INTRODUCTION TO HYDROMETEOROLOGY

CHAPTER 1: INTRODUCTION TO HYDROMETEROLOGY

1.1. Introduction

Water is one of the most important natural resources and essential for all kinds of living. It corresponds to the annual renewable portion of freshwater, which comprises surface water, underground water, and soil water. All fresh water on the planet comes from atmospheric precipitation (snowfall, rainfall, as well as some other forms). Rainfall, the main water resource that came as a response to atmospheric moisture condensation, is regulated by meteorology and is hence regarded as among the most significant meteorological factors (Baidya Roy & Avissar, 2002). Likewise, the science of geology and hydrology governs the distribution and occurrence of rainwater on and below the surface of the earth. The hydrologic cycle or water cycle is associated with the flow and water exchange among oceans, the atmosphere, and the earth in both hydrology and meteorology. The meteorological aspects of evaporation and rainfall along with hydrologic components of river and lake levels, groundwater, infiltration, and river flow, are the most noticeable parts of the hydrologic cycle that are commonly seen and documented for the sake of sustainability of water. River stream data are particularly useful for measuring the availability of water within a river that can be kept in reservoirs for household, hydropower, generation, irrigation, and some other uses (Phillips, 2012; Bruce & Clark, 2013).

The growth of a region's water resources, necessitates hydrological data, like flow of river, at a variety of locations across a river. In general, such statistics are not supplied for many of these rivers, particularly in underdeveloped nations, and observing them at a range of locations across a river is a costly and often challenging job. But at the other side, meteorological data like wind, rainfall, radiation, humidity, humidity, evaporation, vapor pressure, temperature, daylight hours, etc are monitored continuously and archived over many years for a large network of stations across the globe (Wigley et al., 1984; Bruijnzeel et al., 2011). In the lack of true hydrological data, it is now widely accepted that meteorological data can be utilized to analyze and enhance a region's water resources utilizing hydrometeorology science. Hydrometeorology, then, is the field of meteorology that involves the meteorology applicability to resolve hydrologic issues. In general, hydrometeorology is simply the analysis of the hydrologic cycle's land phases and atmospheric, with a focus on interconnections associated. It's a cross-disciplinary science that combines the study of the atmosphere, meteorology, with water-surface hydrology, the study of the occurrence, transport, distribution, and water storage also on the surface of the earth (Betts, 2004; Brown & Seo, 2010).

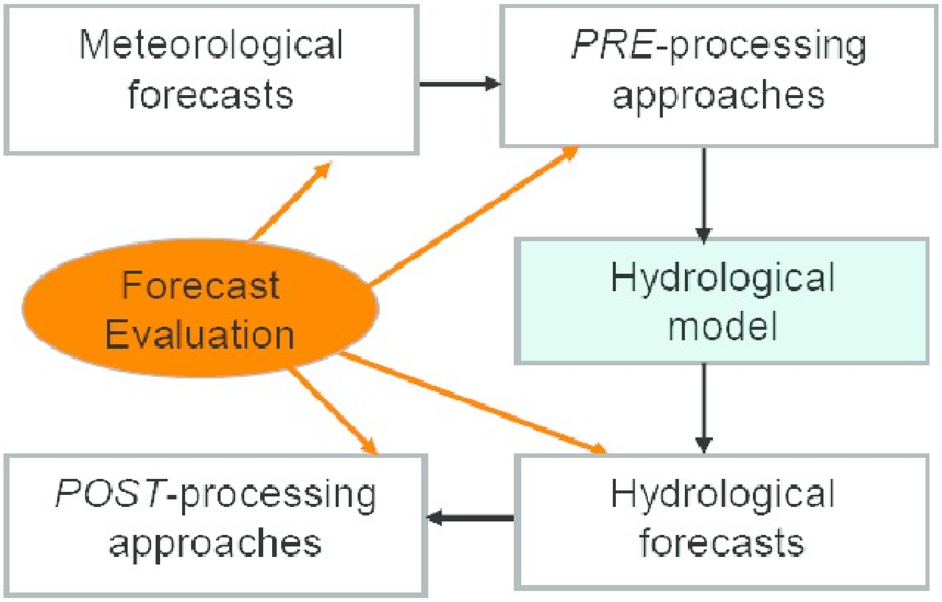


Figure 1.1. Diagrammatic illustration of hydrometeorological forecasting

Source: https://www.researchgate.net/figure/Schematic-of-a-hydro-meteorological-forecast-chain_fig1_258606377

1.2. Scope of Hydrometeorology

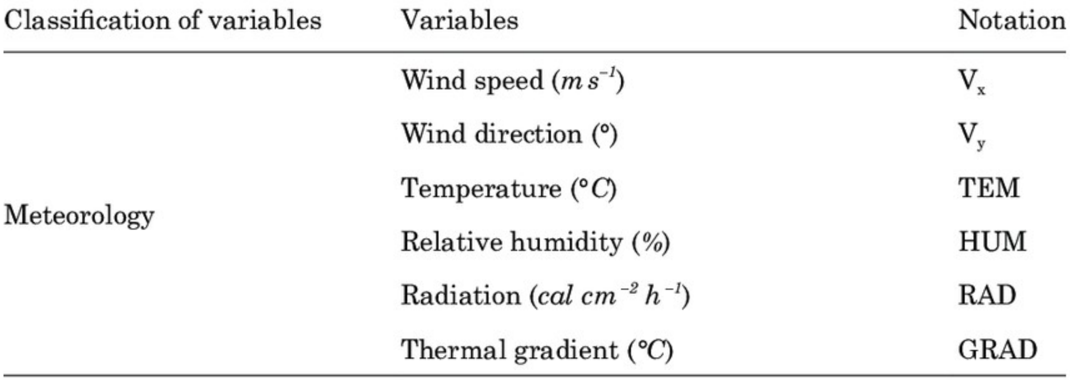
The meteorology growing application to hydrological issues is directly tied to the growth of hydrometeorology as a science. The following examples were chosen to highlight various elements about the utilization of meteorological data in agricultural and hydrological studies. The field encompasses a wide range of topics, but we'll focus on evaporation and rainfall in this section. Evaporation is frequently utilized to calculate losses from reservoirs, ponds and, lakes as well as to estimate agricultural water needs. For hydrological modeling, evaporation estimates from basins(river) are employed (Fletcher, 1951; Rakhecha & Singh, 2009). Surface runoff can be calculated by subtracting losses of evaporation from rainfall. The rate of evaporation is heavily influenced by meteorological factors such as wind speed, radiation, vapor pressure, humidity, cloud cover, daylight hours, and temperature. These components of meteorology are extremely useful in indirectly calculating evaporation for hydrologic research where direct evaporation measurement is not feasible (Bleasdale, 1973; Wigley et al., 1984).

Data on rainfall is utilized in the preparation and building of water management projects. Building reservoirs and dams across rivers to store and collect river water runoff to meet people's needs has been a popular practice for ages. Data of long-period rainfall is utilized in the design and planning of these dams to estimate the flow of water in a stream. Data of streamflow is essential for determining the river basin's water production and determining the size of dam storage capacity. Dams are constructed and built with appropriate spillways to protect them from severe floods generated by severe rainfall. This necessitates estimating the biggest floods based on outflow data which are frequently insufficient due to the scarcity of records and surface gauging stations (Erdil & Arcaklioglu, 2013; Kramareva et al., 2019). In such circumstances, a planned flood derived from a planned storm is used, based on the scope, placement, and type of the dam. A rainfall-runoff model is implemented to turn the design storm into a design flood based on a study of time rainfall information from stations in the region of river basin under examination. For calculating the design storm, many rainfall assessment techniques have been implemented, including storm transposition, depth-area-duration (DAD) and duration of depth (DD). The probable maximum storm (PMS) or probable maximum precipitation (PMP), the standard project storm(SPS) are two design storms that are mostly utilized to estimate design floods(Eskridge et al., 1997; Ishii et al., 2005).

The PMP's goal is to give an absolute safety criterion in cases where a dam's overtopping or failure would result in significant loss of property and life. Small dams are not designed to withstand the storm of PMP because a dam breach will pose little risk downstream. Alternatively, a frequency technique is utilized, in which severe rainfalls at a certain location are evaluated statistically to establish the frequency at which a particular intensity rainstorm for a set time can be forecast. The design flood is then estimated using hydraulic methods based on the storm rainfall designed. (Xu & Singh, 1998; Apadula et al., 2012) The collected data from rain gauges are used to size channels of flow openings beneath bridges, stream control works, channels for railways and highways, urban storm sewers, airfield drainage, and other drainage projects. All of them are created by taking into account the rainfall frequency and then using statistical ways to analyze the necessary rainfall intensity. Rainfall data and forecasts are crucial inputs for river flood alerts. The accuracy of rainfall forecasts is critical to the effective running of a multifunctional dam. The amount of the input is calculated relying on rainfall predictions, as well as the reservoir is maintained to handle the oncoming water flood. Water use through dry seasons has to be properly managed in the case of storage reservoirs. For estimating water wave levels and determining freeboard needs, an evaluation of the likely wind across reservoirs is required (Ziomas et al., 1995; Smith, 2002; Zhi et al., 2021).

1.3. Meteorological Variables

The atmosphere is a fine layer of air that envelope the earth and thins as it rises. The condition of an atmosphere at a given location is represented by numerous meteorological factors such as pressure, humidity, wind, radiation, temperature, sunshine, rain, evaporation, clouds, fog, and so on at a certain time. Continuous monitoring of meteorological parameters is required to have a better knowledge of the atmosphere and its accompanying weather. Calculations are taken with standardized instruments and exposed to standardized conditions. The meteorological science is concerned with both weather origins and how it changes through time and space. Weather is not the same as climate (Thornton et al., 1997; Xavier et al., 2016). Climate refers to the average weather of a location's which is calculated by combining meteorological data of many years (30 years). The cause for this is that the trend of meteorological data variation through time replicates itself every 30 years or so (Flannigan & Harrington, 1988; Gocic & Trajkovic, 2013).



Classification of variables	Variables	Notation
Meteorology	Wind speed ($m\,s^{-1}$)	V_x
	Wind direction (°)	V_y
	Temperature ($°C$)	TEM
	Relative humidity (%)	HUM
	Radiation ($cal\ cm^{-2}\ h^{-1}$)	RAD
	Thermal gradient ($°C$)	GRAD

Table 1.1. Meteorological variables

1.3.1. Temperature

Temperature is a measurement of how hot or cold the air is, and it is measured using Fahrenheit or centigrade scale. The temperature of the earth is mostly determined by the quantity of radiation it receives. Aside from radiation, additional elements that affect temperature include prevailing winds, altitude, closeness to the sea, and so on. Temperature is measured in a Stevenson screen with a mercury thermometer for meteorological applications and pertains to the ambient temperature in shady situation at an altitude of around 1.5 meters. The temperature of the atmosphere is a very important parameter for calculating evaporation and snowmelt (Betts et al., 2005; Hamlet et al., 2005; Roy, 2011).

Lord Kelvin, while studying the gases' nature, the idea of absolute zero was developed, beyond which gases could not be cooled anymore. This temperature is around –273°C. This is where the absolute scale begins. The freezing temperature is 273 degrees Fahrenheit, and the boiling temperature is 373 degrees Fahrenheit. When dealing with extremely low or extremely high-temperature values, the Kelvin scale comes in handy (Marengo, 2009; Panthou et al., 2014; Yang et al., 2016).

1.3.2. Atmospheric Pressure

As previously stated, a gaseous envelope encircled the world from all sides as the termed as an atmosphere, that extends several kilometers just above the earth's surface. Since air possesses weight, an imagined tube having unit area(cross-sectional) filled with air that expands from the ground to its topmost limit would exert a certain pressure on objects presnt on the earth srface. The force exerted on a unit area by a air in a Column is known as atmospheric pressure, and its unite in the CGS system is dynes/cm2. If the column of height h at mean sea level of air with an average density of, then perhaps the gh is the atmospheric pressure(p), while g is the gravitational acceleration (Cleverly et al., 2013; Neiman et al., 2013).

A barometer based on mercury discovered by Torricelli(1643) is used to measure pressure. The mercury column height in a barometer is used to expressed pressure while balancing atmospheric pressure. The mercury column height at sea level is almost 76 cm. Because mercury has a density of 13.59 g/cm3 at 15°C and an acceleration of 980 cm/s2, the sea level average pressure is 1,013,200 dynes/cm2. The dynes/cm2 unit is extremely tiny. The millibar, which is 1000 times greater, was introduced by Bjerknes. In meteorology, It's a pressure unit. The average pressure of sea level is 1013mb. In the SI system of measurement, 1 N/m2 is the unit of pressure. The Pascal (Pa) is a unit of measurement that equals 10 dynes/cm2. As a result, 1 mb=100 Pa (also known as 1 hecto Pascal or 1 hPa). In the SI system, the atmospheric pressure of 1013 mb equals 1013 hPa (Vivoni et al., 2007; Hao et al., 2018).

1.3.3. Atmospheric Humidity

Water vapor is usually available in various proportions in the atmosphere. It can range from roughly 4% by mass in the air during hot humid to about 100times less than in extremely frigid air. Evaporation from water sources such as moist land surfaces, seas, rivers, tanks, and lakes produces this atmospheric vapor of water. Evaporation through the world is predicted to be 1000(mm per year on average). Humidity relates to the quantity of vapor present in the atmosphere and it can be measured using a variety of physical parameters. The vapor pressure, relative humidity, specific humidity, dew point, mixing ratio and absolute humidity, are all relevant humidity factors (Koutsoyiannis et al., 2007; Yamazaki et al., 2007).

The partial pressure of vapor present in the air is unaffected by the existence of many other gases. The vapor pressure, which is the most effecient estimation of the moisture level within atmosphere, is the pressure imposed by water vapor. It is typically represented by the letter "e" and it is estimated in millimeters or millibars of mercury, equivalent to atmospheric pressure. The quantity of vapor and the temperature of air that it can retain have an incredible relationship. The amount of vapor that must be present in the air is determined by the temperature of the air. More the vapor the air can carry, the greater the temperature (Lim et al., 2013; Brenot et al., 2014). At a given pressure and temperature, the air is considered to be saturated whenever it carry the greatest quantity of vapor possible. When vapor introduced is more or the air is chilled well down the saturation point, the vapor remain extra condenses into small dew droplets. The temperature at which dew forms and the pressure of vapor in the atmosphere becomes saturated is known as the dew point. The applied pressure by vapor in air saturated at a particular pressure and temperature is known as saturated vapor pressure, that is the maximum pressure of vapor for all practical uses. It is measured in millimeters or millibars of mercury and is represented by the letter "es." The saturation deficit is the difference of "es– e." The air's relative humidity (RH) is stated as (Zhang et al., 2012; Snook et al., 2019):

$$RH = \frac{e}{e_s} \times 100 \qquad (1)$$

The percent ratio between actual vapor pressure (e) and the maximum feasible vapor pressure (es) over a specific temperature is thus described as relative humidity. Whenever the relative humidity becomes 100 percent, the air becomes saturated with moisture.

The following is the relationship between saturation vapor pressure and air temperature:

$$e_s = 6.107 \times 10^{\frac{7.5T}{(237 + T)}} \qquad (2)$$

where "es" denotes the saturation vapor pressure(millibars) and T denotes the temperature in degrees Celsius. For various temperatures, equation (1.2) could be used to calculate the saturation vapor pressure. Table 1.2 shows the saturation vapor pressure values for different temperature levels.

The utilization of dry and wet bulb thermometers is perhaps the most practical way for measuring air relative humidity. A thermometer bulb covered in a smaller strip of muslin that is maintained wet by a wick placed in a little water bottle should register a lesser air temperature than just an equivalent bare thermometer. A psychrometer is made up of two similar thermometers set side by side. When the overall relative humidity of air reduces, the reading of the wet-bulb thermometer decreases. The lower temperature reading out from the wet-bulb thermometer is attributed to the water evaporation from the muslin(in wet form) into the surrounding atmosphere whenever the air is unsaturated. The air is cooled as the latent heat of vaporization is extracted. The air continues to cool and the moisture content of the air increases due to evaporation from muslin till the wet bulb of air surrounding is saturated. Following that, a thermometer of a wet-bulb consistently records a lower value than the dry bulb. The difference seen among wet bulb and dry bulb thermometer readings regarding the atmospheric temperature provides a measurement of the real relative humidity as well as the vapor pressure. For measuring vapor pressure and relative humidity equations, diagrams, and tables have been produced.

Table 1.2. Vapor pressure at saturation (mb)

Temp °C	***Saturation vapor pressure (mb)****									
	0	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
00	6.11	6.57	7.06	7.58 .	8	8.72	9.	10.02	10.73	11.49

10	12.29	13.14	14.03	14.99	16.00	17.07	18.20	19.39	20.66	22.00
20	23.41	24.90	26.45	28.13	29.88	31.73	33.67	35.71	37.87	40.13
30	42.51	45.01	47.65	50.40	53.31	56.35	59.50	62.89	66.40	70.08
40	73.94	77.97	82.20	86.62	91.24	96.08	101.14	106.42	111.94	117.70

** To acquire the value of proper saturated pressure of vapor from the table regarding a particular temperature, check the temperature in the first column, then value would be add to the very first row. Go to the 4th row, that represent a number of 20, and the eighth column, that refers to a number of 6, and the similar element of 33.67 mb, which is the saturated vapor pressure for 26°C.*

The psychrometric equation for calculating the air vapor pressure is as follows:

$$e = e_s - 0.000660\, P\, (T - T_w)\,(1 + 0.00115\, T_w) \quad (3)$$

e= the vapor pressure in the air expressed in millibars

P = the air pressure in millibars

e_s = the saturated vapor available in millibar at the wet-bulb thermometer's temperature Tw in °C

T_w = the wet-bulb thermometer temperature in °C

T = the dry bulb thermometer temperature in °C

For a 1000 mb pressure, Table 1.3 shows the vapor pressure (e) values that correspond to specific values of the dry bulb and wet bulb temperatures.

Humidity can be show in a variety of ways, including a wet-bulb thermometer, relative humidity, and vapor pressure, as discussed below.

Vapor density is the amount of vapor present in a unit volume of moist air. This is also known as absolute humidity. It is calculated in grams per square meter (gm/m3). The vapor mass contained in a gram of wet air is indicated by the letter "q." It is rarely higher than 0.04.

The mixing ratio is indicated by the letter "r." and is defined as the water vapor mass contains in gram of dry air. The mixing ratio and specific humidity are commonly stated in grams per kilogram.

Table 1.3. Values of e (mb)

T_w (°C)	***$T - T_w$ (°C)***									
	0	*01*	*02*	*03*	*04*	*05*	*06*	*07*	*08*	*09*
0	6.1	5.4	4.7	4.1	3.1	2.7	2.0	1.4	0.7	0.08
2	7.0	6.2	5.7	5.0	4.3	3.7	3.0	2.3	1.6	1.0
4	8.1	7.4	6.7	6.1	5.4	4.7	4.0	3.4	2.7	2.0
6	9.3	8.6	8.0	7.3	6.5	5.9	5.3	4.6	3.9	3.2
8	10.7	10.0	9.3	8.7	8.0	7.3	6.6	6.0	5.3	4.6

10	12.2	11.6	10.9	10.2	9.5	8.8	8.2	7.5	6.8	6.1
12	14.0	13.3	12.6	12.0	11.2	10.6	9.9	9.2	8.6	7.9
14	16.0	15.3	14.6	13.9	13.2	12.5	11.9	11.2	10.5	9.8
16	18.2	17.5	16.8	16.1	15.4	14.6	14.5	13.4	12.7	12.0
18	20.6	19.4	19.2	18.6	17.9	17.2	16.5	15.8	15.1	14.5
20	23.4	22.7	22.0	21.3	20.6	19.9	19.2	18.6	17.9	17.2
22	26.4	25.8	25.0	24.4	23.7	23.0	22.3	21.6	20.9	20.2
24	29.8	29.1	28.4	27.8	27.1	26.4	25.7	25.0	24.3	23.6
26	33.6	32.9	32.2	31.5	30.8	30.2	29.5	28.8	28.1	27.4
28	37.8	37.1	36.4	39.7	35.0	34.3	33.6	33.0	32.3	31.6

When P indicates the total air pressure and e denotes the partial pressure of vapor contained in it, the dry air partial pressure equals (P – e). The mixing ratio(r) and specific humidity (q) are calculated using the following formula:

$$r = \frac{\varepsilon e}{P-e} = \frac{0.622e}{P-e} \qquad (4)$$

where 0.622 is the vapor molecular weight divided by the molecular weight of the dry air. Tables 1.2 and 1.3, as well as equations (2) and (1.3), can be used to calculate humidity parameters (1.3).

$$q = \varepsilon \frac{e}{P} = \frac{0.622e}{P} \qquad (5)$$

1.3.4. Air Density

The density of air represented as-is on the scale of 1/1000 that of water close to the ground and is practically never determined. It is instead calculated using the equation of gas (ρ = P/RT). It is expressed in kg/m3 or gm/cm3 units. The density of air is 0.0012 gm/cm3 at a 1000 mb surface pressure and at 290°K temperature (Snook et al., 2019).

1.3.5. Precipitation

Precipitation, condensation, and evaporation are the three central elements of the water cycle within the atmosphere. Precipitation is the word applied to represent the water that drops on the surface of the earth from the atmosphere in either solid or liquid form. Rain in a state of liquid as well as sleet, hail, and snow in form of solid are all included. Water vapor evaporates from the surfaces of water such as ponds, seas, rivers, and lakes, as well as from vegetation and land. When water vapor reaches significant altitudes well above the earth's surface, it forms clouds by condensation. Condensation is defined as the collection of water vapor molecules into extremely tiny droplets (Zhang et al., 2012; Lim et al., 2013). These little water droplets develop in size and eventually fall as snow or rain on the ground. A raindrop has a radius of 1000 microns on average. Precipitation must be measured to determine the quantity of water collected from the atmosphere in a specific region over a certain period. All types of precipitation are quantified in units of the vertical water depth which would collect on level ground if the complete precipitation stayed in place. Rain gauges are used to measure the two major components of precipitation (snow and rain). The receiver on a rain gauge(standard non-recording) is five inches in diameter The most significant rainfall data for water resource development and hydrologic objectives are the rainfall mean depth for distinct places across different periods, like seasons, months, or the entire year. The average yearly precipitation in the world is roughly 80 centimeters. However, towards the equator between about 40° and 50° latitudes, precipitation is at its maximum. Over mountainous areas, there is unusually strong rainfall. The average annual precipitation in Cherrapunji [25.3°N, 91.8°E] of India is 1087 centimeters (Baidya Roy & Avissar, 2002; Li et al., 2021).

1.3.6. Horizontal Winds

A wind, that is the longitudinal movement of air on the earth's that is defined by its speed and direction. The wind direction is determined by the way the wind blows. The cardinal directions, like N, NNW, NW, and so on, are used to describe the wind directions (Hunter et al., 2015). The north wind (N) is a wind that blows from the north. Speed of wind is expressed in kilometers per hour, meters per second (meter per second), miles per, or knots (nautical miles per hour). The wind vane is used to determine the direction of the wind, while the anemometer calculate wind speed. For winds, the conversion factor is:

1 knot = 1.853 km/hr = 1.57 miles/hr = 0.51 m/s

1.3.7. Evaporation

Evaporation is the transformation of a material from a liquid state to a vapor state. The heat of the sun causes the vaporization of surface water from lakes oceans, rivers, and other bodies of water, resulting in water vapor conatin in the atmosphere. The Pan-measurement method, also known as the weather pan, is used to determine the rate of evaporation. This process involves using a pan with standard dimensions and filling it with water to a specific level. The quantity of water that has evaporated from this pan has been calculated, and the rate of evaporation per unit area per unit time has also been measured (Pellarin et al., 2002).

1.3.8. Visibility

The visibility of an object is described as the maximum parallel distance over which it can be viewed. It is calculated by choosing several visibility marks, like tall buildings, towers, and hills. The visibility would be infinite if there were no particles in suspension. However, there are always a few particles in the suspended form in the atmosphere, reducing visibility. While, dust, smoke, and water particles are small enough to obscure visibility. Haze is created by dust particulates or smoke, while mist or fog is created by water particles. Heavy drizzle, heavy rains or snow, sandstorms, and Dust storms can turn down visibility to just a few hundred meters (Karyampudi & Carlson, 1988).

1.3.9. Vertical Motions of Air

The majority of the cooling and subsequent condensation of air, which leads to cloud formation and precipitation, is caused by the upward perpendicular motion of air on both a large and small scale. The velocity does not remain constant vertically and has a logarithmic distribution or power law up to a certain altitude (Hess et al., 1998).

1.3.10. Clouds

In hydrometeorology, precipitation and clouds play a significant role. At higher elevations, supersaturated anabatic wind causes clouds to form. Just like air rises steadily to the earth's atmosphere, it expands, causing cooling. Vaporation of surface water such as rivers, oceans, lakes, and so on creates water vapor, as previously stated. Because water vapor is light, it rises to the top of the atmosphere, where it swells adiabatically and cools just under the saturation point. Excess moisture condenses as minute droplets of liquid on suspended particulate matter, forming clouds (Plummer & Maynard, 2014).

Clouds are divided into three groups based on their appearance when seen from the surface (Fig. 1.1): (i) layer clouds or stratus, (ii) heap-shaped clouds or cumulus, and (iii) feathery streaks of clouds or cirrus. Clouds are categorized as a medium, high, or low depending on how high above the surface they happen. The ten major categories are listed below and shown in Table 1.3 per the international categorization (Brunsell & Marcks, 2005).

Cirrus clouds have a fibrous structure and appear as if they are made of glass wool drifting across a blue sky. A thin sheet of elevated clouds known as Cirrostratus gives the sky a milky appearance. Cirrocumulus is made up of a particular structure of white globules (Allison, 1997).

Altostratus is a closely packed grey cloud with a sliver of the sun visible through it. Altocumulus is made up of globular masses that are often assembled in parallel bands with straightforward voids in between. Stratus is a low cloud that appears like the fog that has been lifted over the surface of the earth. Massive lumpy masses with disparities make up stratocumulus. Rain falls from Nimbostratus, a dense dark cloud mass.

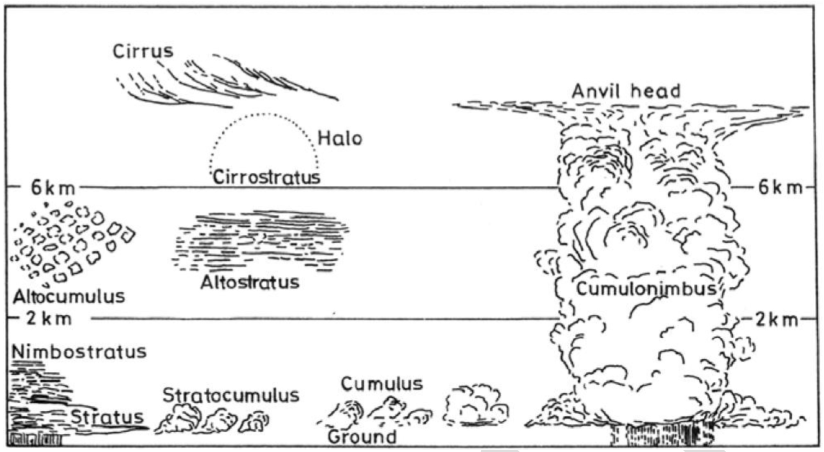


Figure 1.2. Clouds categories.

Source: https://www.sciencedirect.com/science/article/pii/B9780080117140500065

Table 1.4. Clouds classification

Cloud name	***Symbol***	***Occurrence height***
Altostratus	As	2-6 km
Altocumulus	Ac	”
Stratocumulus	Sc	< 2 km
Stratus	St	”
Nimbostratus	Ns	”
Cumulus	Cu	Cloud with great vertical development
Cumulonimbus	Cb	”
Cirrus	Ci	6-15 km
Cirrostratus	Cs	”
Cirrocumulus	Cc	”

1.4. Seasons and Earth Orbital Motions

The radiation input varies in space and time due to the earth's inclination of the axis, revolution around the sun, and rotation around its axis. As a result, the earth has various seasons and climatic zones (Smithsonian Institutions, 1939; Sulis et al., 2019). The earth spins on its axis in an elliptical orbit at 113,000 kilometers per hour, taking per year to complete the 966 million kilometer journey. The earth's (E) orbit around the sun (S) is illustrated in figure 1.3. The earth is said to be at perihelion when it is at P in its orbit around the sun. On or about January 1st, this happens. The earth is said to be at aphelion because it is at (A) and is the furthest away from the sun. This happens on or about July 2nd.

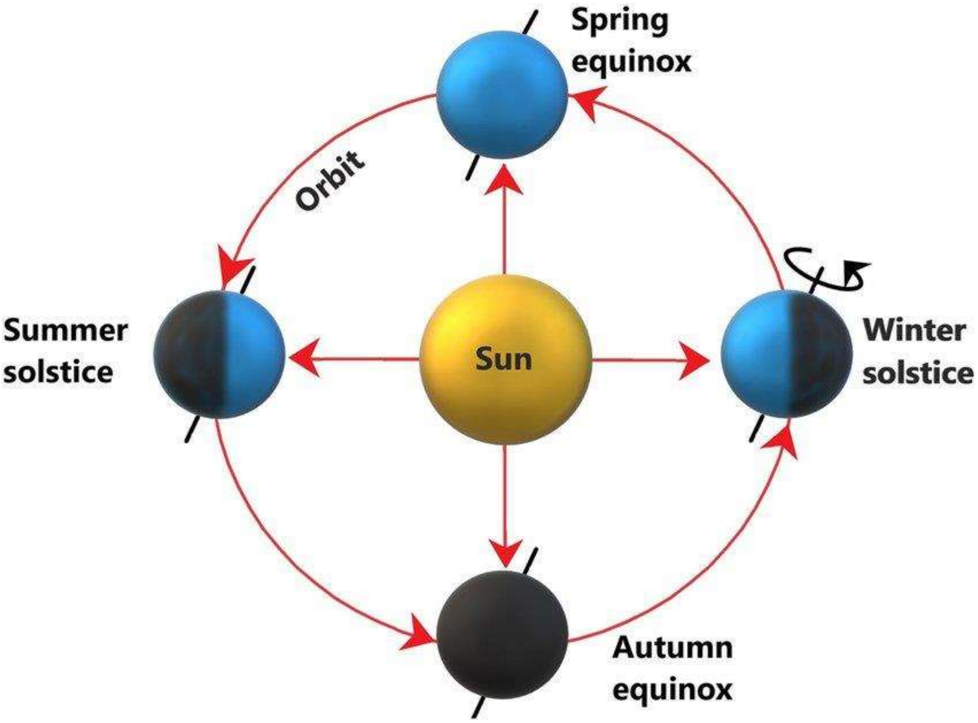


Figure 1.3. The earth's orbit around the sun

Source: https://www.researchgate.net/figure/The-schematic-Earth-orbit-about-the-Sun-48-shown-not-to-the-real-scale-of-the-Sun-and_fig5_333988067

The mean length among the earth and sun, or the earth's orbit semi-major axis, is the unit of astronomical distance. It has a value of 149.6×10^6 km, like, $OA = OP = 149.6 \times 10^6$ km. The earth's eccentricity (ec) path is 0.0167 at present. As (S) is the elliptical focus. We got x.

$OS = OP \text{ x } ec$ $149.6 \text{ x } 10^6 \text{ x } 0.01675 = 2.510^6$ km

$SP = 149.6 \text{ x } 10^6 - 2.510^6 = 147.1 \text{ x } 10^6$ km

SA $149.6 \text{ x } 10^6 + 2.510^6 = 152.1 \text{ x } 10^6$ km

The proclivity of the planet's equator to the plane of its trajectory around the sun is responsible for the winter and summer seasons. The planet's equator is oriented at a 23.5° angle to its orbital plane. This means that as the planet (earth) orbits the sun, the proportion of sunlight falling on it is unequal and varies (Fig. 1.3).

The earth spins once every 24 hours around its elliptical orbit. The earth spins from east to west, and its axis sustains a tilt of 23.5 degrees while it spins and revolves. The sun rotates all-around ecliptic and passes the equator 2 times per year when regarded from Earth. On or around March 21st, the vernal equinox occurs at the equator's point. Whenever the sun passes the equator from north to south. The autumnal equinox, which falls on or about September 22nd, is the other north-to-south crossing. Now or then, the sun rises at midday on the equator. While both day and night have the same period-12 hours-all over the globe (Rao, 1975; Khavrus & Shelevytsky, 2010).

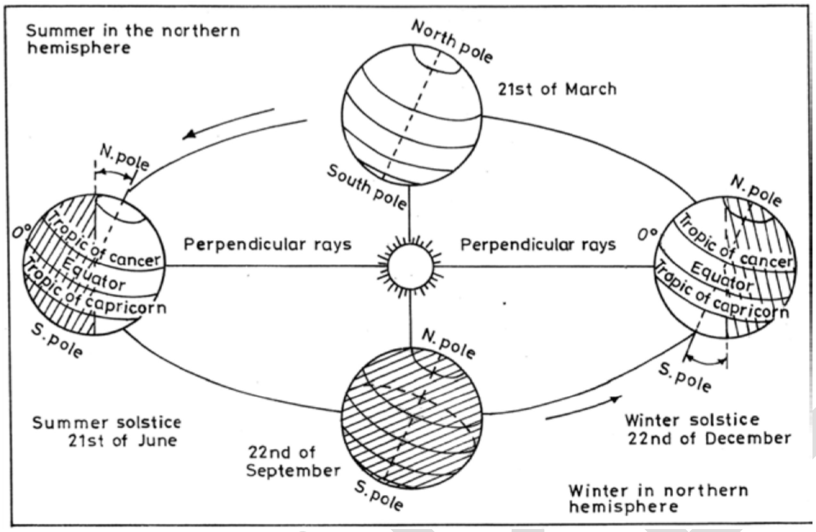


Figure 1.4. Winter and summer seasons are determined by the earth's equator inclination to its plane about the sun.

The sun starts to move northward later passing the vernal equinox on March 21st, attaining the threshold steady decline of 23½ degrees. This happens on June 21st. That day-on the latitude circle of 23.5° N-the sun rises above the horizon at regional midday. While the north pole experiences the year's shortest night and longest day. On June 21st, the summer solstice occurs in the north pole. But on the same day, the winter solstice occurs in the south pole. Solar radiation reaches its highest point in the north pole, while it reaches its lowest point in the south pole. At 66½ degrees north latitude, the day is twenty - four hours long on June 21st. To the north of the 66½ °N parallel of latitude, the timeframe of light continues to increase, and light usually takes 6 months in the northern hemisphere. In the south pole, it is the reverse at this time. The sun does not shine in the south pole. Light reaches only around a portion of the south pole. On the 21st of June, night lasts 24 hours at 66½ °S parallel of latitude. From the south of the 66½° parallel of latitude, the timeframe of darkness increases. whereas the southern hemisphere remains dark for 6 months (Petterssen, 1969; Yu et al., 2015).

The sun's superficial south-ward rotation begins with the summer solstice. Which crosses the equator at the autumnal equinox, and continues southward. On December 22nd, the sun reaches its southernmost declination of – 23.5°. The northern hemisphere's winter solstice falls on December 22nd. Whereas, the southern hemisphere's summer solstice falls on the same day. Thus, solar radiation reaches its peak in the southern pole, though it reaches its lowest in the northern pole (L'vovich, 1979; De Paor et al., 2017).

1.5. Water and Land Global Distribution

The Earth surface is uneven. The earth surface is made up primarily of ice, ocean, and land, with the former covering only a little portion of the planet's surface (three percent). The physical properties of these three components are very different. As a result, the distribution of ocean and land across the globe has a significant impact on climatic and weather management systems. The land covers 29.2% of the earth's surface, while water covers 70.8 percent. The statistics are 60 percent (water) and 39% (land) in the northern hemisphere, and 80 percent (water) and 19% (land) in the southern hemisphere. Furthermore, the land area fluctuates from one latitude belt to the next, as well as from one hemisphere to the next (CGWB, 1991; Sterling et al., 2013). The percentage land distribution fractions for varying 5° latitudinal belts is shown in Table 1.4.

The most important aspects of this apportionment are (Tateishi & Ahn, 1996; Nakaegawa, 2012):

(i) The percentage of land in the southern pole is 20-25 percent up to 30°S, then drops to zero by 50°S, including almost no property in 50°-65°S, and then rises sharply to 100% by 80-90°S.

(ii) In the northern pole, the percentage rises from about 20% closer to the equator to around 70% in the belt between 65° and 70°N latitude, before falling sharply to zero near the north pole.

The latitudinal belts from the equator to 30° latitude (tropical), 30° to 60° latitude (mid-latitude), and 60° to 90° latitude (high latitude zones) are in the two hemispheres, respectively, for meteorological reasons (Ackermann et al., 1955; Cao et al., 2014).

Table 1.5. Land area distribution by latitude [S=south and N=north]

Latitude belt	**% of land**		**Latitude belt**	**% of land**	
	N	**S**		**N**	**S**
0-05°	21	22	45-50°	56	03
05-10°	24	25	50-55°	59	02
10-15°	23	24	55-60°	55	00
15-20°	29	20	60-65°	69	00
20-25°	35	23	65-70°	71	20
25-30°	40	24	70-75°	35	61
30-35°	42	16	75-80°	23	69
35-40°	43	07	80-85°	23	69
40-45°	49	04	85-90°	00	100
			Total land	39	19

1.6. Budget of Global Water

Table 1.6 illustrates an approximation of the global water balance. According to the data, the total volume of water on the planet is approximated to be 1.36×10^9 km^3. Approximately 94 percent of this is in the form of oceanic seawater (Vörösmarty et al., 2000; Milly & Shmakin, 2002; Pfister et al., 2011). The majority of the remaining water (about 2%) is locked up in glaciers and polar ice caps, with a small amount remaining as subsurface water (less than 0.01 percent). Groundwater makes up approximately 4% of the total. Freshwater exists in rivers and lakes in such small amounts (0.01%) that it can be used for domestic, industrial, and agricultural purposes. Approximately 0.001% of the world's water is in the form of clouds in the atmosphere. Atmospheric procedures play a critical role in replenishing the world's fresh water supply by evaporating from the oceans, condensing the vapor into clouds, and transporting moisture via air currents to distant locations, which then precipitates as snow or rain (Byers, 1959; Still et al., 2003; Beer et al., 2010).

Table 1.6. Balance of Global Water (L'vovich, 1970)

Location	***Volume of Water*** $\times 10^6$ km^3	***Global Water Percentage***	***Fresh Water Percentage***
Oceans	1278	94	
Polar Ice and Glaciers	27	2	33.33
Groundwater	54	4	66.66
Soil Water	0.08	0.0066	
Lakes and Rivers	0.13	0.011	0.166
Atmosphere	0.013	0.0011	
Total global water	1360.0	100.0	
FRESHWATER	81.73	6	100.0
FRESHWATER	81.73	6	100.0

1.7. India Water Resources

It's fascinating to learn about the water balance in a specific region of the world, like India. India is the world's seventh-largest state and the second largest in Asia, with a total land area of 3.29 million square kilometers. The country is situated within the Asia monsoon belt, which is known for its heavy rainfall. The country receives about 117 centimeters of rain on average each year (Dhar & Rakhecha, 1979; Nernec, 1983). This is nearly 1.5 times greater than the global average of 80 centimeters per year. The total volume of water in India, calculated by multiplying rainfall by the country's land area, is around 4000 km^3. Around 1400 km^3 of water is lost to evaporation, while 720 km^3 is absorbed by the soil. The average surface overflow in the country's river systems is projected to be 1880 km^3 after accounting for infiltration and evaporation (Rao, 1975; Sahoo et al., 2011). The Central Ground Water Board, New Delhi (1991), calculated a 432 km^3 recharged India's water-table aquifer from rainfall. The state's surface water potency is approximately 1880 km^3, which is distributed across the country's various river basins. These river basins provide water to over 1000 million Indians. The water accessibility per person is 1880 cubic meters per year, and it's about 1/12th of the global average of 21,800 cubic meters per year for each person. India's population is expected to be between 1.5 and 1.8 billion people in 2050, according to estimates. Water accessibility per capita will be about 1200 m^3/yr, putting India on the verge of becoming a water-stressed nation (Chen et al., 1998; Trenberthet al., 2007). Tables 1.7 and 1.8 illustrate the water resources of India overall, as well as the water resources of different Indian river systems. A map of India with river basins can be seen in figure 1.5. There are fourteen major river basins in India. The important Himalayan rivers in northern India are the Brahmaputra, the Ganga, and the Indus. Because these river systems are both snow- and rain-fed, they have a year-round flow. The Ganga River and its side streams stretched out as a fan across India's plains, developing the country's largest river basin, covering roughly a quarter of the country's total land area. The Cauvery, Mahanadi, Sabarmati, Subarnarekha, Krishna, Tapi, Godavari, Pennar, Mahi, and Narmada are the major rivers in southern and central India. These rivers are exclusively dependent on rainfall (Liu et al., 2010; Wong et al., 2011).

The irregular share of these estuary basins' water resources is one of their most striking features. The Indus, Brahmaputra, and Ganga river basins account for 65 percent of total drainage in the state, while the Narmada, Krishna, Tapi, Godavari, and Mahanadi river basins account for only 17 percent (Table 1.8).

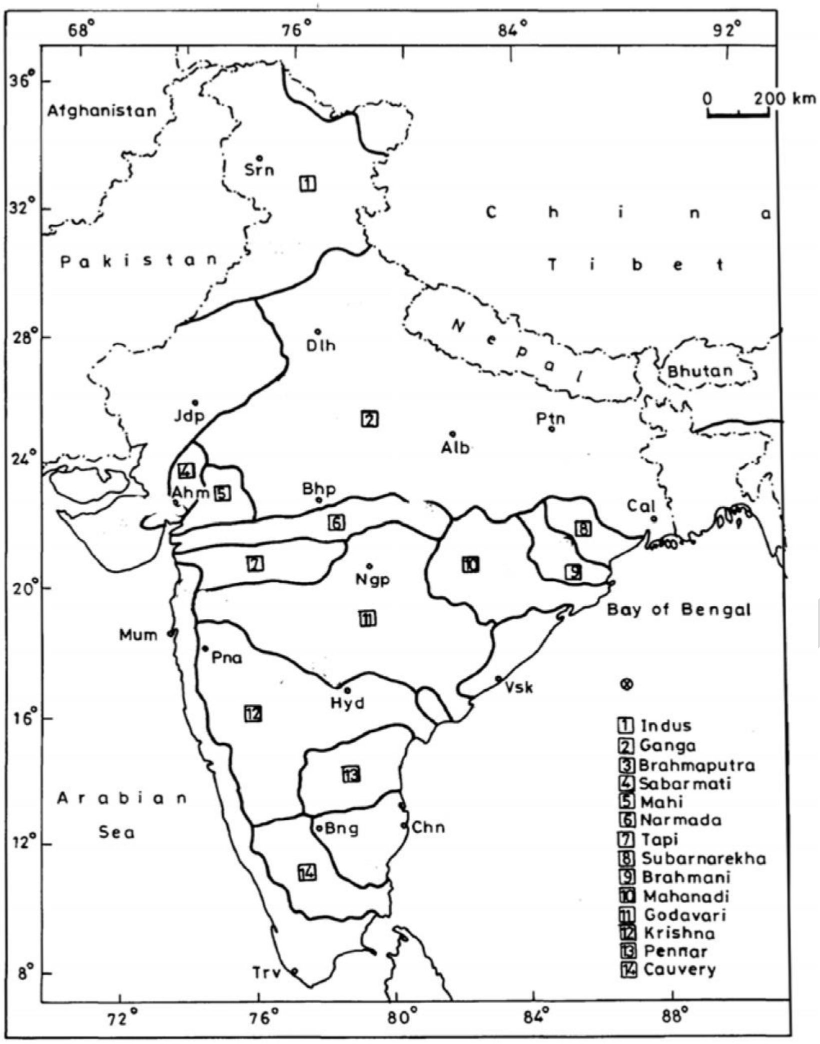


Figure 1.5. India's major river basins.

Source: https://www.sciencedirect.com/book/9780080117140/introduction-to-hydrometeorology

Table 1.7. India water resources

Item	***The volume of Water, km^3***
1. Annual Rainfall over India	4000.0
2. Evaporation loss	1400.0
3. Runoff from rainfall	1880.0
4. Seepage into the subsoil (1 – 2 – 3)	720.0
5. Soil Moisture	288.0
6. Groundwater recharge (4 – 5)	432.0

Table 1.8. The average yearly surface runoff of India's major river basins

S. No.	*River basin*	*Runoff in km^3*	*% of Total*
1.	Indus	80.0	4.20
2.	Ganga	550.0	29.30
3.	Brahmaputra	591.0	31.40
4.	Sabarmati	4.0	0.20
5.	Mahi	11.0	0.60
6.	Narmada	40.0	2.10
7.	Tapi	20.0	1.10
8.	Subarnarekha	12.0	0.60
9.	Brahmani	29.0	1.50
10.	Mahanadi	67.0	3.60
11.	Godavari	116.0	6.20
12.	Krishna	58.0	3.10
13.	Pennar	7.0	0.40
14.	Cauvery	19.0	1.00
15.	West flowing rivers of Kutch-Saurashtra including Luni	13.0	0.70
16.	West flowing rivers south of Tapi	218.0	11.60
17.	East flowing rivers between Pennar and Cauvery	23.0	1.20
18.	East flowing rivers between Mahanadi and Godavari	22.0	1.20
	Total surface runoff	1880.0	

Despite the fact the average annual water flow in multiple rivers is 1880 km^3, climate, soil conditions, and topography confine the amount of water that can be used to only around 720 km^3. In India, there are approximately 3,000 dams with a total storage capacity of 132 km^3 (Stohl & James, 2004; Takle et al., 2007).