; winter 20°N–35°N) in the Northern Hemisphere. Recent researches have shown that these winds exert considerable impact on surface weather conditions.

The influence of jet streams on the origin and development of Indian monsoons may be appreciated from the following description of weather phenomena during the summer and the winter seasons. The upper air westerly jet streams are extended upto 20°N–35°N (Nagpur, Raipur latitudes) due to equator-ward shift of upper air north polar whirl during northern winter (October to February). In the winter season, the upper air westerly jet streams are bifurcated into two branches due to physical obstruction of the Himalayas and Tibetan Plateau. One branch is located to the south of the Himalayas, while the second branch is positioned to the north of the Tibetan Plateau (**Fig. 4.7**). The upper air high pressure and anticyclonic (with clockwise air circulation) conditions are developed in the troposphere over Afghanistan and Pakistan. Consequently, the winds tend to descend over the north-western parts of India, resulting into the development of atmospheric stability and dry conditions. Besides, the upper air westerly jet streams also cause periodic changes in general weather conditions because they lie over the temperate low pressure (cyclonic wave) which moves from west to east under the influence of upper air westerly jet streams across the Mediterranean Sea and reach Afghanistan, Pakistan and north-west India. These storms are not frontal cyclones, but waves which move at the height of 2000 metres from the mean sea level, while at the surface they are north-east trade winds. The arrival of these temperate storms (western disturbances) causes precipitation leading to an abrupt decrease in air temperature. The weather becomes clear after the western disturbance passes away. On an average, 4 to 6 cyclonic waves reach north-western India between October and April each year. They (the western disturbances) affect weather conditions during the winter season up to Patna (Bihar) and give occasional rainfall which is highly beneficial for the standing rabi crops, (wheat, barley, mustard, gram, lentil, etc.).

The tropical easterly jet stream extends far to the north of Tibet and the air flow is roughly along the Kolkata-Bangalore axis. These upper air easterlies descend into the permanent high pressure area formed over the southern Indian Ocean. This naturally intensifies the 'High' already present there. It is from this high pressure cell that the onshore winds start blowing towards the thermally induced low pressure area, developed in the northern part of the Indian subcontinent. After crossing the equator such winds become south-westerly and are known as the south-westerly summer monsoons. These surface winds have vast potentiality for south-westerly summer monsoon and precipitation. It is, therefore, clear that the strength of the easterly jet stream is directly related to the intensification of permanent 'High' formed over the southern Indian Ocean. Since this high pressure makes the pressure gradient steeper, so it is the main causative factor for determining the vigour of the summer monsoon.

During the summer season in the Northern Hemisphere, low pressure areas develop at the ground surface near Peshawar (Pakistan) and north-west India due to intense heating of ground surface during April, May, and June. But as long as the position of the upper air jet stream is maintained above the surface low pressure (to the south of Himalayas), the dynamic cyclonic conditions persist over Iran, Afghanistan, Pakistan, and north-west India. The winds descending from the upper air high pressure obstructs the ascent of winds from the surface low pressure areas, with the result that the weather remains warm and dry. This is why the months of April and May are generally dry and rainless in spite of high temperatures (low pressure on land) and high evaporation. It may be pointed out that monsoon arrives in Myanmar and north east Indian states in May or early June. Upper-air low pressure is formed to the east of the eastern limit of the Himalayas due to upper air easterly jet streams, with the result that the winds coming from the south of Myanmar are forced to ascend and yield copious rainfall. The Myanmar monsoon also affects Bangladesh and the hilly states of north-east India which receive pre-monsoon showers in the months of April, May, and the first week of June.

EL-NINO AND THE INDIAN MONSOON

The Indian monsoon is also influenced by EL-Nino, Southern oscillation and Somalian ocean current. El-Nino, meaning ***"Child Christ",*** is a warm ocean current appearing along the Peru coast, generally in December. It replaces the cold Peru Ocean Current flowing along the Peru coast in normal years. Under normal conditions, the Peru is a cold water current, while over the western Pacific, (Indonesia and eastern Australia) the ocean current is warm and deep **(Fig. 4.10).** The appearance of El-Nino *'reverses the condition'* there, and develops warm conditions over the eastern Pacific (Peru coast) and cold conditions in the western Pacific (east of Australia and Indonesia). Whenever this usually warm ocean current (El-Nino) is produced near the Peruvian coast, the amount of precipitation in the coastal areas of South America is usually high, while the eastern coasts of Australia and Indonesia record drought conditions. In brief, the occurrence of El-Nino results into a weak monsoon causing drought, floods and failure of crops.

The Southern Oscillation (SOI) is the name ascribed to the seesaw pattern of meteorological changes that are often observed between the Pacific and the Indian Oceans. It has been observed that whenever the surface pressure is higher over the Pacific, the pressure over the Indian Ocean tends to be low. As pressures are inversely related to rainfall, this suggests that when low pressure prevails over the Indian Ocean in the winter months (positive Southern Oscillation) the chances are that the coming monsoon rains will be good. In opposition to this, when high pressure prevails over the Indian Ocean in winter season, the coming monsoon will be weak. The term Southern Oscillation was discovered by Sir Gilbert Walker, the first Director General of the Indian Meteorological Service in 1924.

The oscillation has a period varying from 2–7 years. The intensity of Southern Oscillation (SOI) is measured by the differences in sea level pressures at Tahiti (18°S and 149°W), a station in the mid-Pacific, and Port Darwin (12°S and 130°E), a representative station in the Indian Ocean (**Walker Cell, Fig. 4.10)** A negative value of Southern Oscillation Index (SOI) implies low pressure over Peru Current and higher pressure over north Indian Ocean during the winter season and a poor or indifferent monsoon. Thus, there is a close relationship between the appearance of El-Nino and negative SOI. The low and negative phase of the Southern Oscillation in combination with El-Nino is called ENSO event.

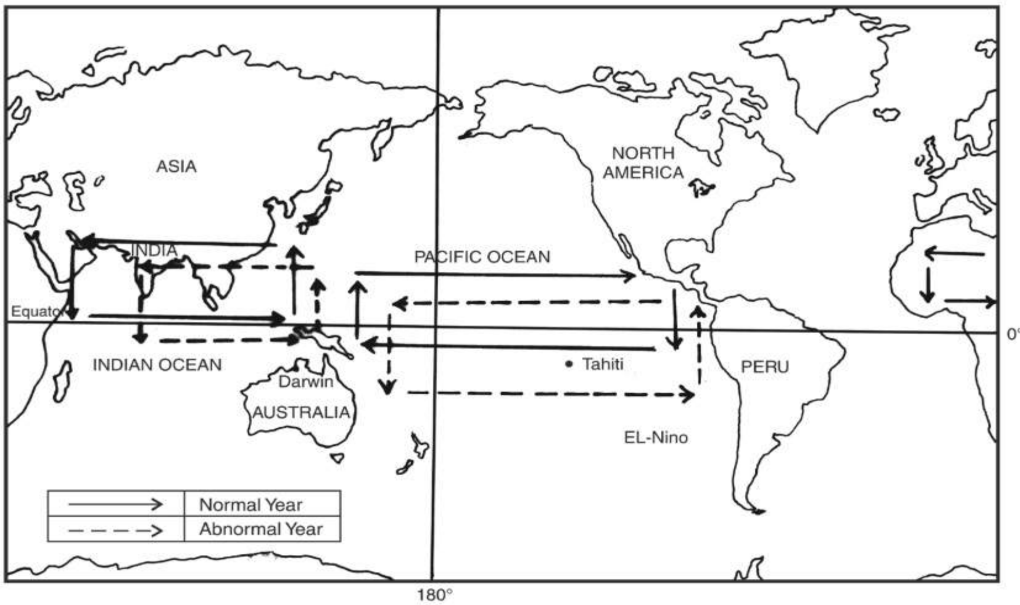


Fig. 4.10 Walker cells (*Southern Oscillation (SOI) and Indian Monsoon*)

As stated above, the Southern Oscillation is closely linked with the Walker Circulation. With a high positive Southern Oscillation, there would be a zone of low atmospheric pressure over Australia and Indonesian Archipelago. It will be accompanied by large convective clouds, heavy rainfall and raining air motion. This air eventually runs eastward, and after traversing the Pacific as a high level westerly wind at 200 mb, it descends over South America.

In terms of global winds, the Walker circulation suggests a strong belt of convergence between the trade winds of both the hemispheres at a location slightly to the north of the equator. These trade winds pile up a huge quantity of warm water in the western Pacific, produce equatorial counter-current from the Indonesian coast and facilitate upwelling of cold water from below, near Peru coast, giving rise to cold Peru current. Hence, high positive value of Southern Oscillation (SOI) indicates:

(i) a cold Peru current,
(ii) strong trade winds,
(iii) accumulation of water in western Pacific which is balanced by the Equatorial Counter Current and under-current,
(iv) a rise in the depth of thermo-cline as we proceed from the western half of the Pacific, and
(v) an ascending branch of the Walker Circulation over Australia and Indonesia with its descending branch over South America (**Fig. 4.10**). Such a normal condition leads to a normal south-west monsoon.

The appearance of El-Nino leads to a *'warm phase'* of the Pacific or negative Southern Oscillation (SOI). Now, the ascending branch of the Walker Cell shifts to the central regions of the Pacific Ocean and the descending air branch to the south-eastern parts of the ocean (**Fig. 4.10**). As upwelling off the South American coast decreases, the sea surface temperature rises. This leads to weaker trade winds, less accumulation of warm water on the western half of the Pacific Ocean, weakening of the Equatorial under current, heavy rain and floods along the South American coast and poor monsoon or monsoon failure over the subcontinent.

Somalian Current

The Somalian current changes its direction of flow after every six months. Normally, there remains a low pressure area along the eastern coast of Somalia. In exceptional years, after every six or seven years, the low pressure area in Western Arabian Sea becomes a high pressure area. Such a pressure reversal results into a weaker monsoon in the subcontinent of India.

BURST OF MONSOON

The suddenness and abruptness of the Indian monsoon is known as the *'burst of monsoon'*. The onset over the Indian sub-continent is abrupt and dramatic. It is always accompanied by turbulent weather. The so called burst of monsoon is associated with certain basic changes in the general upper-air circulation over southern Asia. In April and May, the insolation heating of the sub-continent tends to establish the south-westerly monsoon flow from the adjacent warm ocean, but northward surge of the same is retarded by the westerly zonal flow associated with the subtropical jet stream over northern India. However, in late May or early June, when the thermal conditions are satisfied, the jet stream disappears completely from the south of the Himalayas and shifts to a position to the north of the Himalayas and Tibet. At the same time, the upper trough low (low pressure) also moves westward from 85° E to 75°E. It may be pointed out that the jet stream does not retreat slowly. The process of this shift is rather quick. Now, with the disappearance of the jet, a definite monsoon circulation from the sea on to the land is established. The summer monsoon generally begins in late May in most parts of south-east Asia. But over India, it is delayed until the middle or late June. The change from one regime to another is abrupt. It is well to remember that the onset of monsoon occurs in several stages depending on the periodic advance and withdrawal of the equatorial convergence zone.

In the opinion of Koteswaram, the burst of monsoon is closely related to the development of a warm-core upper anticyclone (high pressure) over the extensive and lofty Tibetan Highland. This upper level anticyclone produces an easterly jet over India which is positioned at about 15°N. It is definitely a part of readjustment in the general planetary circulation pattern. Gradually, the easterly jet covers the entire region extending from India to east Africa. The above mentioned upper air condition paves the way for the advance of south-westerly monsoon current over the subcontinent. The monsoon current, therefore prevails throughout India. The depth of the monsoon in India is about 6.5 km, while over the Gangetic Plain it is only about 5 kilometres. The current is overlain by a layer of easterly winds (easterly jet stream).

The abrupt arrival of monsoon is of great climatic and social significance to the people of the subcontinent of India. The onset of monsoon puts an end to the scorching weather and the local hot winds *(loo)* in the northern plains of India. The relative humidity increases in the atmosphere tremendously. The arrival of monsoon is also the beginning of agricultural operations for the kharif crops in the rain-fed areas. The high temperature and high relative humidity are, however, oppressive and injurious to health. It is in the season of general rains (July to September) that people suffer from many diseases and epidemics.

BREAKS IN THE MONSOON

The migration of the monsoon rainfall zone is one of the major sub-seasonal variations of the summer (or south-westerly) monsoon. Thus, the monsoon is not a continual deluge of a number of months, duration, but has inter-seasonal variability; being made of a series of discrete events, both pluvial and dry. Viewed locally, these are the active and break monsoons respectively which exist on a time scale ranging from a few days to few weeks. Thus, while the monsoon appears to have a well-defined annual cycle, closer examination shows that the monsoon has substantial variability which becomes evident as the intensity of monsoon rains wax and wane through the wet season. Periods during which there is a rapid succession of weather disturbances or storms lasting a few days are referred to as *active periods* of the monsoon. Periods during which there is no rainfall for few days are the *break periods* of the monsoon. During an active phase, the Tropical Easterly Jet Stream (TEJ) remains very strong in the upper troposphere indicating strong convection and latent heating. But, when the maximum cloudiness remains locked up in the foothills of the Himalayas and the monsoon rainfall zone moves in this direction, subsidence occurs to produce a weak easterly flow in the upper troposphere. This creates the condition of break in monsoons.

In break monsoon condition, there is a general rise of pressure (as well as temperature) over the country and the isobars show marked refraction along the west coast. Cloudiness decreases and the south-easterlies at the surface levels over northern India are replaced by hot westerly air which blows over the plains, since the broad-scale surface pressure (the monsoon trough) shifts to the Himalayas and the rainfall practically ceases over the country outside the Himalayan regions and the southern slopes of the Himalayas, leading to high floods in the plains of these Himalayan rivers. Thus, though there is no rain over the plains, all the major northern and eastern Indian rivers rise and floods ensue.

Under weak monsoon conditions and in the years when the eastern end of the axis of the monsoon trough is oriented southward in Odisha, Jharkhand, Chhattisgarh and Madhya Pradesh, a low valley trough develops over the Assam Plain aligned along river Brahmaputra between the eastern Himalayas and the Shillong Plateau. The vertical extent of this low valley trough is 2 to 3 kilometres with the south west Monsoon lying to the south of the trough, remaining independent of the main monsoon trough. But, when the latter moves northwards and extends to the Himalayas, it joins the trough over the Assam Plain to cause heavy rainfall there.

The break in monsoon conditions generally occurs in the peak months of July and August, and lasts for at least 3 to 5 days over 500 to 1000 kilometres length in these months. The breaks occur on two time scales, usually from 10 to 20 days which on some occasions gets locked to a 40 to 50 days' break configuration. Depending upon their timing and duration, the break monsoon conditions are the harbingers of regional droughts.

Onset of the Monsoon

The onset of monsoon rains is viewed in monsoon literature as the burst of the monsoon, commonly in the form of a great thunderstorm. Prediction of the onset of monsoon helps farmers to select the most suitable crops to sow and to determine when to prepare the land. Predicting the timing of the monsoon has been an onerous task for the Indian Meteorological Department (IMD), almost from its beginning. Since 1878, forecasts of monsoon rainfall has been issued by this department regularly.

Progress of the Monsoons

The normal date of the onset of the monsoon is towards the end of May in Sri Lanka and over Andaman and Nicobar Islands in the Bay of Bengal (**Fig. 4.11**). Thereafter, it bursts on the Malabar Coast in Kerala a week later by June 1, and the isolines on the onset chart display a pronounced curve over the Bay of Bengal. The subsequent progress of the monsoon in the country is divided by the tapering peninsula into two bifurcating currents, i.e. (i) the Bay of Bengal Current, and (ii) the Arabian Sea Current. The Arabian Sea branch gradually advances northwards reaching Mumbai by 10^{th} June and Central India by 15^{th} June.

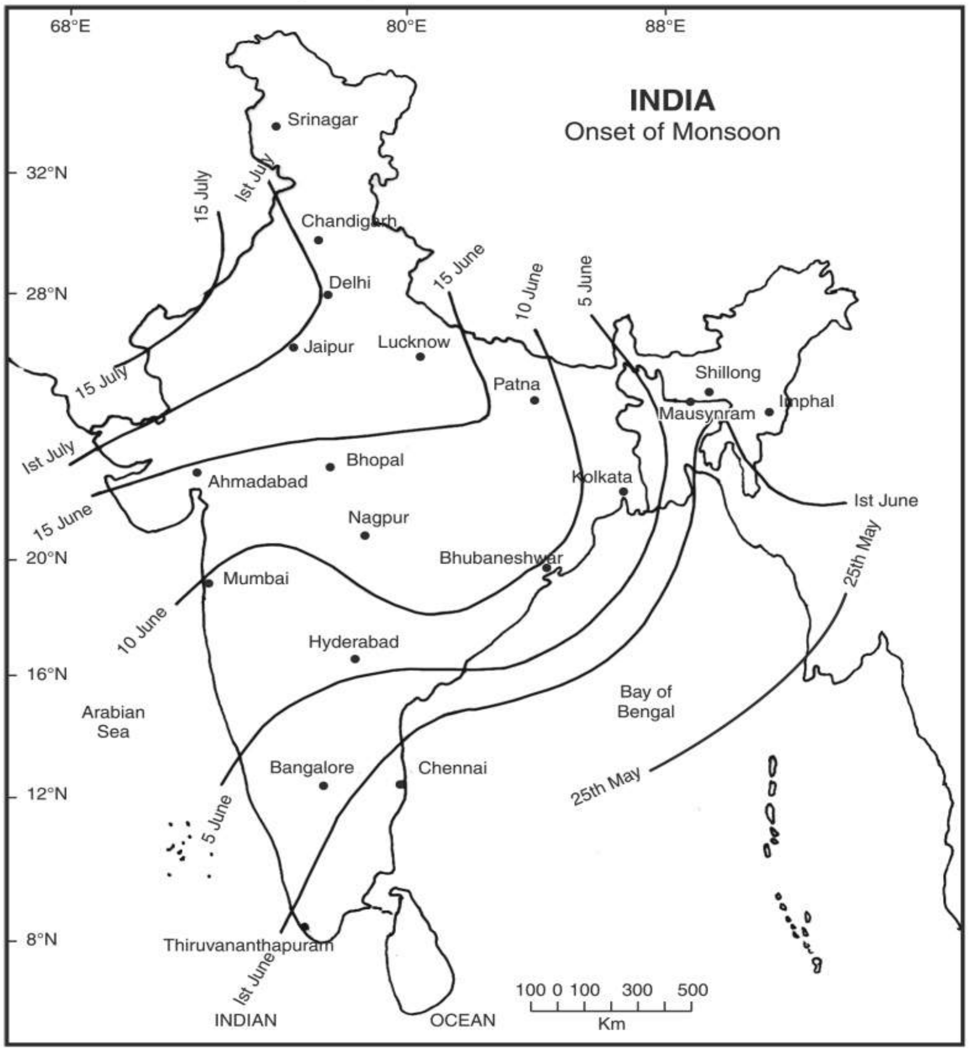


Fig. 4.11 Normal Dates of Onset of South-West Monsson

In the meantime, the progress of the Bay of Bengal branch is no less spectacular. It moves northwards into the central Bay of Bengal and advances to nearly 20° N latitude in the Bay by the third week of May. It rapidly strikes the Arakan Coast and Chittagong Hills with full force, the direction being southwesterly, but the greatest force is felt in the angle between the east-west Meghalaya Plateau of the Khasi Hills and the north-eastern Lushai Hills; Mizoram (Blue Mountains). Here Mawsynram to the west of Cherrapunji at an elevation of about 1313 metres receives nearly 1200 centimetres of rainfall annually. The Brahmaputra Valley is in the rainshadow of the Khasi Hills and receives less than 250 centimetres. The rainfall increases once again in the Himalayas, but the Bay of Bengal monsoon branch is deflected westwards due to the combined effect of the monsoon trough and the channelling by the Himalayas. As a consequence, its further progress is towards the Gangetic Plain of India, giving more rain to Himalayas and less in the plains. The arrival of the monsoon over Kolkata is 7th June, where, as mentioned earlier, the Arabian Sea branch of monsoon normally strikes Mumbai on 10th June. Both the branches of the monsoon current merge in the Gangetic Plain and gradually extend over Bihar, Jharkhand, Chhattisgarh, Uttar Pradesh, Uttarakhand, Haryana, Himachal Pradesh, Punjab, Jammu and Kashmir, and finally to Rajasthan, so that by the first week of July, i.e., within a mean interval of 29 days since the onset in Kerala, the south-west Monsoon is established all over India, excluding the Thar Desert. In the Thar Desert, the monsoon reaches by the middle of July, but only as a descending, drying wind, since by this time it has almost shed most of its moisture. It can be noted from **Fig. 4.11** that for parts of the country west of 80°E and south of 25°N, the advance of monsoon is from south to north, while in the rest of the country it is from south-east to north-west.

SEASONS IN INDIA

The subcontinent of India has great latitudinal dimensions. There are different seasons from Kanniyakumari (Cape-Camorin) to Jammu and Kashmir. The Meteorological Department of India, however, divides the seasons of India into the following four seasons:

A. Seasons of North-East Monsoon

1. Winter season, mid-December to mid-March
2. Hot weather season, mid-March to May.

B. Seasons of South-West Monsoon

3. Rainy season, June to September
4. Season of retreating monsoon, October to mid-December.

I. The Cold Weather Season

The cold weather season in the greater parts of India begins in the later part of November in the north, and by the beginning of December in the rest of the country. The cold weather season is characterised by out-flowing winds, dry and stable air, and clear skies. There develops a high pressure (anti-cyclone) area over north India, and a north-westerly flow prevails down the Indus and Ganges Valleys. During this season the southern branch of the subtropical jet stream is positioned over northern India. The middle latitude westerlies reach down to the surface north of about 25°N. South of this latitude the general movement of air is from the north-east. This north-easterly wind is called the winter monsoon. In Peninsular India, the general direction of wind is from east to west. Because of its trajectory over the Bay of Bengal, the easterlies are full of moisture and yield some precipitation along south-east coastal regions.

During winter season there is a general decrease in temperature from south to north. The isotherms run almost parallel to the latitudes. The 18° C isotherm for the month of January runs in a east-west direction through the middle of the country, connecting the Tapi estuary in the west and the Mahanadi delta in the east (**Fig. 4.12**). In the month of January, the north-western parts of the Great Plains of India (Punjab, Haryana, western Uttar Pradesh and Rajasthan) experience less than 15°C mean monthly temperature. The night temperature in the plains of Punjab, Haryana and Rajasthan (Amritsar, Hissar, and Jodhpur) occasionally reads below the freezing point, producing ground frost condition. Often, there is a decrease of more than 6°C in the mean temperature, resulting into **cold wave** in the northern plains of India. In south India, the isotherms tend to bend to the south and run almost parallel to the coast. The western coast is warmer than that of the eastern coast by about 2°C. The diurnal range of temperature is about 15°C in the Great Plains and only

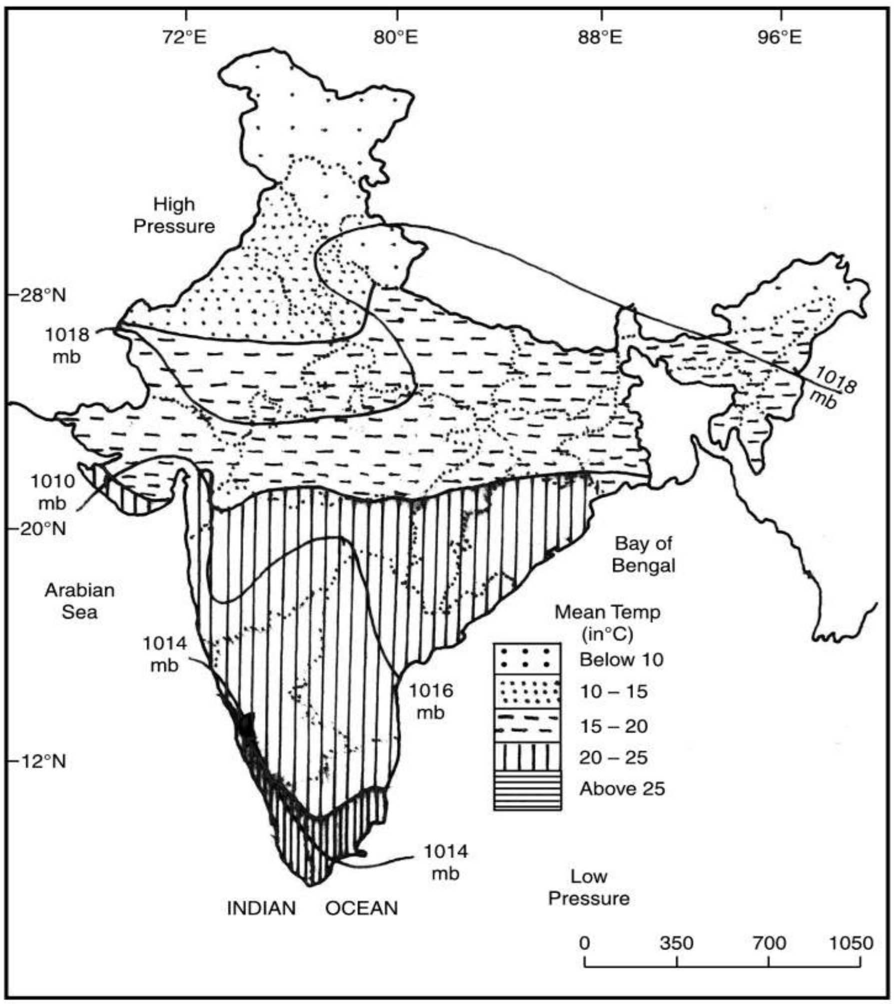


Fig. 4.12 Mean January Temperature

about 5°C in the coastal areas of the Peninsula. January is the coldest month in India, especially in northern India. Peninsular India, however, does not have a well defined cold weather season. The mean maximum temperature for the month of January at Thiruvananthapuram and Chennai reads 31°C and 30°C respectively (**Fig. 4.12**).

A characteristic feature of the cold weather season is the inflow of western disturbances originating from the Mediterranean Sea. The frequency of these disturbances is 4 to 6 per month between December and January. In north-western region of the subcontinent, winter precipitation is caused by the depressions that are associated with the westerly disturbances moving out from the Mediterranean Sea. The cold weather precipitation, though small, is highly beneficial to '*Rabi*' crops. Besides, snowfall from the western disturbances feed the glaciers of the Western Himalayas.

The north-eastern parts of India also get some rainfall during the winter season. Arunachal Pradesh, Nagaland and Assam may get about 50 cm of rainfall during these months (**Fig. 4.13**).

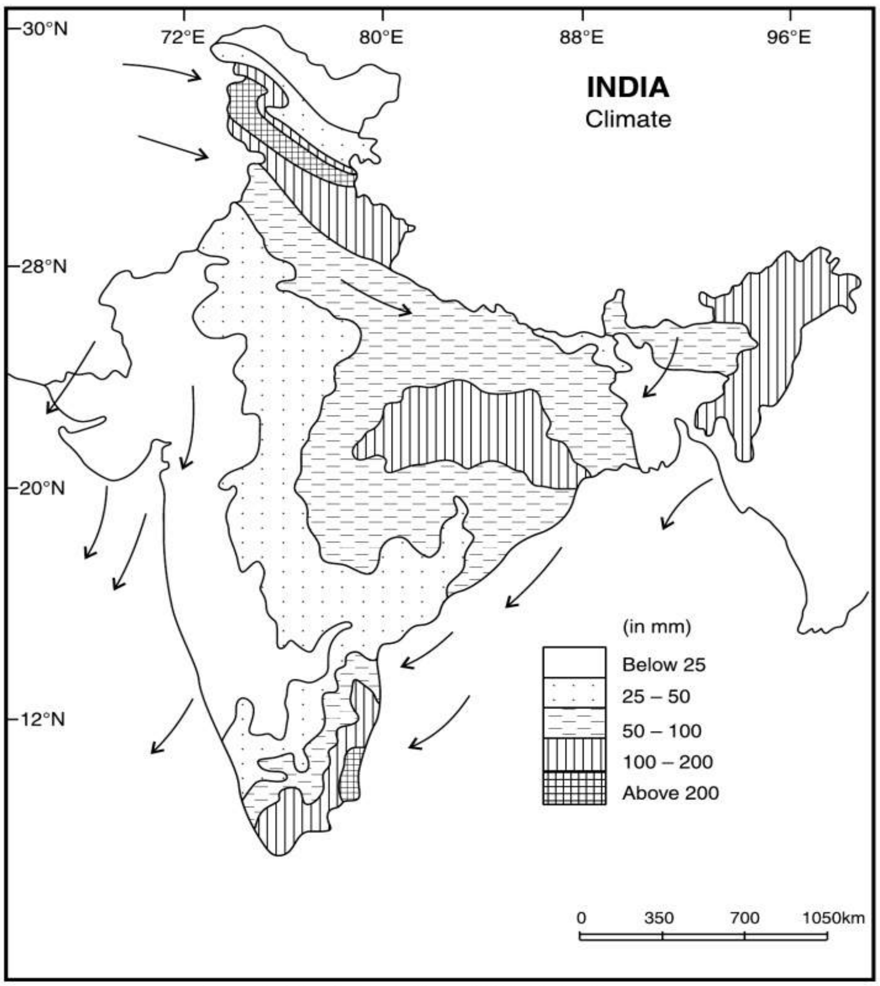


Fig. 4.13 Rainfall and Winds in January

2. The Hot Weather Season

The north Indian region experiences a well defined hot weather season from mid-March to mid-June. With the northward march of the sun towards the Tropic of Cancer after the vernal Equinox the temperature begins to rise. Thermal heating over north-western India gradually establishes a thermal 'low' at the surface but, while the jet stream remains south of the Himalayas, it maintains its dynamic anticyclone aloft over Afghanistan and the borderland of Pakistan. This 'lid' of subsiding warming dry air prevents the surface thermal 'low' from having sufficient effect as a lifting agent to carry air aloft and so to bring about precipitation (Johnson, 1969, p.17).

At the advent of March, the temperature starts rising abruptly. By April, the Peninsular regions south of the Vindhyan Range heat up with mean maximum temperature of 40°C. In May, the mean maximum temperature reaches 42°C in Rajasthan, Delhi, west Uttar Pradesh, south Punjab,

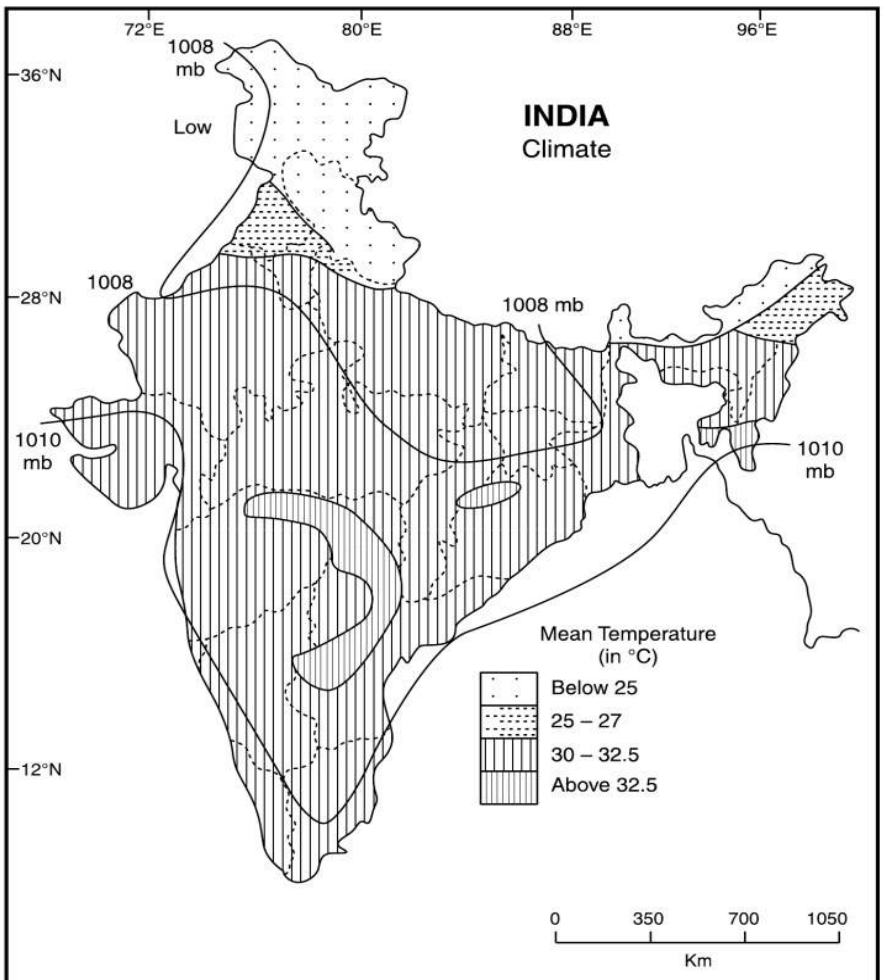


Fig. 4.14 Mean Temperature in April

and reaches Kolkata around 11th June. In Delhi, western Uttar Pradesh, Haryana, and Punjab, the monsoon reaches around 1st July.

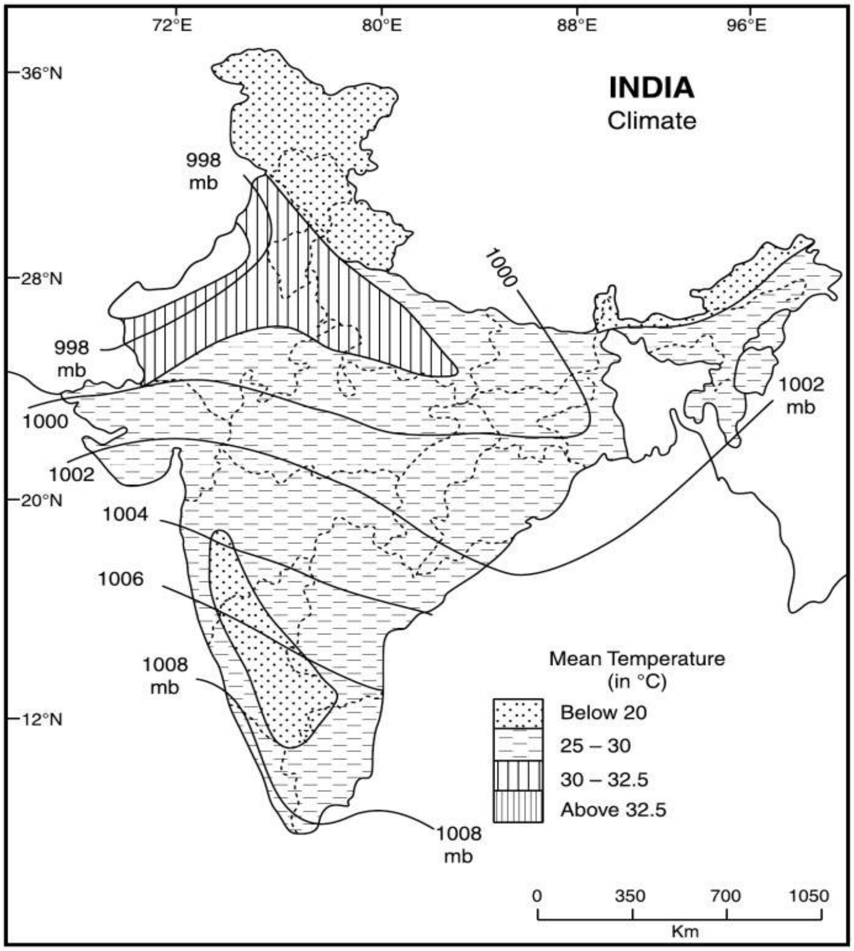


Fig. 4.15 Mean Temperature in July

During the season of general rains, most of the country experiences good cloud cover (from 1/8 to overcast sky). During this season, the relative humidity is generally over 65 per cent. Assam and Kerala record the highest percentage of relative humidity; over 80 per cent over the greater part of the rainy season.

The greater parts of the subcontinent of India receive over 85 per cent of their total rainfall during the season of general rains. The Arabian Sea current causes rainfall all along the Malabar coast, Konkan coast, Western Ghats, Maharashtra, Gujarat, and parts of Madhya Pradesh. Mumbai records about 190 cm of rainfall during this season. As the Arabian current crosses the Sahyadris, the places situated on the leeward side of the Western Ghats receive substantially less rainfall. For example, Pune (about 160 km to the east of Mumbai) gets only 125 cm of rainfall. Nagpur records

Jammu city and Haryana. Temperature exceeding 54°C was recorded at Sri Ganganagar in 1967. At some places, particularly in north-western India, day temperature may be as high as 45°C or 47°C. The mean minimum daily temperature in May also remains quite high being about 26°C at Delhi and Jaipur. The temperature in the eastern states of India and in the hilly regions in the month of May is generally cool and invigorating **(Fig. 4.14).**

In the month of April the 30°C isotherm of average temperature encloses a vast area of the country between 10°N and 26°N latitudes (except the west coast and the hilly states of north -east India). The diurnal range of temperature ranges between 5°C and 6°C in coastal areas, but reaches 20°C in the interior parts of the country and in the north-west Satluj Ganga Plains.

Being a transitional season between the north-east and the south-west monsoon (rainy season), it is characterised by unstable air pressure and wind circulation. With the northward movement of the sun, the low pressure area also moves from south-east to north-west. It finally settles over north-western India in the end of May or early part of June. The pressure generally increases towards south in the neighbouring sea. The general direction of winds is from north-west and west in north-western India; from south-west in the Arabian Sea and the adjoining coasts. The tornado-like dust storms of Punjab, Haryana, and western Uttar Pradesh, the hot winds (*Loo*) in western India, the Norwesters (*Kalbaisakhis*) of West Bengal are the characteristics of summer season.

During summer season, the Sun is scorching and the relative humidity is generally below 30 per cent, occasionally reaching below 10 per cent. The total rainfall of the season is below 2 cm in Rajasthan, Gujarat, Madhya Pradesh; between 5 and 15 cm in the sub-montane region of Uttarakhand, Himachal Pradesh, Punjab, Bihar and Odisha; and between 15 and 25 cm in the Malabar coast and over 50 cm in Assam, Meghalaya, Mizoram, and Nagaland. The rains caused by thunderstorms in Karnataka are called as 'Cherry Blossoms' (where these are beneficial for coffee plantation) and elsewhere in south India as 'mango showers'.

3. The Season of General Rains

By the end of June, a low pressure area develops over Punjab and Rajasthan. The southern branch of the jet stream weakens and is finally withdrawn from the southern slopes of the Himalayas by mid-June, leading to the formation of a dynamic depression over the surface thermal low. The Inter-Tropical-Convergence (ITC) moves further northwards occupying a position of 25°N by mid-June and allowing equatorial westerlies to gush in the subcontinent. The cyclonic vortices developed in the ITC cause rains in the country. The tropical easterly jet streams originating due to thermal heating of Tibet intensifies Indian Ocean high pressure cell from which south-east trade winds are pushed by the Antarctic circumpolar whirl to develop as south-west monsoon.

In the northern plains of India, the temperature reaches its maximum in June to break the monsoon. At places, the day temperature touches 46°C and more. The mean maximum temperature in the month of June at Jodhpur reaches 41°C , Delhi 40°C, Allahabad 39°C, Kolkata 33°C, 29°C at Kochi and 23°C at Shimla and Srinagar. The diurnal range of temperature is high being about 30°C at Leh, and 15°C at Delhi. The diurnal range of temperature is, however, less than that of the month of May (**Fig. 4.15**).

Generally in the afternoon of a scorching day, rains begin suddenly. This is known as a 'monsoon burst'. The Arabian Sea current advances northwards by 1st June on the Kerala coast and reaches Mumbai by about 10^{th} June. By mid-June, it spreads over Saurashtra, Kachchh and Madhya Pradesh.

The Bay of Bengal current first strikes Andaman and Nicobar islands by about 25^{th} of May and reaches Meghalaya, Mizoram and Tripura by about 1^{st} June. It rapidly spreads over most of Assam, 125 cm and Thanjavur only 85 cm of rainfall. The sub-branch of the Arabian Sea current which moves northwards through Kachchh, Gujarat and Rajasthan gives little rainfall to these regions due to the parallel alignment of the Aravallis. The Arabian sea current goes straight up to the western Himalayas, where it gives appreciable rainfall in Uttarakhand and Himachal Pradesh.

The Bay of Bengal current first dashes against the Myanmar coast, and obstructed by the eastern hills, is deflected westward towards the Ganga Plain. This current causes the heaviest rainfall at Mawsynram (about 1200 cm) and Cherrapunji (1100 cm) annually. A major part of this rainfall occurs in the morning hours. Here also, the leeward sides of the Meghalaya Plateau receive lower rainfall; 150 cm and 160 cm at Shillong and Guwahati, between June and September respectively. Moving westward, the Bay of Bengal current gives Kolkata 120 cm, Patna 105 cm, Allahabad 90 cm, Delhi 65 cm, Bikaner 25 cm and Srinagar (J&K) only 20 cm of rainfall between June and September (**Fig. 4.16**).

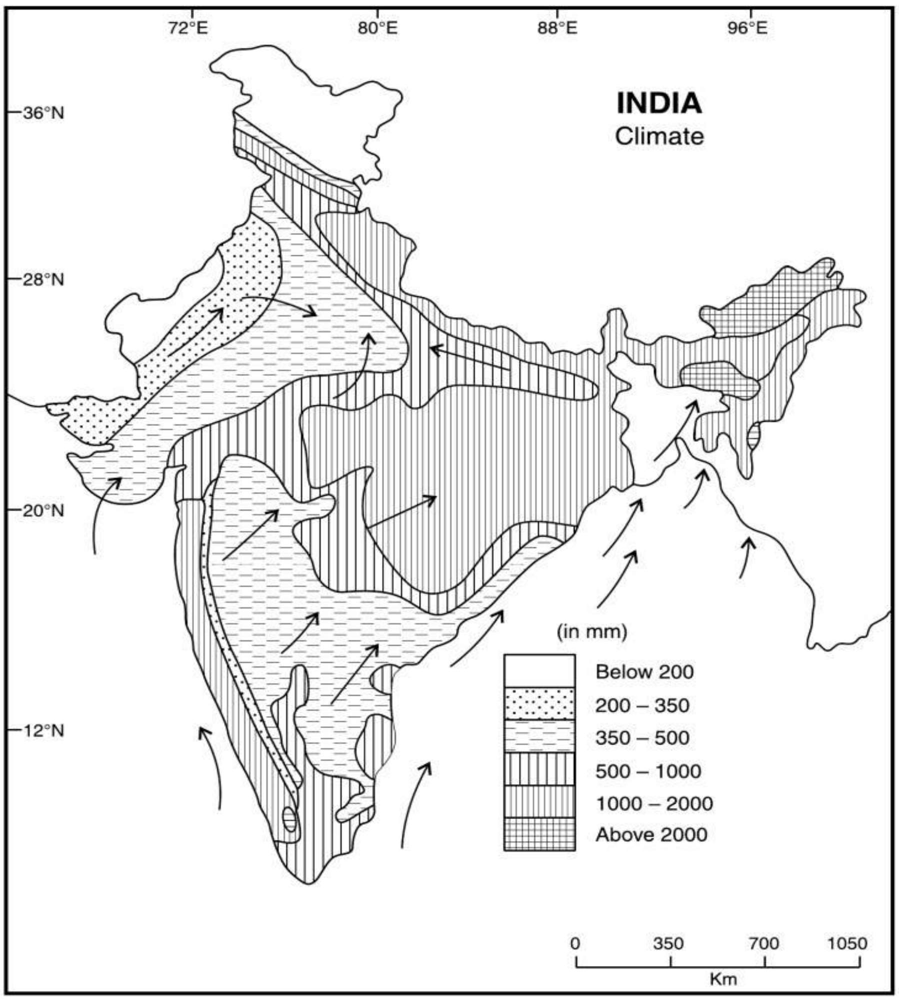


Fig. 4.16 Rainfall and Winds in July

The weather and amount of rainfall received are also affected by a number of cyclonic depressions which enter the country through the Bay of Bengal and the Arabian Sea (**Fig. 4.17**). About 20 to 25 such depressions are developed during the monsoon period, of which some are stronger, causing immense damage to life and property of the people residing in the coastal areas of West—Bengal, Odisha, Andhra Pradesh, Tamil Nadu, and Gujarat. The cyclone of October 29, 1999 with a velocity of over 300km/h killed over one lakh people. More than two million houses were washed away and about 12 million people were rendered homeless. These cyclones are generally accompanied with heavy rain, the amount of which decreases going away from the coastal areas.

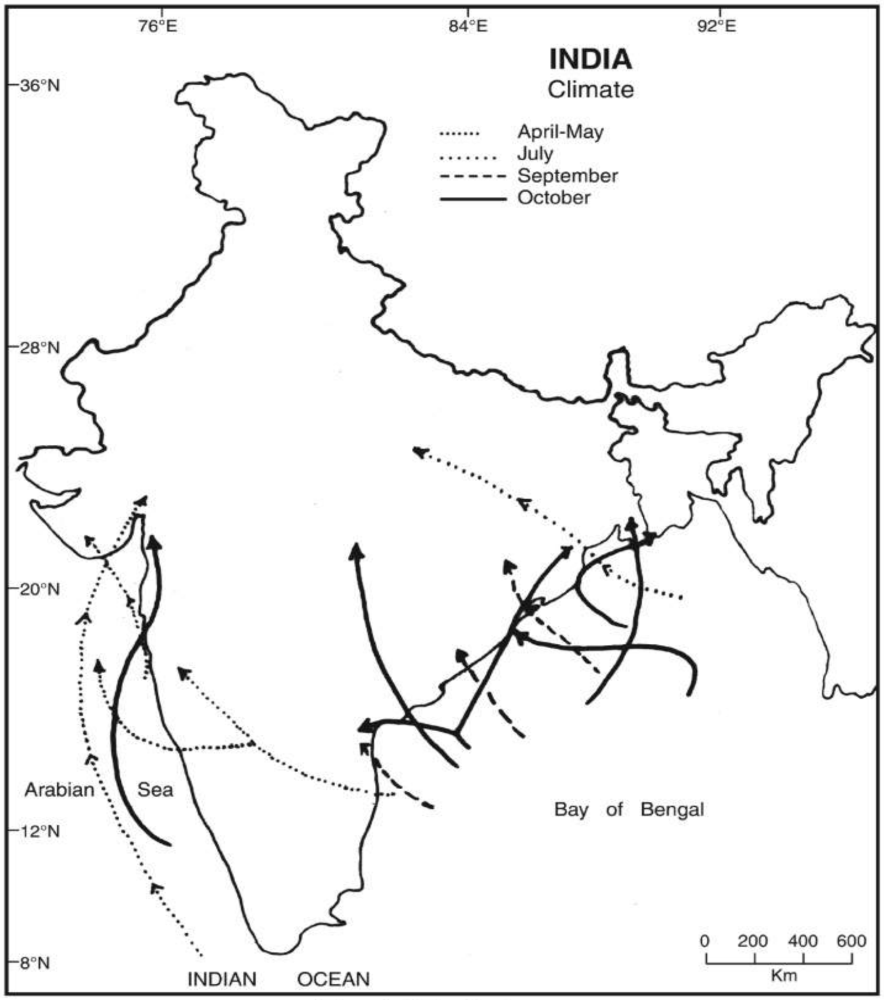


Fig. 4.17 Cyclones

The distribution of rainfall during the rainy season has been plotted in **Fig. 4.16.** It may be seen from this figure that the western coast, Sahyadris, Meghalaya, Arunachal Pradesh, Mizoram, Nagaland, Sikkim, and Darjeeling hills get more than 200 cm of rainfall. The remaining parts of north-eastern India, West Bengal, Odisha, Jharkhand, Bihar, Chhattisgarh, the Tarai region and hills of Uttarakhand and U.P. receive rainfall between 100 to 200 cm. Similarly, the southern and western Uttar Pradesh, northern and western Madhya Pradesh, eastern Maharashtra and Gujarat, and northern Andhra Pradesh experience rainfall between 50 and 100 cm. Rajasthan, western Gujarat, southern Andhra Pradesh, Karnataka plateau, Tamil Nadu, plains of Haryana, Punjab, and Jammu and Kashmir receive less than 60 cm of rainfall. The lowest rainfall is recorded in the Thar desert along the border of Pakistan, and the Ladakh region of Jammu and Kashmir state (**Fig. 4.20**).

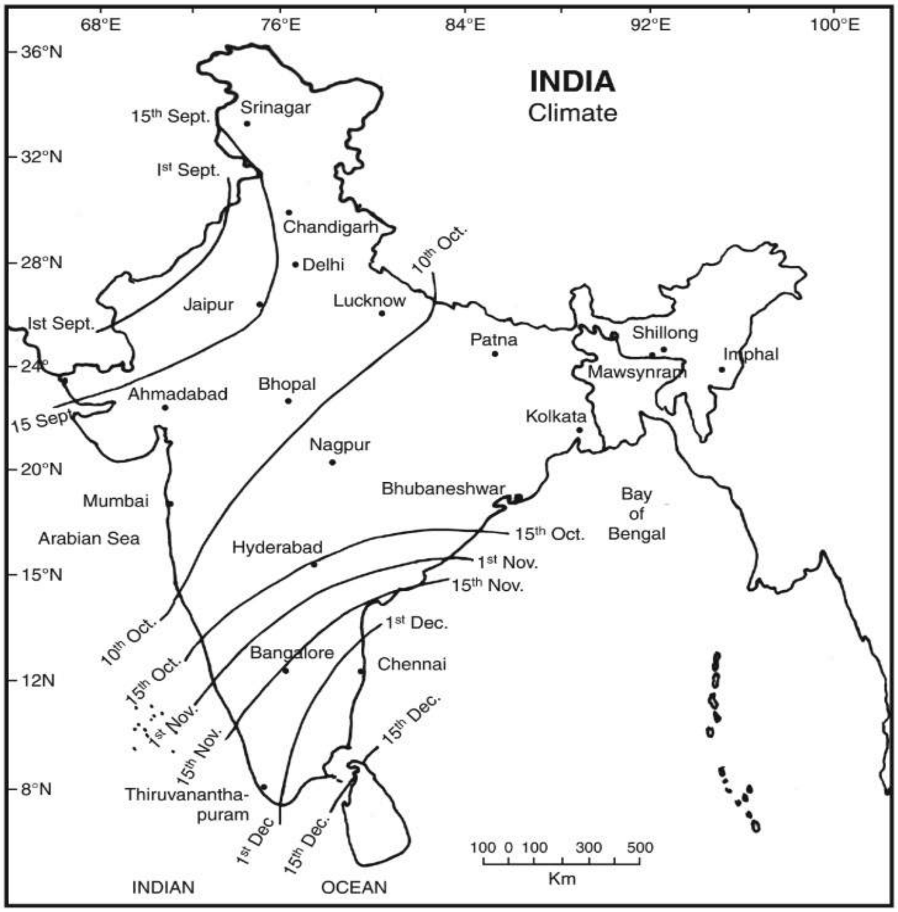


Fig. 4.18 Normal dates of Withdrawal (Retreat) of South-West Monsoon

4. Season of Retreating Monsoon

The south-west monsoon begins to retreat from northern India by the third week of September with the southward migration of the sun. By the end of September, the south-west monsoon retreats from the Punjab plains and adjacent regions. However, unlike the sudden burst of monsoon, the retreat is steady and gradual (**Fig. 4.19**). By mid-October, the southerly branch of the jet stream returns to its winter position south of the Himalayas.

The temperature during the season of retreating monsoon is uniformally high being about 25°C in the beginning of October in Northern India. The day temperature is generally high, but nights become pleasant with the mean going down to 20°C or even lower. The temperature begins to decline in November and by December cold weather sets in with about 15°C average temperature in the north and north-west parts of Indian plains, about 20°C in the central parts of India, and about 25°C along the coasts.

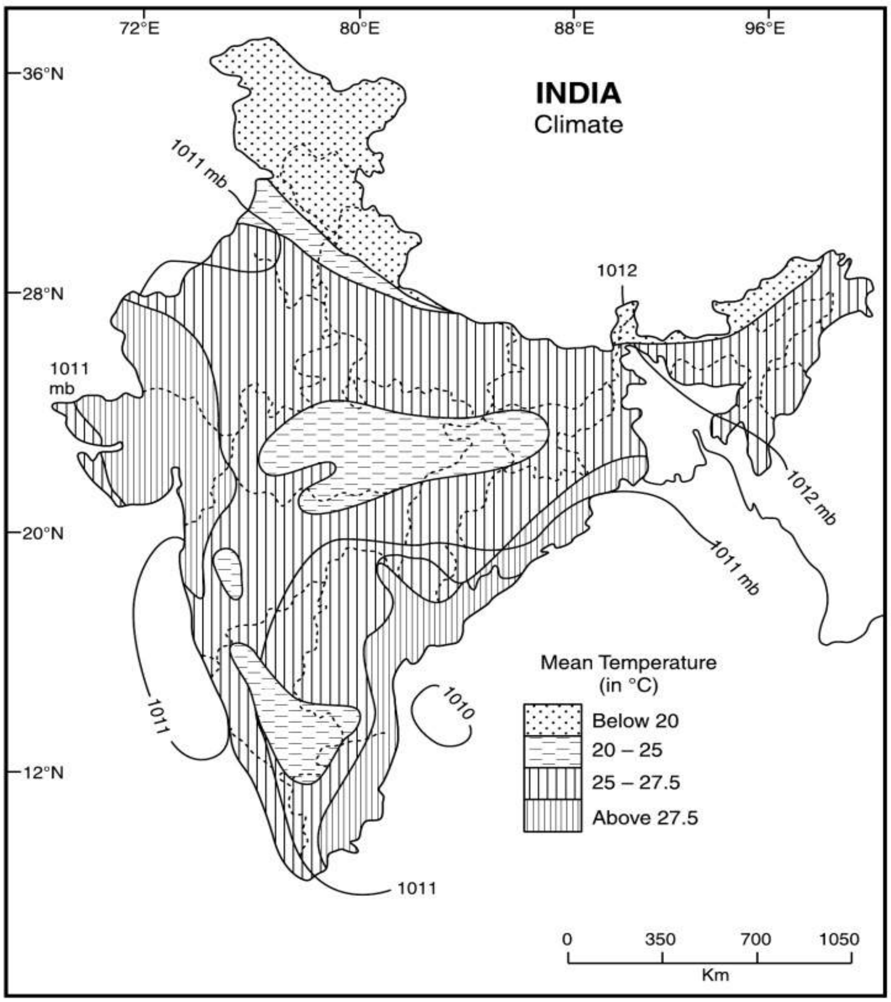


Fig. 4.19 Mean October Temperature

With the advent of October, the low pressure area over the north-western parts of India is dissipated and its place is taken by the low pressure cell located over the northern parts of Bengal. By the beginning of December it moves further southwards and by month end, it merges with the equatorial low. The winds are westerly in the north-western parts of the country and in the Ganga Plain, north-easterly in the Peninsular region and north-westerly in the east coast.

RAINFALL DISTRIBUTION

The distribution of rainfall in India is highly uneven. Its distribution is largely controlled by the nearness of the sea and the orographic features. The influence of the Western Ghats, the Plateau of Meghalaya, the north-eastern Hills, and the Himalaya Mountain is quite significant. The average annual distribution of rainfall in India has been shown in **Fig. 4.20**. It may be observed from **Fig. 4.20** that the regional variations in the distribution of average annual rainfall over India are quite pronounced. In the southern parts of the Meghalaya Plateau (Mawsynram and Cherrapunji), the average annual rainfall is more than 1200 cm. However, it drops to 200 cm or less in the Brahmaputra Valley and the adjoining hills.

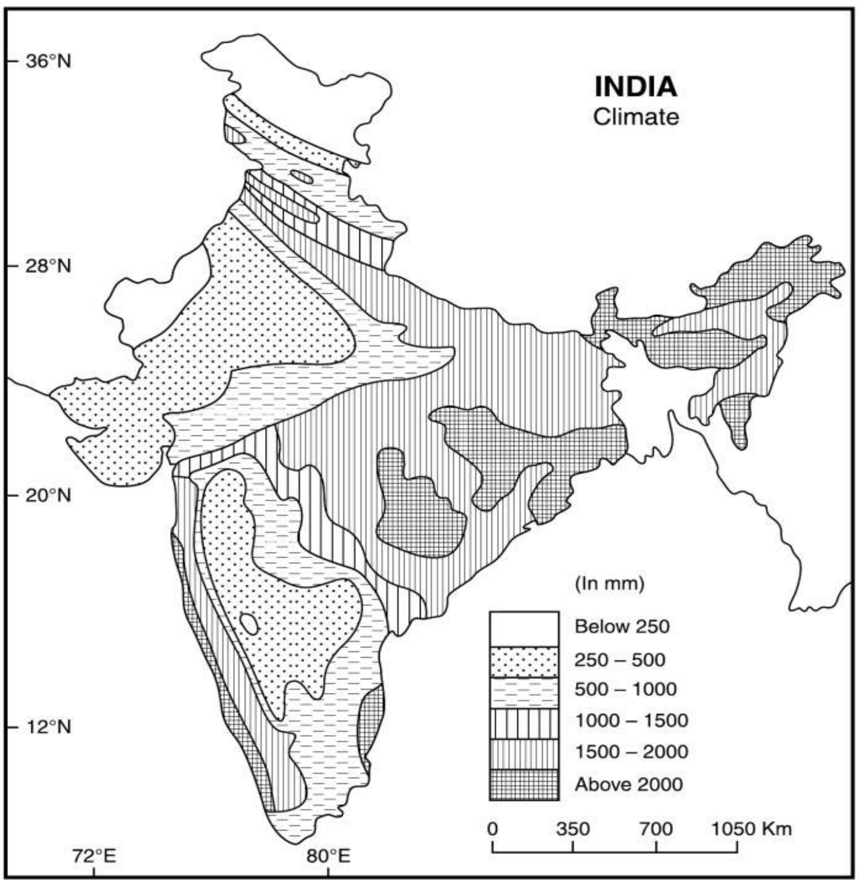


Fig. 4.20 Annual Rainfall (1950–2005)

In Peninsular India, the highest rainfall occurs along the Konkan and Malabar coasts. The isohyte of 150 cm rainfall runs southwards from the Gujarat coast, roughly parallel to the crest of the Western Ghats upto Kanniyakumari. In nortern India, it includes the hills of Himachal Pradesh, Uttarakhand, Chhattisgarh, eastern Maharashtra, and northern Andhra Pradesh. The regions lying to the west and south-west of this line have generally deficient rainfall where agriculture is largely vulnerable to drought. Along the Coromandal Coast of India the average annual rainfall is over 100 cm. In Punjab, Haryana and northern Rajasthan the mean annual rainfall is 60 cm or less. The lowest rainfall is recorded in western Rajasthan, the north-western parts of Gujarat, and Ladakh where it is less than 20 cm (**Fig. 4.20**).

VARIABILITY OF RAINFALL

The rainfall in India is highly variable. The actual rainfall of a place in a year deviates from its average rainfall by 10 to over 60 per cent. The mean annual variability of rainfall in India has been plotted in **Fig. 4.21**.

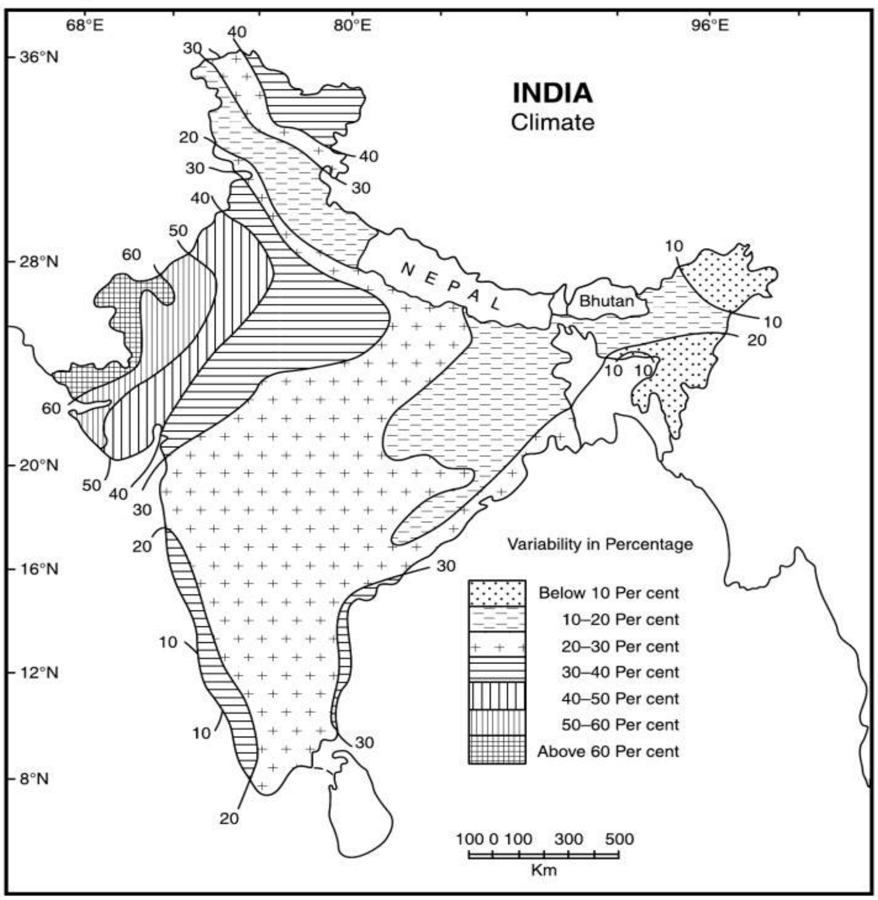


Fig. 4.21 Variability of Rainfall (1950–2005)

It may be noted from **Fig. 4.21** that the highest variability is found in the areas where the average annual rainfall is the lowest. For example, the desert areas of Barmer, Ganganagar, Jaisalmer, Jodhpur, etc. have less than 20 cm of average annual rainfall. In these areas the variability of rainfall is around 60 per cent. Contrary to this, in the areas where the average annual rainfall is over 200 cm (Mawsynram and Cherrapunji, Meghalaya Plateau), the annual variability of rainfall is less than 10 per cent. The Western slopes of Western Ghats, the Lesser Himalayas, the Shiwaliks and the Tarai belt also record between 100–200 cm of average annual rainfall. The variability of rainfall in these regions is around 10 to 20 per cent. Thus, there is an inverse relationship between the average annual rainfall and variability in rainfall.

The variability of rainfall has a significant role in the agricultural operations and other economic activities of the country. The areas showing high variability of rainfall have chronic deficiency of water. Such regions are highly prone to droughts, floods and famines, while the areas with high average annual rainfall are less affected by droughts; though flood is a regular feature in flood prone areas.

CLIMATIC REGIONS OF INDIA

India is often referred to as a country with tropical monsoon type of climate. The large size of India, its latitudinal extent, the presence of the Himalayas in the north, and the Indian Ocean, Arabian Sea and Bay of Bengal in the south have resulted in great variations in the distribution of temperature and precipitation in the subcontinent of India.

A number of attempts have been made by climatologists, geographers and experts of agriculture to divide India into climatic regions. While some of these classifications have been suggested for world climates, others are exclusively applied to Indian conditions. Some of the important climatic divisions of India were made by the following experts:

1. H.E. Blandford, 1889
2. W. Koppen, 1918, 1931, 1936
3. C.W. Thornthwaite 1931,1933, 1948
4. L.D. Stamp and W.G. Kendrew, 1953
5. S.P. Chatterji, 1953
6. G.T. Trewartha, 1954
7. V.P. Subramanyam, 1956
8. B.L.C. Johnson, 1969
9. K.L Rao, et.al., 1971
10. R.L. Singh, 1971

A systematic study of the climatic divisions of India was attempted for the first time by H.E. Blandford—the first Director General of the Indian Meteorological Department—in 1889, who discovered that all types of climates found in the world are present within the subcontinent of India. This classification based on temperature and rainfall of a few selected stations of India was almost an overgeneralisation. A brief description of some of the important classifications of Indian climate has been given in the following:

KOPPEN'S CLASSIFICATION OF INDIAN CLIMATE

A Koppen's classification is empirical in nature based on climatic data. Koppen, for the delineation of climatic regions took into consideration (i) the mean monthly temperature, (ii) the mean monthly rainfall, and (iii) the mean annual rainfall. Koppen divided the country into three broad climatic zones:

1. Humid (A)
2. Arid (B)
3. Semi-Arid (C and D)

These three broad climatic divisions were sub-divided into sub-types on the basis of seasonal variations in the distribution pattern of precipitation and temperature for which the symbols S, W, m, f, w, s, c, and h have been used. Based on Koppen' s climatic scheme, India can be divided into the following nine climatic regions (**Fig. 4.22**).

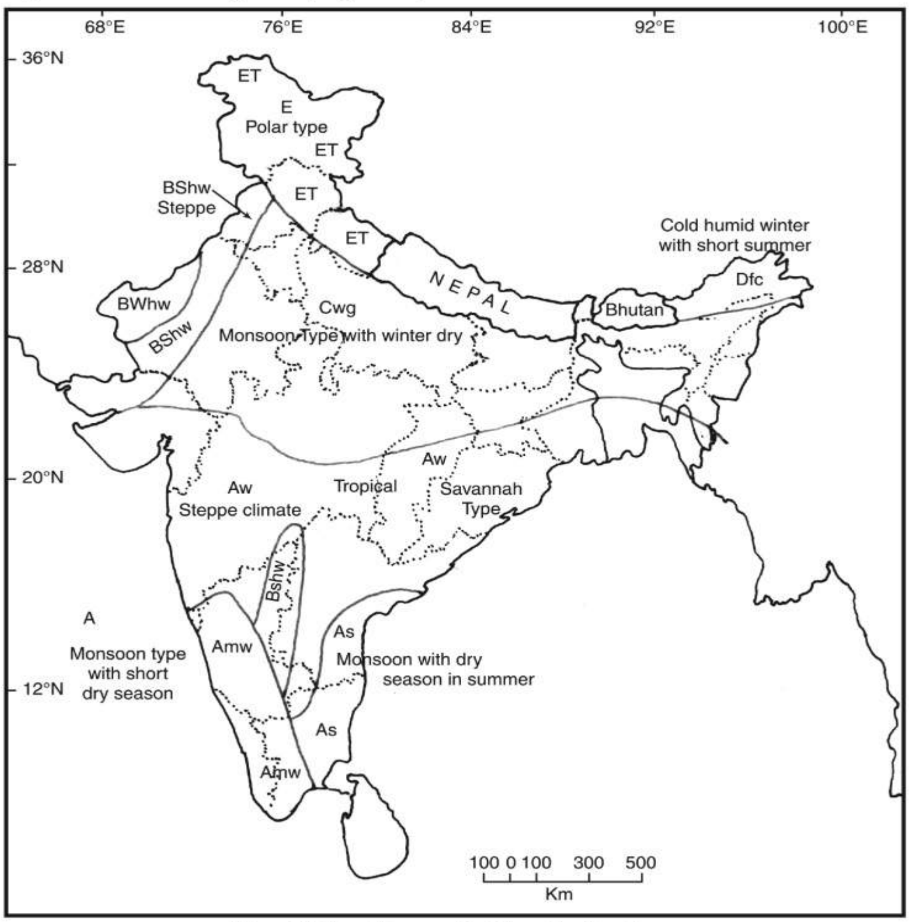


Fig. 4.22 Koppen's Climatic Regions

1. Aw (Tropical Savanna Type)

This is a climate associated with the tropical savanna grassland and monsoon deciduous vegetation. In this type of climate, May is the hottest month (the mean maximum reading around 40°C and the mean minimum 27°C) and the temperature of the coldest month is always more than 18°C. The annual and diurnal ranges of temperature are high. Rainfall occurs mainly during the season of South-West Monsoon (July to September). Winters are generally dry. Such type of climate is found over major parts of Peninsular India including Jharkhand, Chhattisgarh, Odisha, Andhra Pradesh, Maharashtra, and the Purulia district of West Bengal.

2. Amw (Tropical Monsoon Type)

This climate has a short dry winter season. The rainfall is heavy during the season of South-West monsoon, leading to luxurious growth of evergreen rain forests. It occupies parts of Konkan, Malabar Coast and the adjoining areas of the Western Ghats, Plateau of Tamil Nadu, and southern areas of Tripura and Mizoram.

3. As (Tropical Moist Climate)

It is characterised by dry summer season. The mean monthly temperature is more than 18°C in all the months. The average annual rainfall varies between 75–100 cm, and about 75 per cent of the total annual rainfall occurs between September and December. It occupies a narrow zone along the Coromandal coast.

4. BShw (Semi-Arid Steppe Climate)

In this climate the mean annual temperature is above 18°C and the rainfall is seasonal (in summer). It stretches over the rain-shadow zone of Karnataka and Tamil Nadu, eastern Rajasthan, Gujarat and some parts of south-western Haryana.

5. BWhw (Hot Desert Type)

The greater part of Rajasthan lying to the west of the Aravalli has the hot desert type of climate. In fact, it covers the Thar desert of India. The mean annual rainfall is below 25 cm. The mean maximum summer temperature (May–June) often crosses 45°C at Jodhpur and Ganganagar, while the mean minimum temperature in winter seasons may fall to 0°C in the Bikaner, Ganganagar and Jodhpur districts.

6. Cwg (Mesothermal Climate—Gangetic Plain Type)

This climate is characterised by dry winter. The average temperature of the cold months is less than 18°C and the average temperature of the coldest month is over 15°C. The maximum temperature is recorded in the month of May or first half of June.

7. Dfc (Cold Humid Winter Type)

This climate is characterised by short summer and cold humid winter. The winter temperatures are about 10°C and the summer temperature is below 18°C. Summers are short and humid. It is found in Sikkim and Arunachal Pradesh.

8. E (Polar Type)

This type of climate is found in the higher mountainous areas of the Jammu and Kashmir, Himachal Pradesh, and Uttarakhand. In this climate, the temperature of the warmest month is less than 10°C. These areas remain under ice during the greater part of the year.

9. ET (Tundra Type)

In this climate the average temperature of the warmest month is between 0° and 10°C. It occupies the higher altitudes of Ladakh, Kashmir, Himachal Pradesh and Uttarakhand.

CLIMATIC DIVISIONS BY STAMP AND KENDREW

Professor L.D. Stamp and W.G. Kendrew divided India into several climatic divisions. This classification is arbitrary and subjective. Stamp used 18°C isotherm of mean temperature for January to divide the country into two broad climatic regions, namely:

A. the subtropical or continental zone lying to the north of this isotherm, and
B. the tropical zone lying to the south of this isotherm (**Fig. 4.23**). It may be seen from **Fig. 4.23** that the isotherm of 18°C runs roughly parallel to the Tropic of Cancer.

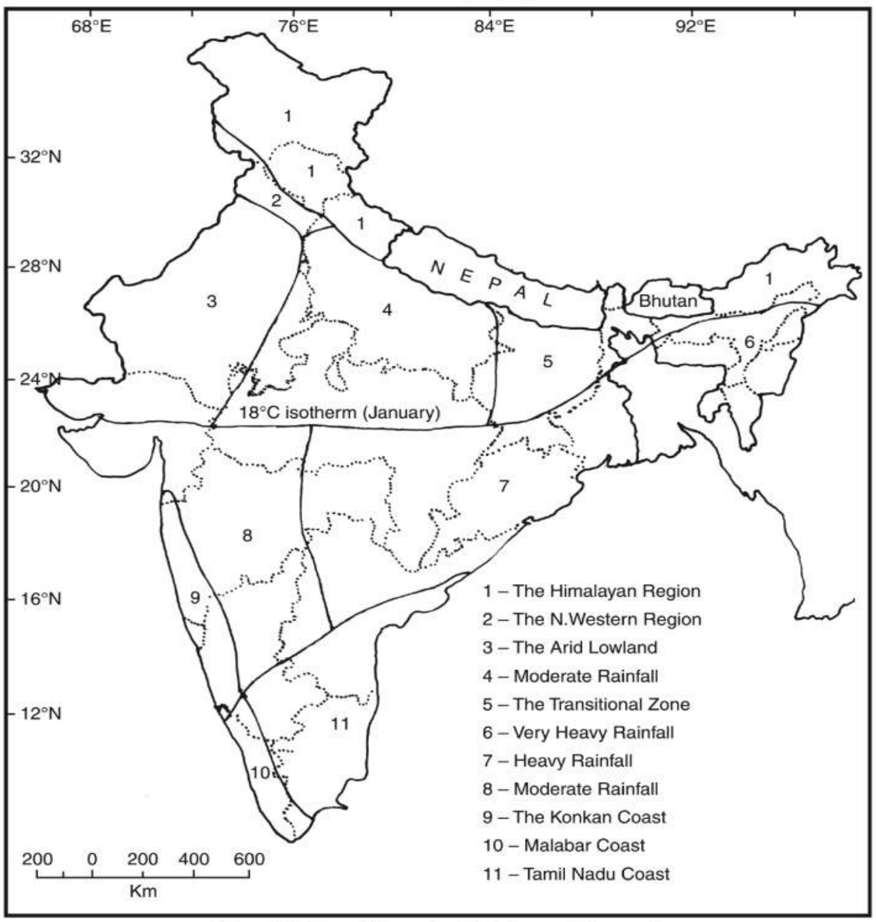


Fig. 4.23 Climatic Divisions (Stamp)

The two major climatic divisions, on the basis of rainfall, have been further divided into eleven regions:

A. The Subtropical or Continental climate has been divided into the following five divisions:
1. The Himalayan Region
2. The North-Western Region
3. The arid lowland (dry plains)
4. The region of moderate rainfall
5. The transitional zone

B. Tropical India has been divided into the following six regions:
6. Region of very heavy rainfall
7. Region of heavy rainfall
8. Region of moderate rainfall
9. The Konkan Coast
10. The Malabar Coast
11. The Tamil Nadu region

A. Subtropical Climate

The subtropical climate has been subdivided into:

1. The Himalayan Region

Stretching over the mountainous parts of the states of Jammu and Kashmir, Himachal Pradesh Uttarakhand, Sikkim and Arunachal Pradesh, it has mild summers and cold winters. The regional distribution of temperature is largely controlled by the topography and aspect of slope. Upto a height of 2500 metres, the average temperature of winter season ranges from 4°C to 8°C, and the summer temperature varies from 12°C to 18°C. Rainfall is recorded from the South-West Monsoon in summer and from the western disturbances in the winter season. The amount of rainfall decreases from east to west. For example, in eastern Uttarakhand the average annual rainfall is over 200 cm, while in western parts of Jammu and Kashmir it falls below 150 cm. Snowfall and sleet are the common features in the Greater and Lesser Himalayas during the winter months (December to March).

2. The North-Western Region

This type of climate is found to the north-west of Satluj river where the average temperature of the winter season reads around 15°C. The mean minimum temperature in the month of January may occasionally fall below the freezing point at Amritsar. The mean maximum temperature in the month of May and June may cross 45°C. Hot winds (*Loo*) and dust storms during the scorching summers are the other features of this climatic region.

3. The Dry Plains of North-West India

This climate stretches over Rajasthan, Kachchh, and south-western parts of Haryana. In this region the winter temperature ranges between 15°C and 25°C, but occasionally, the maximum temperature crosses 47°C in the months of May and June. The average annual rainfall is below 25 cm and occurs mainly during the months of July and August; the season of general rainfall.

4. Areas of Moderate Rainfall

This climatic division stretches over Punjab, Haryana, the Union Territory of Delhi, western Uttar Pradesh, eastern Rajasthan, and western Madhya Pradesh. The average rainfall in this climatic division varies between 40 to 100 cm. The mean temperature of January varies between 15°C to 18°C. Over 85 % of the total rainfall is recorded during the season of general rains. Delhi, Ludhiana and Meerut are typical examples of this climate.

5. The Transitional Zone

This climate is found in Eastern Uttar Pradesh, western and north-western Bihar, and north-western Jharkhand. The average annual rainfall in this zone varies between 100 to 150 cm. Over 90 per cent of the total annual rainfall is recorded during the season of general rains from the Bay of Bengal stream of the South-West Monsoon. The mean January temperature reads about l5ºC while the mean maximum in the month of July reads over 40°C.

B. Tropical India

6. Region of Very Heavy Rainfall

This climatic divison stretches over Assam, Meghalaya, Nagaland, Manipur, Tripura and Mizoram. The average annual rainfall in these areas is over 200 cm. The heaviest rainfall in the world is recorded in this region at the stations of Mawsynram and Cherrapunji. Over 90 per cent of the average annual rainfall is recorded during the season of the South-West Monsoon. There are significant variations in the mean monthly temperature of January and July owing to undulating and mountainous topography.

7. Region of Heavy Rainfall

This region covers West-Bengal, Odisha, Jharkhand and eastern parts of Andhra Pradesh. The average annual rainfall in this region varies between 100–200 cm. There is a general decrease in the amount of rainfall from east to west. The mean January temperature is over 18°C, while about 30°C is recorded during the months of June and July.

8. Region of Moderate Rainfall

This region lies to the east of the Western Ghats and includs Gujarat, south-western Madhya Pradesh, Maharashtra, Karnataka and greater parts of Andhra Pradesh. Being in the rain-shadow area of the Western Ghats, this region receives relatively less rainfall of about 75 cm. The average temperature in the months of January and July varies between 18°C and 32°C respectively.

9. The Konkan Coast

It stretches from the mouth of Tapi river to Goa. The average annual rainfall is more than 200 cm, of which over 90 per cent is recorded from the Arabian stream of the South-West Monsoon. The mean January temperature remains around 24ºC while the mean July temperature reads about 27ºC. The average annual range of temperature varies between 3°C to 6°C depending on the distance from the coast and the equator. In general, the annual range of temperature increases from south to north.

10. The Malabar Coast

This climatic division lies between Goa and Cape Camorin (Kanniyakumari). The Malabar coast records over 250 cm of rainfall. The average annual temperature reads around 27ºC with 3ºC being the annual range of temperature. Kochi is a typical example of this region.

11. The Tamil Nadu Region

This region includes the greater parts of the state of Tamil Nadu and the Coromandal Coast. The average annual rainfall varies between 100–150 cm. Most of the rainfall is recorded during the season of retreating monsoon (October to December). The average temperature for the month of January is 24°C, while the July temperature reads around 30°C.

TREWARTHA'S CLASSIFICATION OF INDIAN CLIMATE

G.T. Trewartha modified the climatic classification of Koppen in 1954. His classification of climate is empirical, based on the temperature and precipitation data. He also used English alphabets as the symbols to show the different types of climate. His scheme, applied to India, divides the country into four major climatic regions which are further sub-divided into seven meso-climatic divisions (**Fig. 4.24(a)**).

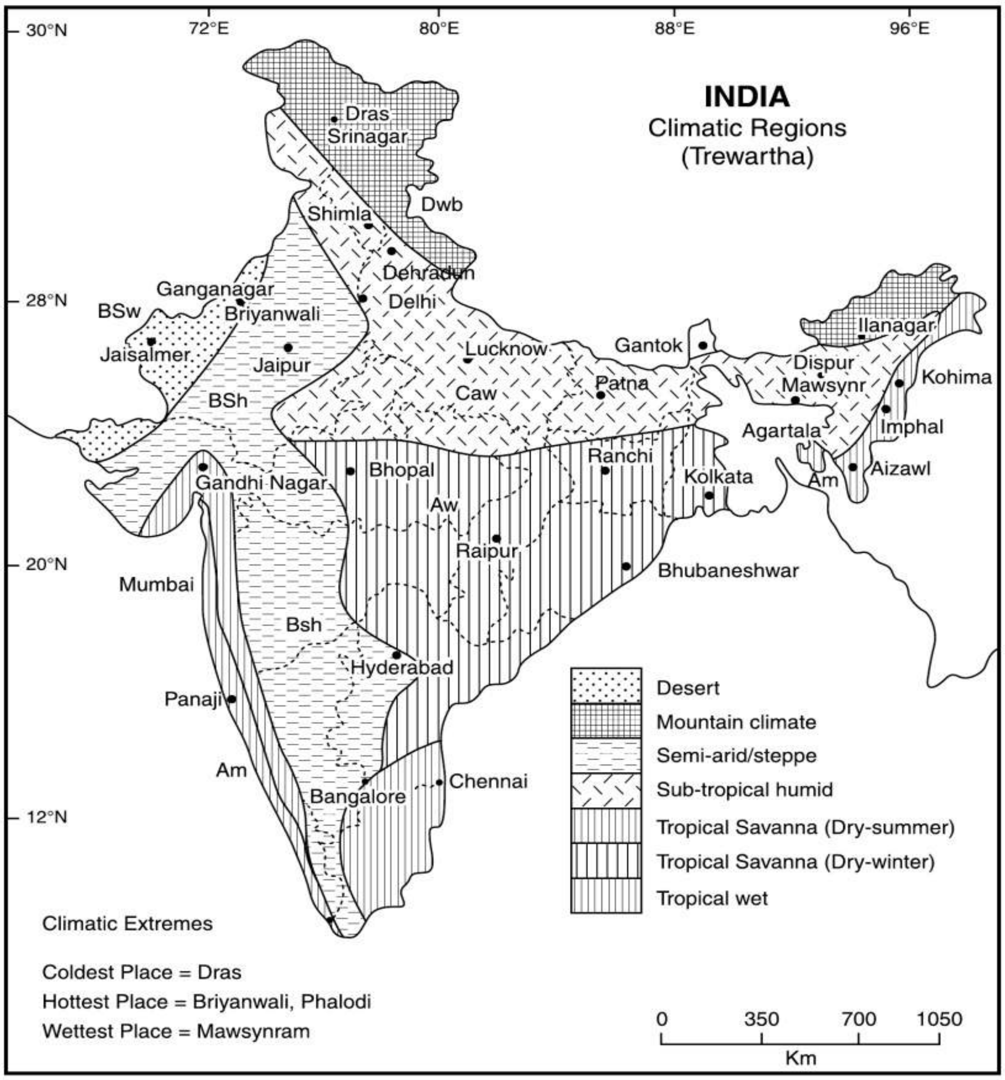


Fig. 4.24(a) Trewartha's Climatic Regions

1. The Tropical Rainy Climate (Am)

The mean annual temperature in this climate is about 27°C and the mean annual rainfall exceeds 250 cm. The Western Ghats and the state of Tripura exhibit this type of climate.

2. The Tropical Savannah Climate (Aw)

In this climatic type, the mean annual temperature remains around 27°C. The mean annual rainfall is less than 100 cm. It has a marked dry season. The greater parts of the Peninsular India, excluding the coastal plains and the western slopes of the Western Ghats, have been included in this climate type.

3. The Tropical Steppe Climate (BSw)

The mean annual temperature in this climatic zone is about 27°C. It covers peninsular India east of the Western Ghats. In fact, it is the rain-shadow area of the Western Ghats including parts of Maharashtra, Andhra Pradesh, Karnataka, and Tamil Nadu.

4. The Sub-tropical Steppe Climate (BSh)

This is a semi-arid climate stretching over parts of Gujarat, eastern Rajasthan, Maharashtra, Andhra Pradesh, and southern Haryana. The mean annual temperature in this climatic region is over 27°C, though the mean monthly January temperature reads only about 15°C. The annual range of temperature is significantly high. The mean annual rainfall varies between 60 to 75 cm.

5. The Tropical Arid Climate (BWh)

It lies to the west of the Aravallis, stretching over the Thar Desert. The mean maximum temperature during the months of May and June occasionally crosses 48ºC. The mean annual rainfall is less than 25 cm. The lowest rainfall in the country is recorded in this climate in the district of Ganganagar. Consequenty, the natural vegetation is in the form of thorny bushes.

6. The Humid Sub-tropical Climate (Caw)

This climate occupies the greater parts of the Great Plains of India, stretching from Punjab to Assam. The mean January temperature for the coldest month of January is less than 18°C, while the mean maximum in the summer season may cross 45°C. The average annual rainfall varies from 250 cm in the east to only about 65 cm in the west.

7. The Humid Mountain Climate (Dwb)

This climate is found in the hilly parts of the states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh, and the other hilly parts of north-east India. In this climate, the average temperature for the summer season reads around 17°C, while the average January temperature is generally around 8°C. The average temperature of all the months is however, closely influenced by the topographical features and slope. In general, the rainfall decreases from east to west. The Western Himalayas record some amount of rainfall from the western disturbances during the winter season.

CLIMATIC DIVISIONS OF INDIA BY R.L. SINGH (1971)

Professor R.L. Singh modified the climatic divisions of Stamp and Kendrew in 1971. Prof. Singh has divided India into 10 major climatic divisions. His classification is quantitative as well as qualitative, largely based on the amount of rainfall and temperature. In fact, the modifications have been done on the basis of variations in temperature (**Fig. 4.24(b)**). A brief account of Singh's classification has been presented in the following section:

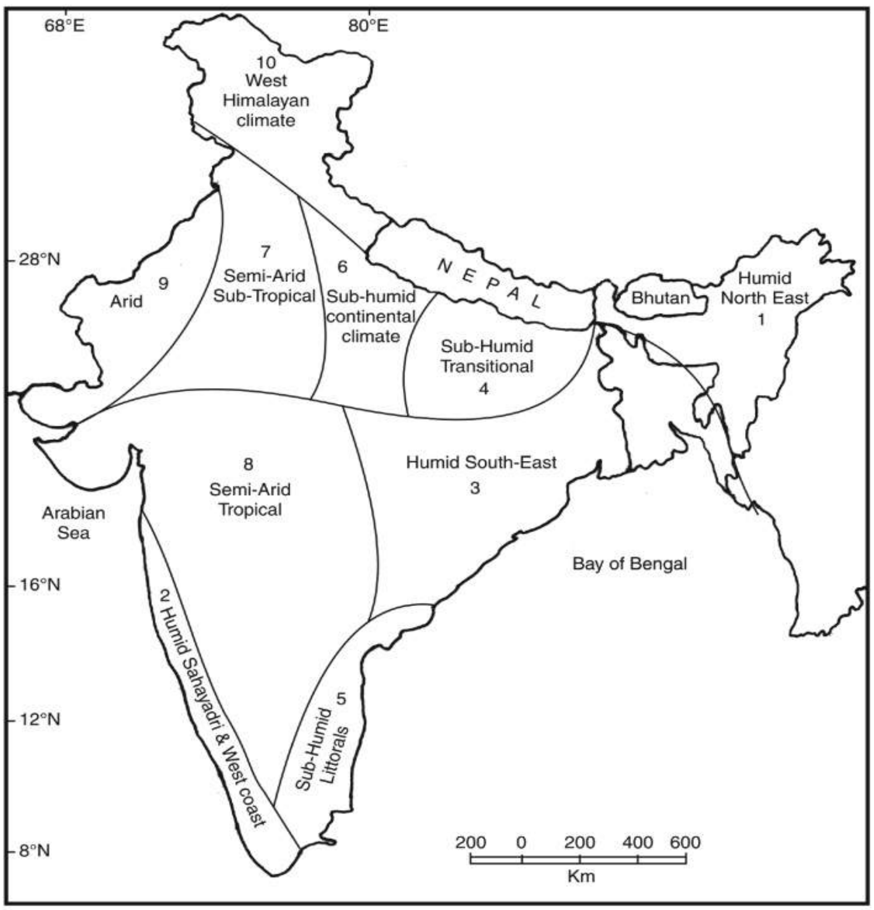


Fig. 4.24(b) R.L. Singh's Climatic Divisions

I. The Humid North-East

This climatic division includes the whole of north-east India (except Tripura), Sikkim and north-western West Bengal. The average annual rainfall in this climatic division is more than 200 cm. The mean July temperature varies between 25°C and 33°C, while mean January temperature reads between 10°C and 25°C.

2. Humid Sahyadri and Western Coast

This climatic zone includes the Konkan and Malabar coasts from the mouth of Tapi river to Kanniyakumari. The average annual rainfall in this zone is about 200 cm. The mean July temperature ranges between 25°C and 30°C, while that of January ranges between 18°C and 28°C.

3. The Humid South-East

This climate spreads over the greater part of West Bengal, Jharkhand, Chhattisgarh, Odisha and parts of Andhra Pardesh. It records an average annual rainfall between 100–200 cm. The mean July temperature varies between 25°C to 35°C, while the mean January temperature reads between 12°C–27°C.

4. The Sub-Humid Transition

This climate includes those parts of the Gangetic Plain in which the average annual rainfall is between 100 and 200 cm, Average temperature for July varies between 25°C, and 40°C and January temperature between 10°C and 25°C.

5. The Sub-Humid Littoral

This type of climate is found along the Coromandal coast. The mean annual rainfall varies between 75–150 cm. The May temperature reads between 28°C and 38° C, while the January temperature ranges between 20°C–30°C.

6. The Sub-Humid Continental

Covering mostly the Upper Ganga Plain, it receives average annual rainfall between 75–150 cm. The average temperature for July ranges between 25°C and 40° C, and the average January temperature recorded varies between 17°C and 25°C.

7. Semi-Arid Subtropical

This type of climate spreads over eastern Rajasthan, Haryana, and Punjab. The average annual rainfall in this climate varies between 25 to 75 cm. The average temperature for January ranges between 25°C to 28°C, while the average temperature for January ranges between 15°C and 25°C.

8. The Semi-Arid Tropical

It covers the largest area of the central and western Peninsula covering Gujarat, Maharashtra, Madhya Pradesh, Karnataka and western Andhra Pradesh. The average annual rainfall in this region varies between 50 and 100 cm, the mean monthly temperature in July varies between 26°C and 40° C, while the mean average temperature for January reads between 15°C and 28°C.

9. Arid

Covering the greater part of Kachchh, western Rajasthan, and south-western Haryana, it receives rainfall less than 25 cm. In fact, the Thar desert of India has been included in this type of climate. June is the hottest month here in which the average temperature varies between 30°C and 40°C. In January, the mean minimum monthly temperature fluctuates between 10°C and 15°C. It is the most drought affected area of the country in which every third year is a drought year.

2. Humid Sahyadri and Western Coast

This climatic zone includes the Konkan and Malabar coasts from the mouth of Tapi river to Kanniyakumari. The average annual rainfall in this zone is about 200 cm. The mean July temperature ranges between 25°C and 30°C, while that of January ranges between 18°C and 28°C.

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It covers the largest area of the central and western Peninsula covering Gujarat, Maharashtra, Madhya Pradesh, Karnataka and western Andhra Pradesh. The average annual rainfall in this region varies between 50 and 100 cm, the mean monthly temperature in July varies between 26°C and 40° C, while the mean average temperature for January reads between 15°C and 28°C.

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10. The Western Himalayas

It includes the mountainous areas of Jammu and Kashmir, Himachal Pradesh and Uttarakhand. The average annual rainfall in this climatic division is up to 150 cm. The rainfall however, decreases from east to west and south to north. Rainfall from the western disturbances during the winter season is also a unique characteristic of this climatic zone. This small amount of rainfall is highly beneficial for the standing ***Rabi*** (winter) crops. The mean July temperature ranges from 5°C to 30° C, while the average temperature of January varies from 0°C to 5° C.

DROUGHTS

Drought is a continuous and lengthy period during which no significant rainfall is recorded. In India, the Meteorological Department of India defined drought as a period of at least 22 consecutive days on none of which is there more than 0.25 mm (0.01 inch) of rainfall. This definition however, does not apply to the whole of India. In areas like Mawsynram and Cherrapunji (recording over 1200 cm of average annual rainfall) even one week recording less than 0.25 mm of rainfall may be considered as a drought period. In general, the areas recording less than 60 cm of rainfall annually and in which the variability of rainfall is more than 20 per cent are the drought prone areas in India. Areas where the variability of rainfall varies between 20 to 60 per cent (like Rajasthan, west of Aravallis, and east of the Western Ghats) are the chronic drought prone areas. In India, droughts are more frequent in the areas where the average annual rainfall is less than 60 cm and the variability of rainfall is over 20 per cent, provided canal and tube-well irrigation is not available. The variability of rainfall over greater parts of the country is more than 25 per cent, and thus over 50 per cent of the country is vulnerable to droughts.

According to the Ministry of Agriculture and the Ministry of Environment, a drought prone area is defined as one in which the probability of a drought year is greater than 20 per cent. A chronic drought prone area is one in which the probability of a drought year is greater than 40 per cent. A drought year occurs when less than 75 per cent of the average annual rainfall is recorded.

On an average, one in every five years is a drought year in India, while in western Rajasthan every third year is a drought year. Although over 60 per cent of the area has high variability of rainfall, there are three areas which are highly vulnerable to droughts (**Fig. 4.25**). The drought prone areas of India are:

1. **The Arid and Semi-arid Areas of Rajasthan:** There is a contiguous region, covering greater parts of northern Gujarat, Rajasthan, south-west Haryana, southern parts of Punjab, western Madhya Pradesh, and parts of the Agra Division of Uttar Pradesh. This drought prone area, having a variability of rainfall of over 40 per cent, stretches over 65 lakh sq km. Parts of these contiguous drought prone areas, irrigated by canals and tube-wells are, however, less affected by droughts.
2. **The Rain-shadow Areas of Western Ghats:** This is the area lying to the east of the Western Ghats (Sahyadri Mts), stretching from Jalgaon (Mahrashtra) to Hyderabad and Mahbubnagar (Andhra Pradesh), Bidar, Bijapur, Gulbarga, and Raichur of Karnataka, and Coimbatore, Madurai, Salem and Remanathapuram of Tamil Nadu. The variability of rainfall in this region varies between 30 to 40 per cent. It is in this areas that several thousand farmers have committed suicide during the last decade.

3. **Other Drought Prone Areas:** There are isolated tracts, covering an area of about one lakh sq km in different parts of the country, which are drought prone areas. These areas include Kalahandi region of Odisha, Purulia District of West Bengal, Palamu plateau of Jharkhand, Mirzapur Plateau, and Bundelkhand (U.P.), Baghelkhand (Madhya Pradesh), Coimbatore, Madurai and Tirunelveli District of Tamil Nadu. These scattered pockets cover over one lakh sq km.

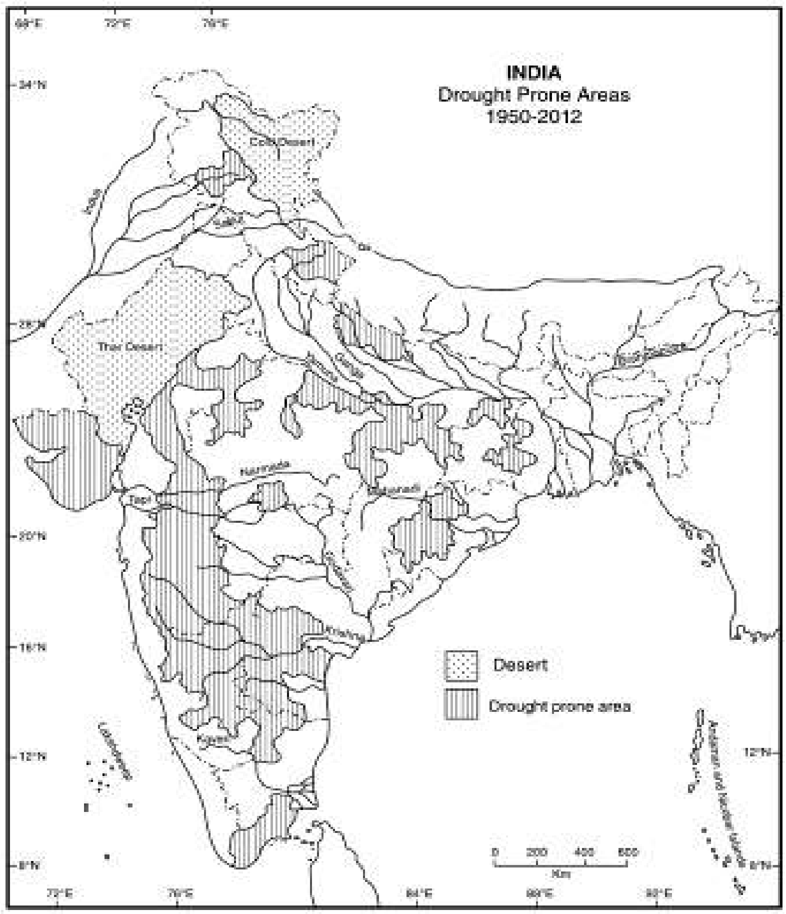

Fig. 4.25 Drought Prone Areas (1950–2012)

Though droughts are recurring physical phenomena and their severity was more during the medieval period, some of the serious droughts of the 20th century have been briefly described in the following section:

The Maharashtra drought of 1965–66, the Bihar drought of 1966–67, the Kalahandi drought of 1996–97 and the continuous deficient rainfall in Andhra Pradesh, Karnataka and western Tamil Nadu during the last decade forced a number of the farmers to commit suicide. The monsoon failure in 2009 over greater parts of the country resulted into drought. Consequently the Kharif cropped area decreased by about 40 per cent.

The adverse effects of droughts can be minimised by an extension in the irrigation projects, adoption of sprinkle irrigation, water harvesting, suitable rotation of crops, deviation from the more water requiring crops, and dry-farming techniques. If all these steps are taken together, the miseries of the farmers and inhabitants of the drought prone areas may be reduced substantially.

Droughts are disasters which affect the people and economy of the country adversely. Their frequency, according to experts of climatology, is likely to increase in future due to greenhouse gases, climatic change and ecological imbalances created by interference of man.

The years of 1965–67, 1972–73, 1979–80, 1985–88, 1999, 2000, 2001, 2002 and 2009 have been the drought years in India after Independence. According to the experts the drought of 2002 and 2009 was one of the worst droughts in the last one hundred years. In these years, the states of Haryana, Punjab, Uttar Pradesh, Uttarakhand, Bihar, Madhya Pradesh, Gujarat, Tamil Nadu, Karnataka, Jharkhand, Odisha, parts of Kerala, and the whole state of Rajasthan were the worst affected.

Drought Management

The government of India has paid enough attention to droughts and drought affected areas right from the first Five Year Plan. Before 1987, the government tried to provide relief to the people of the drought affected areas by providing employment opportunities to the affected population and distribution of food-grains through Public Distribution System (PDS). The contingent drought relief expenditure imposed a serious strain on public finances as huge amounts had to be divested from development for undertaking relief projects. In some states like Rajasthan, the drought relief outlays exceeded the developmental outlays.

In order to overcome this problem, the drought management strategy was adopted in the early 1970s. The drought management approach differed from drought relief approach with regard to objectives, reliance of early warning indicators and timing of public intervention. The objective of relief approach was to protect entitlement of the affected population by ensuring physical and economic access to food through relief projects and public distribution of food-grains. As against this, the drought management approach aimed at ensuring entitlement to produce food so as to obviate the need for taking up ad hoc relief projects. While drought relief approach relied on socio-economic indicators like crop production data, price rise, migration of the drought affected people and increased rate of crimes for drought declaration and intervention; drought management approach relied on hydro-agriculture indicators, like rainfall, water level of reservoirs and progress of cropping pattern to detect early signs of developing drought situation. While drought relief approach enabled the government to intervene only in the months of November and December when the rainy season is over and the kharif crops have been harvested, the drought management approach enabled the government to intervene in the monsoon season itself.

According to the Committee of Disaster Management (2002), drought management is generally done by focusing on employment generation, water conservation, and power supply, standing crop saving and public distribution of supplies of essential commodities.

Drought Prone Area Programme (DPAP)

The drought prone area programme which covers 615 blocks, spread over ninety districts in the western, central and southern parts of the country, is an integrated area development programme in agricultural sector. The main objectives of the Drought Prone Area Programme are:

(i) to make judicious and scientific utilisation of agricultural land, water and livestock resources,

(ii) to enhance and stabilise the income of the people of drought prone areas, particularly of the weaker section of society, and
(iii) restoration of ecological balance.

Some of the important elements of the programme include:

(a) Integrated watershed management and management of water resources.
(b) Soil and moisture conservation measures.
(c) Afforestation with special emphasis on social and agro-forestry.
(d) Development of pasture lands and forest range management in conjunction with development of sheep husbandry.
(e) Livestock development and dairy development.
(f) Restructuring of cropping patterns and changes in agronomic practices.
(g) Adoption of scientific rotation of crops with an emphasis on the leguminous (pulses) crops.
(h) Development of subsidiary occupations.
(i) Water harvesting.
(j) Development of minor irrigation projects.
(k) Construction of underground canals and lined canals.
(l) Desalination of sea-water for irrigation and domestic use.
(m) Diversification of agriculture.
(n) Development of cottage and household industries.
(o) Development of alternate sources of energy (solar, wind and biogas) for domestic and industrial purposes.
(p) More research is required to increase agricultural productivity in the dry farming regions.

These steps, if taken together, can go a long way in minimising the miseries of people living in the drought prone areas of the county.

Some of the important achievements of the Drought Prone Area Programme include the Indira Gandhi Canal Project, Sardar Sarovar Project (Narmada), and the Central Arid Research Institute, Jodhpur to promote drought resistant plants, trees and crops.

FLOODS

Floods occur when peak discharge exceeds channel capacity, and this may be brought about naturally by intense precipitation, snow and ice-melt, storm surges in coastal regions, and the rifting of barriers, such as ice-dams, or by the failure of man-made structures, by deforestation, urbanisations, (which reduce infiltration and interception), and by engineering works such as land drainage or the straightening of embankments of rivers.

Flood has also been defined as a state of high water level along a river channel or coast that leads to inundation of land which is normally submerged. Flood is an important component of hydrological cycle of a drainage basin. In fact, droughts and floods are the two extremes of the hydrological cycle. While droughts occur due to the failure of rainfall; floods generally occur in the event of excessive rainfall. Thus, flood is a natural hazard which occurs in response to heavy rains and it becomes a disaster when it inflicts heavy loss to life and property.

Causes of Floods

The main factors responsible for the occurrence of floods are: (i) Meteorological, (ii) Geomorphic, and (iii) Anthropogenic.

Meteorological factors include heavy rainfall, snowfall due to tropical cyclones, and cloud burst. Most of the floods in India are the result of heavy precipitation, especillay during the season of south-west Monsoon.

Geomorphic factors like the large catchment area of a river, gentle slope and the low gradient of river course, and poor drainage also lead to floods in the Northern Plains and Coastal Plains of India. The Jodhpur Barmer, and Bikaner flood in July 2006 mainly occurred due to cloud burst and poor drainage in the region.

The Anthropogenic causes including deforestation, encroachment for agriculture into pastures and forest areas, shifting cultivation, unscientific rotation of crops, bursting of dams and embankments, urbanisation, and construction of houses in the river beds are also responsible for a number of floods in the country. The July 2005 flood in Mumbai was mainly due to the construction of houses and structures in the bed of the Methi River.

Flood Prone Areas of India

Out of the country's total geographical area (329 millions hectares) about 45 million hectares (13.6 %) is prone to floods (2012). The flood prone areas of India have been plotted in **Fig. 4.26.** An examination of **Fig. 4.26** shows that the flood prone areas are well scattered in different parts of the country, ranging from the heavy rainfall areas to the scanty rainfall areas. Flood is, however, a recurring feature during the rainy season in Assam, West Bengal, Bihar, Uttar Pradesh, Haryana and Punjab. Floods also occur along the eastern coastal plains, the valley of Kashmir, the lower reaches of the rivers discharging their water in the Bay of Bengal and the Gulf of Khambat (Arabian Sea). The flood affected areas of India are as under:

1. The Ganga River Basin
2. The Brahmaputra River Basin
3. The Punjab Haryana Flood Plain
4. Flood Prone Areas of the Coastal Plains.

1. The Ganga River Basin

Stretching over an area of about 861,400 sq km, the Ganga and its tributaries drain the states of Uttarakhand, Himachal Pradesh, Haryana, Uttar Pradesh, Bihar, West Bengal, Jharkhand, Chhattisgarh, Madhya Pradesh, and Rajasthan. Its large left hand tributaries are Sharda, Kali, Gomti, Ghagra, Gandak, Kosi, and Mahananda; while the right hand tributaries include, the Yamuna, Chambal, Sind, Betwa, Ken, Son, and Damodar. Thus, from the mighty Himalayas and the northern Peninsular India, the Ganga and its tributaries carry enormous quantity of water. These rivers, due to heavy rains in the rainy season and melting of snow in the spring season, cause heavy floods in the middle and lower reaches of their catchments. Kosi (means *cuise-Kosna*) has often been called the "Sorrow of Bihar". Its flood in July 2008 caused heavy loss to life and property.

The cloud burst on 16th June, 2013 in Uttarakhand resulted into disaster in which the sacred places such as Kedarnath Rambara, Joshimath were seriously damaged. Except the Kedarnath temple almost the entire settlement was burried under sediments, boulders and coarse-sand.

The state of Uttar Pradesh alone constitutes about 22 per cent of the flood prone area of the country. The river channels of these rivers are increasingly getting shallower, especially in their middle and lower reaches. In the event of heavy rainfall, these rivers cross their banks and inundate the neighbouring khadar areas.

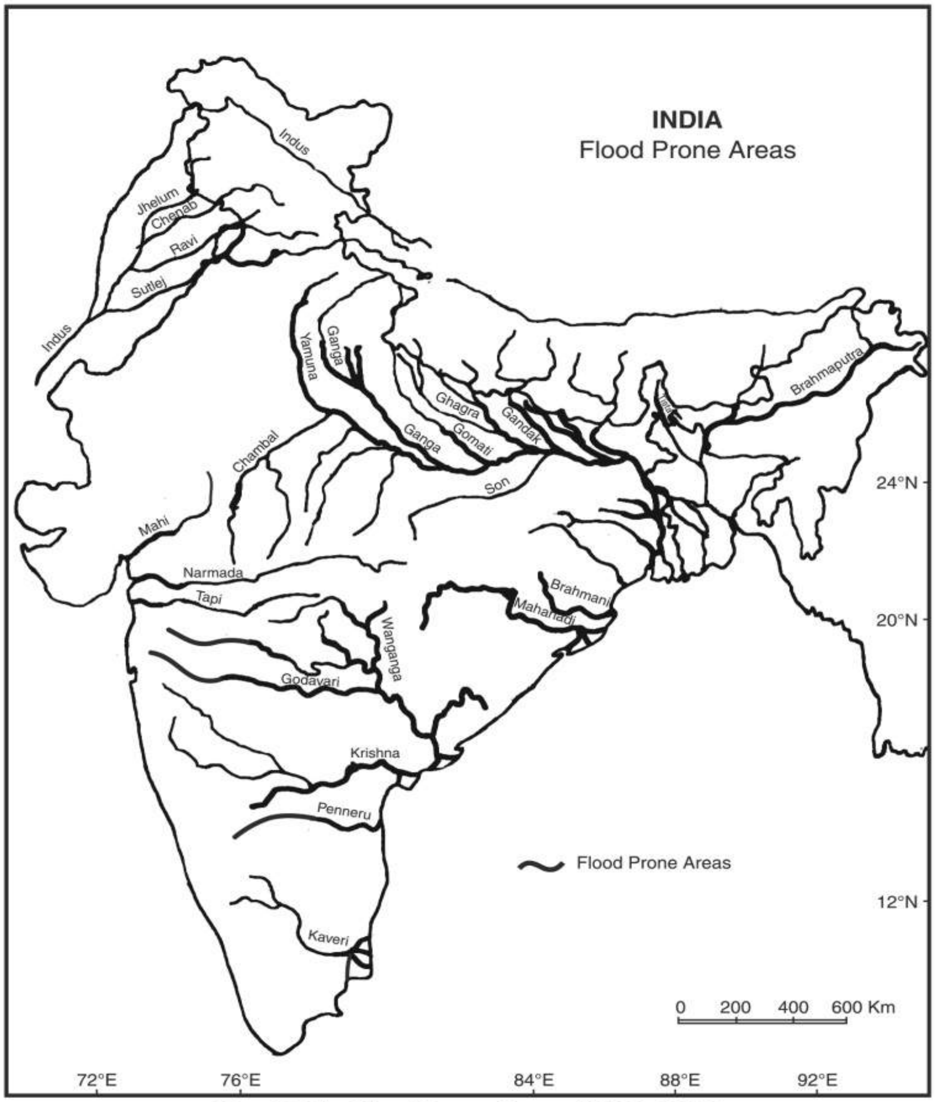

Fig. 4.26 Flood Prone Areas (1950–2012)

In Bihar, floods are largely confined to the northern part of the state where occurrence of flood is almost an annual feature during the season of general rains. The rivers like Burhi Gandak, Bagmati, Kosi, and the lower reaches of the Mahananda spill over their banks and inundate the low lying khadar areas. The Kosi flood 2009, created havoc in the districts Saharsa, Medhapur, and Khagaria of Bihar. Many of the cities and towns were submerged under water causing enromous loss to life and property.

In West Bengal, the southern and central parts are frequently flooded during the season of south-west monsoon. The Mahananda, Bhagirithi, Ajoy, and Damodar (Sorrow of Bengal) are often in floods in rainy season. Even after the formation of the Damodar Valley Corporation (DVC), there occur occasional floods in the rivers.

2. The Brahmaputra River Basin

The maximum discharge of water among the Indian rivers is in the Brahmaputra River. The Assam Valley is considered to be one of the worst flood affected areas of India. In fact, in Assam, floods are almost an annual feature. The main cause of floods in the Brahmaputra basin are: (i) heavy and torrential rainfall—during the rainy season over 200 cm of rainfall is recorded over greater parts of its middle and lower reaches, (ii) silting of the river course due to heavy soil erosion, (iii) landslides, (iv) heavy pressure of population, and (v) shifting cultivation on the surrounding hilly areas. All these factors collectively result in flooding of the vast areas in and around the Brahmaputra Valley.

All the districts of Assam are inundated almost every year. The worst affected areas in Assam are 'Majuli'—India's largest river island, Dhubri, Kokrajhar, Barpeta, Guwahati, Mangaldoi, Sibsagar, Jorhat, Dibrugarh, and Tezpur. According to one estimate, about 80 lakh hectares, i.e. over 45 per cent of the total area of Assam, is flood prone.

3. The Punjab Haryana Flood Plain

This area falls under the scanty rainfall recording areas of India. Despite low rainfall, Punjab and Haryana are adversely affected by floods because of the inadequate surface drainage. In Punjab and Haryana, the rainfall water is waterlogged. Consequently, the ill-drained areas are inundated. The rivers, like Satluj, Beas, Ghaggar, and Markanda record floods almost annually. The main reasons of floods in Punjab and Haryana are: (i) deforestation in the Lower Himalayas and the Siwalik, (ii) increase in soil erosion in the upper reaches of the rivers leading to silting of river beds, (iii) construction of structures in the ***Bet*** (Khadar) areas of the rivers, (iv) unscientific land use, cropping patterns and rotation of crops, and (v) obstruction of natural drainage by the construction of roads, railways and human establishments.

Floods are frequent in the Ghaggar plain of Punjab, Haryana and also Rajasthan. The Ghaggar river is seasonal in character. Its course disappears in the sand-dunes of Rajasthan after crossing Punjab and Haryana.

In the Valley of Kashmir, floods are caused by the Jhelum river. Tawi river is the main cause of floods in Jammu. In 2004, the release of huge quantity of water in Satluj river from the Rakas Lake threatened many areas of Himachal Pradesh.

4. Flood Prone Areas of the Coastal Plains

The coastal areas of Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Maharashtra and Gujarat are included in this region. The magnitude of floods becomes serious in the lower reaches of the Mahanadi, Godavari, Krishna, and Kaveri. The beds of these rivers are shallow which inundate after a heavy downpour in their catchments. Indiscriminate felling of trees in the catchment areas of the main rivers and their tributaries has accelerated soil erosion and silting of river beds. The estuaries of Narmada and Tapi lead to floods at the occurrence of spring tides. The coastal areas also submerge due to the surge of sea water at the time of tropical cyclones in the Bay of Bengal and the Arabia Sea. The occurrence of Tsunamis, as on December 26, 2004, may cause serious damage to life and property of the coastal areas. The small swift moving rivers of the western coastal plains may cause considerable damage when in spate.

Flood Control and Management

The main steps taken by the government of India are briefly given below:

1. Flood Forecasting

The Central Water Commission started flood forecasting since November 1958, when the first forecasting station was established at the Old Railway Bridge of Delhi. Since then, it has extended the flood-forecasting stations to cover almost all the major flood prone rivers of the country. At present, there are 175 flood forecasting stations on different major and minor rivers of the country. The centre issues daily flood forecasts and warnings throughtout the season of general rains.

The Central Flood Forecasting Organisation monitors floods all over the country and issues warnings. The main flood forecasting centres are located at Surat (Tapi), Bharuch (Narmada), Varanasi, Buxar, Patna, Hathidah, and Aimabad (Ganga), Dibrugarh and Guwahati (Assam), Jalpaiguri (Tista), Delhi (Yamuna), Lucknow (Gomti), Bhubaneshwar (Subarnrekha, Burtha, Balang, Brahmani and Baitarni), Sahibi (Rajasthan), and Gandhi-Sagar (Chambal). In addition to these, there are 157 flood forecasting stations from which about 6000 forecasts are issued every year.

2. Reduction of Runoff

Reduction in runoff is one of the most effective methods of flood control. Runoff can be reduced by inducing and increasing the infiltration of the surface water into the ground. Afforestation in the catchment areas of rivers is a very effective step to check the runoff and to increase the percolation of water.

3. Construction of Dams and Reservoirs

The floods can be reduced by construction of dams and reservoirs. Dams have the capacity of holding huge quantity of water during the flood period and help in reducing the menace of floods. Water stored in reservoirs of dams can be released under controlled conditions, depending upon the carrying capacity of the river channel. A number of dams across the Damodar, Kosi, Satluj, Rihand, Mahanadi, Krishna, Kaveri, Chambal, Narmada, Tapi, and Sabarmati have been constructed to check floods.

4. Control of Flood Levels

A number of steps may be taken to control the flood levels. Among these steps, stream channelisation, channel improvement, and flood diversion are important.

5. Construction of Embankments

Construction of embankments is a very effective method against floods. Construction of embankments has been taken in a big way after the establishment of the Central Water Commission and the Flood Control Commission. Over 12,000 km long embankments have been constructed after the establishment of the Flood Control Commission. Most of these embankments have been constructed along the Brahmaputra, Ganga, Yamuna, Satluj, Beas, Ravi, Mahanadi, Kosi, Godavari, Krishna, and the Kaveri.

6. Flood Plain Zoning

Flood plain zoning is another very effective method of flood management. It is based on information regarding land use in flood plains. Some areas are more prone to floods than others. Construction of buildings, factories, etc. in the zone adjacent to the river channels should be prohibited. The areas occasionally flooded after a few years should be under green-belts in which social forestry is a priority.

7. Other Measures

The following additional measures are suggested by the Flood Control Commission: (i) restriction on indiscriminate felling of trees in hilly regions, (ii) protecting one kilometre tract along the major rivers for massive afforestation, where agriculture and house construction prohibited, (iii) Regular dredging of river beds, (iv) formation of National Water Grid through which flood waters could be diverted to dry areas through diversion channels or could be stored in reservoirs, (v) to develop suitable drainage channels in water-logged areas, and (vi) engineering effective methods to protect the coastal areas from tides and sea-surges.

Flood Control Programme and Strategies

The National Flood Control Programme was launched in India after the devastating flood of 1954. The programme consists of three phases which have been briefly described in the following section:

1. **The Immediate Phase:** This phase extends over two years and includes the collection of basic hydrological data and execution of immediate flood protection measures like construction of embankments, improvement of river channels and raising the vulnerable villages above the flood level.
2. **The Short-Term Phase:** This phase lasts for the next five years. In this phase there is emphasis on improvement of surface drainage, establishment of effective flood warning system, shifting or raising of villages above flood level, construction of diversion channels, construction of embankments and raised platforms to be used during the period of floods.
3. **The Long-Term Phase:** The long-term phase includes construction of dams and storage reservoirs, digging large diversion channels, taking suitable steps for land-use improvement, and soil conservation in the catchment area of the main river and its tributaries.

In order to overcome the problem of floods in the country, the Government of India has set up a National Flood Commission ***(Rashtriya Barh Ayog)***. This Commission has taken a holistic view of the flood problem. Many multi-purpose projects and large dams have been constructed to overcome this problem. Recently, the Brahmaputra River Board has been constituted to control floods in the Brahmaputra Valley.

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