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Mechanism of Indian Monsoon

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Abstract: ***Monsoons is a seasonal climatic phenomena experienced by south Asian subcontinent. For India Monsoons not only have impact on agriculture but also directly influences economy, political and cultural calendar. It is extremely important to understand the mechanism of monsoon. Monsoon is global phenomena. El Niño, Southern Oscillation, Location of Jet stream, ITCZ, change in direction of Trade Winds is some of the global events which impact monsoon. Similarly, local climatic conditions and physiography all have impact on monsoon rainfall. The current changes in monsoon due to global heating have made it difficult to predict despite scientific studies and technological advancement. We have seen in recent years that extreme monsoon events like flash floods and cloud burst trigger landslides and floods causing massive damage and destruction in some regions and deficit of rainfall results in droughts in some regions during same year.***

Keywords: ITCZ, El Nino, Jet Stream, Monsoon Trough

1. Introduction

Word MONSOON owes its origin to Arabic word "Mausam", which means season. Therefore, it refers to seasonal winds which predominantly blow in one particular direction during a season. Ancient text RIG-VEDA contains several hymns written in praise of PARJANYA, the God of rains, the creator of all living things - plants, animals and other creatures. Most beautiful description of monsoon clouds appears in the Sanskrit classic MEGHDOOTAM written by Kalidasa in 4th century wherein he mentions the arrival of monsoon over Ujjain on first day of ASHADHA around 15th June which coincides with the date of arrival of rains even today. In 10th century A.D. Al-Masudi the Arab Scholar from Baghdad mentioned about the winds blowing over Arabian Sea and their particular characteristic of total reversal with season.

The present day study of mechanism of monsoon and its prediction is totally scientific and technical with the use of state of art satellites and radars for collection of date apart from various metrological stations located on ground and computers being used for decoding the data and interpretation of data.

Monsoons play a very important role in our national economy. Our agriculture still depends on monsoon rains. The timely onset of monsoon is very important not only for agriculture but also for our industries and other sectors of economy. Delay in monsoon results in hoarding of food grains, creating artificial scarcity and price rise.

Onset of monsoon in our country also heralds the beginning of festival season. Rains over the Northern plains heralds the festival after 2-3 months of relatively calm. Festivals like ***Teej, Rakshbandhan, Amarnath Yatra, Janamashtami, Onam, Ganesh Chaturthi*** etc. all come during the monsoon season. The festival season ends with Diwali which coincides with the date of withdrawal of Monsoons over Northern Plains.

Monsoons play a very important role in the political arena the dates for general elections are decided on basis of monsoon season. Monsoon session is the first session of parliament. Historically also monsoons have played important role. The decline of Harappa Civilization is considered to be due to changes in the rainfall pattern

Mechanism of Monsoon

Definition

Monsoon means seasonal winds which blow with consistency and regularity during a part of the year and which is absent or blows from other direction for rest of the year.

Such seasonal changes are primarily the result of differences in quantity of heat received from sun by different parts of earth.

Monsoon can be described as system of winds with following features:

- A wind system with marked seasonal shift caused by differential heating of land and sea.
- Winds that are largely confined to tropics – 20^0 N and 20^0 S of equator.
- Summer monsoons are the south-east trade winds of southern hemisphere which on crossing the equator are deflected to the right buy earth's rotation and change their direction to south west.
- The prevailing wind system should shift by at least 120^0 between January to July.

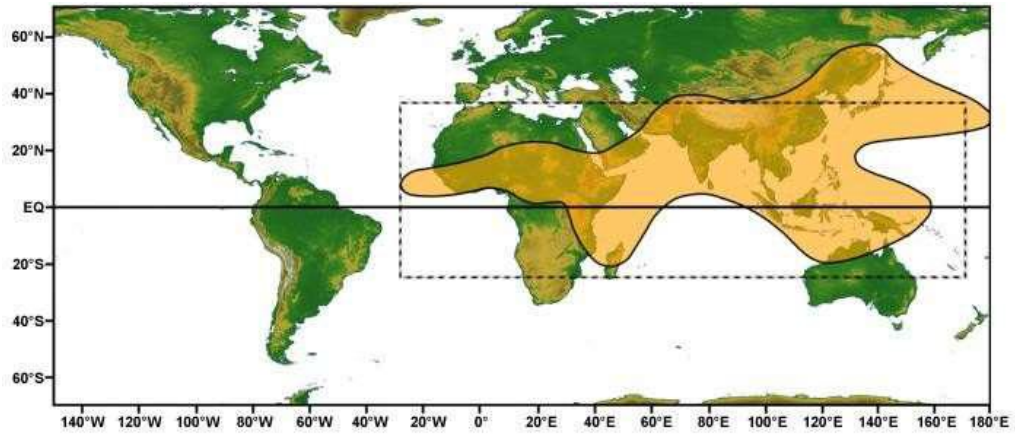

Figure 1: Monsoon Regime
Source: httpswww.dspmuranchi.ac.inpdfBlogM.pdf

Global Factors

Differential Heating of Land And Sea

During the months of April and May the large land mass of North – West India gets immensely heated. It leads to formation of intense Low pressure area over the North West India. The pressure conditions over the Indian Ocean on the other hand are high. As a result, the conditions become favourable for the northward shift of ITCZ.

Shifting of ITCZ and Wind Belts

Inter tropical Convergence Zone is a zone of separation between northern and southern hemisphere trade winds. ITCZ moves to north and south of equator in agreement with seasonal variation in sun's angle of declination. With northward shift of ITCZ in summers the South East Trade Winds Belt also shifts northward. After crossing equator these winds deflect to right because of Coriolis force (due to spinning of earth) in northern hemisphere and becomes South West Trade Winds. Shift in ITCZ is also related to withdrawal of westerly jet stream from its winter position.

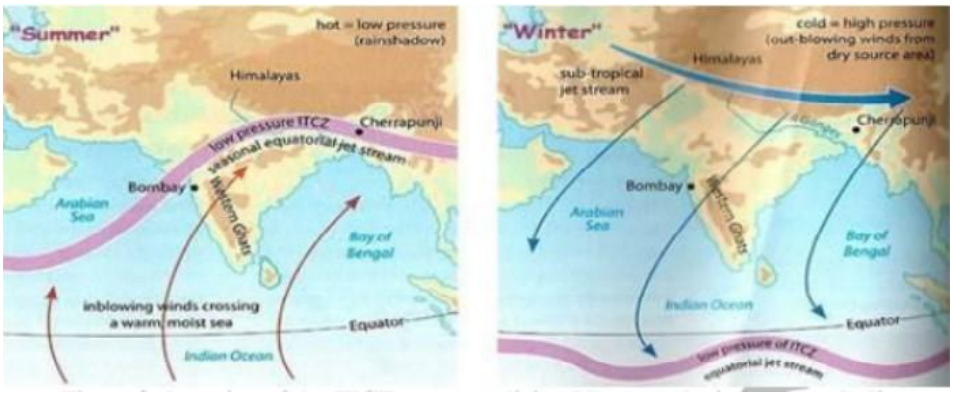

Figure 2: ITCZ and Shifting of Trade Winds
httpswww.dspmuranchi.ac.inpdfBlogM.pdf

Upper Air Circulation – Jet Streams

Jet streams are wide bands of the upper air, high-speed winds that blow in the troposphere consistently in one direction in a meandering course. In winter westerly Jet stream blows over the Indian sub-continent in two parts North of the Himalayas and South of the Himalayas. In summers towards the end of May the Jet Stream blowing south Himalayas suddenly weakens and moves to new location north of Himalayas. Its movement towards north is main feature associated with onset of monsoon over India. As westerly jet stream moves north its place is taken by another jet stream over Southern half of Indian Peninsula.

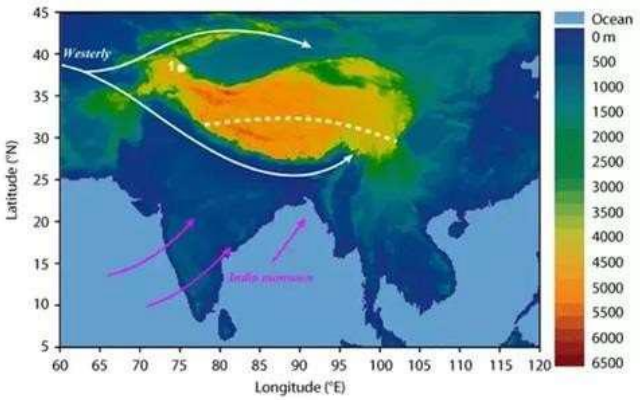

Figure 3: Tibetan Plateau Heating and Westerly Jet Stream Shift
httpswww.dspmuranchi.ac.inpdfBlogM.pdf

This is called tropical easterly jet which flow in reverse direction from east to west. Tropical easterly jet exhibit periodic movement to north and south of its mean location – linked to location of monsoon trough – during 100-day monsoon season. Thus, affecting concentration of rainfall.

Tibetan Highland

Tibet is located in the North of India at height of 4-5 km above sea level. It acts like a "heat island". The heat is derived from two sources. Firstly, widespread thunderstorms over the south-eastern parts of Tibet in the pre-monsoon months of April–May release considerable amount of Latent Heat through the rainfall. There is also some amount of sensible heat given out by plateau.

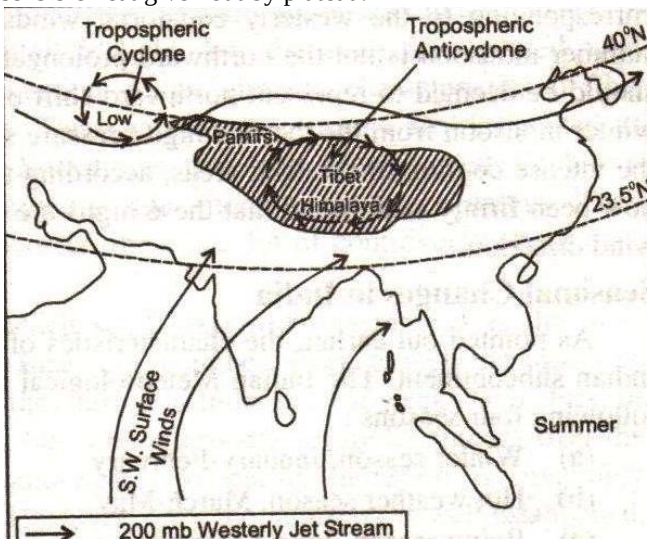

Figure 4: Location of Tibetan High and related Wind Pattern
Source: https://www.dspmuranchi.ac.in/pdf/Blog/M.pdf

There is development of heat low over the Tibet. As a result, ascending air spreads outward both towards North (polar) and south (towards equator) of plateau. The equator ward flow from Tibet Highland prevails over India as Easterly Jet Stream.

Hadley and Walker Cells

Hadley and walker cells are formed due to differential heating of atmosphere. These are like convection cells located in earth's atmosphere on a planetary scale. There movement is effected by earth's rotation, topographic barriers etc.

Hadley cell – Tibet act as elevated heat source. The ascending air above the source gradually spreads southwards to join the descending limb over north Indian Ocean near Mascernas High. The south west winds at surface form the return current to complete Hadley cell.

Walker cell – East-west walker cell also influences the summer monsoon. Ascending branch of Walker cell is located over Indonesia on account of convection and heavy precipitation a heat source is generated. The descending limb of Walker cell is located over semi-arid regions of North-East India – Dry Winds.

Performance of summer monsoon is often determined by relative importance of Hadley and Walker cell. Good monsoon are associated with intense Hadley circulation and Weak Walker cell and vice-versa.

Southern Oscillation and Al-Nino (Enso)

In 1972 series of catastrophic events in different parts of world focussed attention on possibility of global teleconnections in weather. The phenomenon of southern oscillation was discovered by Sir Gilbert walker. It postulates sea-saw pattern of weather between the Pacific Ocean extending from Africa to Australia. When pressures in winters tended to be high over Pacific Ocean there is low pressure over Indian Ocean. Pressures are inversely related to rainfall therefore when low pressures prevail over Indian Ocean in winter months the chances are that coming monsoon will be good in terms of rainfall.

El Nino in Spanish means "Child Christ" because it appears around the time of Christmas. It is abnormally warm ocean current off the coast of Peru in eastern Pacific El-Nino occurrence in preceding winter suggested strong Walker cell and weak monsoon. Historically, El Niño events have often been linked to below-average rainfall in India, while most La Niña years correlate with above-average precipitation. This can be attributed to the warming of sea surface temperatures in the central and eastern Pacific during El Niño events, leading to shifts in atmospheric circulation patterns that can subsequently impact the Indian monsoon. In contrast, La Niña events, characterized by cooler sea surface temperatures in the same regions, are typically associated with above-average rainfall across most of India.

The relationship between the El Niño-Southern Oscillation (ENSO) and India's monsoon rainfall isn't always straightforward. There is a notable connection between ENSO events and monsoon patterns, it's not a consistent. For instance, there have been El Niño years where India received above-normal rainfall, and conversely, some La Niña years resulted in below-normal precipitation. It's essential to note that while there's a statistically significant association between ENSO and the Southwest Monsoon rainfall, it's not the only factor influencing monsoon rainfall over India.

Indian Ocean Dipole (IOD)

Positive Indian Ocean Dipole (IOD) tends to associate with above-average rainfall over India whereas a negative IOD often corresponds with below-average rainfall, particularly over central India and the Western Ghats

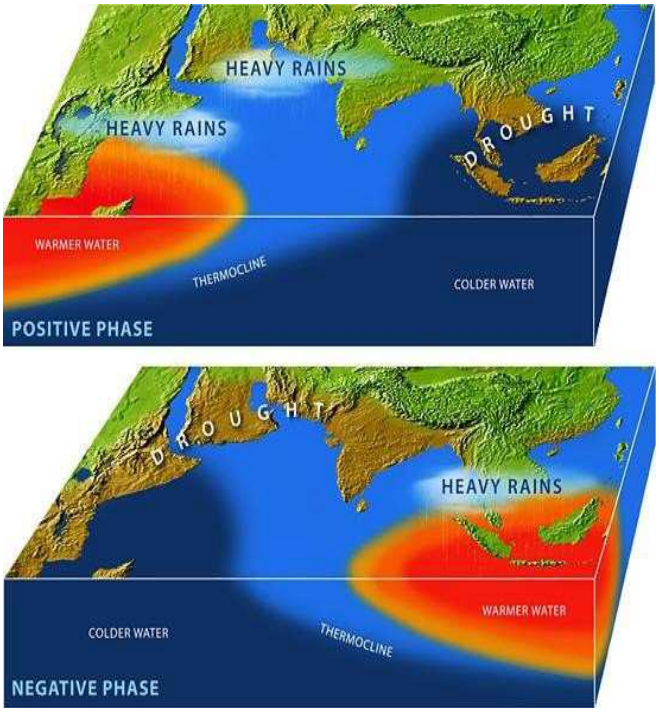

Figure 5: Positive and Negative Phases of Indian Ocean Dipole
Source: https://www.dspmuranchi.ac.in/pdf/Blog/M.pdf

Three types of conditions exist over Indian Ocean Dipole

1) **Positive IOD**. Positive dipole occurs when Sumatra in Indonesia is colder than normal and western coast of Indian Ocean along Africa is warmer than the normal. This condition is favorable for good monsoon.
2) **Negative IOD**: Negative dipole develops when Sumatra in Indonesia (eastern Indian Ocean) is warmer than normal and Malagasy in East Africa (western Indian Ocean) is colder than normal during winter season (December- January). The negative Indian Ocean Dipole results in low rainfall during summer monsoon.
3) **Normal IOD:** Normal dipole refers to the normal thermal conditions over western and eastern coasts of Indian Ocean during winter season. Such conditions result in normal monsoon.

Microscale Factors

Monsoon Depressions

Most of the rainfall during summer monsoon over Indian subcontinent is generated by Westward passage of depressions formed over Bay of Bengal. There is formation of 1-3 depressions in each month.

These depressions move westward over Indo-Gangetic plains along the axis of monsoon trough. There is concentration of rainfall along the south-western sector of depressions.

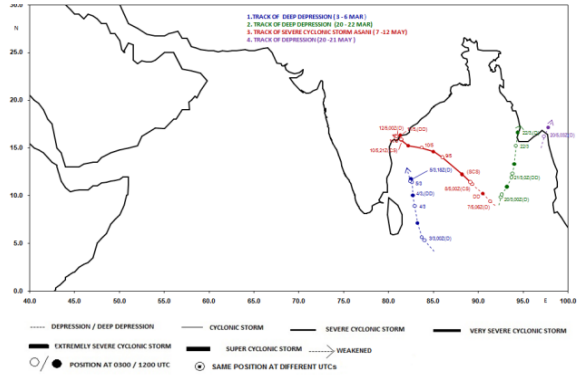

Figure 6 (a): Tracks of intense low-pressure systems formed during Pre-monsoon season (Mar-May) 2022

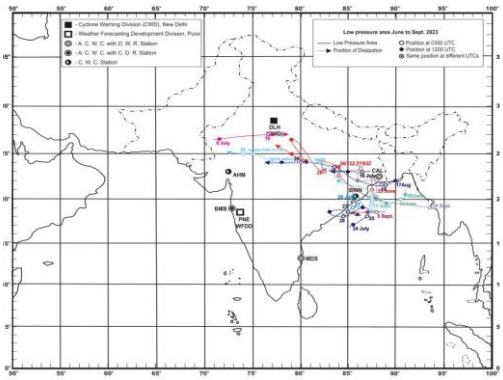

Figure 6 (b): Tracks of intense low-pressure systems formed during Pre-monsoon season (Mar-May) 2022
Source; IMD Annual report 2022 & 2023, https://mausamjournal.imd.gov.in/
Source; IMD Annual report 2022 & 2023

Formation and Location of Monsoon Trough

A zone of low pressure builds up over northwest India as a result of excessive solar insolation. With advance of monsoon this heat low gradually extends eastwards until it forms an elongated low pressure zone running parallel to Himalayan mountains in a west to east direction. It is not a stationary system it shows periodical movement to north and south of its normal position.

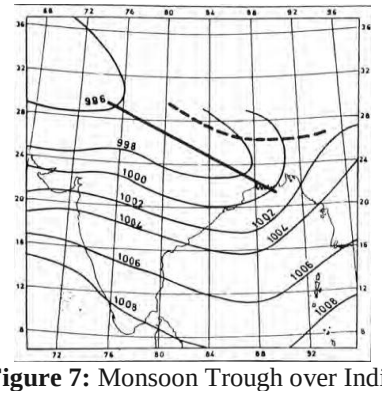

Figure 7: Monsoon Trough over India
Source: *https://library.wmo.int/idurl/4/37019 assessed on 19/9/2023*

When it moves north closer to Himalayan foothills rains are more intense over foothills of north-east India, this also results in Break of Monsoons over the plains. It leads to floods in the plains because most of rivers have source of origin in Himalayas. When the axis of monsoon trough

moves south there is well distributed rainfalls over the plains.

Onset of Monsoons - Branches

Over India the monsoon rains begin towards end of May or first week of June. Its arrival is gradual process beginning with short period of transition from extreme heat to very humid atmosphere with light rain. Subsequent progress of monsoon can be traced in form of two branches –

Arabian Sea branch – Arabian Sea Branch advances northwards to Bombay by 10th June. By mid-June the Arabian Sea branch of monsoon spreads over Saurashtra-Kutch and central parts of country. It reaches Rajasthan by July 15th and the whole India is covered.

Bay of Bengal branch – The Bay of Bengal branch strikes the Myanmar coast and gets deflected northward entering India through the Khasi hills, It spreads over most of Assam by first week of June. On reaching southern periphery of Himalayan barriers the Bay of Bengal branch is deflected westward and progresses towards Gangetic plains. It arrives over Kolkata by June 7th.

The deflected current from Bay of Bengal and Arabian Sea branch of monsoon then merge into single current in central India. And cover remaining parts of west U.P., Haryana, Punjab and eastern Rajasthan by first week of July.

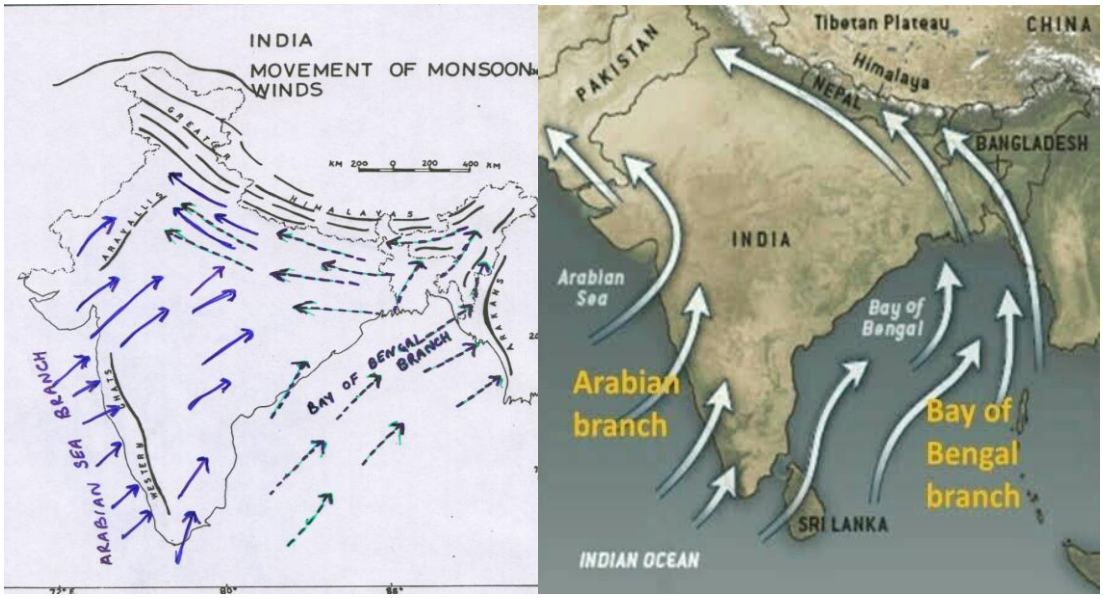

Figure 8: Arabian Sea and Bay of Bengal Branch of Monsoon winds
Source: https://ciet.nic.in/moocspdf/Geography%2002/kegy_20402_e-text.pdf

First monsoon showers in Delhi arrive from east as extension of Bay of Bengal or on some occasion from south i.e. from Arabian Sea. By mid July it extends to Kashmir and remaining parts of country. Normal duration of Monsoons is 100 days beginning from June 1st.

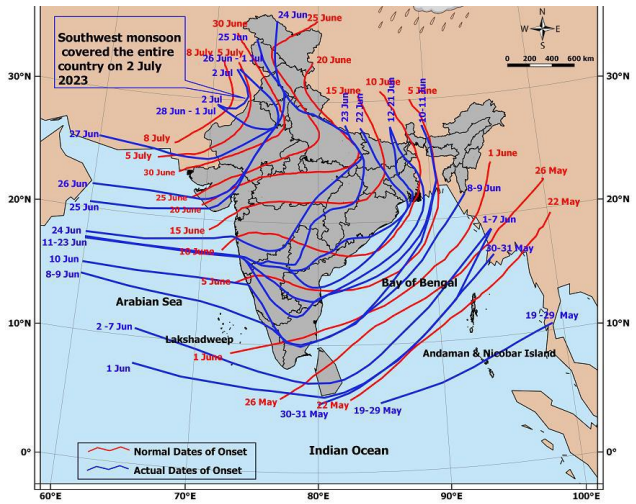

Fig 9: Advance of Monsoon over Indian subcontinent
Source ; IMD Annual report 2022 , https://mausamjournal.imd.gov.in/

Role of Physiography

Western Ghats - Western Ghats act as orographic barrier. They run north –south direction for about 1000km. When the monsoon winds strike the mountains they do not have enough energy to climb over Western Ghats they are deflected and the return current form off shore vortex. These generate spells of heavy rainfall for 2-3 days during monsoon season. Lee –ward side of Western Ghats receive very less rainfall.

Eastern Himalayas – Khasi Hills – Cheerapunji and Mawsynaram located on southern slopes of Khasi Hills receive highest rainfall due to orographic effect. Both are located at Northern end of valley running from north to south. Monsoon winds blowing from south are trapped within the valley and cause heavy rainfall.

Aravallis – Aravallis lie parallel to the flow of monsoon winds. Therefore, although the moisture laden winds flow over western Rajasthan they do not cause much rainfall. Delhi situated on Northern end of Aravallis get higher rainfall because here both the branches meet.

Withdrawal of Monsoons

Monsoons begin to withdraw from North-western India – Punjab and Rajasthan by mid September. From the Northwest India by the end of October and from the country by early December. Withdrawal of monsoon is more gradual process.

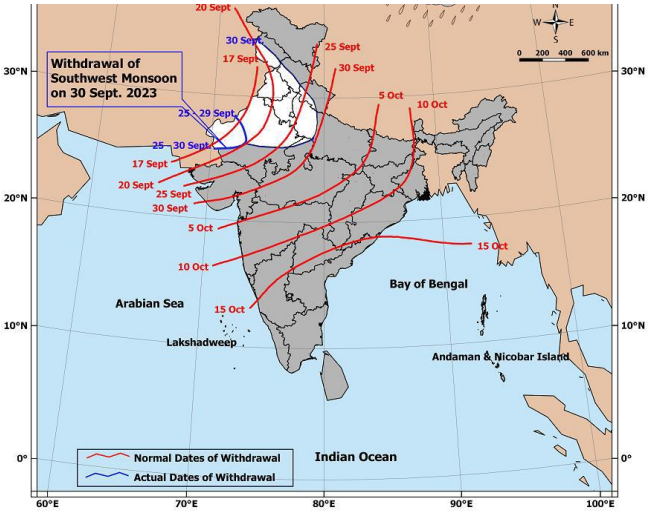

Figure 10: Withdrawal of Monsoon
Source ; IMD Annual report 2023 , https://mausamjournal.imd.gov.in/

MONSOONS AND PATTERN OF RAINFALL
DISTRIBUTION OF RAINFALL

India receives seventy percent of its annual rainfall during the 100 days of south-west monsoon period. Regional variations in the distribution of rainfall are however quite pronounced. Orographic features play important role in determining the amount of rainfall received in a region. India can be divided into following broad categories on the basis of seasonal rainfall from July- September.

More than 200 cm– Western coast of India, Western Ghats, sub-Himalayan regions of north-east and hills of Meghalaya
Between 100-200 cm– Southward of Gujarat coast parallel to crest of Western Ghats up to Kanyakumari. In North India the southern parts of J&K, Himachal Pradesh, Uttaranchal, regions lying east of line joining Allahabad and Bundelkhand, western Madhya Pradesh, east Maharashtra and north Andhra Pradesh.
Between 50-100 cm- Southern Punjab, north Haryana, areas west of Aravallis and central Maharashtra. North south belt all along leeward side of western Ghats.
Between 50-20 cm- Western Rajasthan, Haryana, Punjab and Kutch-Kathiawar regions of Gujarat
Less than 20 cm – Extreme western parts of Rajasthan and J& K.

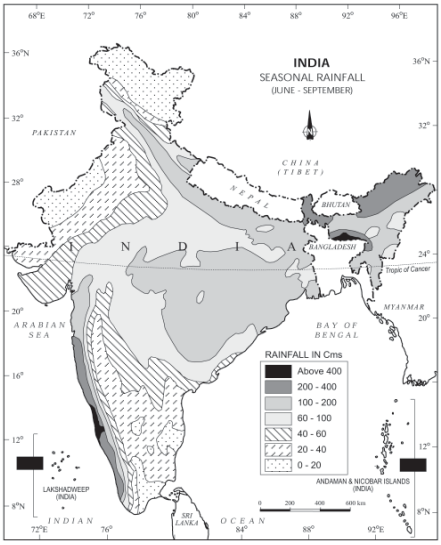

Figure 11: Spatial Distribution of Rainfall During Summers in India
https://ncert.nic.in/textbook.php?kegy1=4-7

Variability of Rainfall

If the rainfall for a year deviates more than 10 % of average, then it is termed as variable. Monsoons have very high degree of variability. Some of the reasons for this are:

- **No fixed date of onset of monsoons** - Sometime it is late arrival of rains or sometimes there is early withdrawal.
- **Long dry spells in between monsoon period due to BREAK in monsoon.** There is gap between formations of monsoon depression over Bay of Bengal if the gap is of longer duration then rainfall varies.
- **Regional variations due to topographical factors**

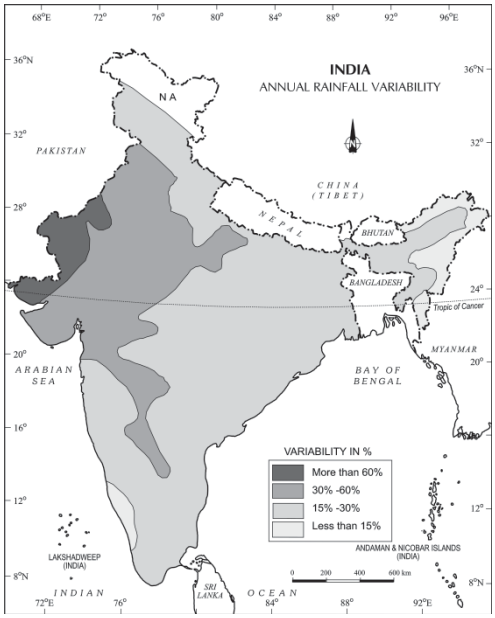

Figure 12: India: Variability of Annual Rainfall
https://ncert.nic.in/textbook.php?kegy1=4-7

It is generally found that areas with low annual rainfall have high degree of variability like Jharkhand region, Interior Maharashtra, Andhra Pradesh, Karnataka, Rajasthan, Gujarat (Kutch and Highland region) and leeward side of Western Ghats.

High degree of variability leads to floods and droughts in the country.

Monsoons and Drought
High degree of variability, erratic nature of rainfall in monsoon, long dry spells accompanied by high temperature results in failure of crops and droughts. Agriculture in India is totally dependent on rainfall**.**

In India there are certain well defined tracks of droughts. These are

Desert and Semi-arid regions – Areas lying west of the line joining Ahmedabad, Kanpur and Jalandhar.

Regions lying east of Western Ghats

Other Regions - Tirunelveli and Coimbatore regions of Tamilnadu, Saurashtra – Kutch Region of Gujarat, Palamau, Purulia and Kalahandi Region of Orissa and Mirzapur.
Various measures can be employed to lessen the impact of drought.

Administrative – Planning for adequate food supplies in drought prone regions

Changes in cropping pattern in dry drought prone regions – Developing drought resistant variety of crops.

Irrigation – Canals, drip irrigation sprinklers can be used in these regions which use less water and conserve the water available.

Better, timely and reliable prediction of onset of rains.

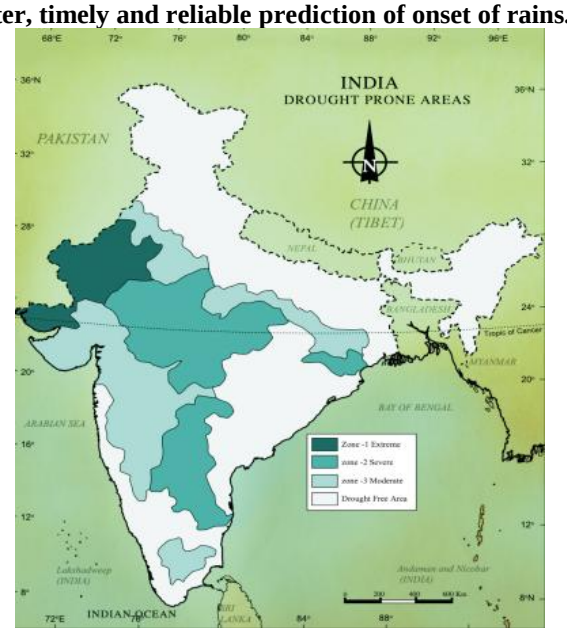

Figure 13: Drought Prone Areas
https://nidm.gov.in/PDF/pubs/NIDM_WRD2019.pdf

Monsoon - 2023
According to report published by IMD at the end of monsoon season 2023, country received 94% of long period average (LPA). Out of the total 36 meteorological subdivisions, 3 subdivisions constituting 9% of the total area of the country received excess, 26 subdivisions received normal rainfall (73% of the total area) and 7 subdivisions (18% of the total area) received deficient season rainfall. The 7 Meteorological subdivisions which got deficient rainfall are Nagaland, Manipur, Mizoram & Tripura (NMMT), Gangetic West Bengal, Jharkhand, Bihar, East UP, South interior Karnataka and Kerala (IMD: Monsoon report 2023)

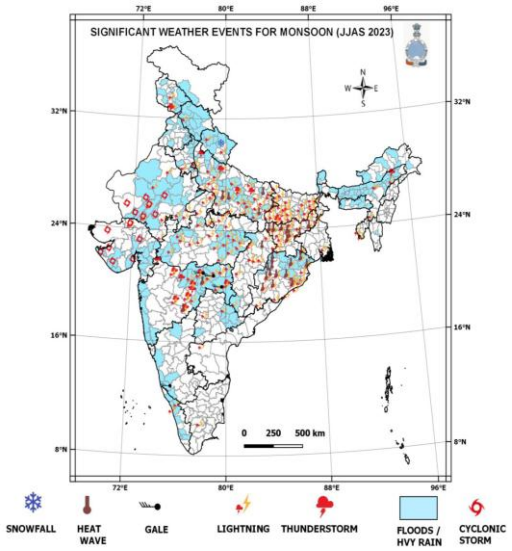

Figure 14: Districts Experiencing Extreme Weather Events Monsoon Season 2023
Source; IMD Annual report 2023, https://mausamjournal.imd.gov.in/

There were many extreme rainfall events observed during 2023 southwest monsoon season. Extremely heavy rainfall events were observed in June mainly over Rajasthan due to extremely severe cyclonic storm “BIPARJOY”. During July, the extremely heavy rainfall events were more realized over Konkan & Goa, coastal Karnataka, Uttarakhand, Himachal Pradesh, Telangana due to formation of low pressure systems. In the month of August, the extremely heavy rainfall events were more realized over Odisha and Gangetic West Bengal due to formation of one Deep depression and one low pressure area over Bay of Bengal. Also two western disturbances (WDs) caused very heavy to extremely heavy 13 rainfalls and floods over Himachal and Uttarakhand mainly by triggering southerly/southwesterly winds from Arabian Sea. During September, the extremely heavy rainfall events were more realized over Madhya Pradesh, Bihar and West Uttar Pradesh due to formation of low pressure area over Bay of Bengal.

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