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NATIONAL METEOROLOGICAL OLYMPIAD

on
Weather & Climate Science for Society

2025

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Study Materials (Junior)

Content

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Chapter 1

Introduction to Weather & Climate System

1.1. Introduction to Weather and Climate

Weather and climate are fundamental components of Earth's environmental system, influencing all living organisms, human activities, agriculture, and water resources. Understanding the difference between weather and climate is essential for comprehending their impact on society and the natural world. Weather refers to the short-term atmospheric conditions in a specific place at a particular time, including temperature, humidity, precipitation, wind speed, and visibility. These conditions can change frequently, often within minutes, hours, or days. For example, a sunny morning can quickly turn into a rainy afternoon due to shifts in atmospheric pressure, temperature, and moisture levels. Climate, on the other hand, refers to the long-term patterns and averages of weather conditions in a region, typically measured over 30 years or more. It encompasses trends in temperature, humidity, wind, and precipitation over extended periods. For instance, a tropical climate is characterized by hot, humid conditions with significant rainfall throughout the year, while a polar climate is defined by persistently cold temperatures.

1.1.1. Importance of Weather and Climate

Weather and climate have far-reaching impacts on ecosystems, agriculture, infrastructure, human health, and economies. They control the distribution of water through rain, snow, and other forms of precipitation, which directly affects agriculture and freshwater availability. Extreme weather events such as droughts, floods, hurricanes, and heatwaves can lead to food shortages, water scarcity, property damage, and even loss of life. A notable example is the 1999 Odisha Super Cyclone in India, which resulted in nearly ten thousand deaths and displaced over a million people. Understanding and monitoring weather patterns are essential for disaster preparedness, while studying climate trends is critical for predicting long-term changes that influence natural resources, human health, energy supplies, infrastructure, and transportation systems. Changes in climate can alter agricultural productivity, biodiversity, and water availability, presenting significant long-term challenges for human societies and the environment.

1.1.2. Climate Impact on Society

Climate has a significant impact on our daily lives, natural resources, and ecosystems. Weather patterns influence the distribution of water on Earth, which is essential for the survival of all living organisms. The availability of fresh water for drinking and agriculture depends on weather patterns and seasonal changes. For example, droughts can devastate agricultural production, leading to food shortages and the loss of livelihoods. Historical records reveal that severe droughts have caused millions of deaths worldwide. Extreme weather events, such as hurricanes, tornadoes, floods, and heatwaves, profoundly affect human civilization. For instance, the Odisha Super Cyclone in 1999 resulted in nearly 10,000 deaths and displaced over a million people. These catastrophic events highlight the importance of understanding weather and climate to minimize their societal impact. Climate Change poses new challenges to society by impacting health, infrastructure, food and water security, and ecosystems. The frequency and intensity of natural disasters are increasing, emphasizing the need for society to adapt to changing weather patterns and mitigate its adverse effects.

1.1.3. Weather and Climate Services

To monitor and predict weather and climate patterns, scientists use advanced observational techniques and technologies. Data on atmospheric conditions such as temperature, humidity, pressure, wind speed, and precipitation are gathered globally through surface weather stations, satellites, weather radars, and upper-air measurements. These observations form the foundation for weather forecasts, climate research, and disaster preparedness. Surface observations are conducted at weather stations worldwide, which use instruments like thermometers (to measure temperature), barometers (for pressure), hygrometers (to measure humidity), anemometers (for wind speed), and rain gauges (to track precipitation). Upper air data is collected using pilot balloons and radiosondes, providing crucial information on temperature, humidity, and pressure at various altitudes, which is key to predicting weather patterns. Weather radars detect precipitation, storm intensity, and movement, offering real-time monitoring of hazardous weather phenomena such as heavy rainfall, thunderstorms, and cyclones, thereby facilitating timely warnings. Satellites provide a global perspective by monitoring land, oceans, and the atmosphere, collecting data on cloud formation, sea surface temperatures, rainfall, and upper atmospheric conditions. For instance, the INSAT series of satellites in India contributes significantly to weather forecasting and climate research by providing essential meteorological data.

1.1.4. Ancient Meteorology

The beginnings of meteorology in India can be traced to ancient times. Early philosophical writings of the 3000 B.C. era, such as the Upanishadas, contain serious discussion about the processes of cloud formation and rain and the seasonal cycles caused by the movement of earth round the sun. Varahamihira's classical work, the Brihatsamhita, written around 500 A.D. provides clear evidence that a deep knowledge of atmospheric processes existed even in those times. It was understood that rains come from the sun (Adityat Jayate Vrishti) and that good rainfall in the rainy season was the key to bountiful agriculture and food for the people. Kautilya's Arthashastra contains records of scientific measurements of rainfall and its application to the country's revenue and relief work. Kalidasa in his epic, 'Meghdoot', written around the seventh century, even mentions the date of onset of the monsoon over central India and traces the path of the monsoon clouds. Meteorologica written by Aristotle around 350 BCE is one of earliest treatise on meteorology.

Long before the development of modern scientific instruments, cultures around the world attempted to explain weather patterns through a combination of observation, mythology and rudimentary techniques. Many folklores developed in earlier periods hold good even today. Meteorology, as we perceive it now, may be said to have had its firm scientific foundation in the 17th century after the invention of the thermometer and the barometer and the formulation of laws governing the behaviour of atmospheric gases. It was in 1636 that Halley, a British scientist, published his treatise on the Indian summer monsoon, which he attributed to a seasonal reversal of winds due to the differential heating of the Asian land mass and the Indian Ocean.

India is fortunate to have some of the oldest meteorological observatories of the world. The British East India Company established several such stations, for example, those at Calcutta in 1785 and Madras (now Chennai) in 1796 for studying the weather and climate of India. The Asiatic Society of Bengal founded in 1784 at Calcutta. A disastrous tropical cyclone struck Calcutta in 1864 and this was followed by failures of the monsoon rains in 1866 and 1871. In the year 1875, the Government of India established the India Meteorological Department, bringing all meteorological work in the country under a central authority. Mr. H. F. Blanford was appointed Meteorological Reporter to the Government of India. The first Director of Bombay (now Mumbai), promoted scientific studies in meteorology in India. Captain Harry Piddington at Calcutta published 40 papers during 1835-1855 in the Journal of the Asiatic Society dealing with tropical storms and coined the word "cyclone", meaning the coil of a snake. In 1842 he published his monumental work on the "Laws of the Storms". In the first half of the 19th century, several observatories began functioning in India under the provincial governments.

1.1.5. India Meteorological Department (IMD)

A disastrous tropical cyclone struck Calcutta in 1864 and this was followed by failures of the monsoon rains in 1866 and 1871. In the year 1875, the Government of India (under British rule) established the India Meteorological Department, bringing all meteorological work in the country under a central authority, with its headquarters at Calcutta (now Kolkata). Mr. H. F. Blanford was appointed Meteorological Reporter to the Government of India. The IMD, is India's primary agency for meteorological observations, and weather forecasting. Current national Headquarters of the IMD is located in New Delhi. It plays a critical role in monitoring weather patterns and issuing forecasts that aid agriculture, aviation, shipping, disaster management, and other sectors vital to the economy and public safety. IMD's responsibilities include cyclone warnings, which help coastal regions prepare for storms, and monsoon forecasts, essential for agriculture and water management. Equipped with a network of weather stations, radars, and satellites, IMD continuously monitors atmospheric conditions, providing real-time updates to the public while supporting climate research. IMD provides its services upto village level through six Regions Meteorological Centres located at Delhi, Mumbai, Kolkata, Chennai, Guwahati, Nagpur and State Met Centres located at the state capitals.

IMD has also established itself as a global leader in weather science. It was among the first meteorological institutions to adopt telegraphy for weather communication, setting up observatories that contributed to international data sharing. Its historical focus on monsoon and cyclone forecasting has made IMD a key contributor to the World Meteorological Organization (WMO) and a pioneer in global weather science.

Monsoon forecasting is one of IMD's most significant contributions. The Indian monsoon is crucial for the nation's agriculture and water resources, and its impact extends globally, affecting the climate of the Indian Ocean region and Southeast Asia. IMD's expertise in understanding atmospheric patterns, such as the El Niño-Southern Oscillation (ENSO), contributes to international efforts in climate prediction. The department also collaborates with initiatives like the Asian-Australian Monsoon Project, advancing global monsoon research.

Cyclone forecasting is another area where IMD excels. Using advanced numerical weather prediction (NWP) models and satellite observations, IMD accurately predicts the intensity and path of cyclones in the Bay of Bengal and the Arabian Sea. Its Regional Specialized Meteorological Centre (RSMC) provides cyclone advisories to neighbouring countries, helping to minimize the loss of life and property. This service is part of the global early warning system under the WMO framework.

IMD's technological advancements have further enhanced global weather forecasting. The department utilizes India's INSAT and Oceansat series of satellites, providing real-time weather data shared with international organizations. Its network of Doppler Weather Radars (DWRs) has improved short-term forecasts and monitoring of severe weather events. IMD also uses sophisticated NWP models like the Global Forecast System (GFS) and the Weather Research and Forecasting (WRF) model, contributing to global weather predictions.

In addition to its technological contributions, IMD collaborates with global organizations like the WMO and UNFCCC, providing technical assistance and training to regional meteorologists. It leads initiatives such as the South Asian Climate Outlook Forum (SASCOF), offering seasonal climate forecasts that support resilience in South Asia. IMD's research contributions, especially in climate change studies, have been invaluable. Its long-term climate records are critical for analyzing trends in extreme weather events, and its work in developing climate adaptation strategies benefits global climate resilience efforts.

IMD also offers essential services to marine and aviation sectors, providing weather forecasts for maritime operations and real-time weather information for air travel safety. Its oceanographic data contributes to global programs like the Global Ocean Observing System (GOOS), while its aviation services are integral to both domestic and international flights.

Looking ahead, IMD continues to expand its role in global weather science, enhancing its forecasting capabilities through initiatives like the Monsoon Mission and exploring the use of artificial intelligence and machine learning. Its ongoing leadership in weather forecasting, climate research, and disaster management ensures that IMD will remain a key player in global meteorology for years to come.

Further details on evolution of India Meteorological department are described in Appendix-B

1.1.6. World Meteorological Organization (WMO)

The World Meteorological Organization (WMO), established in 1950, with its headquarters at Geneva (Switzerland) is a specialized agency of the United Nations that coordinates global efforts in weather, climate, and water resource monitoring. Its mission is to promote international cooperation in sharing meteorological data and information, ensuring standardized methods for observation and forecasting. WMO's global network of observational systems forms the foundation of weather forecasting, climate research, and disaster risk reduction. This coordination helps improve weather predictions and supports international climate science efforts.

One of WMO's primary functions is to support climate change research by compiling and analyzing weather and climate data from around the world. This data is crucial for informing policymakers and assisting them in developing effective mitigation and adaptation strategies to address the impacts of climate change. The organization's Global Framework for Climate Services (GFCS) ensures that climate-sensitive sectors, such as agriculture and disaster management, have access to reliable climate information.

WMO also plays a significant role in disaster risk reduction by enhancing early warning systems for extreme weather events like cyclones, floods, and droughts. Through initiatives such as the Multi-Hazard Early Warning Systems (MHEWS) and Regional Specialized Meteorological Centers (RSMCs), WMO provides timely warnings to vulnerable regions, helping to mitigate the impacts of these hazards.

In addition, WMO is involved in capacity building, particularly in developing countries. India has been an active member of the WMO since its inception. It provides training, resources, and technical support to strengthen national meteorological and hydrological services. This support helps improve local forecasting abilities and enhances preparedness for weather-related disasters. By fostering international collaboration and providing critical weather and climate services, WMO plays a vital role in addressing the global challenges posed by climate variability and extreme weather events.

1.2. The Earth in the Solar System

The Earth is one of the eight planets in our solar system, part of the vast Milky Way galaxy. Our solar system consists of the Sun, the eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune), their moons, and other celestial objects like asteroids and comets (Figure 1.1). Earth is the third planet from the Sun and is unique because it supports life. This ability is due to several factors: its perfect distance from the Sun, the presence of liquid water, and an atmosphere that contains essential gases like oxygen. These features allow life to thrive in various forms, from microscopic bacteria to large mammals like elephants and whales.

1.2.1. The Position of Earth:

Earth orbits the Sun at an average distance of about 93 million miles (150 million kilometres). This distance is referred to as one Astronomical Unit (AU). Our planet's orbit is not a perfect circle; instead, it is slightly elliptical, meaning it's oval-shaped. This orbit, combined with Earth's axial tilt, causes seasonal changes that we experience each year.

1.2.2. The Earth's Rotation and Revolution:

Earth's Rotation and Revolution: Earth rotates on its axis—an imaginary line that runs from the North Pole to the South Pole. It takes approximately 24 hours to complete one rotation, giving us day and night. As Earth rotates, the side facing the Sun experiences daylight, while the opposite side is in darkness. Additionally, Earth revolves around the Sun, taking about 365.25 days to complete one orbit. This revolution, along with the tilt of Earth's axis (about 23.5 degrees), is responsible for the changing seasons. When the Northern Hemisphere tilts towards the Sun, it experiences summer, while the Southern Hemisphere has winter, and vice versa.

1.2.3. The Sun:

The Sun is a giant star at the center of our solar system. It is composed mainly of Hydrogen and Helium gases. The Sun's immense energy powers weather systems and climate patterns on Earth. The sunlight we receive is crucial for processes like photosynthesis, which allows plants to produce food and release oxygen—both vital for life.

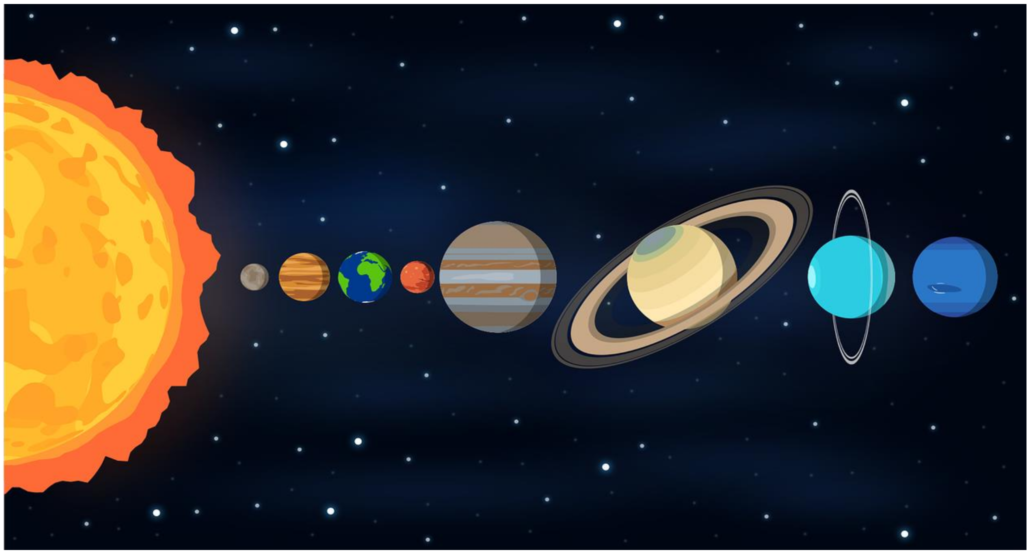

Figure 1.1: The Solar System (Image Credit: Pixabay)

1.3.Origin and Evolution of Our Atmosphere and Ocean

1.3.1. Origin of the Atmosphere:

The Earth's atmosphere was formed about 4.5 billion years ago during the planet's early development. Initially, the atmosphere was composed mainly of hydrogen and helium, captured from a cloud of gas and dust called the solar nebula. This primary atmosphere was lost because the Earth's gravity was too weak to hold onto these light gases, and the strong solar wind blew them away.

A new atmosphere, known as the secondary atmosphere, formed from gases released by volcanic eruptions, a process called volcanic outgassing. Volcanic eruptions released water vapor, carbon dioxide, ammonia, and methane into the atmosphere. These gases were crucial in creating an environment that could support life.

1.3.2. Evolution of the Atmosphere:

As the Earth cooled, water vapor in the atmosphere condensed to form liquid water, leading to the creation of oceans. This was a pivotal moment in Earth's history, as it allowed for the development of life. Early life forms, such as cyanobacteria, began using sunlight to make food through photosynthesis, a process that produces oxygen. Over millions of years, oxygen accumulated in the atmosphere, forming the ozone layer. The ozone layer is important because it protects life on Earth from the Sun's harmful ultraviolet (UV) rays, allowing more complex life forms to develop.

1.3.3. Formation of the Oceans:

The formation of oceans is closely linked to the atmosphere. Water vapor released by volcanic activity and possibly from icy comets that collided with Earth contributed to the early oceans. These bodies of water played a vital role in regulating the planet's climate and providing a habitat for early life. The oceans cover about 71% of the Earth's surface and play a crucial role in regulating the planet's climate.

They absorb carbon dioxide from the atmosphere, helping to stabilize global temperatures. Oceans also support diverse ecosystems, ranging from tiny plankton to large marine mammals.

1.4. Land, Air, Water, and Ecosystem

Land: The land includes various landscapes such as mountains, plains, and valleys, providing habitats and resources for terrestrial life. Landforms can affect weather patterns, such as mountains influencing wind and precipitation.

Air: The air is essential for respiration and photosynthesis, maintaining the balance of gases necessary for life. The air's composition includes nitrogen (78%), oxygen (21%), and trace gases.

Water: Water covers most of the Earth's surface and exists in various forms: liquid (oceans, rivers, lakes), solid (ice, snow), and gas (water vapor). Water is vital for life, weather, and climate systems.

Ecosystem: An ecosystem consists of living organisms interacting with their physical environment. Ecosystems include biomes such as forests, deserts, tundras, and aquatic systems, each supporting different life forms.

Chapter 2

Weather and Climate Processes

2.1 Principles of Weather and Climate Systems

Understanding the principles of weather and climate systems is vital for comprehending how these natural processes impact our daily lives and the planet as a whole. Weather and climate shape ecosystems, agriculture, water resources, and even human activities. By studying these processes, we can better prepare for weather changes and understand long-term climate trends, which is increasingly important in the context of climate change.

2.1.1 Weather: Short-Term Atmospheric Conditions

Weather refers to the short-term state of the atmosphere at a specific place and time. It encompasses various elements, including temperature, humidity, precipitation, wind, and visibility. Weather can change rapidly, often within minutes or hours, and is influenced by several factors such as atmospheric pressure, temperature differences, moisture levels, and the movement of air masses. Each of these elements plays a critical role in defining the weather of a particular area**:**

- **Temperature**: This measures how hot or cold the atmosphere is at a given place and time. Temperature is typically measured in degrees Celsius (°C) or Fahrenheit (°F). The Sun is the primary source of heat energy, warming the Earth's surface. When the Sun's rays hit the Earth, they warm the land, air, and water, resulting in varying temperatures across different regions. During the day, temperatures are generally higher because of direct sunlight, while at night, the absence of sunlight causes the temperature to drop.
- **Humidity**: Humidity refers to the amount of water vapor present in the air. It is usually expressed as a percentage, indicating how saturated the air is with moisture. For example, if the humidity is 100%, the air is fully saturated and cannot hold more water vapor, which often leads to the formation of clouds and precipitation. High humidity levels can make warm temperatures feel even hotter because the body's ability to cool itself through sweat evaporation is reduced. Humidity plays a crucial role in weather patterns, especially in tropical climates, where high humidity levels can lead to frequent rainfall.
- **Precipitation**: Precipitation includes all forms of water—liquid or solid—that fall from clouds to the ground. This includes rain, snow, sleet, and hail. Precipitation occurs when clouds, which are composed of tiny water droplets or ice crystals, become too heavy to remain suspended in the air. When this happens, gravity pulls the water down to Earth. Precipitation is essential for maintaining freshwater supplies and supporting plant and animal life.
- **Wind**: Wind is the movement of air from areas of high pressure to areas of low pressure. It is caused by the uneven heating of the Earth's surface by the Sun. Wind speed and direction are influenced by factors such as the Earth's rotation, pressure systems, and geographic features like mountains and oceans. Winds play a vital role in transporting heat, moisture, and even pollutants around the globe, influencing weather patterns. For example, sea breezes occur when cooler air from the sea moves toward the land, creating a refreshing breeze during the day.

- **Visibility**: Visibility is a measure of the distance one can clearly see. It is affected by weather conditions such as fog, rain, snow, or smoke. Reduced visibility can impact daily activities, such as driving and air travel, making it important for weather forecasts to include visibility reports.

- **Clouds: Formation, Categories, and Role in Rainfall**: Clouds play a crucial role in weather forecasting, as their types and patterns can provide early signs of changing weather conditions. Clouds form when warm, moist air rises and cools, causing the water vapor within it to condense into tiny droplets. These droplets cluster together to create clouds. Clouds are classified based on their appearance, height, and the weather they bring. There are three main types: cirrus, cumulus, and stratus. Cirrus clouds are high, thin, and wispy, often seen in fair weather. They are often seen ahead of a change in the weather, such as an approaching storm. Cumulus clouds are fluffy, white clouds with a flat base, typically indicating fair weather. However, when they grow larger, they can develop into cumulonimbus clouds, which are towering and dark, bringing thunderstorms, heavy rain, and sometimes even hail. Stratus clouds form low, gray layers that cover the sky, bringing overcast weather or light rain/drizzle. A graphical representation of different types of clouds based on its height is Figure 2.1.

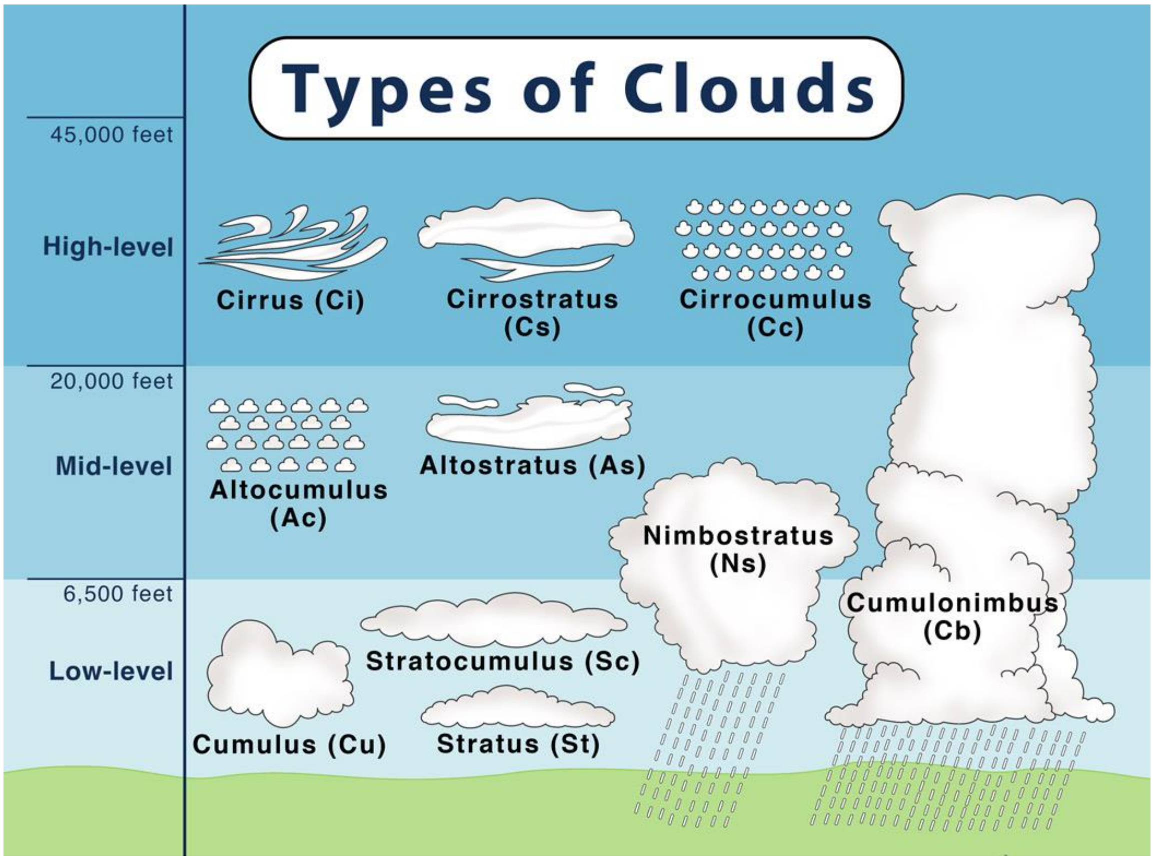

Figure 2.1: Cloud types (Image credit (Science Facts)

- **Weather phenomena**: Weather phenomena refer to various atmospheric events and conditions that occur naturally in the Earth's atmosphere and affect different regions around the globe. These phenomena are driven by complex interactions between temperature, humidity, air pressure, and wind patterns. Common weather phenomena include precipitation events such as rain, snow, sleet, and hail, as well as storms like thunderstorms, cyclones, tornadoes, and hurricanes. Lightning, thunder, and windstorms are also categorized under weather phenomena. Fog and mist, which reduce visibility, are other examples. Severe weather phenomena, like heatwaves, cold snaps, and droughts, can significantly impact human activities, agriculture, and the environment. Weather phenomena vary widely depending on geographic location and the season, and their study helps meteorologists forecast weather patterns and develop strategies for mitigating their effects on communities. Understanding these phenomena is crucial for safety, disaster preparedness, and efficient management of natural resources.

2.2 Weather and Climate forecasting process

Weather and climate forecasting involves using scientific principles and tools to predict atmospheric conditions over various time scales. Understanding the dynamics of the atmosphere and ocean is crucial for accurate forecasting. The forecasting system encompasses everything from seasonal predictions to real-time nowcasts, providing timely and accurate weather information for various sectors. Long Range Weather Prediction (LRF) focuses on seasonal patterns, such as the monsoon, months in advance by integrating oceanic, atmospheric, and land surface data to predict large-scale climate phenomena. Extended Range Weather Prediction (ERF) models provide forecasts ranging from 10 to 30 days, assisting in predicting trends like heatwaves and rainfall patterns. For medium-range forecasting (up to 10 days) and short-range forecasts (up to 3 days), Numerical Weather Prediction (NWP) models are utilized, enhancing accuracy through observed weather data from different sources. Nowcasting, which offers immediate forecasts (for the next 3 hours), employs high-resolution models and integrates radar, satellite, surface, and upper air observations to track weather events. A schematic diagram of IMD's operational forecasting system is provided in the Figure 2.2.

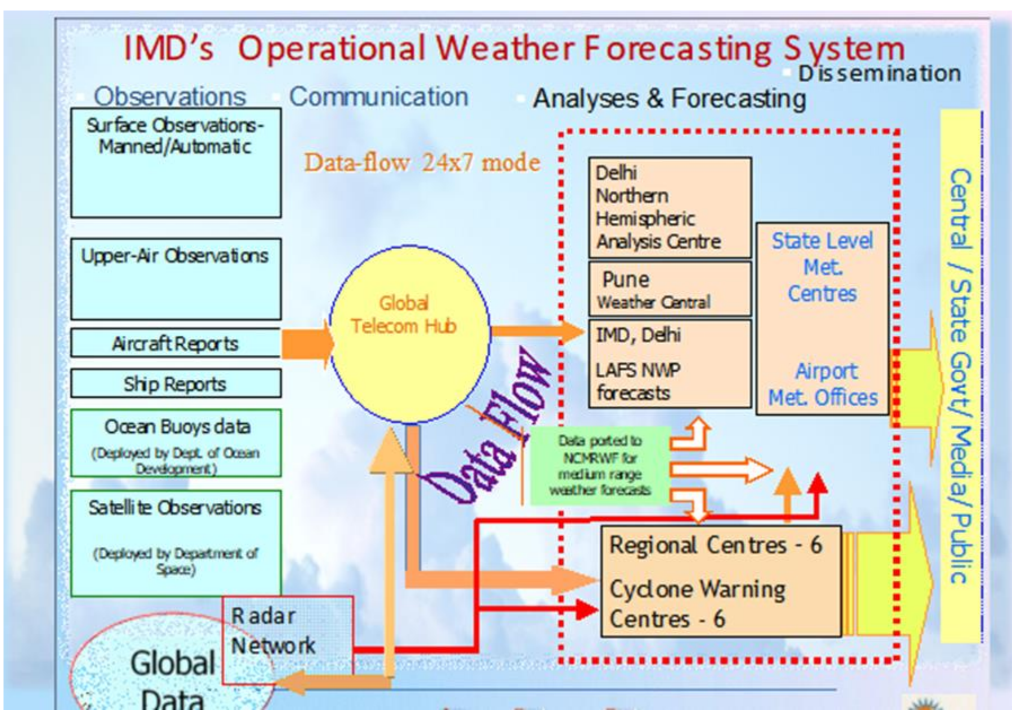

Figure 2.2: IMD's Weather Forecasting System

2.2.1 Data Observations

Weather forecasting begins with the collection of meteorological data, and the IMD has established a comprehensive network to gather this data from across the country, as well as global data through various collaborations. A map of integrated observing system is provided in the Figure 2.3.

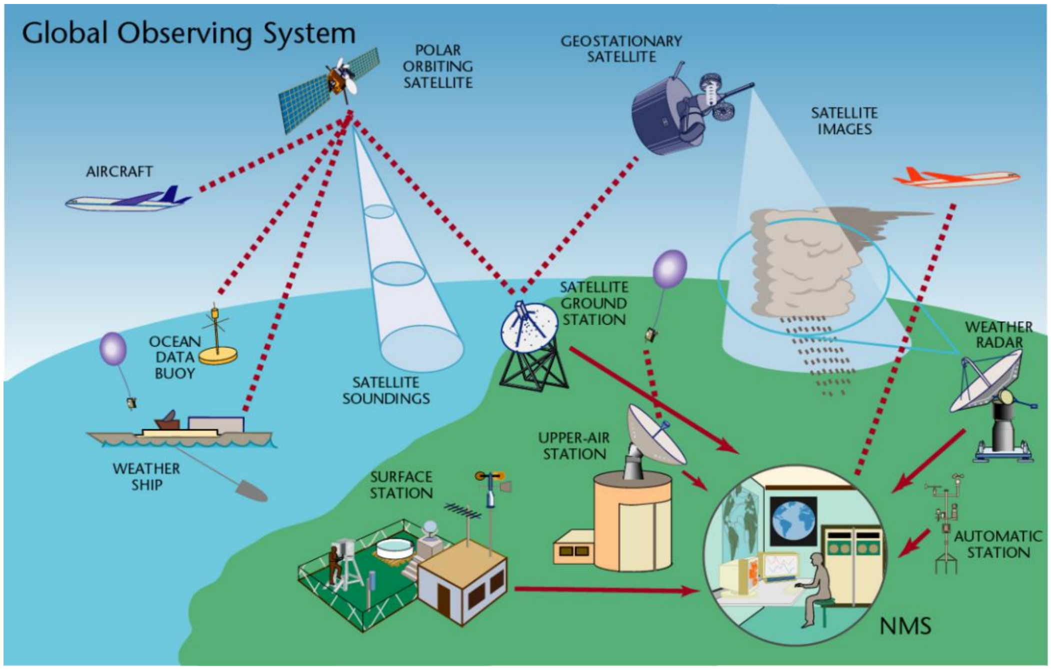

Figure 2.3: Integrated Observing System

The data collection methods include:

- **Surface Observatories**: IMD operates around 206 meteorological observatories (synoptic stations) across India, which collect essential weather parameters like temperature, humidity, pressure, wind speed/direction, clouds, and rainfall, etc. These observatories form the backbone of IMD's data network, ensuring continuous monitoring of weather patterns. In addition, IMD has also deployed around 735 automatic weather stations (AWS) (Figure 2.4a) and 1350 automatic rain gauge (ARG) stations, which are equipped with sensors to measure various weather parameters without the need for human intervention. These stations provide real-time data, particularly in remote areas where manual observations might be limited.
- **Upper Air Observation:** IMD conducts upper air observations using radiosondes (Figure 2.4b) and pilot balloons to measure atmospheric conditions at various altitudes. Currently, the India Meteorological Department (IMD) conducts radiosonde launches from 56 locations and pilot balloon launches from 62 locations across India. These upper air data include critical parameters like temperature, humidity, wind, and pressure at different heights, which are essential for accurate weather forecasting, particularly in tracking large-scale weather systems and cyclonic developments.
- **Satellites:** Satellite data plays an indispensable role in modern meteorological predictions. IMD utilizes the Indian Space Research Organization (ISRO)'s INSAT-3D, INSAT-3DR, INSAT-3DS, and Oceansat-3 satellites, which provide a continuous feed of meteorological data, including cloud cover, atmospheric temperature, humidity, sea surface temperatures, rainfall, wind speed &

direction, clouds, cloud temperature, ocean surface wind, cyclone position, cyclone tracking, etc. Satellite image of cyclone “Mocha” captured from INSAT-3D satellite is shown in Figure 2.5. These satellites deliver real-time data crucial for weather forecasting and disaster warnings. IMD also utilizes weather satellites of foreign nations

(a) IMD Surface observatory (b) Radiosonde

Figure 2.4: IMD Surface Observatory and Radiosonde

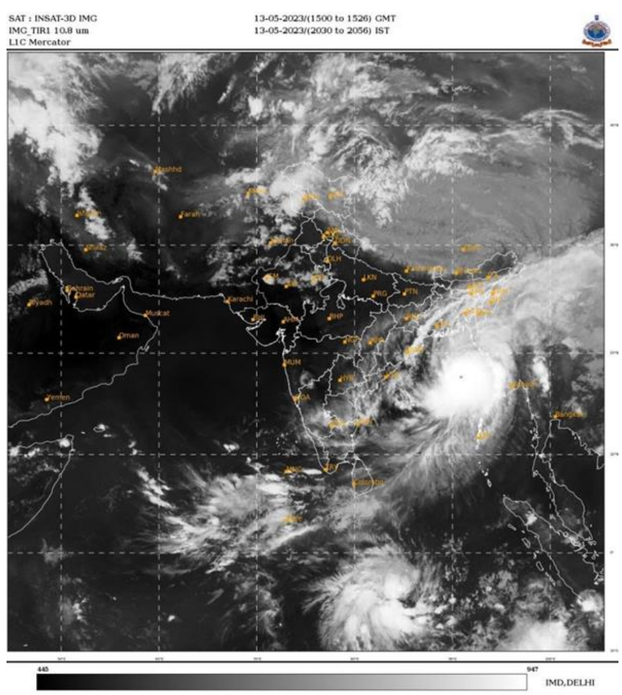

Figure 2.5: Satellite Image of Cyclone “Mocha”

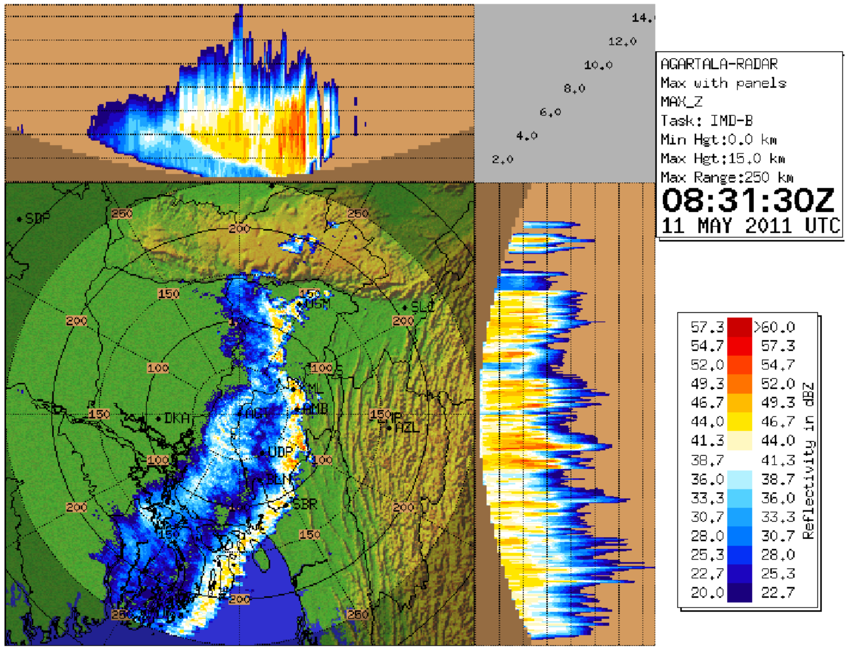

Figure 2.6: A Squall line observed by Doppler radar at Agartala on 11 May 2011.

- **Doppler Weather Radars (DWR):** The Doppler Weather Radar network is a crucial component of IMD's forecasting infrastructure. These radars provide real-time information on rainfall intensity, storm structure, wind patterns, and the movement of cyclonic storms. IMD's Doppler radars are particularly vital in predicting short-term weather phenomena like thunderstorms and severe storms. A Squall line (narrow band of thunderstorms that can produce strong winds, heavy rain, and severe weather) observed by Doppler radar at Agartala on 11 May 2011 is shown in Figure 2.6.
- **Global Data Networks:** In addition to domestic data, IMD is part of global data-sharing networks facilitated by the World Meteorological Organization (WMO). This ensures that IMD has access to global weather data, which is essential for long-term forecasting and understanding broader weather patterns.

2.2.2 Climate: Long-Term Atmospheric Patterns

Weather is a short-term phenomenon, often varying from day to day. For instance, it might be sunny in the morning and rainy by afternoon, or warm today and cold tomorrow. Understanding weather elements and how they interact helps meteorologists predict short-term weather patterns, allowing people to prepare for immediate changes. Climate, on the other hand, refers to the long-term average of weather patterns in a specific region, typically measured over 30 years or more. While weather is what happens in the atmosphere on a day-to-day basis, climate is the overall trend and pattern of these conditions over an extended period. Climate is influenced by several key factors:

- **Latitude:** This is the distance of a place from the equator, measured in degrees. Latitude plays a crucial role in climate because it affects the amount of solar energy a region receives. Areas near the equator receive direct sunlight year-round, resulting in warm, tropical climates. In contrast, regions near the poles receive less direct sunlight, leading to colder, polar climates. For example, equatorial regions like the Amazon rainforest experience hot and humid conditions, while the Arctic has a frigid polar climate.

- **Altitude:** Altitude is the height of a place above sea level. Higher altitudes tend to have cooler temperatures because the atmosphere becomes thinner, and air pressure decreases as you go higher. This is why mountainous regions, even those near the equator, can have colder climates than surrounding lowlands. For instance, the Himalayan mountains in Asia have snow-covered peaks year-round despite being in a tropical region.
- **Ocean Currents:** Ocean currents are large-scale movements of seawater that play a significant role in regulating climate. Warm currents, such as the Gulf Stream, carry heat from the tropics toward higher latitudes, influencing the climate of nearby coastal areas. For example, the Gulf Stream warms the climate of Western Europe, making it milder than other regions at similar latitudes. Conversely, cold currents can lower temperatures along coastlines, as seen in the cool waters off the west coast of South America.
- **Human Activities:** Activities such as deforestation, urbanization, and the burning of fossil fuels release greenhouse gases into the atmosphere, contributing to climate change. These human-induced changes can alter climate patterns by increasing the Earth's overall temperature, causing shifts in weather, sea level rise, and more frequent extreme weather events like hurricanes and droughts.

Understanding climate is essential because it helps predict long-term changes and their potential impacts on the environment and human societies. For example, knowing that a region has a tropical climate with a rainy season helps farmers plan their planting and harvesting schedules.

2.2.3 Weather and Climate: Differences and Similarities

Both weather and climate are influenced by similar processes, such as atmospheric pressure, solar energy, and the Earth's rotation, but they operate on different timescales. Weather is concerned with short-term changes in the atmosphere, while climate focuses on the long-term trends and averages of these weather patterns. Studying both is crucial for understanding the Earth's atmospheric behaviour and how it affects ecosystems, agriculture, and human activities.

2.2.4 Atmospheric Circulation

One of the main drivers of both weather and climate is atmospheric circulation. The Earth's rotation and the uneven heating of its surface cause air to move, creating wind patterns that transport heat and moisture around the globe. This circulation is responsible for the movement of air masses and the formation of weather systems. Key features of atmospheric circulation include:

- **Trade Winds**: Steady winds that flow from east to west between 30 degrees latitude and the equator in both hemispheres. These winds are crucial for moving warm ocean waters and influencing weather patterns in tropical regions. For example, they play a key role in bringing moisture-laden air to coastal areas, leading to rainfall.
- **Westerlies**: Winds that blow from west to east between 30 and 60 degrees latitude in both hemispheres. The westerlies influence weather patterns in the mid-latitudes, where many

major cities are located. For instance, they bring warm air from the tropics to Europe, moderating its climate.

- **Polar Easterlies**: Winds that blow from east to west near the poles. They contribute to the formation of polar weather systems, which are characterized by extremely cold temperatures. These winds play a part in shaping weather patterns in regions like Antarctica and the Arctic.

Atmospheric circulation not only dictates daily weather but also contributes to the long-term climate of a region. For example, the steady flow of trade winds helps create tropical rainforests near the equator, while the westerlies contribute to the temperate climates found in parts of North America and Europe.

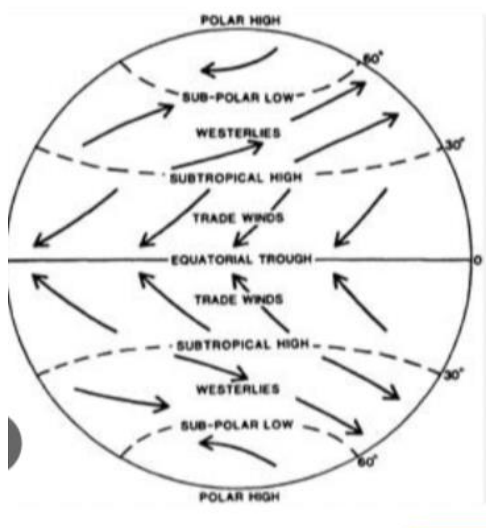

Figure 2.7: Atmospheric Circulation

2.2.5 Solar Radiation and Heat Balance:

The Earth receives energy from the Sun in the form of solar radiation. This energy is absorbed, reflected, and emitted by the Earth's surface and atmosphere. The balance between incoming and outgoing radiation determines the Earth's temperature and climate. Factors such as greenhouse gases, albedo (reflectivity), and cloud cover influence this heat balance.

- **Greenhouse Gases:** These gases, such as carbon dioxide, methane, and water vapor, trap heat in the atmosphere and keep the Earth's surface warm.
- **Albedo:** This is the reflectivity of the Earth's surface. Surfaces like ice and snow have high albedo and reflect most of the sunlight, while darker surfaces like oceans and forests have low albedo and absorb more heat.
- **Cloud Cover:** Clouds can both reflect sunlight back into space and trap heat in the atmosphere, influencing the Earth's heat balance.

2.2.6 Weather Systems:

Weather systems, such as cyclones, anticyclones, and frontal systems, are formed by the interaction of air masses with different temperatures and humidity levels. These systems bring changes in weather conditions, including precipitation, wind, and temperature variations. Major weather affecting India is shown in Figure 2.8.

- **Cyclones:** Low-pressure systems characterized by inward spiraling winds and often associated with stormy weather. In the Northern Hemisphere, they rotate counterclockwise, while in the Southern Hemisphere, they rotate clockwise (Details in Chapter 3).
- **Anticyclones:** High-pressure systems characterized by outward spiraling winds and typically associated with calm and clear weather. In the Northern Hemisphere, they rotate clockwise, while in the Southern Hemisphere, they rotate counterclockwise.
- **Frontal Systems:** Boundaries between two air masses of different temperatures and humidity levels. They can cause dramatic weather changes, including storms and heavy precipitation.

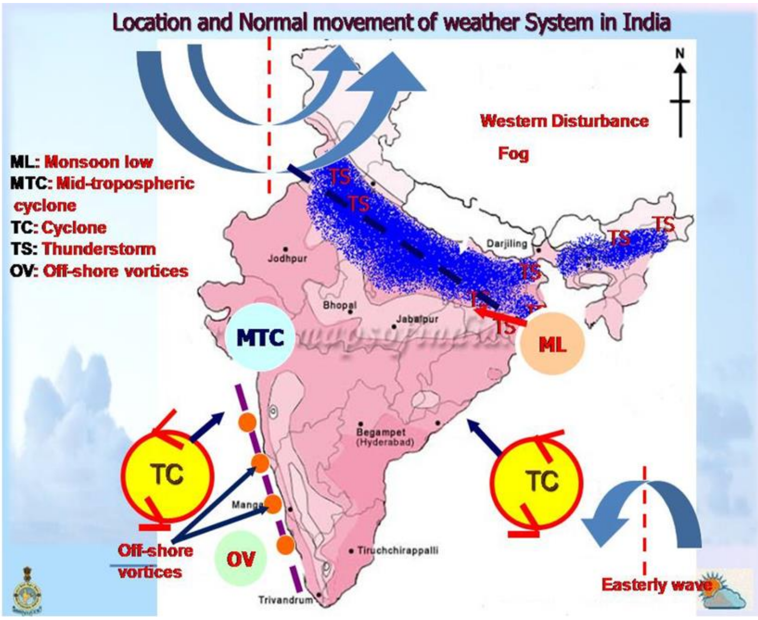

Figure 2.8: Weather System and Extreme Weather in India

2.2.7 Climate Systems:

Climate systems are influenced by long-term factors such as ocean currents, volcanic activity, solar radiation variations, and human activities. These factors interact in complex ways to shape regional and global climate patterns. Understanding these interactions is crucial for predicting future climate changes and their potential impacts.

- **Ocean Currents:** Large-scale movements of seawater that distribute heat around the globe. For example, the Gulf Stream carries warm water from the tropics to the North Atlantic, moderating the climate of Western Europe.
- **Volcanic Activity:** Volcanic eruptions can release large amounts of ash and gases into the atmosphere, affecting climate. For example, the eruption of Mount Pinatubo in 1991 caused global temperatures to drop temporarily.
- **Solar Radiation Variations:** Changes in the amount of solar energy reaching the Earth can influence climate. For example, periods of reduced solar activity, such as the Maunder Minimum, have been associated with cooler global temperatures.

- **Human Activities:** The burning of fossil fuels, deforestation, and industrial processes release greenhouse gases into the atmosphere, contributing to global warming and climate change.

2.2.8 Climate Classification

Climate classification is a system used to categorize the world's different climate types based on various factors like temperature, rainfall, and seasonal patterns. It helps scientists, farmers, and policymakers understand and predict the climate conditions of a particular region. By grouping areas with similar weather patterns, climate classification makes it easier to study global climate systems and how they affect agriculture, ecosystems, and human activities. For example, the Köppen Climate Classification divides climates into groups like tropical, dry, temperate, continental, and polar, based on temperature and precipitation. Similarly, the Thornthwaite Classification focuses on moisture availability and how water is used and stored in an area. The map of Indian climatic zones is depicted in Figure 2.9. Overall, climate classification helps us make informed decisions about water management, farming, and preparing for weather changes.

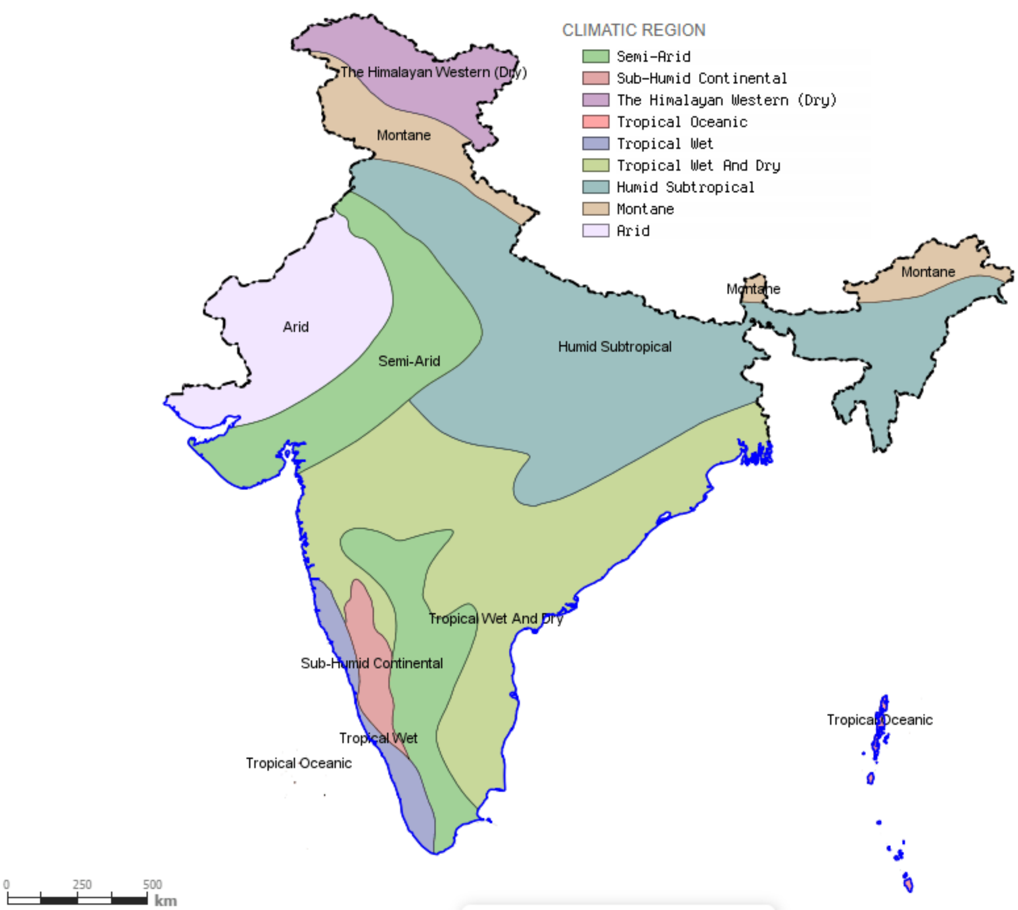

Figure 2.9: The map of Indian climatic zones.

2.3 Seasons

- **Winter:** Winter occurs when a hemisphere is tilted away from the Sun, resulting in shorter days and cooler temperatures. In India, winter typically lasts from December to February. The weather is generally dry and cold, with occasional rain brought by Western Disturbances in northern regions. Snowfall occurs in mountainous areas. The Indo-Gangetic Plains (IGP) of northern India frequently experience fog and poor air quality, especially during the winter months. Fog occurs when cooler air traps moisture near the surface, leading to reduced visibility. This phenomenon is particularly common from November to January, when cooler temperatures and high humidity contribute to dense fog formation. The situation is exacerbated by human activities such as vehicular emissions, industrial pollution, and agricultural burning, particularly the practice of stubble burning in states like Punjab and Haryana. These pollutants, combined with the stagnant air, contribute to severe air pollution, forming a toxic mixture of fog and smog, often called "smog episodes." The lack of wind and atmospheric circulation traps pollutants close to the surface, leading to hazardous air quality. Poor air quality over the IGP not only disrupts transportation and daily activities due to reduced visibility but also poses significant health risks, including respiratory problems and other chronic conditions, affecting millions of people across densely populated areas.
- **Pre-Monsoon (Summer):** The pre-monsoon season, also known as summer, spans from March to May. During this time, temperatures rise significantly, especially in inland regions. Hot winds, known as "loo" in northern India, blow across the plains. This period also marks the buildup to the monsoon, with increased humidity and occasional thunderstorms.
- **Southwest Monsoon (Rainy Season):** The southwest monsoon season extends from June to September. Moist winds from the Indian Ocean and the Arabian Sea blow towards the land, bringing heavy rainfall across much of India. This rain is crucial for agriculture, replenishing water sources and supporting crop growth. However, excessive monsoon rains can lead to floods and landslides, especially in coastal and hilly regions.
- **Post-Monsoon (Autumn):** The post-monsoon season, or autumn, occurs from October to November. During this period, the southwest monsoon withdraws, and the weather becomes more stable. Temperatures begin to cool, and the skies are generally clear. This season is also known as the retreating monsoon, as the winds shift direction, leading to sporadic rainfall in certain regions like the southeastern coast of India.

2.4 Rainfall and Monsoons

The monsoon is a seasonal wind system that plays a crucial role in shaping the climate and weather patterns of India and many other regions in South Asia. In India, the monsoon is divided into two primary phases: the Southwest Monsoon and the Northeast Monsoon, each with distinct characteristics and effects on the subcontinent. The climate and rainfall of India and its neighbourhood to a large extent is determined by the geographic location. India is an extension of the great Asiatic continent with the vast expanse of the Indian ocean to the south and the loftiest Himalayas to the north. The rainfall over India and neighbourhood is dominated by two monsoons - Southwest monsoon and Northeast monsoon. All India normal rainfall is 118 cm of which 75% (86.8 cm) rainfall takes place in the monsoon season. Rainfed agriculture in India covers 68% of the net sown area. Rainfall monitoring and forecast for rainfed agriculture areas is important as it accounts for almost 40% of the country's food production. Figure 2.10 shows the district-wise annual normal rainfall map of India, generated using data from 1971 to 2020.

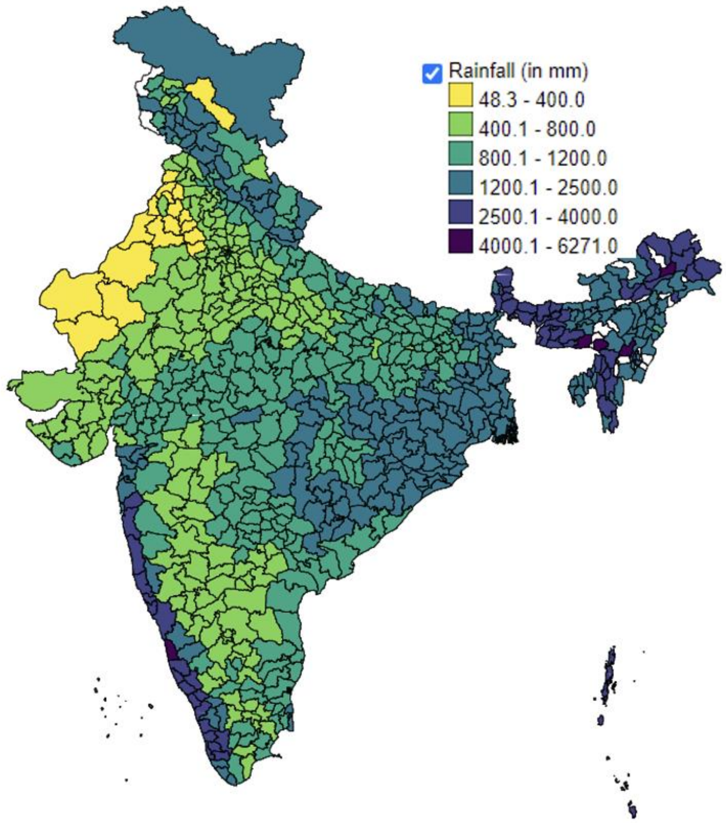

Figure 2.10.: All India District wise annual rainfall normal using the data during 1971-2020 (Image Credit: IMD).

2.4.1 Southwest Monsoon (June to September)

The Southwest Monsoon is the most significant monsoon season in India, responsible for around 70-90% of the country's annual rainfall. It occurs from June to September and is crucial for the country's agriculture, economy, and water resources.

1. **Mechanism**: The Southwest Monsoon is driven by the differential heating of land and water. During summer, the Indian landmass heats up more quickly than the surrounding oceans, creating a low-pressure zone over the northern plains. At the same time, the Indian Ocean remains cooler, generating a high-pressure zone. This difference in pressure causes moist winds from the southwest, originating over the Arabian Sea and the Bay of Bengal, to move towards the Indian subcontinent.

2. **Onset**: The monsoon generally makes landfall over the Kerala coast around June 1st. It progresses northwards, reaching the central and northern parts of India by mid-July. The winds carry moisture from the ocean, which condenses as they move over land, leading to widespread rainfall. The normal dates for onset of southwest monsoon over different part of the country is illustrated in the Figure 2.11.

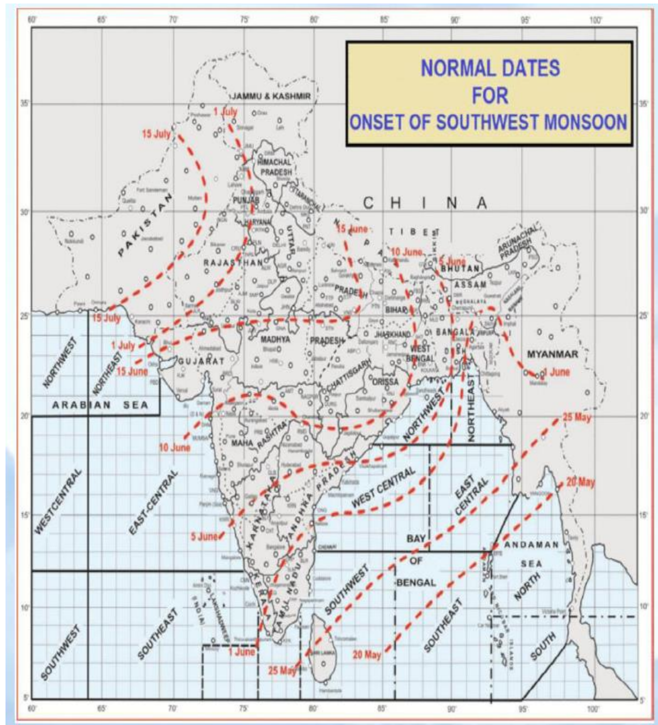

Figure 2.11.: Map of Onset of Southwest Monsoon in India (Image Credit: IMD)

Rainfall Distribution: The Western Ghats and northeastern states receive the heaviest rainfall due to the orographic effect, where mountains force the moisture-laden air to rise, cool, and release rain. States like Kerala, Karnataka, Maharashtra, and the northeastern regions experience significant downpours. Central and northern India also benefit from the monsoon rains, which are vital for crops like rice, cotton, and sugarcane. Figure 2.12 shows the district-wise normal rainfall map of India during southwest monsoon season, generated using data from 1971 to 2020.

The 4 zones of rainfall throughout India are categorized below.

a). Insufficient Rainfall Zone (less than 50cm of rainfall): This rainfall zone is found in Andhra Pradesh, some regions of Karnataka as well as regions of Maharashtra, Ladakh, and a vast area of Rajasthan. Jaisalmer is an area in Rajasthan that counts for receiving the least rainfall in India.

b). Low Rainfall Zone (50cm – 100cm of rainfall): This rainfall zone is found in Maharashtra, some areas in Gujarat, some places in Karnataka, Tamil Nadu, Andhra Pradesh, Madhya Pradesh, Punjab, Haryana, and sparsely in Western Uttar Pradesh.

c). Medium Rainfall Zone (100cm – 200cm of rainfall): The various zones of abundant rainfall in India are geographically separated from each other. First, the Western Ghats have a thin strip that runs North-to-South across the Ghats' entire length. The frequency of rainy seasons rises as one travels South. For example, the North has 4 rainy periods between June and September whereas the Midlands have 5 rainy months ranging from June to October.

d). High Rainfall Zone (200cm – 300cm of rainfall): The most notable rainfall occurs on the West side, in the Western Ghats, including the sub-Himalayan areas of the upper East along

Meghalaya's slopes. The North-Eastern region and also the windward portion of the Central Highlands receive an average of 400cm of rain every year. Rain in the Brahmaputra Valley and its surrounding hills experience less than 200cm of rainfall. This zone includes locations that receive 200cm-300cm of rain each year. This zone is primarily found in Eastern India

3. **Impact**: The Southwest Monsoon is essential for the Kharif crop season, and the livelihood of millions of farmers depends on its timely arrival and adequate distribution. However, the monsoon can also cause challenges such as flooding, landslides, and waterlogging, especially in regions prone to heavy rainfall like Assam, Bihar, and parts of Maharashtra.

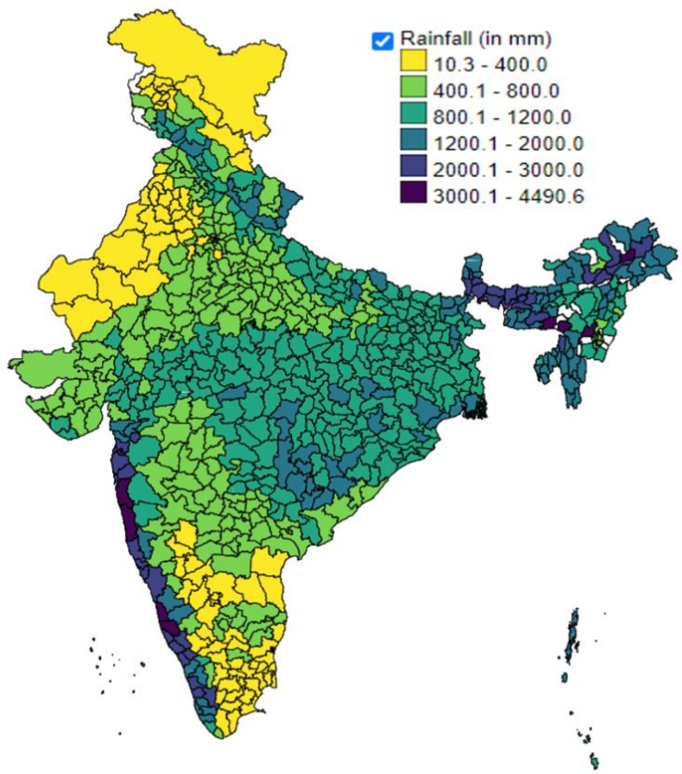

Figure 2.12: Map of All India Districtwise Rainfall Normals using the data during 1971-2020 for the southwest Monsoon season (June to September) (Image Credit: IMD)

2.4.2 Northeast Monsoon (October to December)

The Northeast Monsoon, also known as the retreating monsoon, occurs from October to December and mainly affects the southeastern part of India, particularly Tamil Nadu, Andhra Pradesh, and parts of Karnataka and Kerala.

1. **Mechanism**: The Northeast Monsoon is caused by the reversal of wind patterns as the Indian subcontinent begins to cool after the intense heat of summer. By October, the low-pressure zone over the northern plains weakens, and a high-pressure zone forms over the landmass as temperatures drop. Cold, dry winds from the northeast blow toward the ocean, but as they pass over the Bay of Bengal, they pick up moisture and bring rainfall to southeastern India.

2. **Onset**: The Northeast Monsoon typically begins in October and continues until December. Unlike the Southwest Monsoon, which covers most of India, the Northeast Monsoon affects a smaller region, primarily the southeastern coastal areas.

3. **Rainfall Distribution**: Tamil Nadu receives about 50-60% of its annual rainfall from the Northeast Monsoon. Coastal areas like Chennai, Puducherry, and other parts of Tamil Nadu and southern Andhra Pradesh benefit from this monsoon. The rainfall is generally less intense compared to the Southwest Monsoon but is vital for the Rabi crops grown in these regions. Figure 2.13 shows the district-wise normal rainfall map of India during northeast monsoon season, generated using data from 1971 to 2020.

4. **Impact**: The Northeast Monsoon is important for replenishing water reservoirs and supporting agriculture in the southeastern states. However, it can also cause localized flooding, especially in low-lying areas and coastal cities like Chennai.

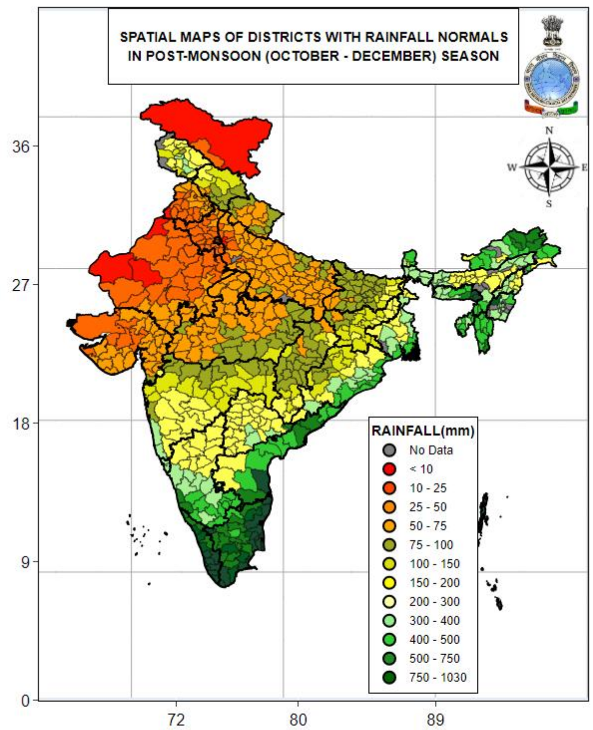

Figure 2.13.: District-wise Post Monsoon Season Rainfall (Image Credit: IMD)

2.4.3 Importance of Monsoons in India

Monsoons play a critical role in India’s agrarian economy, determining water availability for agriculture, drinking water, and hydropower generation. The timely arrival and adequate spread of the monsoons are vital for the country’s food security. However, the monsoons also present challenges, as both excessive and deficient rainfall can lead to floods, droughts, and economic losses. Understanding and predicting monsoon patterns is therefore crucial for disaster preparedness, agricultural planning, and water resource management in India.

Chapter 3
Natural Hazards and Disasters

3.1. Introduction to Natural Hazards

3.1.1. Overview of Natural Hazards on Earth

Natural hazards are naturally occurring events that can pose significant threats to human life, property, and the environment. These hazards are caused by different Earth processes, including atmospheric, geological, and hydrological phenomena. They vary in type, scale, and impact, ranging from localized events like landslides to widespread disasters like hurricanes or earthquakes. While natural hazards themselves are inevitable, their effects can be mitigated through preparedness, early warning systems, and effective disaster management strategies.

3.1.2 Types of Natural Hazards

Natural hazards can be broadly categorized into Hydrometeorological hazards and Geological hazards:

(i) Hydrometeorological Hazards

These are hazards associated with weather and climate processes. They often stem from atmospheric conditions and include the following:

Cyclones: Cyclones are large-scale storm systems characterized by low pressure at the center and strong winds rotating around it. These storms can cause extensive flooding, damage to infrastructure, and loss of life.

Thunderstorms: A localized storm often accompanied by lightning, thunder, and heavy rainfall. Thunderstorms can cause flash floods, landslides, and damage due to strong winds and lightning strikes.

Heavy Rainfall: Excessive rain over a short period of time can lead to urban flooding, river overflows, landslides, and soil erosion, severely impacting communities and agriculture.

Heat Waves: Prolonged periods of excessively high temperatures can lead to health crises, particularly affecting vulnerable populations like the elderly and those with pre-existing conditions.

Cold Waves: Periods of unusually low temperatures can cause severe cold stress on humans and animals, damage crops, and disrupt energy systems.

Fog: Dense fog can reduce visibility, leading to transportation accidents, particularly in aviation and road traffic. It also poses health risks, especially for respiratory conditions.

3.1.3 Geological Hazards

Geological hazards arise from Earth’s internal processes and include the following:

Landslides: Landslides refer to the downward movement of soil, rock, or debris due to gravity, often triggered by factors such as heavy rainfall, earthquakes, or human activities like deforestation. They can block roads, damage buildings, and cause fatalities.

Earthquakes: Sudden shaking or movement of the Earth's crust due to the release of energy along fault lines. Earthquakes can lead to severe structural damage, ground rupture, and secondary hazards like tsunamis and landslides.

Volcanic Eruptions: When magma from beneath the Earth's surface is ejected through a volcano, causing pyroclastic flows, ash clouds, lava flows, and volcanic gases. Volcanic eruptions can devastate communities, ecosystems, and infrastructure.

3.2 Hydro-meteorological hazards over India

India is prone to a variety of hydro-meteorological hazards that vary by season and region, significantly impacting the lives and livelihoods of its population. During the monsoon season, which typically lasts from June to September, heavy rainfall leads to flooding in many states, often resulting in loss of life and property. In contrast, the pre-monsoon months of April and May witness severe heatwaves affecting northern and central India, with states like Rajasthan, Gujarat, Uttar Pradesh, Haryana, Delhi and Madhya Pradesh experiencing soaring temperatures that can lead to heat-related illnesses and agricultural losses. The winter months, particularly from December to February, bring dense fog to northern plains, disrupting transportation and posing risks to travellers. Additionally, the coastal regions of India, including Tamil Nadu, Odisha, West Bengal, Gujarat and Andhra Pradesh, are frequently impacted by cyclones, particularly during April to June and September to December, leading to storm surges, heavy rainfall, and widespread destruction. Furthermore, regions like Uttarakhand and Himachal Pradesh are vulnerable to landslides triggered by heavy rains, especially during the monsoon. Overall, the diverse climatic conditions across India create a complex landscape of hydro-meteorological hazards that necessitate comprehensive disaster management strategies to mitigate their impacts.

3.3 Cyclones

A cyclone is a powerful storm with strong winds and heavy rain that forms over warm ocean waters. It spins in a circular motion because of the Earth's rotation, with winds moving around a calm center called the eye. Cyclones can cause damage to buildings, trees, and roads, and may lead to flooding. In the Indian Ocean, particularly the Bay of Bengal and the Arabian Sea, cyclones are common during pre-monsoon (April-June) and post-monsoon (October-December) seasons. The shape of a tropical cyclone is typically circular or spiral, characterized by a well-defined central core called the eye. Surrounding the eye is the eye wall, a ring of towering thunderstorms where the most intense winds and heavy rainfall occur.

3.3.1 Climatology of tropical cyclone

The climatology of tropical cyclones involves the study of their frequency, distribution, and intensity across various ocean basins. In the Indian Ocean, tropical cyclones typically form between April to June and September to December, affecting South Asian nations, particularly India, Bangladesh, and Sri Lanka. The Bay of Bengal sees more intense cyclones compared to the Arabian Sea, largely due to geographic and climatic factors. The India Meteorological Department (IMD) has significantly improved its accuracy in predicting tropical cyclones, using advanced tools such as satellite data, Doppler radars, and numerical models. This enhanced forecasting has reduced the lead time for warnings, enabling timely evacuations and minimizing loss of life and property, especially during major cyclones in the Indian Ocean.

3.3.2 Impacts of cyclones on human life and property

Cyclones have devastating impacts on human life and property, particularly in India's coastal regions, where densely populated areas are vulnerable. These powerful storms bring heavy rainfall, storm surges, and strong winds, leading to widespread flooding, destruction of homes, and damage to infrastructure like roads, bridges, and power supplies. In coastal states like Odisha, Andhra Pradesh, and West Bengal, agricultural losses, displacement of communities, and loss of life are common consequences. Cyclones also disrupt fishing activities and can cause long-term economic and environmental damage to coastal ecosystems. Figure 3.1 shows cyclone-prone districts in India, based on cyclone frequency, severity, and related hazards like maximum wind speeds, storm surges, and precipitation.

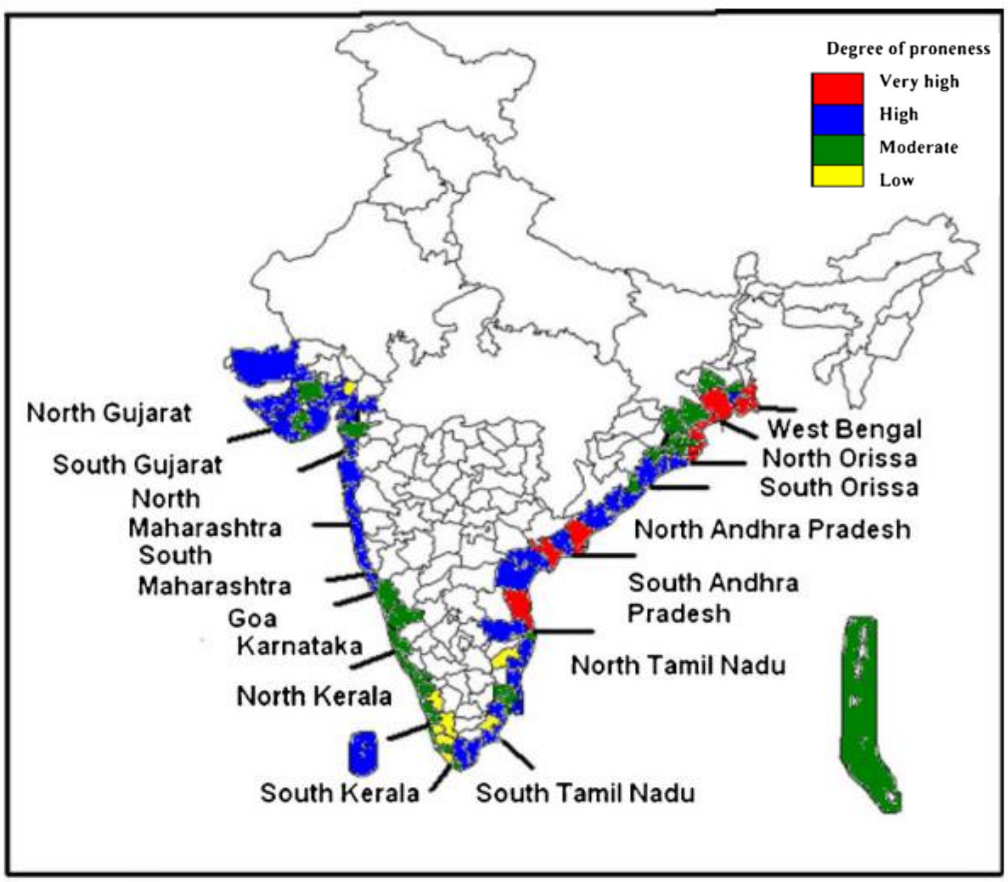

Figure 3.1: Cyclone hazard prone districts of India based on frequency of total cyclones, total severe cyclones, actual/estimated maximum wind, probable maximum storm surge associated with the cyclones and probable maximum precipitation for all districts (Mohapatra et al. 2012).

3.4 **Thunderstorm and Lightning**

A thunderstorm is a type of weather with lightning, thunder, strong winds, heavy rain, and sometimes hail. It forms when warm, moist air quickly rises and cools, creating tall clouds called cumulonimbus clouds. Lightning is a bright flash of electricity caused by the imbalance between the clouds and the ground or within the clouds. Thunder is the loud sound made when lightning heats the air suddenly. Thunderstorms can be strong and cause dangers like flash floods, high winds, and lightning, which can harm people and damage property.

Intense and high frequency thunderstorm activities during the pre-monsoon season generally occur in East and Northeast India followed by southwest Peninsular India. The thunderstorm associated with dust storm mostly occurs over Northwest India. Thunderstorm climatology of India based on data from 1981-2020 is shown in Figure 3.2.

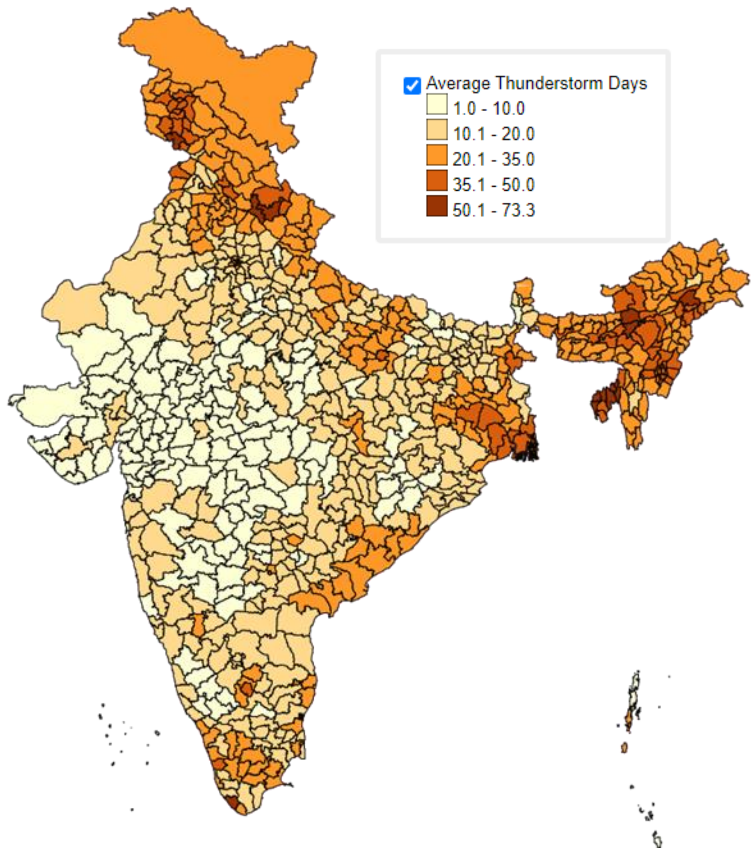

Figure 3.2 : Annual thunderstorm climatology (average number of thunderstorm days) over India based on the data of the period 1981-2019 (Image Credit: IMD).

3.4.1 Safety measures for thunderstorms and lightning

- If outdoors, seek shelter from lightning.
    - The best shelter is a building.
    - If no buildings are available, seek protection in a cave, ditch, car, hard-top automobile, or a canyon.
    - Avoid trees as they attract lightning.

- If no shelter is available:
  - Avoid the tallest object in the area.
  - If only isolated trees are nearby, crouch in the open for better protection.
- If you hear thunder:
  - Avoid going outside unless absolutely necessary.
  - To estimate the distance from a lightning strike: count the seconds between a lightning flash and thunder, then divide by 3 (in kilometres).
- Stay away from anything that conducts electricity:
  - Avoid radios, toasters, hairdryers, and unplug electronic equipment before the thunderstorm arrives. This also includes fireplaces, radiators, stoves, metal pipes, sinks, and phones.
- Stay away from windows, doors, and verandas.
- Avoid contact with plumbing and metal pipes:
  - Do not wash your hands, take a shower, wash dishes, or do laundry during a thunderstorm.
- Stay away from: TVs, sinks, tubs, radiators, and stoves.
- Get out of water: This includes small boats on the water, pools, lakes, and other water bodies.
- If you feel an electric charge (hair standing up or tingling skin):
  - Drop to the ground immediately, as lightning may be about to strike.
- Protect livestock:
  - Livestock often gathers under trees during thunderstorms, making them vulnerable.
  - Move animals into a shelter, preferably one with a lightning protection system.

3.5 Heat Waves and Cold Waves

3.5.1 Heat Wave

Heatwaves have emerged in many parts of the world as one of the deadliest natural hazards which has caused more deaths than any other natural hazards like cyclones, floods, Thunderstorms, lightning. Heat waves are silent killers unlike Cyclones, In August 2003 Heat Wave in Europe killed more than 70,000 people. Because of ongoing global warming, significant increase in the frequency, intensity, duration and geographical spread of heatwaves has been observed.

A heat wave is a period of very hot weather that lasts for several days. It can make people feel very uncomfortable and can even be dangerous if they don't stay cool and drink enough water.

There is no universal definition of heatwave as it depends on climatic condition of the region, For example in Rajasthan 40 degree centigrade does not meet heatwave criteria whereas in hilly areas heatwave may occur at 35 degree centigrade

3.5.2 Climatology of heat waves

Heat waves typically occur during the pre-monsoon months of April to June, when temperatures soar, particularly in the northwestern, central, and eastern regions. These extreme heat events are driven by factors such as dry continental air masses, prolonged clear skies, and high solar radiation. The Thar Desert and Deccan Plateau often experience the most intense heat waves, with temperatures exceeding 45°C in some areas. Climate change has also contributed to an increase in the frequency and intensity of heat waves in recent years, posing significant health risks and impacting agriculture. Figure 3.3 showing total heat wave days based on the data during the period 1969 to 2019.

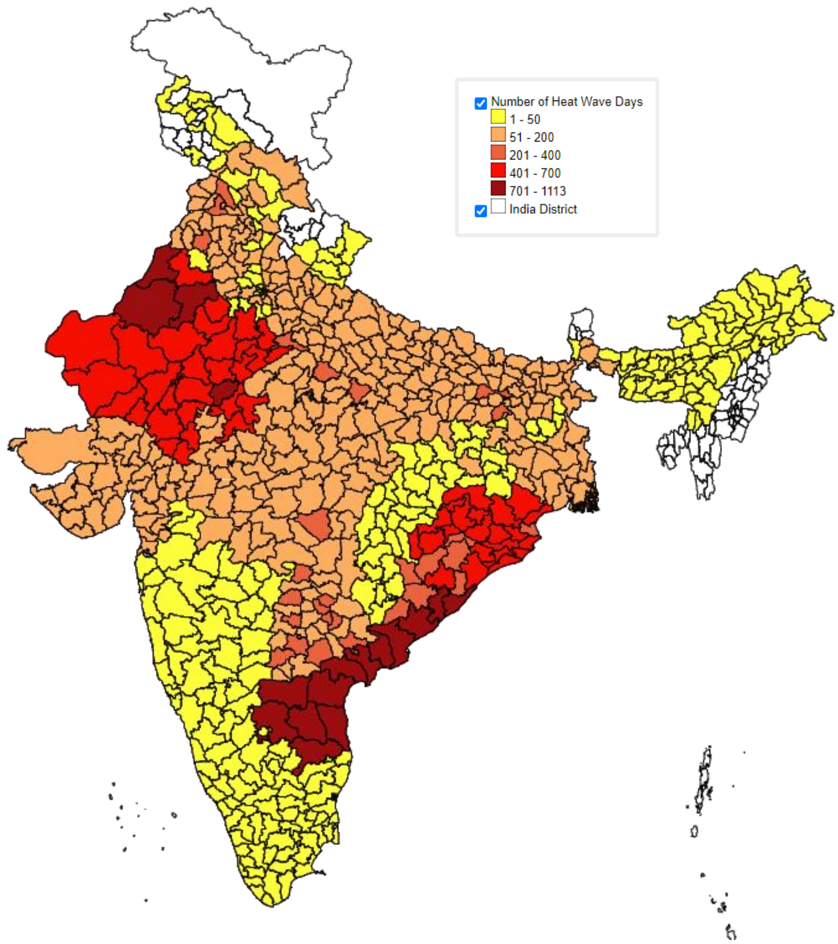

Figure 3.3 Total heat wave days (Total Number of Disasterous Heat Wave Days) using the data during the Period from 1969 to 2019 (Image Credit: IMD).

3.5.3 Cold Waves:

Cold Wave: A cold wave is a period of very cold weather that lasts for several days. It can make it very chilly outside and can be dangerous if people don’t stay warm and protect themselves from the cold.

3.5.4 Climatology of cold waves

The climatology of cold waves over India is primarily influenced by the winter season, typically from December to February, when cold, dry winds from the Himalayas sweep across northern and central parts of the country. Cold waves are most intense in northern states like Punjab, Haryana, Delhi, Uttar Pradesh, and Bihar, where temperatures can drop significantly, sometimes below freezing in extreme cases. These cold spells are driven by large-scale high-pressure systems over northern latitudes and the penetration of polar air masses into the subcontinent. The occurrence of cold waves varies from year to year, but climate variability and changing weather patterns can sometimes intensify these events, leading to frost, crop damage, and health impacts, particularly among vulnerable populations. Figure 3.4 showing annual cold wave climatology based on the data during the period 1969 to 2019.

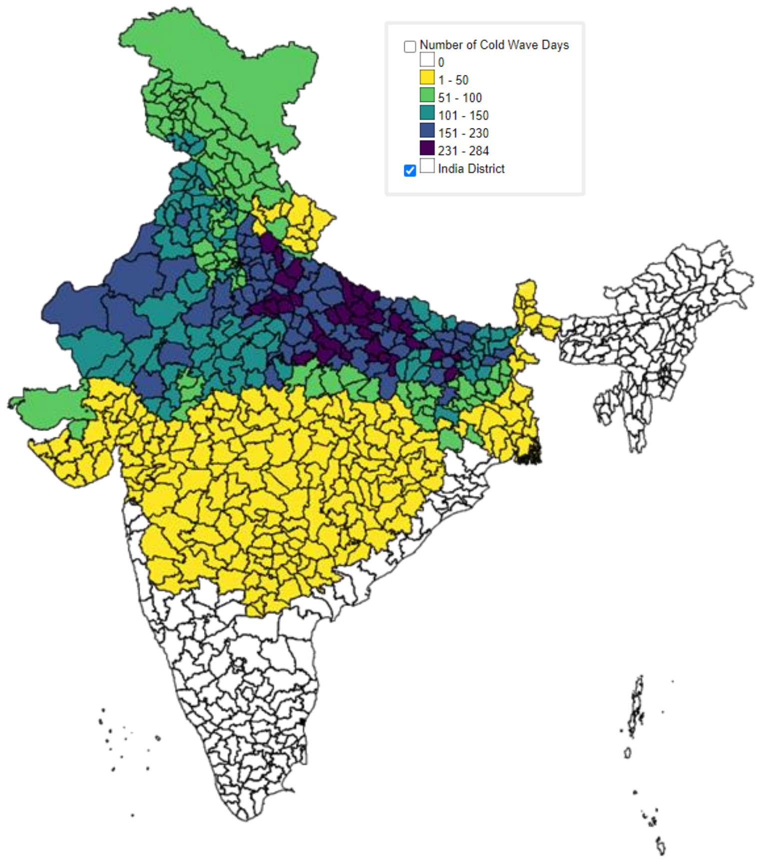

Figure 3.4 Total cold wave days (Total Number of Disasterous Heat Wave Days) using the data during the Period from 1969 to 2019 (Image Credit: IMD).

3.6 Floods and Droughts:

3.6.1 Floods

Floods are a recurrent natural disaster in India, caused by heavy rainfall, river overflow, dam breaks, or storm surges. They can lead to significant economic losses, destruction of infrastructure, and loss of life, particularly in vulnerable communities. India's diverse geography, with its numerous rivers and monsoon climate, makes it especially susceptible to flooding. In recent years, the increasing trend of urban floods has become a major concern, especially in cities like Mumbai, Delhi, and Chennai. Rapid urbanization, inadequate drainage systems, and the loss of natural water bodies have worsened the situation, making urban areas highly vulnerable to flash floods, which occur in a short time (usually less than six hours) after heavy rainfall or dam failure.

Causes of Floods:

Floods can be triggered by various factors, both natural and human-induced. The primary causes include:

(i) Heavy Rainfall: Prolonged or heavy rainfall is one of the most common causes of flooding. When the ground becomes saturated and cannot absorb any more water, the excess flows overland, filling rivers and lakes beyond their capacity.

(ii) River Overflow: Rivers can overflow their banks due to excessive rainfall, snowmelt, or other upstream activities, leading to flooding of adjacent land areas.

(iii) Storm Surges and Coastal Flooding: Tropical cyclones, hurricanes, or typhoons can generate storm surges—rising sea levels due to strong winds—which inundate coastal areas. Coastal flooding is also exacerbated by high tides, especially during storm conditions.

(iv) Dam Failure: The structural failure of dams or levees can cause significant and sudden flooding downstream. These artificial structures hold large quantities of water, and their collapse can release water rapidly into surrounding areas, leading to catastrophic flooding.

(v) Urbanization: Human activities like deforestation and urbanization reduce the land's natural ability to absorb water. Impervious surfaces such as roads and buildings block water infiltration into the soil, leading to higher runoff during rain events, causing urban flooding.

3.6.2 Drought:

Drought is the consequence of a natural reduction in the amount of precipitation over an extended period of time, usually a season or more in length, often associated with other climatic factors (viz. high temperatures, high winds and low relative humidity) that can aggravate the severity of the drought event. There are four types of droughts:

(i) Meteorological Drought (ii) Hydrological Drought (iii) Agricultural Drought, and (iv) Socio-Economic Drought

Meteorological Drought: According to India Meteorological Department, meteorological drought over an area is defined as a situation when the seasonal rainfall received over the area is less than 75% of its long term average value. It is further classified as "moderate drought" if the rainfall deficit is between 26-50% and "severe drought" when the deficit exceeds 50% of the normal.

Hydrological Drought: Hydrological Drought can be defined as a period during which the stream flows are inadequate to supply established use of water under a given water management system.

Agricultural Drought: It occurs when available soil moisture is inadequate for healthy crop growth and cause extreme stress and wilting.

Socio-economic drought: Abnormal water shortage affects all aspects of established economy of a region. This in turn adversely affects the social fabric of the society creating unemployment, migration, discontent and various other problems in the society. Thus, meteorological, hydrological and agricultural drought often leads to what is termed as Socio-economic drought.

Causes of Droughts:

Droughts occur due to a prolonged lack of rainfall, but several factors can contribute to their development:

(i) Lack of Precipitation: The primary cause of droughts is an extended period of below-average rainfall. Weather patterns like El Niño can disrupt normal rainfall distribution, leading to drought conditions in certain regions.

(ii) Climate Change: Global climate change has altered weather patterns, making droughts more frequent and intense. Rising global temperatures increase evaporation rates, reduce soil moisture, and contribute to longer periods of dryness in susceptible regions.

(iii) Overuse of Water Resources: Human activities, such as excessive irrigation for agriculture, industrial use, and urban water consumption, can deplete available water resources, exacerbating drought conditions. Overdrawing groundwater and draining lakes or rivers can accelerate water scarcity.

(iv) Deforestation and Land Degradation: Deforestation and land degradation reduce the ability of the soil to retain moisture.

(v) Poor Water Management: Inefficient water management practices, such as the over-extraction of water from rivers and aquifers, can lead to the depletion of freshwater resources, making regions more vulnerable to drought. This is especially problematic in areas already experiencing low rainfall.

3.7 Fog

Fog is a major weather hazard over north India during the winter season. It impacts various sectors resulting in disruption and economic losses. Fog can be defined as a suspension of water droplets in the atmosphere with the base at the earth’s surface. As per WMO, fog reduces the horizontal visibility to less than 1000 m at the surface of Earth.

3.7.1 Classification of Fog Type

Fog can be categorized into four distinct types—shallow, moderate, dense, and very dense—based on the range of general visibility. The visibility range for each fog type is summarized in the table below.

Fog Type	General Visibility Range (in meters)
Shallow	Visibility fall up to 500 m
Moderate	Up to 200 m
Dense	Up to 50 m
Very dense	< 50 m

Chapter 4

Hazard Prediction, Warning Systems, and Disaster Management

4.1 Prediction of Natural Hazard

4.1.1 Early warning system of different Hazards

A natural hazard refers to a natural event, such as earthquakes, floods, landslides, cyclones or other weather extremes, that has the potential to cause significant harm to people, property, or the environment. Predicting such hazards is crucial to mitigating their adverse effects. Hazard assessment plays a critical role in this process by determining the likelihood and potential impact of a hazardous event. Through careful analysis of historical data, environmental factors, and technological tools, scientists and disaster management authorities can assess the probability and intensity of these hazards. This assessment informs preparedness plans, allowing communities to take preventive measures to reduce the risk and damage from impending natural hazards.

4.1.2 Early Warning Systems and its components

Early warning systems are designed to detect and predict hazardous events, providing timely information that enables individuals, communities, and authorities to take preventive action. Key components include:

Risk Knowledge: Understanding the types of hazards, their frequency, potential impacts, and vulnerable areas is crucial. This information comes from historical data, hazard mapping, and scientific research.

Monitoring and Forecasting: Advanced technologies like satellites, radar systems, seismographs, and numerical weather prediction models help detect and monitor hazards in real time. Continuous monitoring allows for forecasting the likelihood and intensity of events.

Communication Systems: Effective communication is essential to ensure that early warnings reach all stakeholders. This involves reliable dissemination channels such as TV, radio, mobile networks, sirens, and social media.

Response Capability: Communities and authorities need to have pre-established plans and resources to respond to warnings. This includes evacuation plans, disaster shelters, and emergency response teams to minimize damage and protect lives.

4.1.3 Role of Early Warnings in Disaster Risk Reduction

Early warning systems are critical in reducing the impacts of natural hazards by enabling proactive disaster risk management. They serve several essential functions:

Minimizing Loss of Life: Timely warnings give people enough time to evacuate or take shelter, significantly reducing fatalities during disasters like cyclones, tsunamis, and floods.

Reducing Economic Losses: Early warnings allow industries, businesses, and governments to secure infrastructure, relocate resources, and halt operations in high-risk areas, helping to mitigate the economic impact.

Enhancing Preparedness: By providing clear information on upcoming hazards, early warnings promote community preparedness and ensure that response teams are activated ahead of time.

Protecting Livelihoods: Early warnings help farmers protect their crops and livestock, communities to secure food and water supplies, and health systems to prepare for potential outbreaks of disease following disasters.
Supporting Resilience Building: Over time, the presence of reliable early warning systems encourages a culture of preparedness, enabling communities to build resilience against recurring natural hazards.

4.1.4 IMD's seamless forecasting system from seasonal to nowcast

The India Meteorological Department (IMD) has created a weather forecasting system to provide timely and accurate information.
Seasonal Predictions: IMD uses models to predict weather patterns like monsoons months in advance. These forecasts help plan for farming, managing water resources, and preparing for extreme weather.
10-30 Day Forecasts: IMD predicts weather trends like heatwaves, cold spells, and rainfall for up to a month. This helps farmers make decisions about crops and irrigation.
3-10 Day Forecasts: Using advanced tools, IMD gives forecasts for the next few days, helping people plan better for short-term weather changes.
Nowcasting: IMD provides very short-term forecasts for the next 3 hours using satellite images and radar to track storms, heavy rain, or fog. This helps communities prepare for sudden weather changes. These forecasts ensure safety and better planning for various activities like farming, travel, and disaster preparedness.

4.2 IMD's Website: A Vital Resource for Weather Forecasting and Disaster Management

The India Meteorological Department (IMD) website, www.mausam.imd.gov.in, is a comprehensive platform that acts as a powerful tool in weather forecasting and disaster management. It offers real-time weather observations, including meteorological sub-division, district, and station-wise forecasts and warnings, covering up to a 7-day medium range and nowcast (for next 2-3 hour), crucial for timely interventions during adverse weather conditions. The website also provides special forecasts for diverse sectors such as marine regions, aviation, agriculture, and transport, as well as warnings for health, tourism, and pilgrimages
IMD's integration of advanced technology is key to its role in disaster preparedness. It provides real-time satellite and radar images, lightning observations, and cyclone forecasts, making it easier to track and predict hazardous events. The platform also disseminates critical information on the monsoon, flash floods, and climate services, ensuring effective risk management and awareness. For sectors like agriculture and power, it offers tailored advisories, ensuring the safety and continuity of essential services
Additionally, the IMD website enables public participation through its weather reporting system, making it an interactive hub for accurate weather data. By making detailed National Weather Prediction Model

(NWP) outputs available, it aids in the short-to-seasonal forecasting process, improving decision-making at all levels. Through these features, the IMD website supports rapid responses and mitigates the impact of natural disasters.

In addition to the IMD’s Mausam websites, the IMD's regional websites serve as critical resources for disseminating localized weather forecasts and warnings, enhancing public awareness and preparedness for extreme weather events. These regional platforms play a pivotal role in disaster management by providing timely information, enabling communities to respond effectively to weather-related emergencies. A screenshot of IMD’s website is provided as Figure 4.1

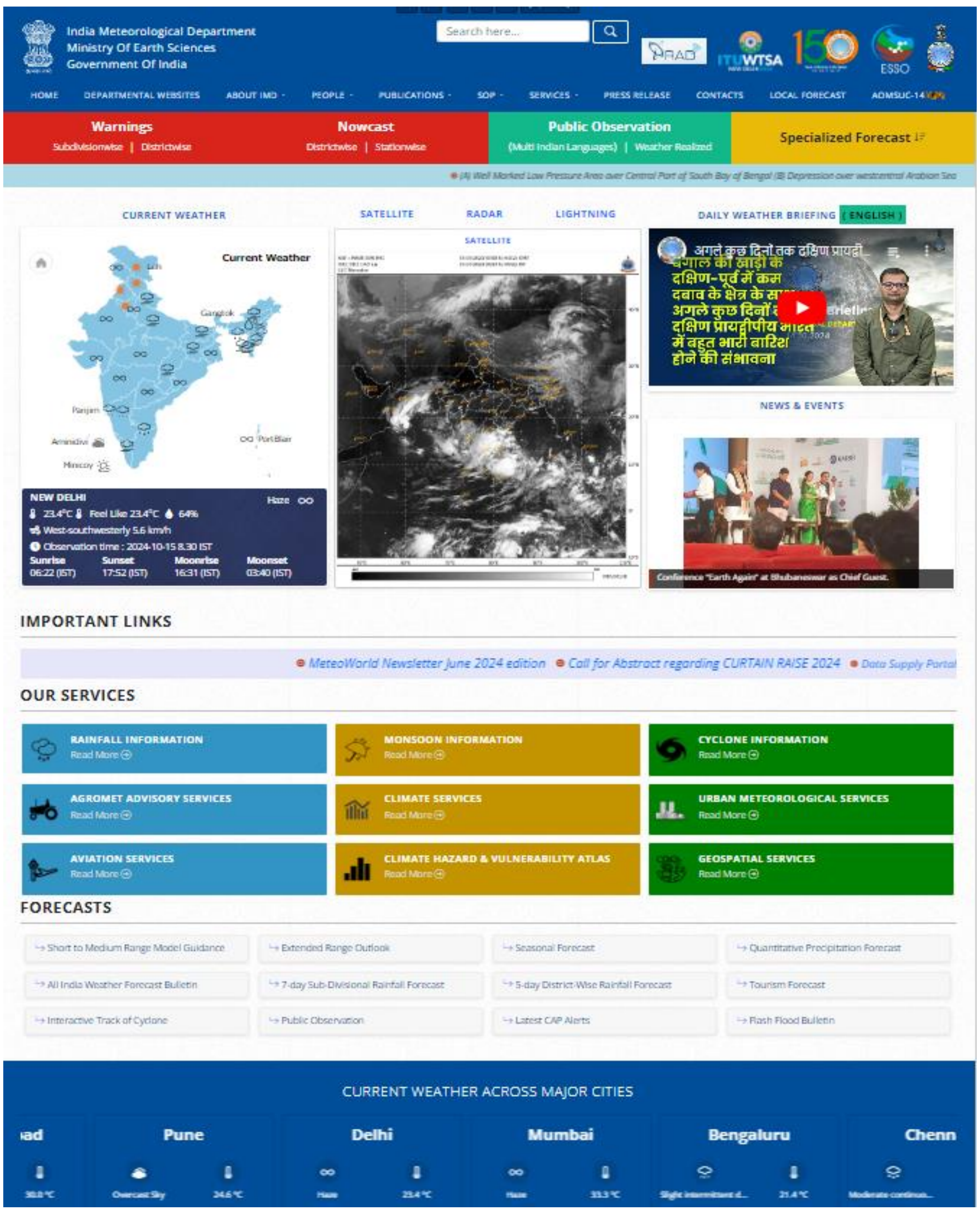

Figure 4.1 Screenshot of IMD’s website

4.3 Involving Communities in Hazard Preparedness

Community involvement plays a vital role in enhancing natural hazard awareness and promoting effective action. Local communities often possess invaluable knowledge about their environments, including the specific risks they face and historical experiences with past disasters. By actively engaging community members in disaster preparedness programs, authorities can leverage this knowledge to develop tailored strategies that resonate with local needs and conditions. Workshops, training sessions, and simulations empower residents to recognize early warning signs, understand emergency procedures, and adopt safety measures, ultimately fostering a culture of preparedness. When communities are well-informed and actively participate in these initiatives, they become more resilient and better equipped to respond to natural hazards.

Moreover, community involvement facilitates stronger social networks, which are crucial during disasters. In times of crisis, neighbours often rely on one another for support, information, and resources. By encouraging collaboration and communication among community members, local organizations can create a sense of solidarity that enhances collective response efforts. Initiatives such as neighbourhood watch programs, local disaster response teams, and community drills not only build skills and awareness but also strengthen relationships among residents. This social cohesion proves invaluable during emergencies, as it enables quicker mobilization of resources, effective sharing of information, and more efficient recovery efforts. Ultimately, active community involvement in natural hazard awareness and action is essential for building resilient societies capable of effectively mitigating the impacts of disasters.

Chapter 5:
Climate change: Causes and Impacts

5.1 What is Climate Change?

Climate change means the long-term changes in the Earth's weather patterns and temperatures. While the climate has always changed naturally over millions of years, recent changes are happening much faster because of human activities like burning fossil fuels (coal, oil, and gas), cutting down forests, and producing too much waste.

5.2 What Causes Climate Change?

i. Greenhouse Gases: These are gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) that trap heat in the Earth's atmosphere, making it warmer. This is called the "greenhouse effect."
ii. Deforestation: Trees absorb CO_2, but cutting down too many trees reduces this natural process, leaving more CO_2 in the air.
iii. Burning Fossil Fuels: Cars, factories, and power plants release large amounts of greenhouse gases into the atmosphere when burning coal, oil, and gas for energy.
iv. Pollution: Waste in landfills and industries also release harmful gases, adding to the problem.

5.3 Impacts of Climate Change

i. Rising Temperatures: The Earth is getting hotter, causing heatwaves in some places.
ii. Melting Ice and Rising Seas: Ice at the North and South Poles is melting, causing sea levels to rise and flooding coastal areas.
iii. Extreme Weather: Climate change causes stronger storms, heavy rainfall, longer droughts, and wildfires.
iv. Effect on Plants and Animals: Many plants and animals are struggling to survive as their habitats change.
v. Impact on People: Farmers face problems growing crops, and people living near the sea or in hot areas may have to move to safer places.
vi. And more

5.4 Climate Change Adaptation and Mitigation

Climate change is causing big changes to our planet, like rising temperatures, stronger storms, and melting ice. To deal with these challenges, we need two important strategies: adaptation and mitigation. Adaptation means adjusting to the changes happening around us. For example, farmers can grow crops that need less water in areas facing droughts, or people living near the sea can build stronger walls to protect their homes from flooding. By adapting, we can stay safe and continue to live comfortably even as the climate changes.

Mitigation, on the other hand, focuses on stopping climate change from getting worse. This means reducing the number of harmful gases, like carbon dioxide, that go into the air. Simple actions, like using less electricity, planting trees, and choosing bikes or buses instead of cars, can make a big difference. Scientists and governments are also working to create clean energy sources, like wind and solar power, to help protect our planet. Together, adaptation and mitigation are the keys to fighting climate change and ensuring a healthy, safe future for everyone.

How Can We Help?

i. Save Energy: Turn off lights, fans, and devices when not in use. Use energy-saving appliances.
ii. Plant More Trees: Trees absorb CO_2 and clean the air.
iii. Reduce, Reuse, recycle: Recycle waste, use reusable bags, and avoid single-use plastics.
iv. Use Clean Energy: Use solar panels, wind power, or other renewable energy sources instead of fossil fuels.
v. Walk or Use Public Transport: Walking, cycling, or taking a bus instead of driving helps reduce pollution.
vi. And more

Why Should We Care?

Climate change affects everyone—plants, animals, and people. If we work together to reduce its effects, we can protect our planet for future generations. Small actions like saving energy, reducing waste, and planting trees can make a big difference.

Remember: The Earth is our home, and it's our responsibility to take care of it! Let's act now to keep our planet healthy and beautiful.