

## UNIT-I

### Introduction and precipitation.

Introduction to Hydrology and Its Application:

Hydrology:

\* Science of water means Hydrology. Hydrology deals with the occurrence, circulation and distribution of water on the earth and atmosphere.

\* Hydrology is defined as the science that deals with the charging and discharging of our water resource.

Applications of Hydrology

\* Applications of Hydrology is required in design and operation of [Hydrology] Hydraulic structures.

\* In water supply

\* Irrigation systems

\* In hydropower generation

\* In flood control.

Hydrologic cycle

\* Water occurs on the surface of the earth in three states liquid, gaseous, solid state. There is circulation of water between the earth and atmosphere and this cycle is called Hydrologic cycle.

\* Hydrologic cycle has no ending or not fixed beginning. Water is present in the zone namely called as Hydrosphere and it has boundary 15km upto atmosphere and cycle moves with boundary.

\* Sun imparts the energy for movement of hydrologic cycle.

Hydrologic cycle involves the following processes:

1. Evaporation

2. Transpiration

3. Precipitation

4. Runoff

1. Evaporation:

\* When the water come into contact with heat radiation, it turns into vapour and that process is called as Evaporation.

\* Water evaporates from the water bodies like oceans, rivers, lakes and moist soil and it mainly occurs from ocean.

\* Ocean evaporation contributes large part and the evaporation really occurs from land mass and raindrop evaporation.

2. Transpiration:

\* When water is lost from leaves of plant and pores of trees or plants. This process is called as Transpiration.

\* Water is extracted by plants roots and transported upward through its stem and diffused into the atmosphere through leaves.

### 3. Precipitation:

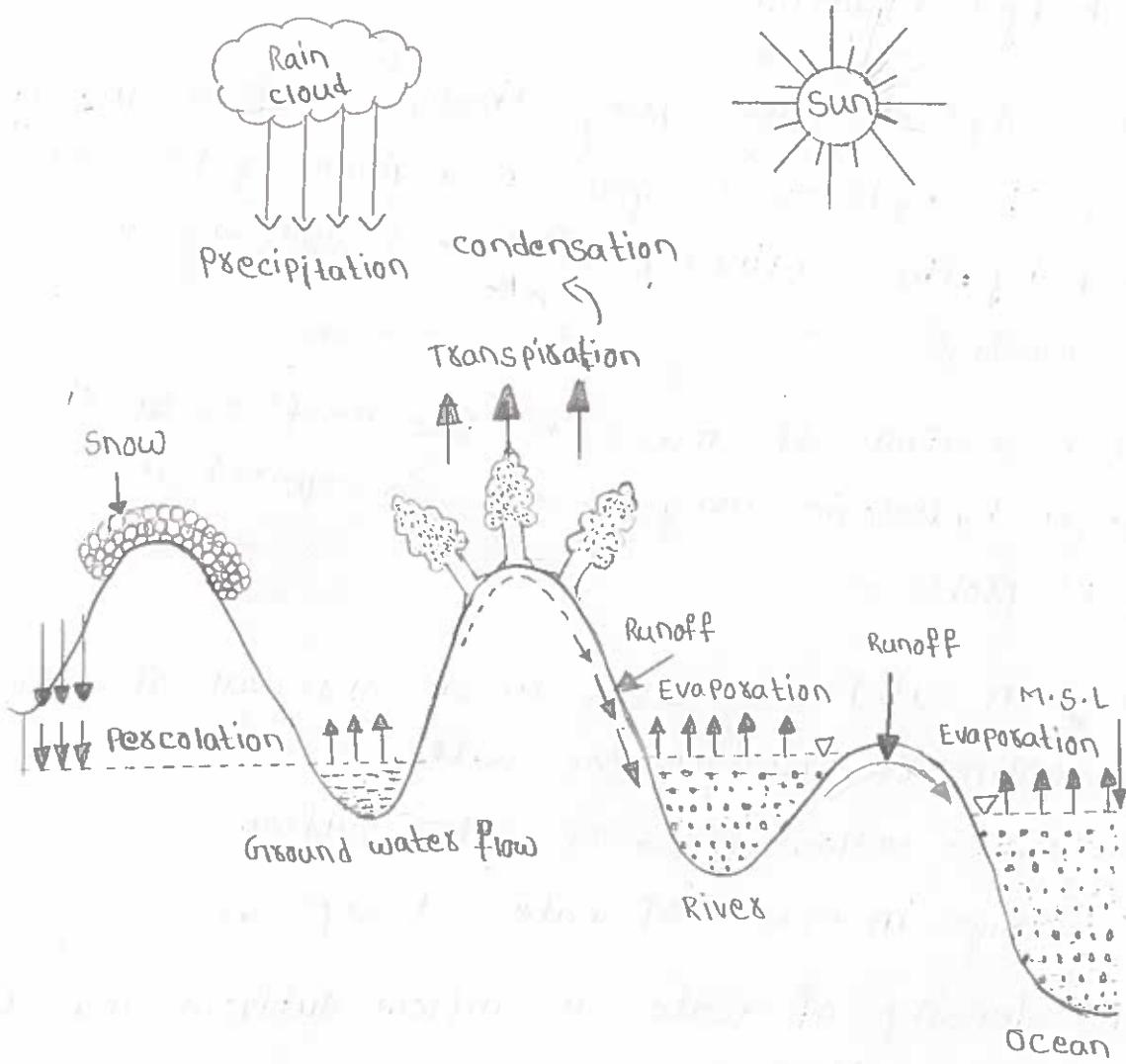
\* The fall of water in any form it may be liquid, gas, solid on the surface of the earth from atmosphere is known as precipitation.

\* There are many forms of precipitations such as Rainfall, snowfall, drizzle, Hail, Glaze etc.

### 4. Runoff:

\* The portion or part of precipitation which come on the surface of earth and reach the stream channel above and below the surface of earth is called runoff.

\* Runoff may be surface runoff, sub surface runoff or ground water runoff.



## Global Water Budget:

global or water budget and equation:

- \* A water budget is very much like a financial budget, but instead of tracing how money flows in and out it traces water.
- \* A water budget accounts for all water into and out of a watershed.
- \* This include precipitation, evaporation, transpiration, runoff as well as the movement of water within the watershed such as infiltration, recharge to groundwater and reservoir storage.

## 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.
- \* 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 At, the continuity equation for water is  
$$\text{Mass of water inflow} - \text{Mass of water outflow} = \text{change in mass of water storage.}$$
- \* If the density of water in inflow, outflow and storage water are same, then

3

\* Volume of inflow water - Volume of outflow water  
= change in storage volume of water

$$V_i - V_o = \Delta S$$

Water budget equation:

1. For a catchment:

For a particular time  $\Delta t$ ,

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

2. For water bodies:

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

3. For surface flow:

$$P + I + I_u - O - E - T - In = \Delta S$$

4. For underground flow:

$$I_u + In - O_u - O_g - T = \Delta S$$

Where,

P = Precipitation

R = Surface runoff

$G_t$  = Net ground water flow out of the catchment

E = Evaporation

T = Transpiration

$\Delta S$  = change in storage

$$= S_s + S_{sm} + S_g$$

Where

$S_s$  = Surface water storage

$S_{sm}$  = Water in storage as soil moisture

$S_g$  = Water in storage as ground water

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 expressed as,

$$R = P - L$$

Where

$R$  = Runoff

$P$  = Precipitation

$L$  = Losses

\* 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.

Application in Engineering:

Applications of hydrology in engineering:

\* Hydrology finds its greatest application in the design and operation of water resource engineering project such as those for

1. Irrigation
2. Water supply
3. Flood control
4. Water power
5. Navigation

\* In all these projects hydrological investigations for the proper assessment of the following factors are necessary:

1. The capacity of storage structures such as reservoirs.
2. The magnitude of flood flows to enable safe disposal of the excess flow.
3. The interaction of the flood wave and hydraulic structures, such as levees, reservoirs, barrages and bridges.
4. The minimum flow and quantity of flow available at various seasons.

\* Many important projects in the past have failed due to improper assessment of the hydrological factors.

\* Some typical failures of hydraulic structures are:

1. Overtopping and consequent failure of an earthen dam due to an inadequate spillway capacity.
2. Failure of bridges and culverts due to excess flood flow.
3. Inability of a large reservoir to fill up with water due to overestimation of the stream flow.

\* Such failures, often called hydraulic failures underscore the uncertainty aspect inherent in hydrological studies.

\* The probability analysis of hydrologic data is an important component of present day hydrologic studies and enables the engineer to take suitable design decisions consistent with economic and other criteria to be taken in a given project.

## Sources of Data:

Short note on sources of data

- \* Depending upon the problem at hand, a hydrologist would require data relating to the various relevant phases of the hydrological cycle playing on problem catchment.
- \* The data normally required in the studies are:
  1. Weather records - Temperature, humidity and wind velocity.
  2. Precipitation data
  3. Stream flow records
  4. Evaporation and evapotranspiration data.
  5. Infiltration characteristics of the study area.
  6. Soils of the area
  7. Land use and land cover
  8. Groundwater characteristics
  9. Physical and geological characteristics of the area.
  10. Water quality data.

\* In India, hydro-meteorological data are collected by the India meteorological department (IMD) and by some state government agencies.

\* The central water commission (CWC) monitors flow in major rivers of the country.

Types and Forms of precipitation

Precipitation:

- \* Any form of water that reaches the earth from the atmosphere, is called as precipitation.
- \* The usual forms of precipitation are rainfall, snowfall, hail, frost etc.

## Types of precipitation:

1. Rainfall: When the precipitation is in the form of rain drop it is called rainfall.

\* The size of raindrop varies from 0.5mm to 6mm

\* Rainfall can be divided into three types depending upon intensity values:

Intensity	Type of Rain
Light	0 to 2.5 mm/hr
Medium	2.5 to 7.5 mm/hr
Heavy	7.5 mm/hr above

2. Snowfall: Snowfall is a type of precipitation, which constitutes ice crystals when it fall. It combines to form flakes.

\* Initial density of snow is  $0.66 \text{ g/cm}^3$  and it ranges up to  $0.15 \text{ g/cm}^3$ . Average density of snow is  $0.1 \text{ g/cm}^3$

3. Drizzle: In this type of precipitation, the size of water droplets are less than 0.5mm and intensity is less than 1 mm/hr and due to low density the drops floats in air.

4. Glaze: When raindrops or drizzles fall on cold surface of ground whose temperature is  $0^\circ\text{C}$ , forms a layer of ice known as glaze.

5. Hail: precipitation in the form of lumps of ice and its size is more than 8 mm and it occurs in violent thunderstorm.

## Characteristics of precipitation in India:

From the point of view of climate the India subcontinent can be considered to have two major seasons and two transitional period as:

- (a) South-West monsoon (June - September)
- (b) Transition-I-Post-monsoon (October - November)
- (c) Winter season (December - February)
- (d) Transition-II, summer (March - May)

The chief precipitation characteristics of these seasons are given below:

### 1. South-West monsoon (June - September)

\* The south-West monsoon is the principal rainy season of India when over 75% of the annual rainfall is received over a major portion of country.

\* Excepting the south-eastern part of the peninsula and Jammu and Kashmir, for the rest of the country, the south-West monsoon is the principle source of rain with July as the month which has maximum rain.

\* The monsoon originates in the India ocean and heralds its appearance in the southern part of Kerala by the end of May.

\* The monsoon winds advance across the country in two branches:

- 1. The Arabian sea branch and
- 2. The Bay of Bengal branch

- \* The monsoon is not a period of continuous rainfall.
- \* The weather is generally cloudy with frequent spells of rainfall.

#### 2. Post-monsoon (October - November)

- \* As the south-west monsoon retreats, low-pressure areas form in the Bay of Bengal and a north easterly flow of air that pick up moisture in the Bay of Bengal is formed.
- \* This air mass strikes the east coast of the southern peninsula (Tamilnadu) and causes rainfall.
- \* Also in this period, especially in November severe tropical cyclones form in the Bay of Bengal and the Arabian sea.

#### 3. Winter season (December - February)

- \* By about mid-december, disturbances of extra tropical origin travel eastwards across Afghanistan and Pakistan known as western disturbances, they cause moderate to heavy rain and snowfall (about 25 cm) in the Himalayas and Kashmir.
- \* Some light rainfall also occurs in the northern plains.
- \* Low pressure areas in the Bay of Bengal formed in these months cause 10-12 cm of rainfall in the southern parts of Tamil Nadu.

#### 4. Summer (Pre-monsoon) (March - May):

- \* There is very little rainfall in India in this season.

- \* Convective cell cause some thunderstorms mainly in Kerala, West Bengal and Assam.
- \* Some cyclone activity dominantly on the east cost also occurs.

Measurement of precipitation:

Different types of rain gauges

There are mainly two types of rain gauges:

1. Non Recording rain gauge

→ Symon's rain gauge

2. Recording rain gauge

→ Weighing bucket rain-gauge.

→ Tipping bucket rain-gauge.

→ Float bucket rain-gauge.

1. Non-Recording rain gauge:

\* These rain gauge are most widely adopted in India.

\* They are known as non recording rain gauge because it only collects the water without recording.

Symon's rain gauge:

\* It is a non-recording type rain gauge which is mostly used in India till the year 1969.

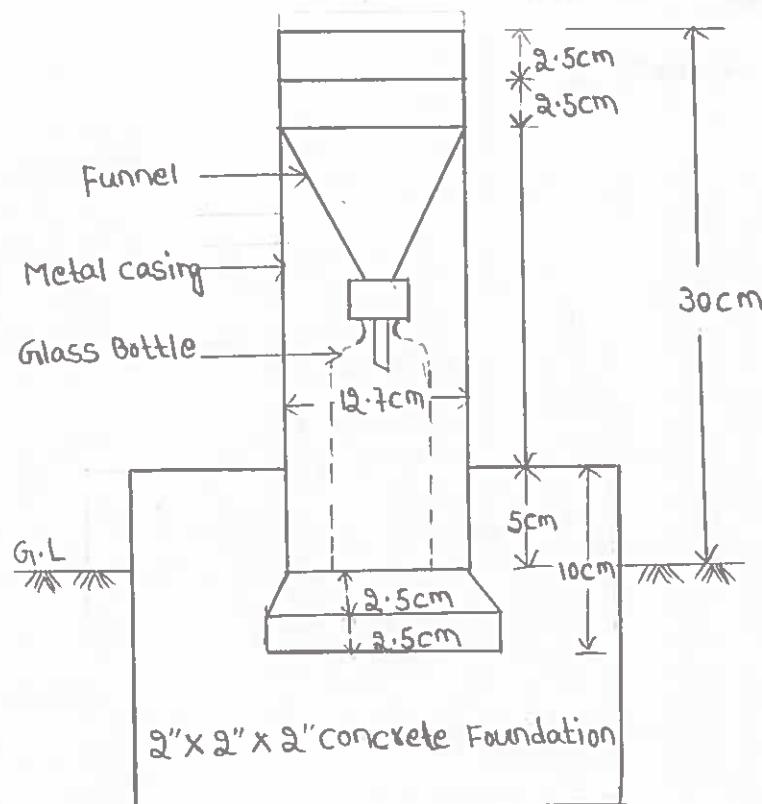
\* Indian Meteorological department has adopted new model called as 'standard gauge'.

Working of Symon's rain gauge:

\* During rainfall, the water is collected in the bottle

through the funnel, with the help of graduations on the glass and the quantity is measured.

\* During heavy rainfall the bottle fills 3 to 4 times a day, so the bottle is replaced at a time when it fully filled and reading are taken by observer who replaces that bottle. (Refer Fig. Q.9.1)



Symon's rain gauge

## 2. Recording type rain gauge:

\* This type of rain gauges are used to record the rainfall and they are automatic gauges.

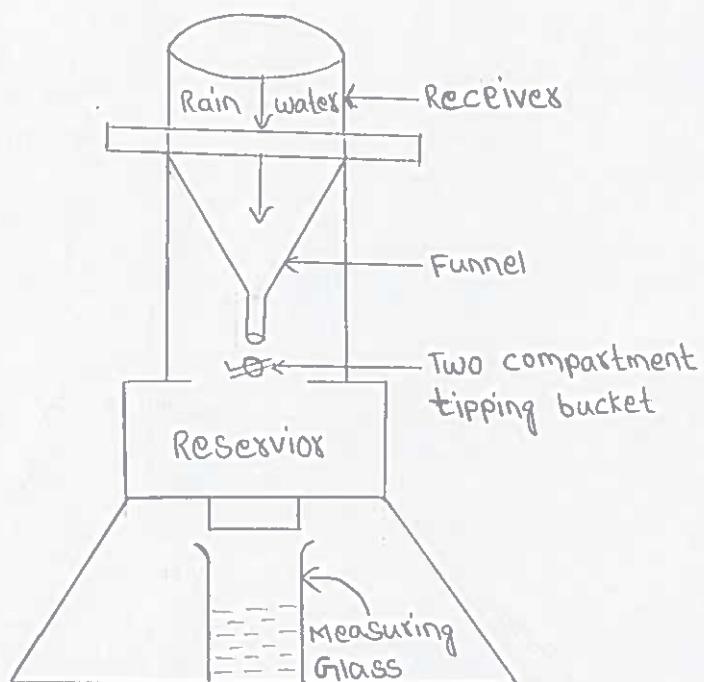
\* These is mechanical arrangement by which rain fallen vs. Time plot come on graph paper.

\* These type of gauges are mainly used in hilly areas.

The commonly used recording type rain gauges are.

### a. Tipping bucket type:

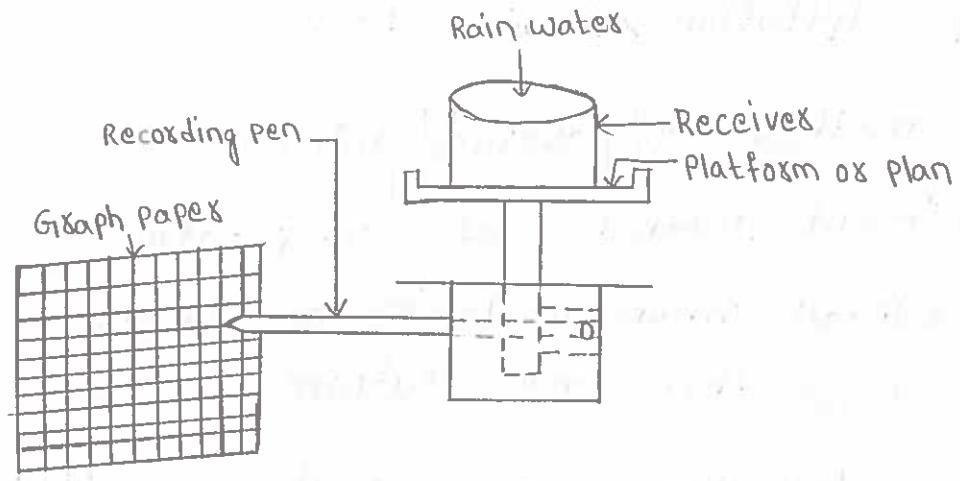
- \* In this, rain water is first received in the receiver and passes through funnel.
- \* The funnel discharge the water into a two bucket compartment when rain gets filled up in one compartment the bucket tips, emptying into a reservoir and moving the second compartment into place beneath the funnel.



Tipping bucket type rain gauge

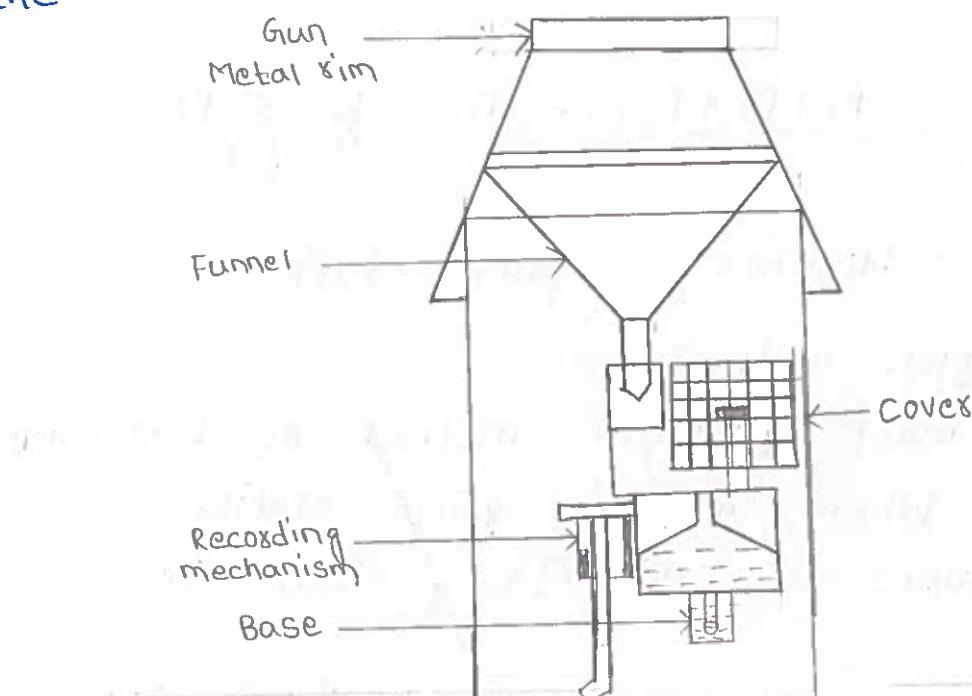
### (b) Weighing-Bucket type gauges:

- \* In this type of rain gauge, the weight of rain which falls into a bucket placed on the platform of a spacing on other weighing mechanism.
- \* The increasing weight of bucket helps in recording the quantity of rainfall, with time by moving a pen on recording drum.



### C. Natural - Syphon type:

- \* First of all, in this rain gauge, the rainfall is collected by a receiver or collector.
- \* Float is arranged at the bottom of the vessel and with rise in water level, float also rises simultaneously.
- \* After that increase in water level is noted by pen on a recording drum caused by clock work.
- \* As the level of water increases in the container, float rises and touches the top, then the siphon tends to release the water and the water is removed from the box.



## Mean precipitation over an Area

Different methods of average rainfall.

Different methods of computation of average rainfall when a basin or catchment area contains more than one station:

1. Arithmetic mean method

2. Thiessen polygon method

3. Isohyetal method

4. Grid point method

1. Arithmetic Mean Method:

\* It is an easy and simple method to calculate the average rainfall to get the arithmetic value of different stations when the rainfall is distributed uniformly, on its areal pattern.

\* Let  $(P_1, P_2, P_3, \dots, P_n)$  are the different stations of different values of precipitations are recorded.

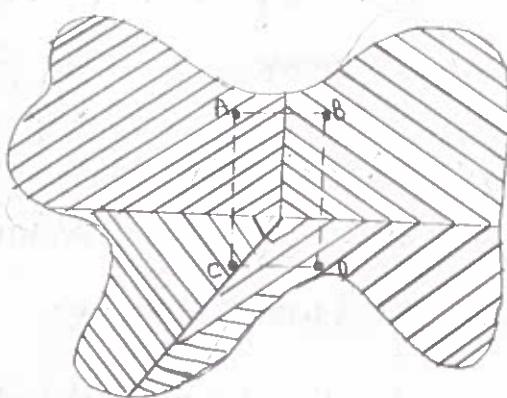
$$\therefore P_{avg} = \frac{P_1 + P_2 + P_3 + \dots + P_n}{n} = \frac{1}{n} \sum_{j=1}^n P_i$$

$\therefore n$  = Number of gauge stations

2. Thiessen Polygon Method:

\* It is the most accurate method of determining average rainfall. When the rain gauge stations records the values of rainfall, they should be

Weighted according to the area they are assumed to present.



\*The average precipitation is calculated by

$$\therefore P_{avg} = \frac{A_1 P_1 + A_2 P_2 + \dots + A_n P_n}{A_1 + A_2 + \dots + A_n}$$
$$= \frac{\sum (A \cdot P)}{\sum A}$$

where  $P_1, P_2, \dots, P_n$  are precipitations at various stations.

$A_1, A_2, \dots, A_n$  are area at polygons.

### 3. Isohyetal Method:

\*The lines on a map of rainfall which joins the place of uniform rainfall readings are known as isohyets.

\*To draw the Isohyets, the depth of rainfall is recorded at all the stations of rain gauge and noted on the area of map.

\*The linear variation of rainfall between the two stations are considered and the expected positions of values of rainfall at a particular

interval are incorporated between the stations.

\* The smooth curve is drawn along the points with uniform values of rainfall, which forms isohyetal design for the area and by using planimeter the area of different Isohyets are measured.

\* The average rainfall depth ( $P$ ) for the whole area ( $A$ ) can be determined by equation,

$$\Sigma \text{Area between two Isohyets}$$

$$P = \frac{\Sigma \text{Area between two Isohyets} \times \text{Average of the two Isohyet values}}{A}$$

#### 4. Grid point Method:

\* In this method, the area to be surveyed is divided into grid or series of squares.

\* The grid size may vary  $5m \times 5m$  to  $25m \times 25m$  depending upon the nature of the terrain the contour interval required and the scale of the map desired.

\* Also, the grids may not be of the same size throughout but may vary depending upon the requirement and field conditions.

\* The method is used for large scale mapping and at average precision.

#### Missing Rainfall Data

##### Estimation of missing rainfall data:

\* The numerical value of precipitation missing at a site, can be estimated using concurrent

observation at these or more neighbouring stations are known as index stations and the method is known as the normal-ratio method.

\*The method uses the following equation.

$$\frac{P_x}{N_x} = \frac{1}{n} \left[ \frac{P_1}{N_1} + \frac{P_2}{N_2} + \dots + \frac{P_n}{N_n} \right]$$

Where,

$P_x$  = Missing precipitation value for station X.

$P_1, P_2, \dots, P_n$  = precipitation values at the neighbouring stations for the concurrent period.

$N_x$  = Normal long term, usually annual, precipitation at station X.

$N_1, N_2, \dots, N_n$  = Normal long term precipitation for neighbouring station, and

$n$  = Number of index (neighbouring) stations.

Consistency of Rainfall Record

Double mass curve:

\*Double mass curve is a technique used when the rainfall record at any rain gauge system contain certain deviation.

\*Though there is long and continuous rainfall record, the complete data is not homogeneous with reference to the existing location of the gauge.

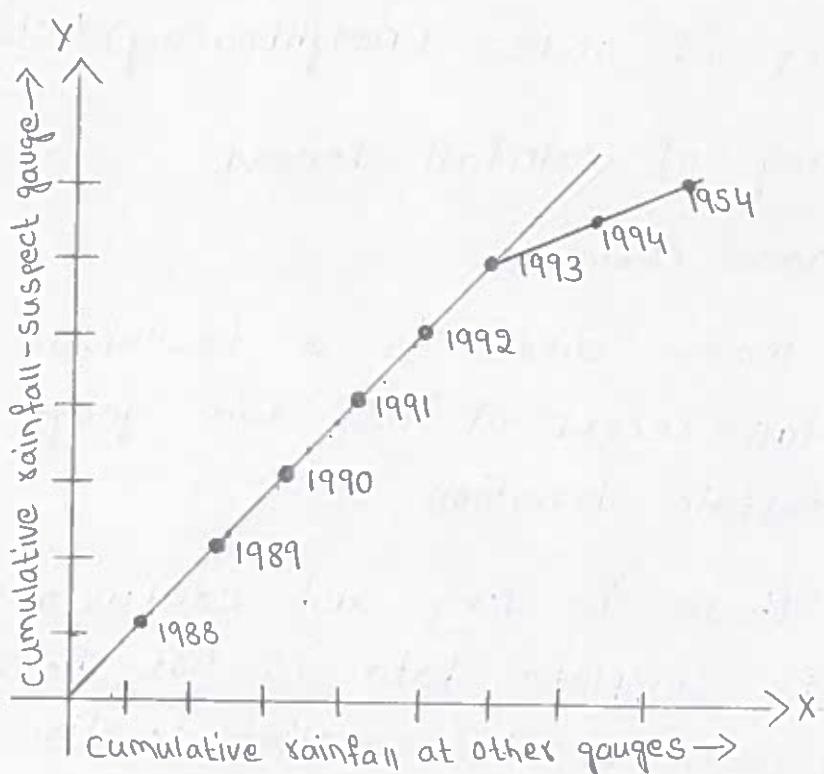
\* The double mass curve is used to check the consistency of rainfall and to adjust inconsistent precipitation data.

\* The double mass curve is a straight line when the station 'x' is homogeneous and consistent with the data of base station.

\* The theory of the double mass curve is based on the fact that a plot of the two cumulative quantities during the same period represent straight line so long as the proportionality between the two remain unchanged, the slope of the line represents the proportionality.

\* Correction factor K is calculated as

$$K = \frac{\text{Gradient of line before change}}{\text{Gradient of line after change}}$$



## Depth Area Duration Relationship:

### Depth area duration relationship:

- \* A rain gauge station gives the point rainfall, which do not actually represent the rainfall in that area.
- \* To find out how much of rainfall will occur in an area by converting the point rainfall data to areal rainfall data, depth area, duration curve is used.
- \* This curve express graphically the relation between progressively decreasing average depth of rainfall over a progressively increasing area from the centre of the storm outward to its edges for a given duration of rainfall.
- \* The purpose of this analysis of a particular storm is to determine the largest average depth of rainfall that fall over various sizes of area during the standard passages of time.
- \* Following step are taken to make the depth area duration curve.

Step 1: Prepare the isohytes from the rainfall data.

Step 2: Plot the catchment area on paper and with the help of planimeter find the area between the isohytes.

Step 3: The volume of rainfall is calculated between the isohytes by taking the average of isohytes multiplied with the area between the isohytes.

Step 4: calculate volume of rainfall of all area between the isohytes.

Step 5: calculate cumulative volume and cumulative area.

Step 6: This cumulative volume is divided by cumulative area and average depth of rainfall over the area for that storm is found out.

Step 7: Same procedure is applied for other storm also

Step 8: This graph between average depth and cumulative area is plotted. That is called depth area duration curve.

### Intensity - Duration - Frequency Relationship

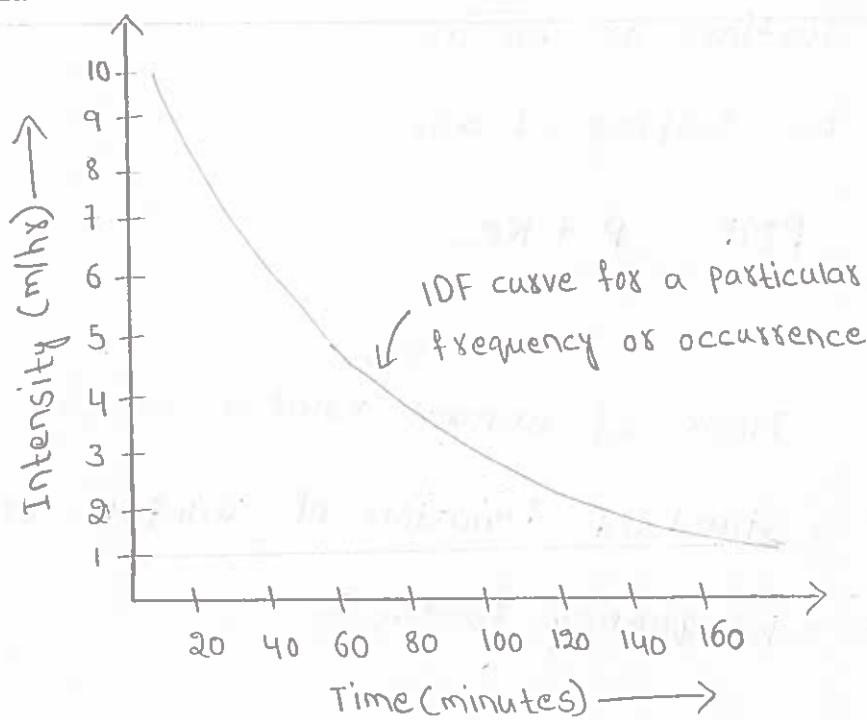
\* The point precipitation data of various storms are analysed in an IDF study.

\* Since the precipitation data are used for the purpose of estimating the stream flows in many instances, not only the total precipitation but its rate, known as the intensity.

\* For the design of any hydraulic structure we should know about the peak flood and what will be its frequency, so this can be easily computed from intensity duration frequency curve.

\* It is a plot between average rainfall intensity and duration.

$$\text{Intensity} = \frac{\text{Rainfall depth}}{\text{Duration}}$$



Typical IDF curve

\* The following steps include for plotting the curve.

1. Arrange the data in descending order of magnitude of all time interval which has to be taken.
2. Give them numbers as largest have number '1' and lowest have number 'N' and find the recurrence interval for each data.
3. For finding the intensity of particular frequency, the precipitation which is given for a particular time period, convert into / hr

### Probable Maximum Precipitation

- \* It is the maximum possible precipitation that can reasonably be expected at a given location.
- \* It is defined as the greatest or extreme rainfall for a given duration that is physically possible

over a station or basin.

\* It can be expressed as,

$$PMP = \bar{P} + k\sigma$$

Where

$\bar{P}$  = Mean of annual rainfall series

$\sigma$  = Standard deviation of rainfall series

$k$  = Frequency factor

## Rainfall Data in India

Rainfall data in India:

\* Rainfall measurement in India began in the eighteenth century.

\* The first recorded data were obtained at Calcutta (1784) and it was followed by observation at Madras (1792), Bombay (1823) and Simla (1840).

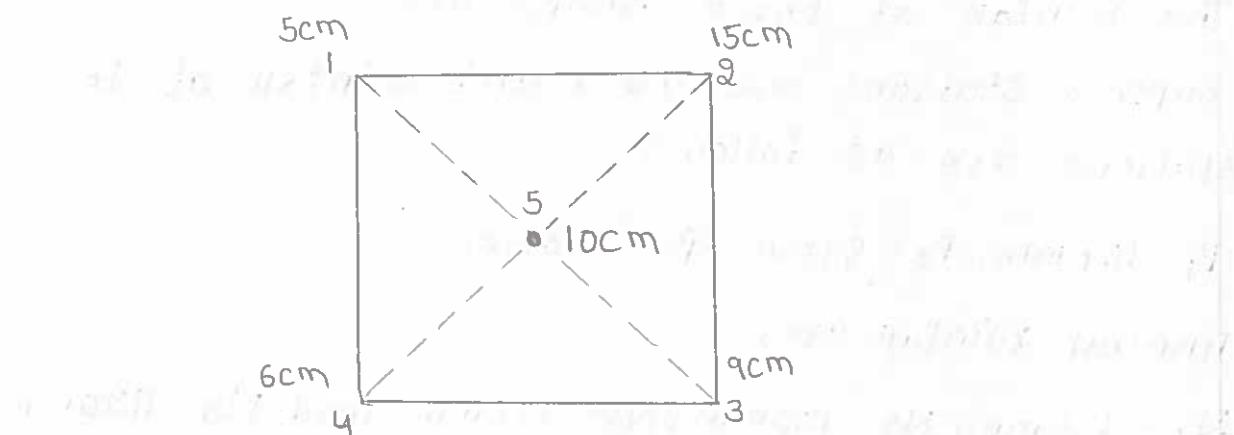
\* The India Meteorological Department (IMD) was established in 1875 and the rainfall resolution of the government of India in 1930 empowered IMD to have overall technical control of rainfall registration in country.

\* The state government have the obligation to supply daily, monthly, the annual rainfall data to IMD for compilation of its two important annual publications entitled daily rainfall of India and monthly rainfall of India.

- \* India has a network of observatories and rain gauges maintained by IMD.
- \* Currently (2005), IMD has 701 hydro-meteorological observatories and 201 agro-meteorological observatories.
- \* In addition there are 8579 rain gauge stations out of which 3540 stations report their data to IMD.
- \* A fair amount of these gauges are of self recording type and IMD operates nearly 400 self recording rain gauge.
- \* A set of 21 snow gauges, 10 ordinary rain gauges and 6 seasonal snow poles form part of glaciological observatories of the country.

### Numericals:

Find the mean precipitation for the area sketched below by Thiessen method. The area is composed of a square plot of side 6km. Rainfall readings are given in the figure for the five rain gauge stations in cms.



Area of a square plot side,  $S = 6 \text{ km}$

Rain Gauge Station	Area of Thiessen Polygon ( $A$ ) ( $\text{km}^2$ or $\text{mm}$ )	Precipitation (mm)	$A \times P$ ( $\text{mm}^2$ )
1.	6	50	30
2.	6	150	900
3.	6	90	540
4.	6	60	360
5.	6	100	600

$$\sum A = 30 \quad \sum P \cdot A = 2700$$

$$P = \frac{\sum P_i A_i}{\sum A} = \frac{2700}{30}$$

$$= 90 \text{ mm} \approx 9 \text{ cm}$$

$$P = \text{Mean precipitation} = 9 \text{ cm}$$

During a month a rain gauge went out of order while the other three gauges in the basin reported rainfalls of 107, 89 and 120 mm. If the normal annual rainfalls of three gauges are 1120, 935 and 1200 mm respectively and the normal annual rainfall of the broken.

The rainfall at three basins are:

Suppose stations are 1, 2, 3 and rainfall at three stations are as follows:

$$P_1 = 107 \text{ mm}, P_2 = 89 \text{ mm}, P_3 = 120 \text{ mm}$$

Annual rainfall are,

$$N_1 = 935 \text{ mm}, N_2 = 1200 \text{ mm}, N_3 = 978 \text{ mm} \text{ and } N_0 = 1120 \text{ mm}$$

Missing rainfall data is given as,

$$\begin{aligned}
 P_x &= \frac{1}{3} \left[ \frac{N_0}{N_1} p_1 + \frac{N_0}{N_2} p_2 + \frac{N_0}{N_3} p_3 \right] \\
 &= \frac{1}{3} \left[ \frac{1120}{935} \times 107 + \frac{1120}{1200} \times 89 + \frac{1120}{978} \times 120 \right] \\
 &= \frac{1}{3} [348.6] = 116.2 \text{ mm}
 \end{aligned}$$

$P_x = 116.2 \text{ mm}$

A basin has the area in the form of a pentagon with each side of length 50km. The five rain gauges located at the corners A, B, C, D and E have recorded 80, 91, 93, 69 and 65mm respectively. compute the average depth of rain fall over the basin using the Arithmetic mean and Thiessen methods.

Given:

$$P_1 = 80 \text{ mm}$$

$$P_2 = 91 \text{ mm}$$

$$P_3 = 93 \text{ mm}$$

$$P_4 = 69 \text{ mm}$$

$$P_5 = 65 \text{ mm}$$

No. of gauge stations = 5

By Thiessen method,

Rain Gauge Station	Area of Thiessen Polygon (A)	Precipitation (P) (mm)	$A \times P$ ( $\text{mm}^2$ )
1.	50	80	4000
2.	50	91	4550
3.	50	93	4650
4.	50	69	3450
5.	50	65	3250
$\sum A = 250$			$\sum P_i A_i = 19900$

$$\therefore P = \frac{\sum P_i A_i}{\sum A} = \frac{19900}{250}$$

$$= 79.6 \text{ mm} \approx 80 \text{ mm}$$

By Arithmetic mean method,

$$P_{avg} = \frac{P_1 + P_2 + P_3 + P_4 + P_5}{n}$$

$$= 79.6 \approx 80 \text{ mm}$$

$$= \frac{80 + 91 + 93 + 74 + 65}{5}$$

$$\approx 80 \text{ mm}$$

A basin has the area in the form of a pentagon with each side of length 70km. The five rain gauges located at the corners A, B, C, D and E have recorded 90, 96, 98, 74 and 65mm respectively. Calculate the average depth of rain fall over the basin using the arithmetic mean.

Given:

$$P_1 = 90 \text{ mm}$$

$$P_2 = 96 \text{ mm}$$

$$P_3 = 98 \text{ mm}$$

$$P_4 = 74 \text{ mm}$$

$$P_5 = 65 \text{ mm}$$

No. of gauge stations = 5

By Thiessen method

Rain gauge station	Area of Thiessen Polygon (A)	Precipitation (P) (mm)	A × P (mm²)
1	70	90	6300
2	70	96	6720
3	70	98	6820
4	70	76	5180
5	70	65	4550
$\sum A = 350$		$\sum = 29570.00$	

$$\frac{\sum P_i A_i}{\sum A} = \frac{29570}{350} = 84.48 \\ \approx 85 \text{ mm}$$

By arithmetic mean method

$$P_{avg} = \frac{P_1 + P_2 + P_3 + P_4 + P_5}{n} \\ = \frac{90 + 96 + 98 + 74 + 65}{5} \\ = 84.6 \approx 85 \text{ mm}$$

[View all posts by \[Author Name\]](#) | [View all posts in \[Category Name\]](#)