SSC-JE 2025

Staff Selection Commission

Junior Engineer Examination

Civil Engineering

Hydrology

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY PUBLICATIONS

Hydrology

Contents

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CHAPTER 1

Introduction

1.1 Hydrology

Hydrology means the science of water. Hydrology deals with the occurrence, circulation and distribution of water on the earth and atmosphere. *Hydrology may be defined as the science that deals with the charging and discharging of our water resource.* Practical application of hydrology is required in the design and operation of hydraulic structure, water supply, irrigation, hydro power generation, flood control, etc.

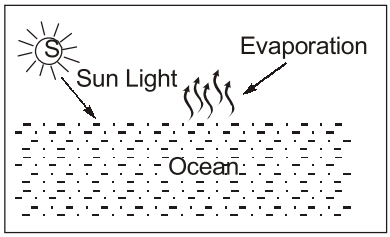
1.2 The Hydrologic Cycle

- Water occur on the earth and atmosphere in all three states (liquid, gas, solid). There is endless circulation of water between the earth and atmosphere. This circulation is called hydrologic cycle.
- Hydrologic cycle has no beginning or end and its many process occurs simultaneously.
- Water on earth exists in a space called hydrosphere and it has boundary 15 km up into atmosphere and 1 km down into lithosphere. Hydrologic cycle also moves within this boundary.
- Sun imparts energy for movement of this cycle.
- Sun and Coriolis force (due to this force, wind moves in different direction) play important role in completion of hydrologic cycle. Sun evaporates water and Coriolis force, by controlling wind circulate the water vapour, where precipitation occurs.

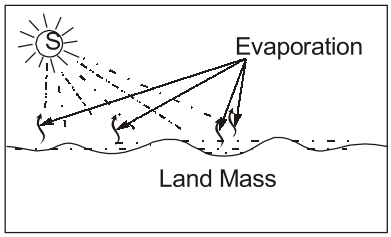
1.3 Components of Hydrologic Cycle

(i) **Evaporation:** When the water come into contact with heat radiation, it turns into vapour. It is called evaporation.

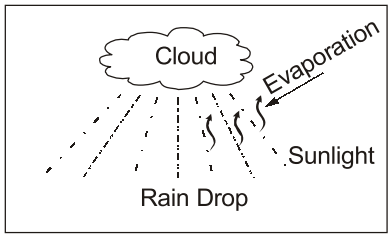
- In hydrologic cycle, evaporation mainly occur from ocean. Ocean evaporation contributes in large part and the real evaporation occur from land mass and raindrop evaporation.
- When rain drop comes to the earth surface, and come in contact with sunlight than they also get evaporated in air.



Evaporation from Ocean



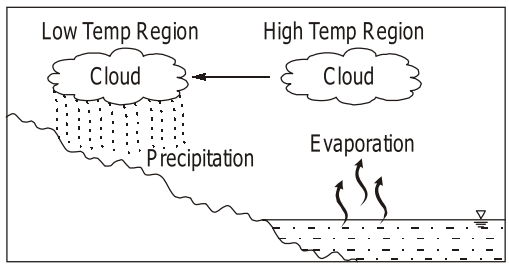
Evaporation from land mass



Rain drop evaporation

(ii) **Precipitation:** As the evaporation continues, the amount of vapour in atmosphere goes on increasing, after reaching a certain amount, the vapour condense and come to earth's surface in solid or liquid form, this is called precipitation.

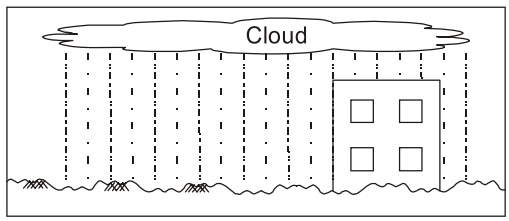
- As the air temperature decrease, its moisture holding capacity decreases.



Precipitation

(iii) **Interception:** Some amount of precipitation is evaporated back to the atmosphere and another part of precipitation is intercepted by vegetation, structure etc. from where it may be either evaporated back to atmosphere or move down to ground surface.

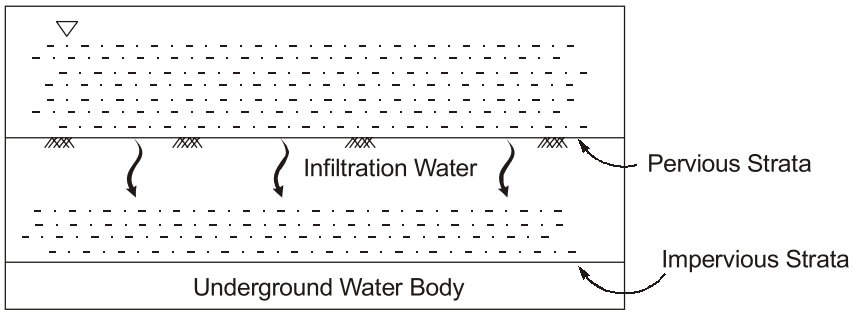
- Amount of rainfall on the roof building is intercepted rainfall or simply interception.



Interception

(iv) **Infiltration:** When the water come in to the earth surface. Some portion of it penetrate the ground and increase the moisture capacity of soil beneath the surface.

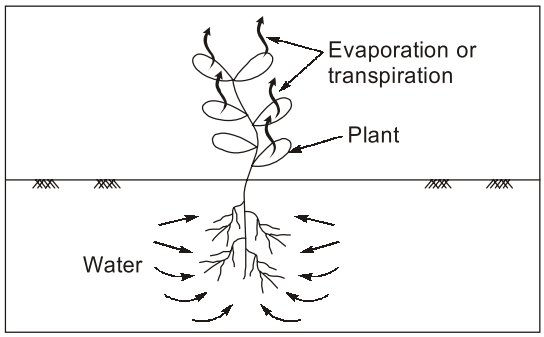
- This water is called infiltrated water and this process is called infiltration.
- Through infiltration the water level of underground water bodies increases.
- Infiltration is important for underground water movement, by increasing in its volume.
- Infiltration will be more in a village in comparison to town, because the town have pacca road which is treated as impervious strata.
- Infiltration will be more in forest area in comparison to dessert land because the tree make the surface pervious and increase the infiltration.



Infiltration Beneath a Water Body

(v) **Transpiration:** Vegetation use the ground water or soil moisture for their growth. This moisture again convert in evaporation through vegetation. This is called transpiration.

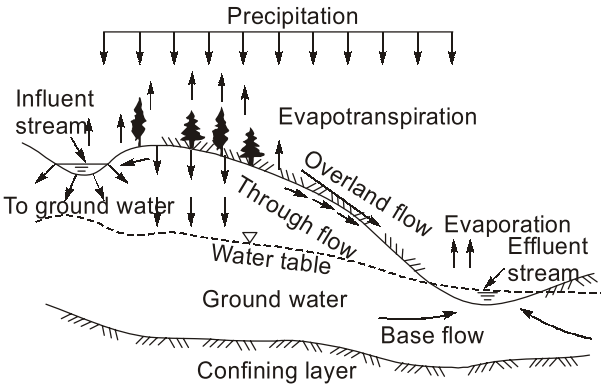
- Water extracted by plant's roots, transported upward through its stem and diffused into the atmosphere through tiny openings in the leaves is called transpiration water and process is called transpiration.



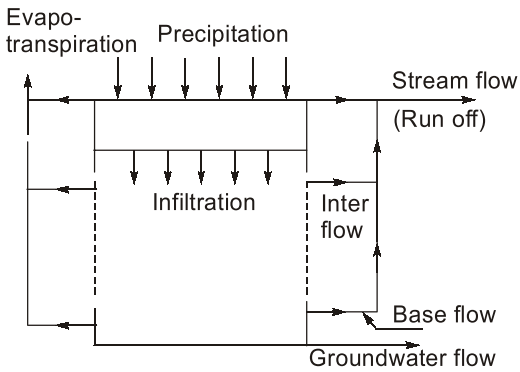
Transpiration

(vi) **Runoff:** The portion of precipitation which come on the surface and reach the stream channel by above and below the surface of earth is called runoff.

- The portion of precipitation that reach the stream after reaching on surface, only from above the surface is called surface runoff.
- The runoff reach in stream channel is called *stream flow*.
- Runoff means the draining or flowing off of precipitation from a catchment area through a surface channel.



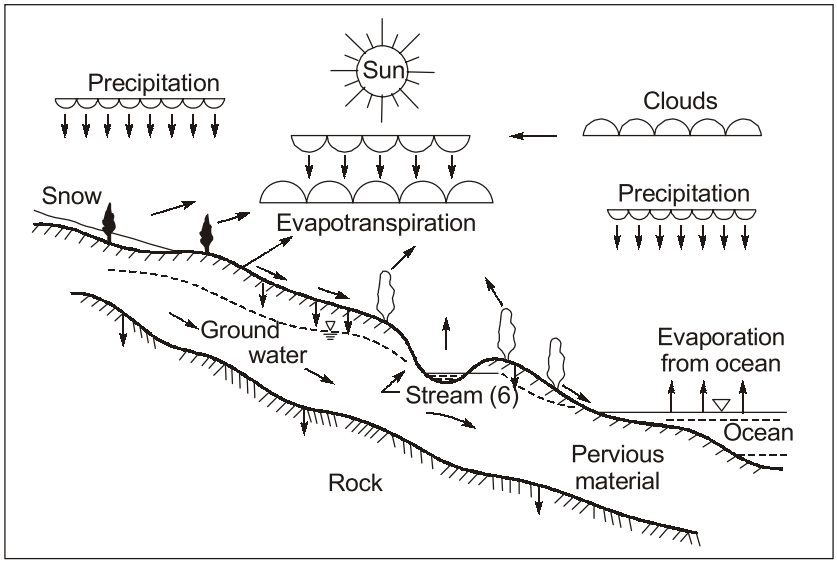
Different routes of runoff



Transportation Components of the Hydrologic Cycle

World Water Balance

- 96.5 percent of water on the earth's surface is in the ocean. Remaining 1.7 percent is in the polar ice, 1.7 percent in ground water and 0.1 percent in the surface and atmospheric water system.
- If we assume that the 100 parts of water come to the land area through precipitation then 61 parts of this precipitation goes to atmosphere through evaporation and 39 parts form runoff to the ocean.
- Average annual depth of precipitation over the world is 0.752 m, but 0.428 m depth of water gets evaporated. Only 0.342 m water is available for runoff.
- Average annual precipitation in India is 120 cm in a highly uneven portion.
- The per capita water availability for the Indian people is less in comparison to world's. As we have 4% of world's average annual water supply and 16% of world's population.



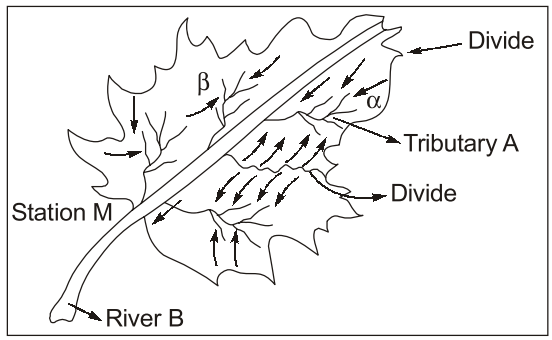
The global hydrologic cycle represented as a system

- Due to unevenness in precipitation at different place of world, a large quantity of available river runoff is wasted as they join the ocean. We use water around 20% of available water.

- The Amazon river carries about 17% of total flow of world.
- Per capita average annual runoff of India is about 1700 m^3.
- The percentage of total quantity of **fresh water** in the world is only 0.3% available in liquid form.
- Most of the water that evaporate from the ocean gets back to the ocean in the form of precipitation. About 9% more water evaporates from the ocean than what falls back on them as precipitation.

1.4 Catchment Area

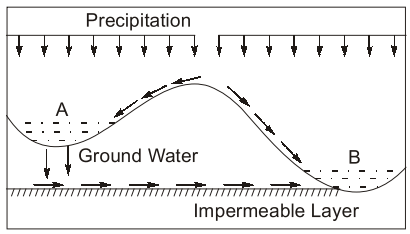
- The area of land from which the runoff comes into a stream is called the catchment area of that stream.
- It is also called as *drainage basin* or *drainage area* or *water shed*.
- The area of land draining into a stream or water course at a given location is known as catchment area.
- A catchment area is separated from its neighbouring areas by a ridge called *divide* or *watershed*.
- The catchment area of tributary river *A* is α and $(\alpha + \beta)$ is the catchment area of river B.
- If the catchment has no outlet point than it is called a *closed catchment*. In closed catchment water converges to a single point inside the basin known as *sink*, which may be a permanent lake, or a point where surface water is lost underground.



Schematic Sketch of Catchment of River B at station M

Leakage of Catchment:

- We measure the runoff at the outlet of catchment area, sometimes, it happens that runoff from nearby catchment also come so due to this the error will come in result. This generally occur due to subsurface water. Thus, the catchment leakage is said to occur.
- Catchment leakage also occur when the topographic divide are not coincident with the ground water divide.



Leakage of Catchment

1.5 Water Budget Equation

The quantity of water going through various individual paths of the hydrological cycle in a given system can be described by the continuity principle known as *Water Budget Equation* or *Hydrologic Equations*. The *Conservation of Mass* is the most useful physical principle in hydrologic analysis and is required in almost all applied problem.

For a given catchment area in an interval of time Δt, the continuity equation for water is

Mass of water inflow – Mass of water outflow = Change in mass of water storage

If the density of water in inflow, outflow and storage water are same, then

Vol. of inflow water – Vol. of outflow water = Change in storage vol. of water

$$V_i - V_o = \Delta S$$

For solving the problem of water budget equation we should be clear in mind, what factor recharges the water discharged in the water body.

(i) **Water Budget Equation for a Catchment**

For a particular time Δt,

$P - R - G - E - T = \Delta S$

(ii) **Water Budget Equation for Water Bodies**

$I + P - G - E - O = \Delta S$

(iii) **Water Budget Equation for Surface Flow**

$P + I + I_G - O - E - T - I_n = \Delta S$

(iv) **Water Budget Equation for Underground Flow**

$I_G + I_n - O_G - O_S - T = \Delta S$

Where,

P = Precipitation; R = Surface runoff; G = Net ground water flow out of the catchment

E = Evaporation; T = Transpiration; ΔS = Change in storage = $S_s + S_{sm} + S_g$

S_s = Surface water storage; S_{sm} = Water in storage as soil moisture

S_g = water in storage as groundwater; I = Inflow; O = Outflow

I_G = Ground water come to the surface; I_n = Infiltration

O_G = Ground water outflow; O_S = Ground water come to the surface

Water budget equation in terms of rainfall runoff relationship can be represented as

$R = P - L$

R = Runoff, P = Precipitation and L = Losses (infiltration, evaporation, transpiration and surface storage)

- For large catchment area, ground water inflow and outflow are almost equal.
- In general, after a long period the storage in catchment be same as prior.

Example 1.1 A small catchment of area 150 Ha received a rainfall of 10.5 cm in 90 minutes due to a storm. At the outlet of the catchment, the stream draining the catchment was dry before the storm and experienced a runoff lasting for 10 hours with an average discharge of 1.5 m^3/s. The stream was again dry after the runoff event. (a) What is the amount of water which was not available to runoff due to combined effect of infiltration, evaporation and transpiration? What is the ratio of runoff to precipitation?

Solution: The water budget equation for the catchment in a time Δt is

$$R = P - L$$

Where, L = losses = water not available to runoff due to infiltration (causing addition to soil moisture and groundwater storage), evaporation, transpiration and surface storage.

In the present case Δt = duration of the runoff = 10 hours.

Note that the rainfall occurred in the first 90 minutes and the rest 8.5 hours the precipitation was zero.

(a) P = Inflow due to precipitation in 10 hours

$= 150 \times 10^4 \times (10.5/100) = 157{,}500\ m^3$

R = Runoff volume = outflow volume at the catchment outlet in 10 hours

$= 1.5 \times 10 \times 60 \times 60 = 54{,}000\ m^3$

Hence losses $L = 157{,}500 - 54{,}000 = 103{,}500\ m^3$

(b) Runoff/rainfall = 54,000/157500 = 0.343

Example 1.2 The plan area of a reservoir is 1 km^2. The water level in the reservoir is observed to decline by 20 cm in a certain period. During this period the reservoir receives a surface inflow of 10 hectare-meters, and 20 hectare-meters are abstracted from the reservoir for irrigation and power. The pan evaporation and rainfall recorded during the same period at a nearby meteorological station are 12 cm and 3 cm respectively. The calibrated pan factor is 0.7. The seepage loss from the reservoir during this period in hectare-meters is

(a) 0.0 (b) 1.0
(c) 2.4 (d) 4.6

Answer: (d)

Inflow to reservoir, $I = 10$ ha-m

Outflow from reservoir, $Q = 20$ ha-m

Evaporation loss, $E = 1 \times 10^6 \times \frac{12}{100} \times 0.7 = 8.4$ ha-m

Rainfall, $P = 1 \times 10^6 \times \frac{3}{100} = 3$ ha-m

Change in storage, $\Delta S = 1 \times 10^6 \times \frac{20}{100} = -20$ ha-m

We know that

$$(I + P) - (E + Q + \text{seepage}) = \Delta S$$
$$\Rightarrow (10 + 3) - (8.4 + 20 + \text{seepage}) = -20$$
$$\Rightarrow 13 - 28.4 - \text{seepage} = -20$$
$$\Rightarrow \text{seepage} = 4.6 \text{ ha-m}$$

1.6 Residence Time

- The residence time is the average duration for a water molecule to pass through a subsystem of hydrological cycle.
- Average time taken by the water molecule to pass through a particular part of hydrological cycle is known as residence time of that part of hydrological cycle.

  Residence time is calculated by

$$T_r = \frac{S}{Q}$$

  S = Storage of water in that particular subsystem or part
  Q = Flow of water through that particular subsystem or part

Example 1.3 The volume of atmosphere moisture is 12900 km^3 and the flow rate of precipitation is 577000 km^3/yr. Find the residence time of moisture.

Solution: Storage of water in form of moisture

$S = 12900$ km^3

Flow of water as precipitation, $Q = 577000$ km^3/yr

So the residence time is $T_r = \frac{S}{Q} = \frac{12900 \text{ km}^3}{577000 \text{ km}^3/\text{yr}} = 0.022$ year $= 8.2$ days

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STUDENT'S ASSIGNMENTS

Q.1 What is hydrological cycle?
(a) processes involved in transfer of moisture from sea to land
(b) processes involved in transfer of moisture from sea back to sea again
(c) process involved in transfer of water from snowmelt in mountains to sea
(d) process involved in transfer of water from sea to land and back to sea again.
[ESE-2009]

Q.2 The percentage of earth is covered by oceans is about
(a) 31% (b) 51%
(c) 71% (d) 97%

Q.3 The percentage of total quantity of water in the World that is saline about
(a) 71% (b) 33%
(c) 67% (d) 97%

Q.4 The percentage of total quantity of fresh water in World available in liquid form is about
(a) 30% (b) 70%
(c) 11% (d) 51%

Q.5 In a hydrological cycle, the average residence time of water in the global
(a) atmospheric moisture is larger than that in global rivers
(b) ocean is smaller than that of global ground water
(c) rivers is larger than that of global ground water
(d) ocean is larger than that of the global ground water.

Q.6 By which simple equation the hydrologic cycle can be expressed?
(a) Precipitation = Evaporation – Run-off
(b) Evaporation = Precipitation + Run-off
(c) Run-off = Precipitation + Evaporation
(d) Precipitation = Evaporation + Run-off
[KPSC-2015]

Q.7 The quantitative statement of balance between water gains and losses in a certain basin during a specified period of time is known as which of the following.
(a) Water budget
(b) Hydraulic budget
(c) Ground water budge
(d) None

Q.8 Which of the following are pertinent to the realization of hydrological cycle?
1. Latitudinal difference in solar heating of earth surface.
2. Inclination of earth's axis.
3. Uneven distribution of land and water.
4. Coriolis effect.
(a) 1 only (b) 2 only
(c) 3 only (d) all of the above

Q.9 Catchment of area 120 km^2 has three distinct zones as below:

Zone	Area (km^2)	Annual run - off (cm)
A	61	52
B	39	42
C	20	32

The annual run-off from catchment is
(a) 126 cm (b) 42 cm
(c) 45.4 cm (d) 47.3 cm

ANSWER KEY // STUDENT'S ASSIGNMENTS

1. (d)	**2.** (c)	**3.** (b)	**4.** (a)	**5.** (d)
6. (d)	**7.** (a)	**8.** (d)	**9.** (c)	

HINTS & SOLUTIONS // STUDENT'S ASSIGNMENTS

9. (c)

$$\text{Annual run-off} = \frac{R_1 A_1 + R_2 A_2 + R_3 A_3}{A_1 + A_2 + A_3}$$

$$= \frac{61\times 52 + 39\times 42 + 20\times 32}{61+39+32}$$

$$= \frac{5450}{120} = 45.4 \text{ cm}$$

■■■■

CHAPTER 2

Precipitation and General Aspects of Hydrology

2.1 Precipitation

- The term precipitation denotes all forms of water that reach the earth from the atmosphere.
- Rainfall is used synonymously with precipitation.
- The magnitude of precipitation varies with time and space.
- For precipitation to form
  (i) the atmosphere must have moisture.
  (ii) there must be sufficient nuclei present to aid condensation.
  (iii) weather conditions must be good for condensation of water vapour to take place.
  (iv) the products of condensation must reach the earth.

2.2 Forms of Precipitation

Rain, Snow, Drizzle, Glaze, Sleet and Hail.

Rain

- It is the principal form of precipitation in India. The term rainfall is used to describe precipitations in the form of water drops of sizes larger than 0.5 mm. The maximum size of a raindrop is about 6 mm.
- This term is used when water drops are of sizes between 0.5 mm to 6 mm.

	Types	Intensity
1.	Light rain	trace to 2.5 mm/h
2.	Moderate rain	2.5 mm/h to 7.5 mm/h
3.	Heavy rain	>7.5 mm/h

- Rainfall is measured at 8.30 A.M. and recording the rainfall of the past 24 hours is common throughout the country.
- When the rainfall on a given day exceeds 2.5 mm, then that day is called a rainy day.

Snow

- Snow consists of ice crystals. Snow has an average density of 0.1 gm/cm^3.
- When fresh, snow has an initial density varying from 0.06 to 0.15 g/cm^3 and it is usual to assume an average density of 0.1 g/cm^3. In India, snow occurs only in the Himalayan regions.

Drizzle

A fine sprinkle of droplets of sizes less than 0.5 mm and intensity less than 1 mm/h is known as drizzle.

Glaze

When rain or drizzle comes in contact with cold ground at around 0°C. The water drops freeze to form an ice, coating called glaze or freezing rain.

Sleet

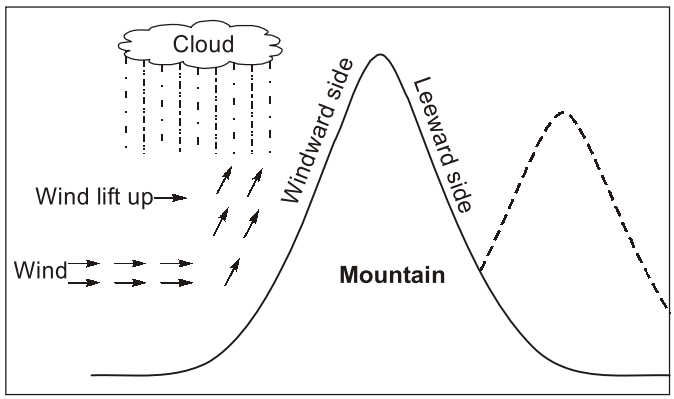
Sleet is frozen raindrops of transparent grains, which form when rain falls through air at subfreezing temperature.

Hail

These are lumps of ice of size more than 8 mm. These are formed due to vertical movement of air current at sub freezing temperature.

2.3 Types of Precipitation

(i) **Orographic Precipitation:** This type of precipitation occur when moist air mass may get lifted up to higher altitude due to presence of mountain barriers because they can not move forward. Due to rise, air undergo cooling, condensation and precipitation.



Orographic Precipitaiton

Remember

- In India, most of the precipitation occur due to ***orographic precipitation***.
- The greatest amount of precipitation falls on the windward side, and the leeward side has often very little precipitation.

(ii) **Convective Precipitation:** It is caused due to pocket of air is warmer than the surrounding air. The warmer air is lesser dense in comparison to colder one. Due to localised heating, air becomes warm and rises up and air from colder area flow towards to fill the void. The warmer air continue to rise, undergo cooling and result in precipitation.

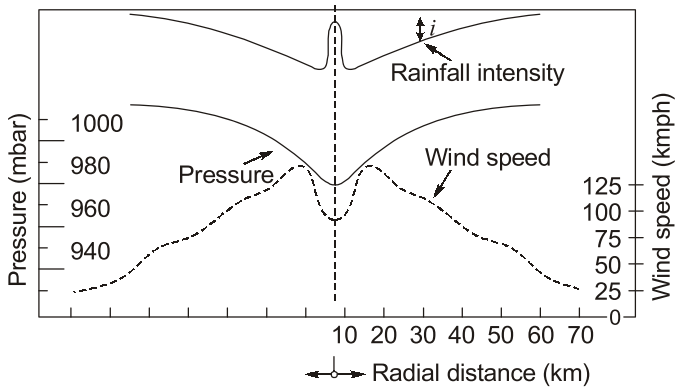
- Usually the areal extent of such type of rain is small, limited to a diameter of about 10 km.
- Convective precipitation occurs in the form of ***showers of high intensity*** and ***short duration***.

(iii) **Cyclonic Precipitation:** A cyclone is a large low pressure region with circular wind motion. In low pressure area, air will flow horizontally from the surrounding area, causing the air in the low pressure area to lift causing precipitation.

2.4 Types of Cyclone

(i) **Tropical Cyclone:** A tropical cycle in India is called cyclone. In it isobars are closely spaced and winds are anticlockwise in northern hemisphere.

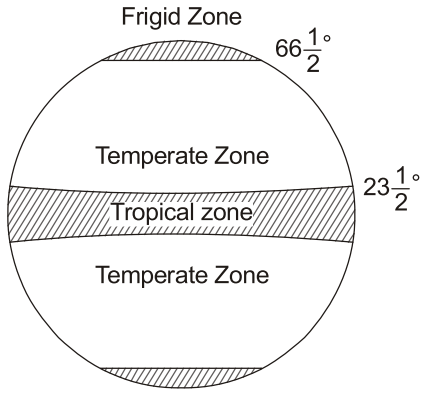
- The wind speed gradually decreases towards the outer edge of tropical cyclone.
- Pressure increases towards outer edge of cyclone.
- These are called tropical cyclone as these occur in tropical region of world.
- The centre of storm is called eye, which may have the size of about 10-50 km in diameter.
- The area of eye is quiet in comparison to other part of cyclone.
- Just right outside of the eye's area, there is very strong winds.



Schematic Section of a Tropical Cyclone

(ii) **Extra Tropical Cyclone:** These cyclone are formed in location outside the ***Tropical Zone*** of world. This type of cyclone posses a strong *counter-clockwise wind circulation in the northern hemisphere.*

- The magnitude of precipitation and wind velocities are relatively lower than those of tropical cyclone.
- The duration of precipitation is usually longer and areal extent is also larger.

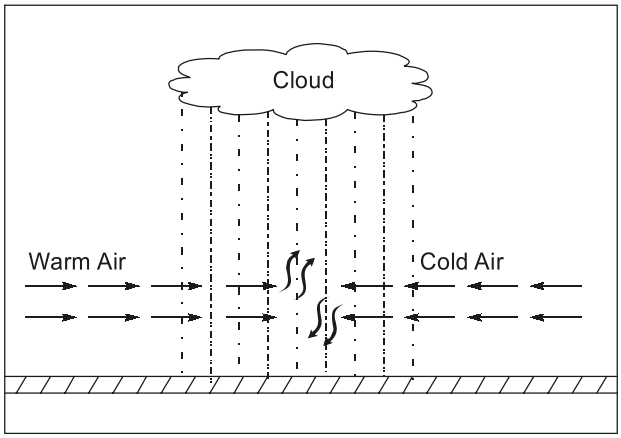


Temperature zones

(iii) **Anti Cyclone:** In such type of cyclone wind circulation is clockwise in the northern hemisphere.

- The weather is usually calm at the centre
- Winds flow with the moderate speed.

(iv) **Frontal Cyclone:** This is also a type of cyclone but the formation of it is different, when a warm air mass and cold air mass meet under favourable conditions, as the warm air are less dense so they rise up and colder air mass due to high density settle down. The ascending warmer air cools adiabatically and form the cloud and precipitates.



Frontal Cyclone

NOTE: A *Front* is the interface between two distinct air mass.

Computation of Average Annual Rainfall Over a Basin

- The amount of rain collected by given rain gauge in 24 hours is known as daily rainfall, and the amount collected in one year is known as annual rainfall.
- The annual rainfall at a given station should be averaged over a period of 35 years or so, it is therefore known as average annual rainfall or normal annual rainfall.

2.5 Measurement of Precipitation

All forms of precipitation are measured as the vertical depth of water that would accumulate on a level surface, if the entire precipitation remained where it fall.

- If 1 cm rainfall occur over a area of 1 km^2, then it represents that the total volume of water over that area is 10^4 m^3.

$$\text{Volume of water} = \text{Rainfall depth} \times \text{Area}$$

- In case of snowfall, an equivalent depth of water is used as the depth of precipitation.
- As it is not possible to collect all the precipitation which comes down on an area. We use an instrument for measurement of rainfall called as ***raingauge***. They should be placed in place, so that it clearly represent the precipitation of that area.
- These raingauge also called as *pluviometer*, *ombrometer*, ***hyetometer*** and *udometer*.
- For placing a raingauge in an area, following guidelines should be followed:
  - (i) The ground must be in the open, levelled and the instrument must present a horizontal catch surface.
  - (ii) It must be set as near the ground as possible to reduce wind effect but it must be sufficiently high to prevent from flooding.
  - (iii) It must be surrounded by an open fenced area of atleast 5.5 m × 5.5 m.
  - (iv) There should not be any object nearer to the instrument in a radius of 30 m.
  - (v) If there is any obstruction within 30 m radius than the raingauge should be kept at same distance from the obstruction and that distance should be more than *twice the height of obstruction*.