UNIT – I - INTRODUCTION

Hydrology

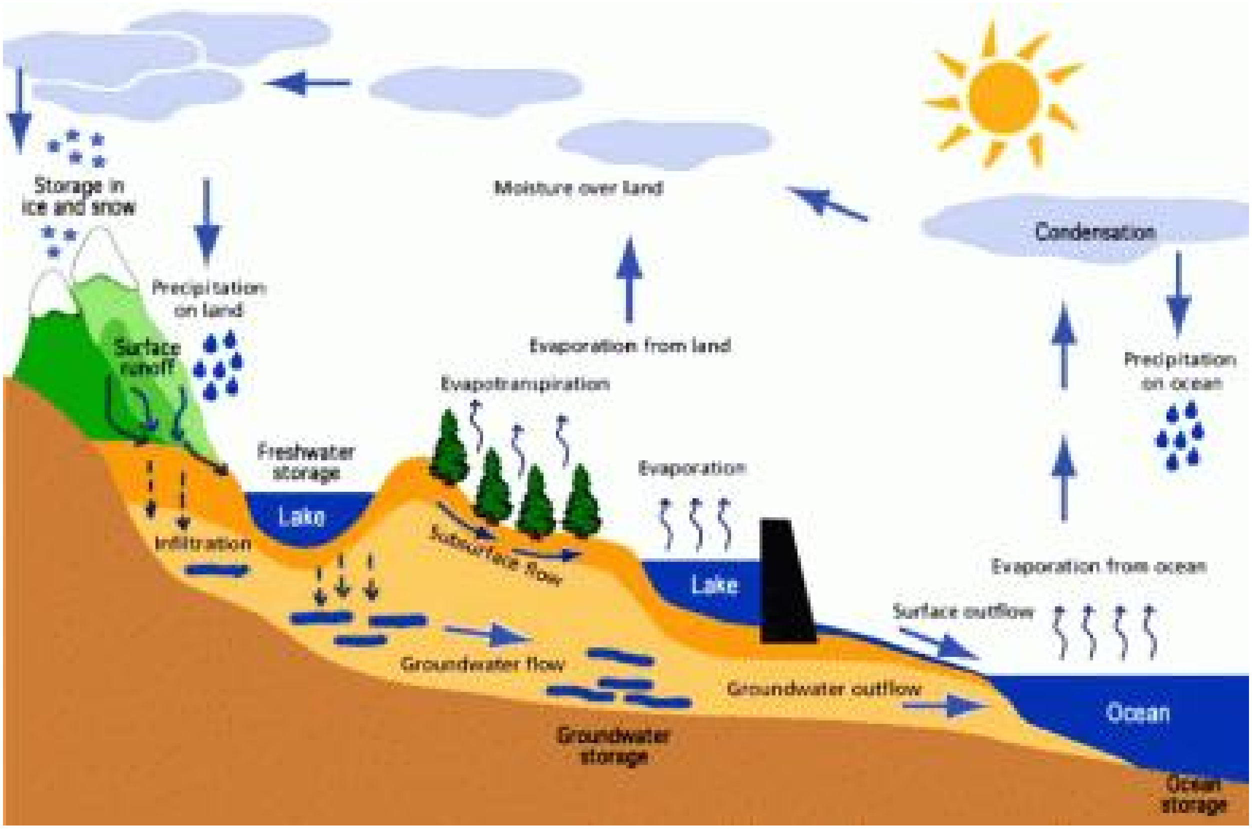
Hydrology is the science which deals with **occurrence, circulation and distribution of water** on and below the **earth's surface** and in the **atmosphere**.

Hydrological Cycle

The **hydrological cycle**, also called the **water cycle**, is a continuous process in which **water evaporates** from water surfaces such as **oceans, lakes, and rivers**, forms **moist air masses**, and **moves inland**. When the **vertical atmospheric conditions** are favourable, this moisture **condenses** and falls as **precipitation** (rain, snow, etc.). This water then **returns to the oceans** through **runoff, infiltration, and groundwater flow**, completing the cycle.

- It extends 1km below the earth surface and 15km above the earth surface.

<u>Hydrologic cycle consists of the following processes:</u>



Evaporation

Evaporation is the **first major step** in the hydrological (water) cycle. It is the **process by which water changes from a liquid to a vapour (gas)** due to **heat energy**, primarily from the **Sun**.

Or

The water from the surfaces of **lakes, rivers, oceans** and also from the **moist soil** evaporates. The vapours are carried over the land by air in the **form of clouds**.

Condensation

Condensation is the process through which the physical state of matter changes from the gaseous phase into the liquid phase. For example, condensation occurs when water vapour (gaseous form) in the air changes into liquid water when it comes in contact with a cooler surface. When the water in the air comes in contact with a cold surface, it condenses to form water droplets. The opposite of condensation is evaporation reaction.

Precipitation

Precipitation is the process where water in the atmosphere falls back to Earth's surface in liquid or solid form.

Precipitation may be in 2 forms:

1. Liquid precipitation i.e., Rainfall
2. Frozen Precipitation
    - Snow
    - Hail
    - Sleet
    - Freezing rain

Infiltration

Infiltration is the process of water on the ground surface entering the soil.

Percolation

Percolation is the subsequent movement of that infiltrated water downward through the soil, eventually reaching the water table

Interception

interception refers to the process where precipitation (rain, snow, etc.) is temporarily prevented from reaching the ground surface by vegetation or other objects

Transpiration

Transpiration is the process of water being lost from the **leaves of the plant** from their pores. The total evaporation from the inclusive of the transpiration consists of

- Surface evaporation
- Water surface evaporation
- From river surface
- From oceans
- Evaporation from the plants and leaves (Transpiration)
- Atmospheric evaporation

Run-off

Run-off is the portion of precipitation i.e., not evaporated. When moisture falls to the earth surface, as precipitation a part of it is evaporated from the water surface, soil, vegetation and through transpiration by plants and leaves and the reminder precipitation is available as run-off which ultimately runs to the ocean through surface and subsurface streams.

The run-off may be classified as follows:

1. **Surface runoff**

Water flows over the land and is first to reach the streams, rivers which ultimately discharge the water to the sea.

2. **Sub Surface runoff**

A portion of precipitation infiltrates into the surface soil and depending upon the geology of the basins runs of subsurface runoff and reaches the streams and rivers.

Groundwater runoff/Base flow

It is portion of precipitation which after infiltration percolates down and joins the ground water reservoir which is ultimately connected to the ocean. Thus the hydrologic cycle may be expressed by the following equations:

$$\text{Precipitation} = \text{Evaporation} + \text{Run-off}$$

$$\boxed{P = E + R}$$

Depression Storage

The water that is temporarily held in small, natural depressions on the land surface, such as puddles, ditches, or uneven terrain, before it either infiltrates into the ground or evaporates

Base Flow

Constant input of water to the stream from ground water sources

interflow

ground water flow horizontal above the ground water table and below the sub surface

Hydrological data

In the hydrological data, the main components of the hydrological cycle are

1. Precipitation
2. Evaporation
3. Runoff

A part from information about the above components, information about climate, meteorology, geology is also required.

Following hydrology data are required

1. Weather and climate records:

Data about temperature, humidity, radiation, wind etc. since there are directly affect hydrological parameters.

2. Precipitation data:

These data help in predicting runoff volume and its peak. It is also helpful in estimating the water budget equation for the basin.

3. Stream flow data:

These data help in the planning of reservoirs design of spillways, bridges and water power development.

It is also utilized for determination of floods, flood magnitude, flood frequency and water budgets.

4. Evaporation and transpiration data:

These data help in water budget for the river basin and reservoir capacity for water resource development

5. Infiltration data:

These data help in determining excess rainfall effect and runoff computation

6. Ground water characteristics:

These data help in estimating and location of ground water reservoir and for ground water development.

7. Physical and Geological data:

This data help in the determination of runoff pattern silt loam movement central water communication (CWC) mentions the stream flow data for major rivers.

Forms of Precipitation

The various forms of precipitation are

- Rainfall
- Snowfall
- Drizzle

- Glaze
- Sleet
- Hail

Out of all the forms, rainfall and snowfall are predominant and contribute an amount of water.

Rainfall: Rainfall is the most predominant one and it is the principal form of this precipitation in many parts of the world including India, and it is the principal form of precipitation in India. Precipitation in the form of water drops of sizes larger than 0.5 mm. The maximum size of a raindrop is about 6 mm. So, there are different types of rains we generally categorize just like the light rain or moderate rain, or heavy rain and their intensity is like this is shown in table

Type	Intensity
Light rain	trace to 2.5 mm/h
Moderate rain	2.5 mm/h to 7.5 mm/h
Heavy rain	> 7.5 mm/h

Snowfall: Snow consists of ice crystals which usually combine to form flakes. Fresh snow has an initial density varying from 0.06 to 0.15 gm/cm3.

Drizzle: A fine sprinkle of numerous water droplets of size less than 0.5 mm and intensity less than 1 mm/h.

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

Sleet: Frozen raindrops of transparent grains formed during rain falls through the air at subfreezing temperature.

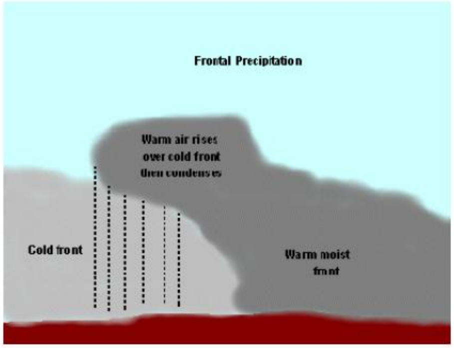
Hail: It is showery precipitation in the form of irregular pellets or lumps of ice of size > 8 mm

Types of Precipitation

1. Cyclonic Precipitation

Cyclonic or Frontal precipitation results when the leading edge of a warm, moist air mass (warm front) meets a cool and dry air mass (cold front). The molecules in the cold air are more tightly packed together (i.e., more dense), and thus, the cold air is heavier than the warm air. The warmer air mass is forced up over the cool air.

As it rises, the warm air cools, the water vapour in the air condenses, and clouds and precipitation result. This type of system is called Frontal Precipitation because the moisture tends to occur along the front of the air mass



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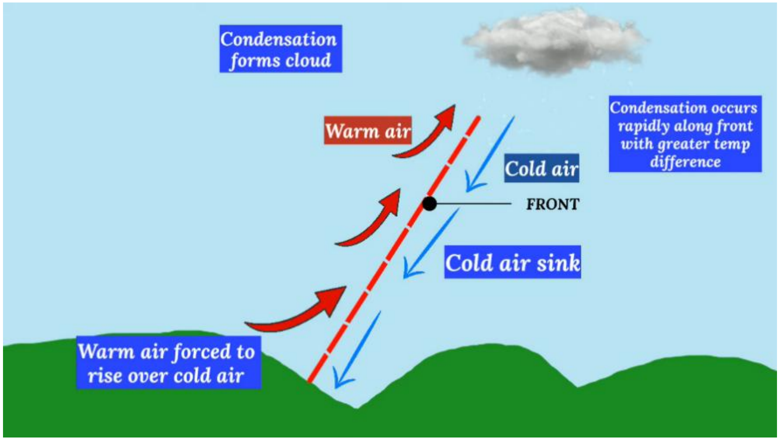
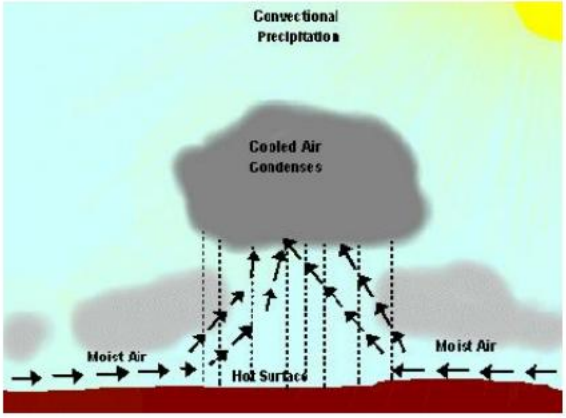
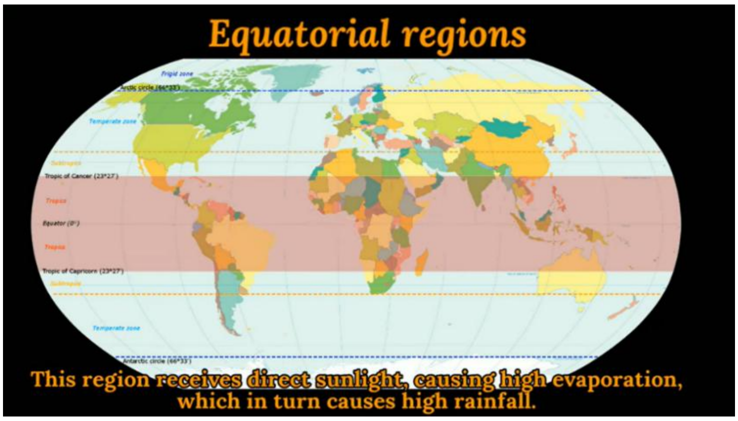
A cyclonic storm is a large, low pressure system that forms when a warm air mass and a cold air mass collide. This collision often occurs under the polar-front jet stream which spreads cold, dry arctic air near warm, moist tropical air. The rotation of the earth causes the air to circulate in a counter clockwise direction around an area of low pressure



2. Convectional Precipitation

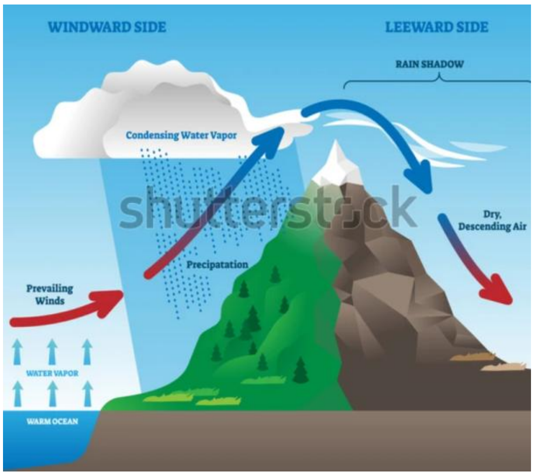
Convectional precipitation results from the heating of the earth's surface. The warm ground heats the air over it. As the air warms, the air molecules begin to move further apart. With increased distance between molecules, the molecules are less densely packed. Thus, the air becomes "lighter" and rises rapidly into the atmosphere. As the air rises, it cools. Water vapour in the air condenses into clouds and precipitation.

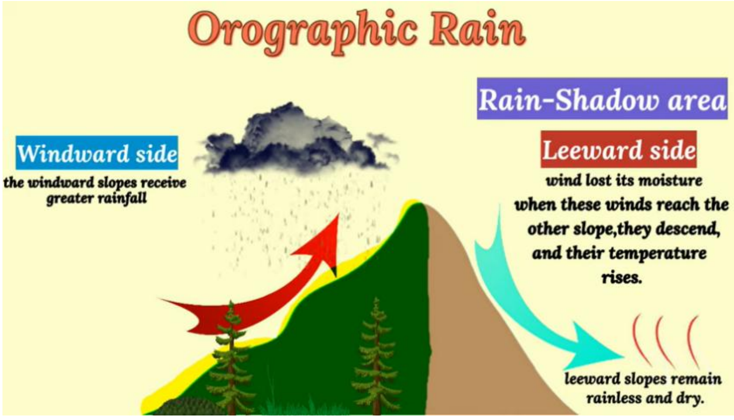




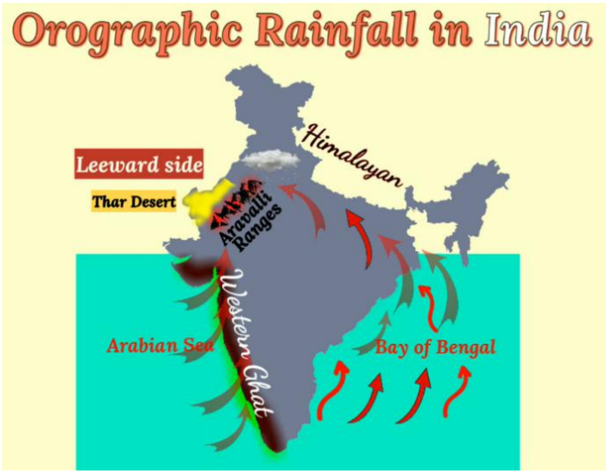
3. Orographic Precipitation

Orographic precipitation results when warm moist air moving across the ocean is forced to rise by large mountains. As the air rises, it cools. Why? A higher elevation results in cooler temperatures





Cold air cannot hold as much moisture as warm air. As air cools, the water vapour in the air condenses and water droplets form. Clouds forms and precipitation (rain or snow) occurs on the windward side of the mountain (see diagram). The air is now dry and rises over top the mountain. As the air moves back down the mountain, it collects moisture from the ground via evaporation. This side of the mountain is called the leeward side. It receives very little precipitation.



<u>Rainfall in India:</u>

The major rainfall season in India is between June to October. India lies in the tropical belt (i.e., North of Equator) and has the following four distinct weather periods:

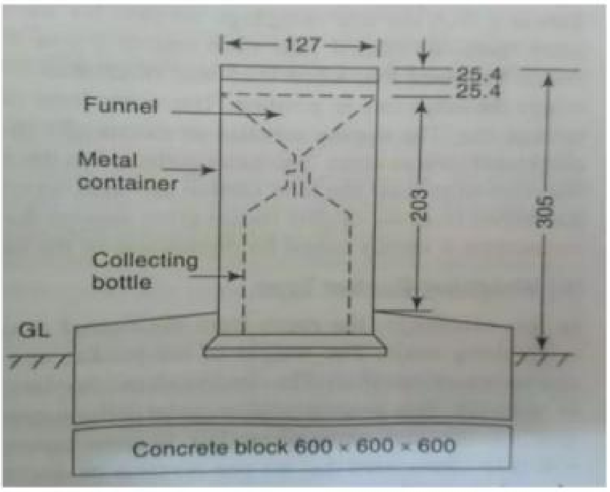
1. Monsoon Period – June to October
2. Post Monsoon Period - October to November
3. Winter Period – December to February
4. Summer Period – March to May

Measurements of Precipitation

Measurement of rainfall is the process of determining the amount of precipitation that has fallen in a particular area during a specified time period. This is done using a device called a rain gauge, which collects and measures the rainfall on a particular surface. Accurate measurement of rainfall is important for various applications, such as agriculture, hydrology, and weather forecasting.

Rain gauges can be classified into two categories:

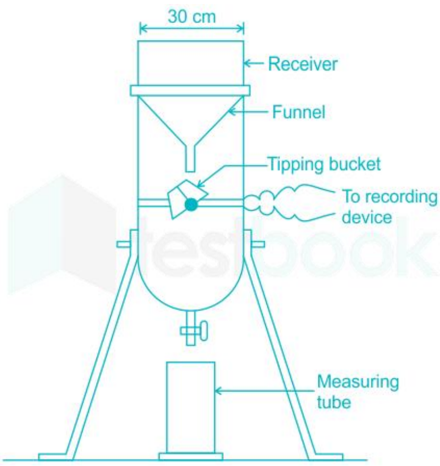
1. **Non recording gauges:** These are simple devices that collect rainfall in a container and require manual measurement, like the Symon's rain gauge.



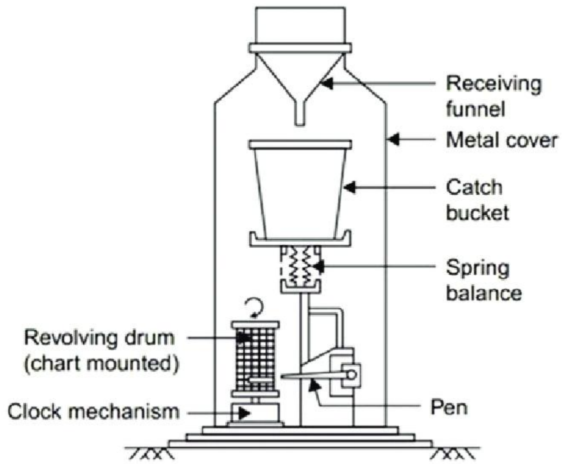
   - Consists of circular collecting area of 12.7 cm diameter connected to the funnel and the rim of the collector is set in a horizontal plane at a height of 30.5 cm above the ground level.
   - The funnel discharges the rainfall catch into a receiving vessel which is housed in a metallic container.
   - The water in the receiving vessel is measured by a graduated measuring glass with an accuracy of 0.1mm.
   - The rainfall is measured at 8:30 a.m. and is recorded as the rainfall of the day.
   - The collecting bottle cannot hold more than 10 cm of rain and thus in case of heavy rainfall frequent readings must be taken.
   - However last reading must be taken at 8:30 a.m. and the sum of previous readings in the past 24 hours in the rainfall of that day.
   - Precautions must be taken and raingauges must be inspected regularly.
   - The details of non-recording rainguages and measurement of rain are specified in IS: 4986-1968.
   - It can also be used to measure snowfall. During snowfall the funnel and received bottle are removed and snow is collected in metallic container which is then melted and depth of resulting water is measured.
     Antifreeze agents may also be used
     In areas of heavy rainfall special snow gauges are used with storage pipes.

2. **Recording gauges:** These instruments provide a continuous record of rainfall over time, using mechanisms like tipping buckets, weighing buckets, or float systems.
   - Tipping Bucket Type
     - This is a 30.5 cm size raingauge used by US Weather Bureau.
     - The catch from the funnel falls onto one of a pair of small buckets.

- These buckets are so balanced that when 0.25mm of rainfall collects in one bucket it tips and brings the other bucket in position and the water is collected in storage can.
- The tipping actuates an electrically driven pen to plot the intensity of rainfall with time.
- The water in storage can is measured regularly to give total rainfall.



- Weighing Bucket Type
  - In this the catch empties into a bucket mounted on a weighing scale.
  - The weight of the bucket is recorded with time
  - The mechanism has the capacity to run for as long as one week.
  - The instrument gives a plot of accumulated rainfall against time.



- Natural Syphon Type
  - Also called as float type gauge
  - In this the rainfall collected by a funnel shaped collector is led into a float chamber causing a float to rise.
  - Due to this, a pen attached to the float through a level records the elevation of float driven by clockwork mechanism.
  - A syphon arrangement empties the float chamber when float reaches the maximum present value.

- Its details are prescribed in IS: 5235-1969.
- The chart shows a rainfall of 58.3 mm in 30h. the vertical lines correspond to sudden emptying of float by syphon action.

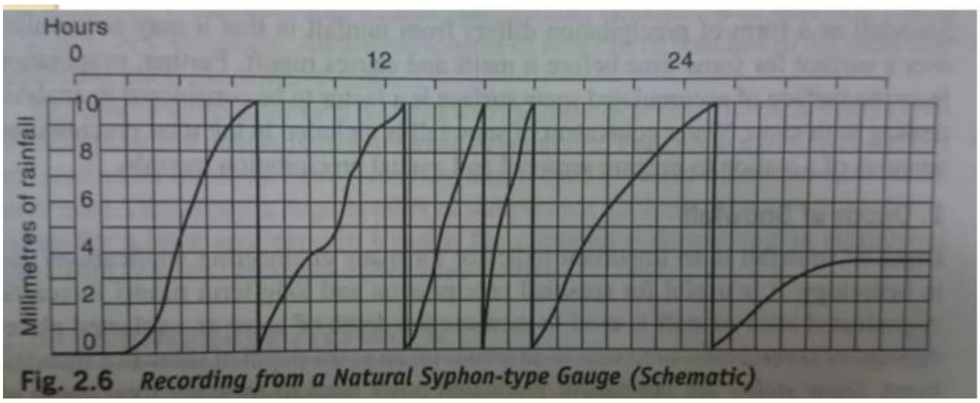


Fig. 2.6 Recording from a Natural Syphon-type Gauge (Schematic)

Rain gauge Network

- The rain gauges density or network density is define as the ratio of total area of the catchment to the total number of rain gauges in the catchment.
- To obtain reliable results, the various rain gauges should be evenly and uniformly distributed within a given catchment.
- The total number of rain gauges installed within a given catchment area should neither be too many as to be costly nor should be to less as to give unreliable results.
- The world meterological organization (WMO) has laid down the following norms for minimum network density.

Ragion	Description	Network density	
		Minimum	tolerable
1	Flat region of temperate, mediterranean and tropical zones.	1 gauge for 600 to $900 km^2$	1 gauge for 900 to $3000 km^2$
2	Mountainous area of temperate, mediterranean and trpical zones.	1 gauge for 100 to $250 km^2$	1 gauge fo 250 to $1000 km^2$
3	Arid and polar zones	1 gauge for 1500 to $10000 km^2$	-

- IS recommendations on rainguage density
- IS: 4987-1968 recommendeds the following rain gauge densities.
  - In Plains – 1 station for every 520 sq.km.
  - In Regions with average elevation 1000m – 1 station per 260 – 390 sq.km.
  - In hilly areas with heavy rainfall – 1 station for every 130 sq.km.

Optimum Number of Rain gauges

The optimum number of raingauge stations that should exist in order that the mean rainfall can be estimated with an assigned percentage of error is given by:

$$N = \left(\frac{C_v}{e}\right)^2$$

Where,

N = Optimum number of raingauges

C_v = Coefficient of variation of rainfall

e = Allowable percentage error in estimate of mean rainfall

C_v can be computed as follows:

$$C_v = \frac{\sigma_{n-1}}{P_m} \times 100$$

Where,

σ_{n-1} = Standard deviation

$$\sigma_{n-1} = \sqrt{\frac{(P_1 - P_m)^2 + (P_2 - P_m)^2 + (P_3 - P_m)^2 + (P_4 - P_m)^2 + \dots + (P_n - P_m)^2}{n-1}}$$

P_m = Mean precipitation of existing raingauge

$$P_m = \frac{P_1 + P_2 + P_3 + P_4 + \dots + P_n}{n}$$

n = Number of raingauge stations

Additional raingauge required = N – n

- According to WMO at least 10% of raingauge are must be recording type.

Question

1. In a Watershed 4 Non-Recording Raingauges have been installed. The Annual Precipitation of one of the year is given as Below. Calculate the Existing % of Error in the Estimating of Mean Rainfall. Also Calculate Optimum number of Raingauges Required for an Error of 10% in Mean Precipitation

Station	Rainfall (mm)
A	100
B	120
C	140
D	80.

Solution

C_v Can be computed as:

$$C_v = \frac{\sigma_{n-1}}{P_m} \times 100$$

Where,

$$P_m = \frac{P_A + P_B + P_C + P_D}{n}$$

$$= \frac{100 + 120 + 140 + 80}{4}$$

$$= 110\,mm$$

$$C_v = \frac{\sigma_{n-1}}{P_m} \times 100$$

$$\sigma_{n-1} = \sqrt{\frac{(P_A - P_m)^2 + (P_B - P_m)^2 + (P_C - P_m)^2 + (P_D - P_m)^2}{n-1}}$$

$$= \sqrt{\frac{(100-110)^2 + (120-110)^2 + (140-110)^2 + (80-110)^2}{4-1}}$$

$$= 25.82$$

$$C_v = \frac{25.82}{110} \times 100$$

$$= 23.46\%$$

For Existing % of Error

$$N = \left(\frac{C_v}{e}\right)^2$$

$$4 = \left(\frac{23.46}{e}\right)^2$$

$$\boxed{e = 11.73\%}$$

For Optimum Number of Raingauge

Given $\Rightarrow$ $e = 10\%$

$$N = \left(\frac{C_v}{e}\right)^2$$

$$N = \left(\frac{23.46}{10}\right)^2$$

$$= 5.5 \simeq 6$$

$\therefore$ Additional Number of Raingauges Required $\Rightarrow$ $N - n$

$$= 6 - 4$$

$$= 2$$

Out of which one should be Recording type.

2. A catchment has 5 raingauge stations. In a year, the annual rainfall recoded by the gauges are 78.80 cm, 90.20 cm, 98.60 cm, 102.40 cm and 70.40 cm. for 6% error in the estimation of the mean rainfall, determine the additional number of gauges needed.

$$P_m = \frac{78.80 + 90.20 + 98.6 + 102.40 + 70.40}{5}$$

$$\boxed{P_m = 88.08\ cm}$$

$$\sigma_{n-1} = \sqrt{\frac{(P_1 - P_m)^2 + (P_2 - P_m)^2 + (P_3 - P_m)^2 + (P_4 - P_m)^2 + (P_5 - P_m)^2}{n-1}}$$

$$= \sqrt{\frac{(78.80 - 88.08)^2 + (90.20 - 88.08)^2 + (98.60 - 88.08)^2 + (102.40 - 88.08)^2 + (70.40 - 88.08)^2}{5-1}}$$

$$= 13.41$$

$$C_v = \frac{13.41}{88.08} \times 100$$

$$C_v = 15.22$$

$$N = \left[\frac{15.22}{6}\right]^2$$

$$= 6.43 \simeq 7$$

$\therefore$ Additional Number of Gauges $= N - n = 7 - 5$
$= 2$

Annual Rainfall: The total amount of rainfall collected in 1 year is called as annual rainfall.

Average Annual Rainfall: The average of annual data of last 30 years is called average annual rainfall.

Normal Precipitation: The normal rainfall is the average value of rainfall of a particular date, month or year over a specified 30-year period.

Estimation of missing data

Methods to find missing data

1. Arithmetic Mean Method: If the normal annual precipitation at various stations are within about 10% of normal annual precipitation at station X, then

$$P_x = \frac{P_1 + P_2 + P_3 + P_4 + P_5 + \dots P_n}{n}$$

2. Normal Ratio Method: If normal precipitation varies more than 10% the Px is estimated by weighing the precipitation at the various stations by the ratios of normal annual precipitations. This method is known as normal ratio method.

$$P_x = \frac{N_x}{n}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \dots \frac{P_n}{N_n}\right]$$

Problems

1. A watershed has four rain gauge stations, A, B, C and D. During a storm, rain gauge station 'A' was inoperative, while stations B, C and D, surrounding station 'A', recorded rainfall of 48 mm, 51 mm and 45 mm respectively. Estimate the missing storm precipitation of station 'A', using arithmetic mean method.

Given Data

$P_B = 48\,mm$

$P_C = 51\,mm$

$P_D = 45\,mm$

Formula

$$P_x = \frac{P_1 + P_2 + P_3 + \dots + P_n}{n}$$

$$P_A = \frac{P_B + P_C + P_D}{3}$$

$$\boxed{P_A = 48\,mm}$$

2. The normal annual rainfall at station A, B, C and D in a catchment are 80.97, 67.59, 76.28 and 92.01 cm respectively. In year 2019, the station D was inoperative and the stations A, B and C recorded annual precipitations of 91.11, 72.23 and 79.89 cm respectively. Estimate the rainfall at station D in that year.

$\therefore\ N_A = 80.97\,cm \qquad P_A = 91.11\,cm$

$N_B = 67.59\,cm \qquad P_B = 72.23\,cm$

$N_C = 76.28\,cm \qquad P_C = 79.89\,cm$

$N_X = 92.01\,cm$

$$P_X = \frac{N_X}{n}\left(\frac{P_A}{N_A} + \frac{P_B}{N_B} + \frac{P_C}{N_C}\right)$$

$$P_X = \frac{92.01}{3}\left(\frac{91.11}{80.97} + \frac{72.23}{67.59} + \frac{79.89}{76.28}\right) = \underline{99.41\,cm}$$

3. The normal annual precipitation of five raingauge stations P, Q, R, S and T are 125, 102, 76, 113 and 137 cm respectively. During a particular storm the precipitation recorded by stations P, Q, R and S are 13.20, 9.20, 6.80 and 10.20 cm respectively. The instrument at station T was inoperative during that storm. Estimate the rainfall at station T during the storm.

$N_P = 125\,cm \qquad N_S = 113\,cm \qquad P_P = 13.2\,cm$

$N_Q = 102\,cm \qquad N_T = 137\,cm \qquad P_Q = 9.2\,cm$

$N_R = 76\,cm \qquad P_R = 6.8\,cm$

$P_S = 10.2\,cm$

$$P_X = \frac{137}{4}\left(\frac{13.2}{125} + \frac{9.2}{102} + \frac{6.8}{76} + \frac{10.2}{113}\right) = \underline{12.86\,cm}$$

4. In a catchment there are four raingauge stations P, Q, R and S. Normal annual precipitation values at these stations are 780mm, 850mm, 920mm and 980mm respectively. in the year 2013, station Q, R and S were operative but P is not working. using normal ratio method, the precipitation at station P for the year 2013 has been estimated as 860mm. if the observed precipitation at station Q and R for the year 2013 were 930mm and 1010mm respectively. what was the observed precipitation at station S for that year?

$$N_P = 780\ mm \qquad P_X = 860\ mm$$
$$N_Q = 850\ mm \qquad P_Q = 930\ mm$$
$$N_R = 920\ mm \qquad P_R = 1010\ mm$$
$$N_S = 980\ mm \qquad P_S = ?$$

$$P_X = \frac{N_X}{n}\left(\frac{P_Q}{N_Q} + \frac{P_R}{N_R} + \frac{P_S}{N_S}\right)$$

$$860 = \frac{780}{3}\left(\frac{930}{850} + \frac{1010}{920} + \frac{P_S}{980}\right)$$

$$P_S = 1093.433\ mm$$

<u>Preparation of Rainfall Data</u>

There are three methods of presentation of rainfall data collected through measurements at a given station:

1. Hyetograph Method
2. Mass Curve of Rainfall
3. Double Mass Curve of Rainfall

Hyetograph Method

- A hyetograph is a plot of the intensity of rainfall against time interval.
- Hyetograph is derived from mass curve.
- It is represented as bar chart
- Area under a hyetograph represents the total precipitation received in the period.

<u>Intensity of Rainfall</u>

The intensity of rainfall (i) is defined as the rate at which rainfall occurs.

Unit: cm/hr or mm/hr

The intensity of rainfall is given by

$$\boxed{i = \frac{P}{t}}$$

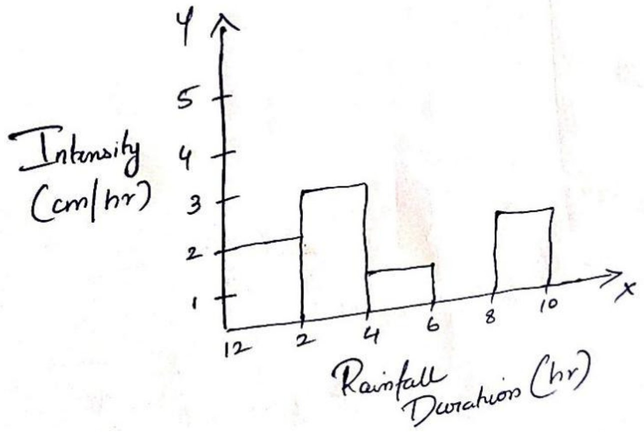
Where,

i = Intensity of Rainfall

P = Depth of Rainfall

t = Duration of Rainfall

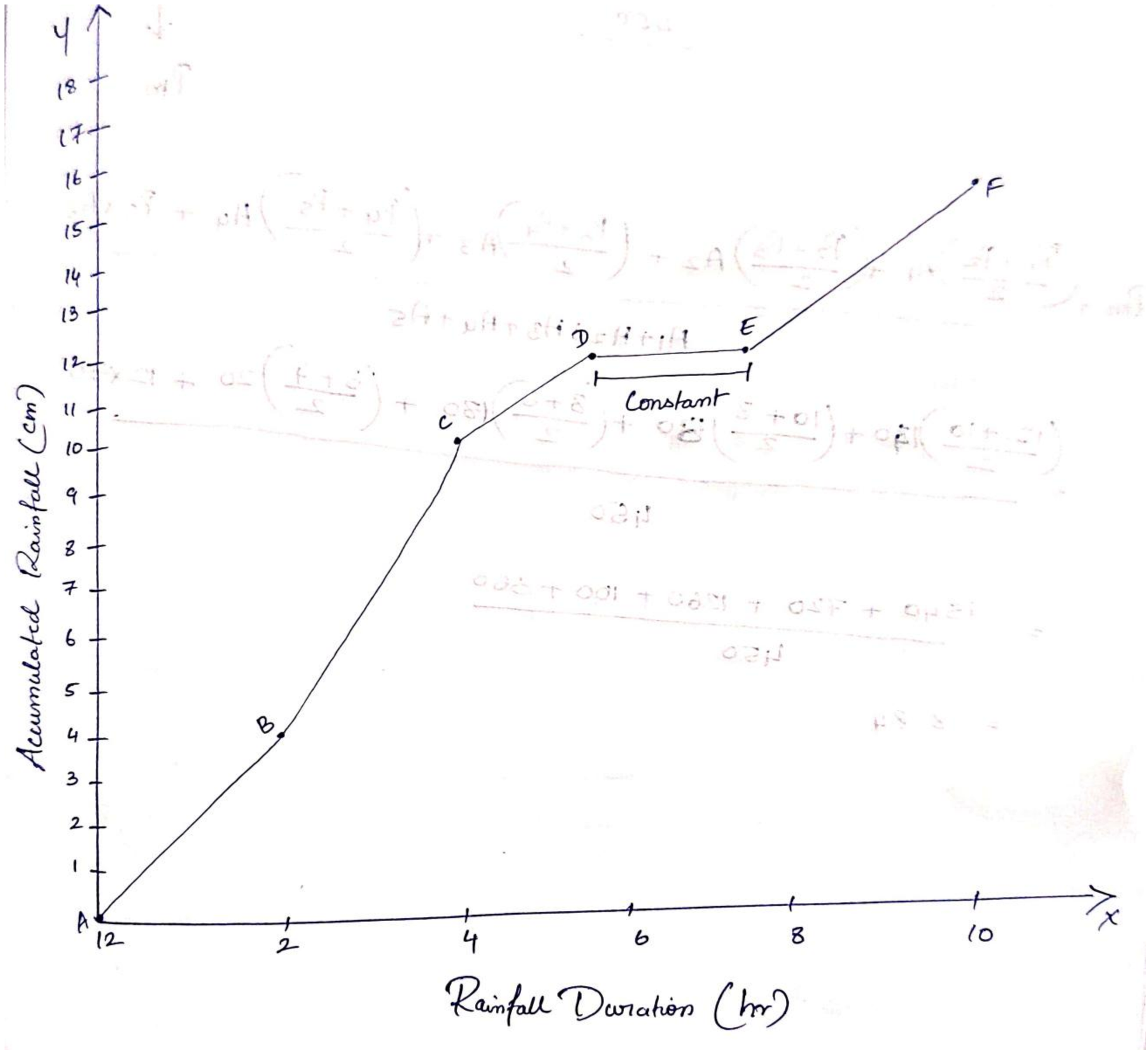
Rainfall Duration	Intensity (cm/hr)
12 - 2 pm	2
2 - 4 pm	3
4 - 6 pm	1
6 - 8 pm	0
8 - 10 pm	2



Mass Curve of Rainfall

- It is a plot of the accumulated precipitation against time plotted in chronological order.
- It gives various information such as duration and magnitude of a storm.
- Records of float type and weighing bucket type gauges are of this form.

Rainfall Duration	Intensity (cm/hr)	Depth of Rainfall	Accumulated Rainfall
12 - 2pm	2	4	4
2 - 4 pm	3	6	10
4 - 6 pm	1	2	12
6 - 8 pm	0	0	0 / 12
8 - 10 pm	2	4	16



Double Mass Curve

Following Steps are taken

Step 1: A group of 5 to 10 base stations in the neighbourhood of the problem station X is selected.

Step 2: The data of rainfall of the station X and the average rainfall of the group of station is arrange in reverse chronological order. The latest record as the first entry and the oldest record as the last entry in the list.

Step 3: From the list, calculate the accumulated precipitation of the station X ($\sum P_x$) and accumulated values of the group of base stations ($\sum P_{avg}$).

Step 4: A graph is plotted between $\sum P_x$ and $\sum P_{avg}$, $\sum P_x$ taken as ordinate and $\sum P_{avg}$ taken as abscissa.

Step 5: Find the break is slope in the plot. If there is any in consistency than slope will change immediately.

Step 6: Correct the reading of plot by using

$$P_{cx} = \frac{m_c}{m_a} \times P_x$$

The checking for inconsistency of a record is done by double mass curve technique.

P_{cx} = Corrected Precipitation

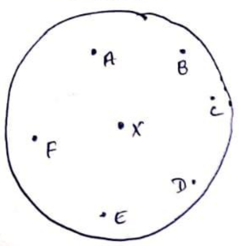
P_x = Original Recorded Precipitation

m_c = Corrected Slope

m_a = Actual Slope

$\frac{m_c}{m_a}$ = Correction Ratio

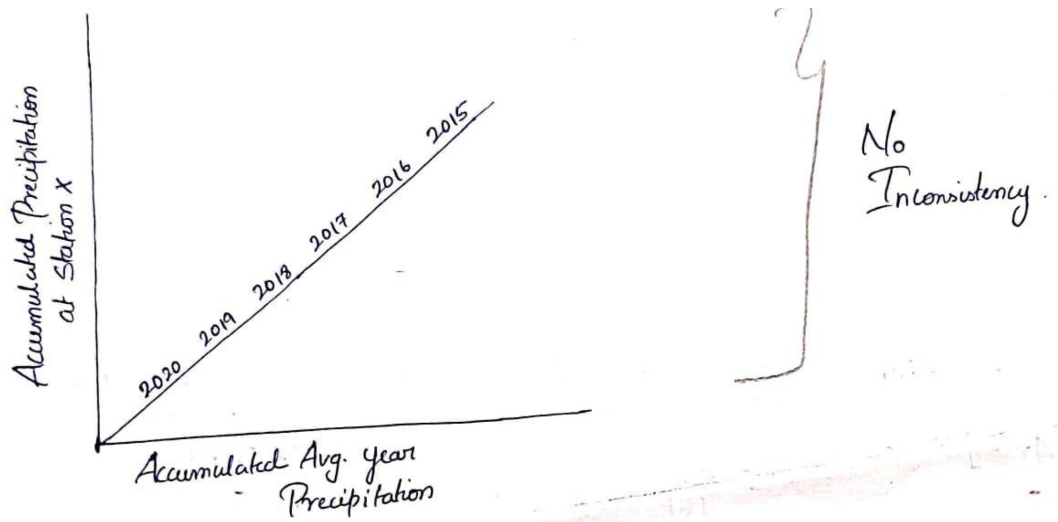
Catchment

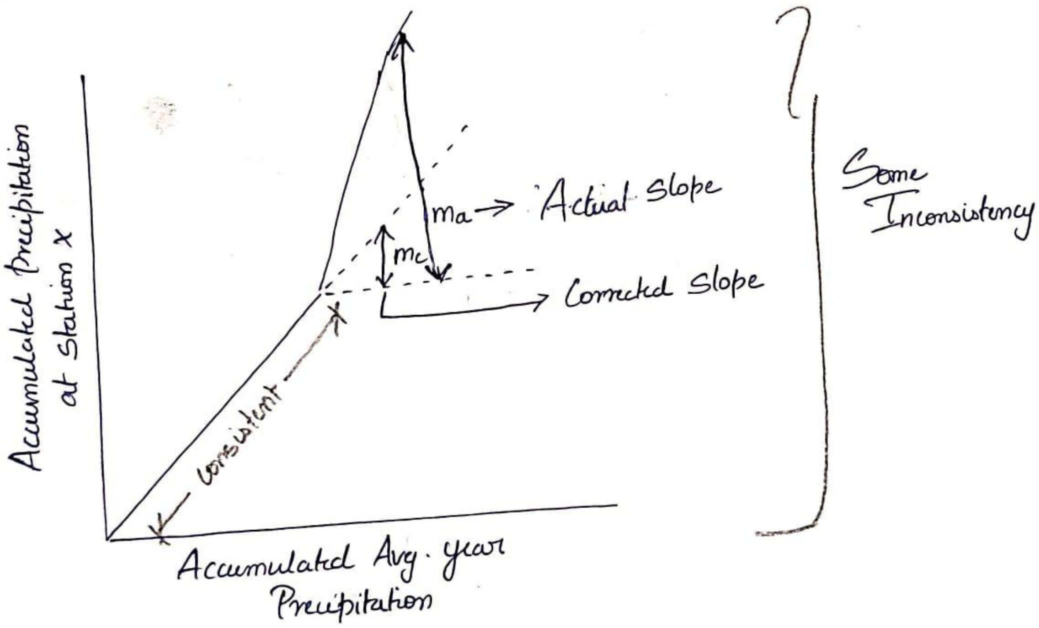


∵ A, B, C, D, E, F – Nearby Base Stations

∵ Problem Station – X

Year	Year Precipitation at Station X	Accumulated Precipitation at Station X [Y-Axis]	6 Base Station Avg. Year Precipitation	Accumulated Average Year Precipitation [X-Axis]
2020	163	163	161	161
2019	130	293 = 163+130	146	307 = 161+146
2018	137	430 = 293+137	130	437 = 307+130
2017	130	560 = 430+130	143	580 = 437+143
2016	140	700 = 560+140	135	715 = 580+135
2015	142	842 = 700+142	163	878 = 715+163





Mean Precipitation over an Area

- It is the amount of precipitation which can be assumed uniform over an area.
- If the average precipitation over an area is known than total rain volume of water can be computed for that area.

Some Methods to compute mean precipitation

1. Arithmetic Mean Method
2. Thiessen Polygon Method
3. Isohyetal Method

Arithmetic Mean Method

- It is a very simple method.

- This method is used, when the rainfall measured at various stations in a catchment area show little variations or when rain is uniformly distributed.
- It does not consider raingauges located outside the catchment
- It has least accuracy

$$P_m = \frac{P_1 + P_2 + P_3 \ldots P_n}{n}$$

Where,

$P_1, P_2, P_3, \ldots, P_n$ are the rainfall depth measured by raingauges at station 1,2,3,…,n

Thiessen Polygon Method

- In this method, the rainfall recoded at each station is given a weightage on the basis of area closest to the station.
- It is more accurate than Arithmetic mean method but less accurate than Isohyetal Method.
- Suitable for plain area as it does not consider elevation difference.
- In this method whole area divided into smaller areas on which we assume the uniform rainfall.

Following steps for dividing the catchment into smaller polygon

Step 1: Divide the area into number of conventional triangles or join any two station but it should not cross any other line

Step 2: Draw perpendicular bisector and extend it [extended line should not pass through any station].

Step 3: Find the enclosed area by each polygon

$$P_m = \frac{P_1 A_1 + P_2 A_2 + \ldots + P_n A_n}{A_1 + A_2 + A_3 + \ldots + A_n}$$

Isohyetal Method

Isohyet: It is a line joining the points of equal rainfall magnitude or isohyets are contours of equal rainfall.

- Plot gauge locations on map
- Subjectively interpolate between gauges at a selected interval.
- Connect point of equal rain depth to produce lines of equal rainfall amount.
- If the rainfall values $P_1, P_2, P_3, \ldots, P_n$ and $A_1, A_2, A_3, \ldots, A_n$ are corresponding inter isohyet areas, the average rainfall over the catchment. P_m is computed as

$$P_m = \frac{\left(\frac{P_0+P_1}{2}\right)\times A_1 + \left(\frac{P_1+P_2}{2}\right)\times A_2 + \left(\frac{P_2+P_3}{2}\right)\times A_3 + \cdots + \left(\frac{P_{n-1}+P_n}{2}\right)\times A_n}{A_1+A_2+A_3+\cdots+A_n}$$

- Stations outside the catchment are also considered.
- It is more accurate.

Problems

1. In a catchment there were 5 raingauges. The rainfall data collected by them in year 2018 are as follows, Find the average rainfall in the catchment.

Station	Rainfall (cm)
1	58
2	59
3	60
4	63
5	61

$$\overline{P_m} = \frac{P_1+P_2+P_3+P_4+P_5}{5}$$

$$P_m = \frac{58+59+60+63+61}{5}$$

$$= \frac{301}{5}$$

$$P_m = 60.20\ \text{cm}$$

2. Find the average rainfall over a catchment with thiessen polygon method

Station	Rainfall (cm)	Area (km^2)
A	5	8
B	15	6
C	10	5
D	25	2
E	35	4

$$P_m = \frac{P_A A_A + P_B A_B + P_C A_C + P_D A_D + P_E A_E}{A_A + A_B + A_C + A_D + A_E}$$

$$= \frac{(5 \times 8) + (15 \times 6) + (10 \times 5) + (25 \times 2) + (35 \times 4)}{8 + 6 + 5 + 2 + 4}$$

$$= \frac{40 + 90 + 50 + 50 + 140}{25}$$

$$= 14.80 \text{ cm}$$

3. Calculate the average depth of rainfall using Arithmetic Mean Method and Thiessen Polygon Method. The rainfall amounts are indicated in mm at the respective gauge site. The station 4, 6 and 8 are outside the catchment area.

Station	**Rainfall (mm)**	**Area (km^2)**
1	10	7
2	20	4
3	15	10
4	12	12
5	8	5
6	14	8
7	25	4
8	18	10

1. Arithmetic Mean Method

In this Method, The Raingauges located Outside the Catchment are not Considered, So The Stations 4, 6 and 8 are Ignored.

$$P_m = \frac{P_1 + P_2 + P_3 + P_5 + P_7}{5}$$

$$= \frac{10 + 20 + 15 + 8 + 25}{5}$$

$$= \frac{78}{5}$$

$$P_m = 15.60\,mm$$

2. Thiessen Polygon Method

$$P_m = \frac{P_1A_1 + P_2A_2 + P_3A_3 + P_4A_4 + P_5A_5 + P_6A_6 + P_7A_7 + P_8A_8}{A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8}$$

$$= \frac{(10\times7)+(20\times4)+(15\times10)+(12\times12)+(8\times5)+(14\times8)+(25\times4)+(18\times10)}{7+4+10+12+5+8+4+10}$$

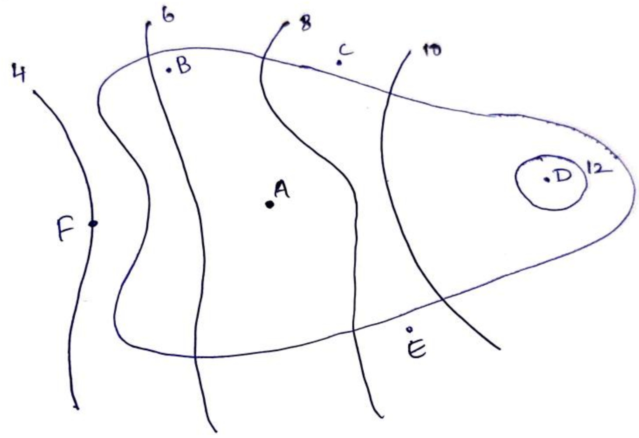
$$= \frac{70 + 80 + 150 + 144 + 40 + 112 + 100 + 180}{60}$$

$$= \frac{876}{60}$$

$$P_m = 14.60\,mm$$

4. The isohyets due to a storm in a catchment was drawn and the area of the catchment bounded by isohyets were tabulated as below, estimate the mean precipitation due to the storm.

Isohyets (cm)	Area (km^2)
Station -12	30
12-10	140
10-8	80
8-6	180
6-4	20



Isohyets **[Given]**	**Average Value of Isohyets** $\left(\frac{P_1+P_2}{2}\right)$	**Area** **[Given]**	**Fraction of Total Area** **[Particular area/Total area of the catchment]**	**Weightage P_m** $\left(\frac{P_1+P_2}{2}\right)$ x **Fraction of Total Area**
12	12	30	30/450 = 0.066	0.792
12 – 10	11	140	140/450 = 0.311	3.421
10 – 8	9	80	80/450 = 0.177	1.583
8 – 6	7	180	180/450 = 0.40	2.80
6 – 4	5	20	20/450 = 0.044	0.22
		Total = 450		$\mathbf{P_m}$ = 8.816

OR

$$P_m = \frac{P_1 \times A_1 + \left(\frac{P_1+P_2}{2}\right)A_2 + \left(\frac{P_2+P_3}{2}\right)A_3 + \left(\frac{P_3+P_4}{5}\right)A_4 + \left(\frac{P_4+P_5}{5}\right)A_5}{A_1 + A_2 + A_3 + A_4 + A_5}$$

$$= \frac{12 \times 30 + \left(\frac{12+10}{2}\right)140 + \left(\frac{10+8}{2}\right)80 + \left(\frac{8+6}{2}\right)180 + \left(\frac{6+4}{2}\right)20}{30 + 140 + 80 + 130 + 20}$$

$$= \frac{360 + 1540 + 720 + 1260 + 100}{450}$$

$$P_m = 8.816$$

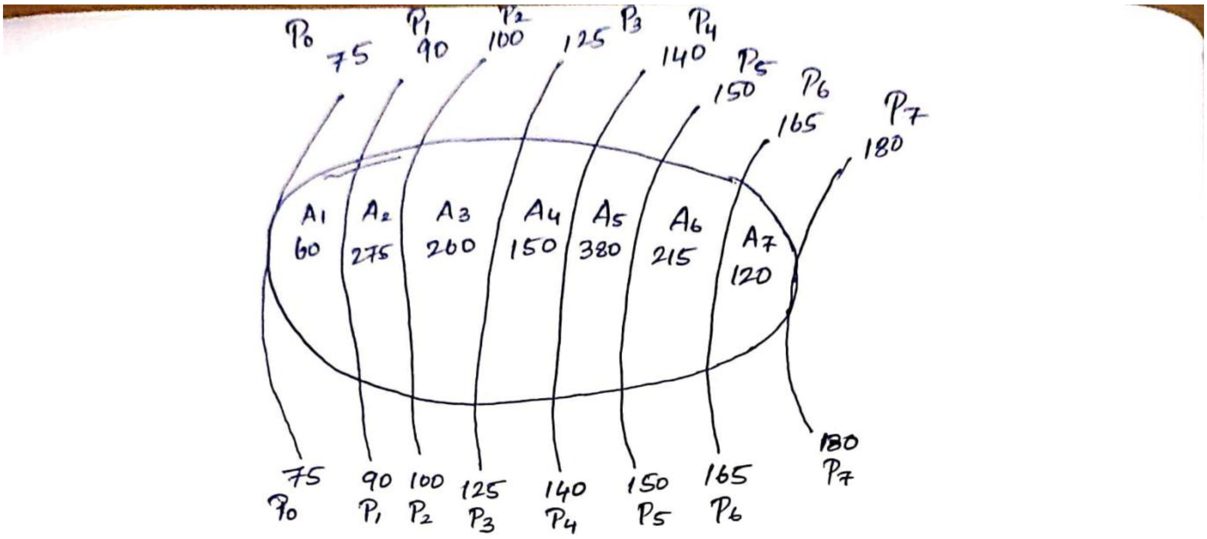
5. For a drainage basin of 600 km^2, estimate the average depth of precipitation over the catchment

Isohyets (cm)	Area (km^2)
15 -12	92
12-9	128
9-6	120
6-3	175
3-1	85

Isohyets [Given]	Average Value of Isohyets $\left(\frac{P_1+P_2}{2}\right)$	Area [Given]	Fraction of Total Area [Particular area/Total area of the catchment]	Weightage P_m $\left(\frac{P_1+P_2}{2}\right)$ x Fraction of Total Area
15 -12	13.50	92	92/600 = 0.1533	2.06955
12-9	10.50	128	128/600 = 0.2133	2.23965
9-6	7.50	120	120/600 = 0.20	1.50
6-3	4.50	175	175/600 = 0.2916	1.3122
3-1	2	85	85/600 = 0.1416	0.2832
		Total = 600		P_m = 7.4046

6. Estimate the average depth of precipitation over the catchment

<table>
<tr><th>Isohyets (mm)</th><th>Area between Isohyets (km^2)</th></tr>
<tr><td>75</td><td rowspan="2">60</td></tr>
<tr><td>90</td></tr>
<tr><td>100</td><td>275</td></tr>
<tr><td>125</td><td>260</td></tr>
<tr><td>140</td><td>150</td></tr>
<tr><td>150</td><td>380</td></tr>
<tr><td>165</td><td>215</td></tr>
<tr><td>180</td><td>120</td></tr>
</table>



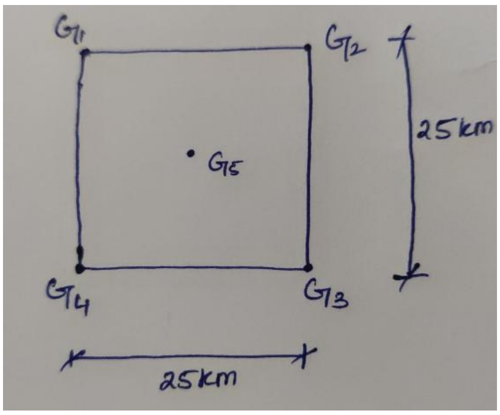
$$P_m = \frac{\left(\frac{75+90}{2}\right)60 + \left(\frac{90+100}{2}\right)275 + \left(\frac{100+125}{2}\right)260 + \left(\frac{125+140}{2}\right)150 + \left(\frac{140+150}{2}\right)380 + \left(\frac{150+165}{2}\right)215 + \left(\frac{165+180}{2}\right)120}{60+275+260+150+380+215+120}$$

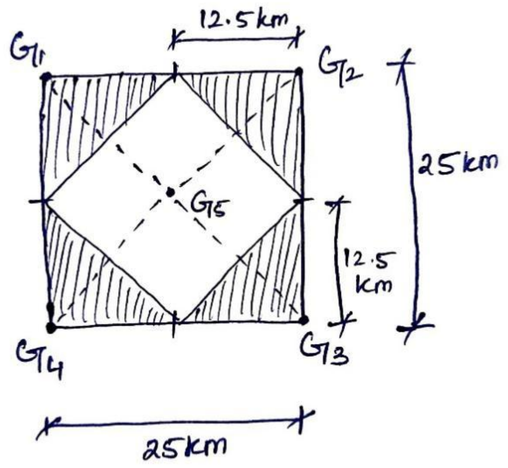
$$= \frac{4950 + 26125 + 29250 + 19875 + 55100 + 33862.5 + 20700}{1460}$$

$$= 130.04 \text{ mm}$$

7. Compute the average precipitation (in cm) over the catchment using Thiessen Polygon Method

Station	Rainfall (mm)
G_1	300
G_2	285
G_3	272
G_4	290
G_5	288





$$\text{Area of triangle} = \frac{1}{2}bh$$
$$= \frac{1}{2} \times 12.5 \times 12.5$$
$$= 78.125\, km^2$$

So, $A_1 = A_2 = A_3 = A_4 = 78.125\, km^2$

$$\therefore A_5 = (25 \times 25) - (4 \times 78.125)$$
$$= 625 - 312.5$$
$$A_5 = 312.5\, km^2$$

$$P_m = \frac{P_1A_1 + P_2A_2 + P_3A_3 + P_4A_4 + P_5A_5}{A_1 + A_2 + A_3 + A_4 + A_5}$$

$$= \frac{(300 \times 78.125) + (285 \times 78.125) + (272 \times 78.125) + (290 \times 78.125) + (288 \times 312.5)}{625}$$

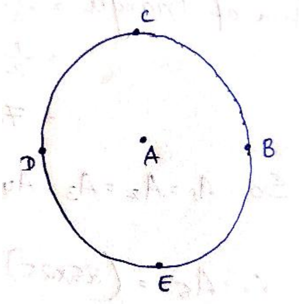
$$= \frac{23437.5 + 22265.625 + 21250 + 22656.25 + 90000}{625}$$

$$= \frac{179609.375}{625}$$

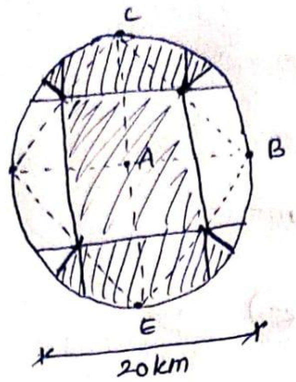
$$= 287.375\ mm.$$

$$P_m = 28.7375\ cm$$

8. Five raingauge stations namely A,B,C,D and E are located on a circular shape basin of diameter 20 km.



Station	Rainfall (mm)
A	100
B	90
C	110
D	120
E	80



$A_A = 10 \times 10 = 100 km^2$

$A_B = A_C = A_D = A_E \Rightarrow 100\pi - 100 \Rightarrow 214.16 km^2 \rightarrow \frac{214.16}{4} = 53.54 km^2$

total Area of Circle $= \frac{\pi}{4} \times d^2$

$= \frac{\pi}{4} \times 20^2$

$= 100\pi$

$$P_m = \frac{P_A A_A + P_B A_B + P_C A_C + P_D A_D + P_E A_E}{A_A + A_B + A_C + A_D + A_E}$$

$$= \frac{(100 \times 100) + (90 \times 53.54) + (110 \times 53.54) + (120 \times 53.54) + (80 \times 53.54)}{100\pi}$$

$$= \frac{10000 + \overset{4818.6}{\cancel{4300.6}} + 5889.4 + 6424.8 + 4283.2}{100\pi}$$

$P_m = 100cm.$

Depth – Area – Duration Relationships

- The areal distribution of characteristics of a storm of given duration is reflected in the depth area relationships and depth area curves.
- Precipitation rarely occurs uniformly over the whole area.

Depth – Area Relation

For a rainfall of a given duration, the average depth of rainfall decreases from the maximum or highest value as considered area increases.

The depth area relationship can be expressed by the following equation:

$$\bar{P} = P_0 \exp\left(-KA^n\right)$$

Where,

P = Average depth of rainfall in cm, over an area

P_o = Highest amount of rainfall observed at the storm centre

A = Area (km^2)

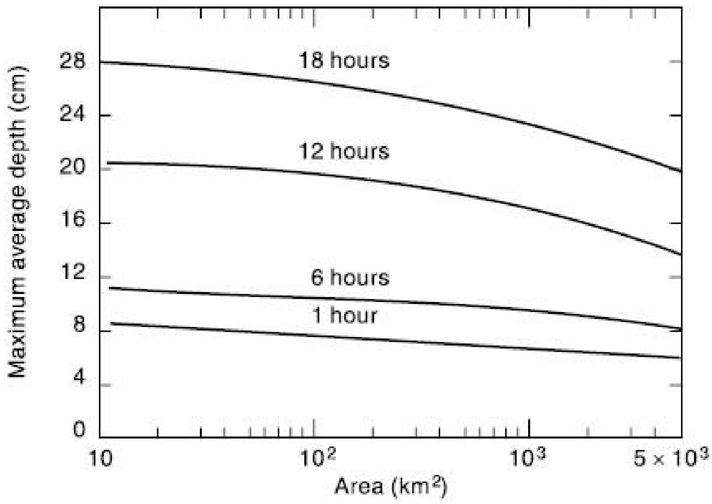
K, n = Constant for a given region

Typical values of K, n

Duration	*K*	*n*
1 day	0.0008526	0.6614
2 days	0.0009877	0.6306
3 days	0.001745	0.5961

Maximum Depth – Area – Duration Curves

- Rainfall rarely occurs uniformly over the whole of the catchment.
- Variations in total depth of rainfall and intensity occur from the centre of storms.
- The knowledge of maximum depth of rainfall occurring on areas of various sizes for storms of different durations is of great importance in many hydrological design problems.
- The development of relationship between maximum depth, area, duration for a region is known as “DAD Analysis”.
- DAD Analysis is performed to determine the maximum amounts of precipitation of various duration over the areas of various sizes.

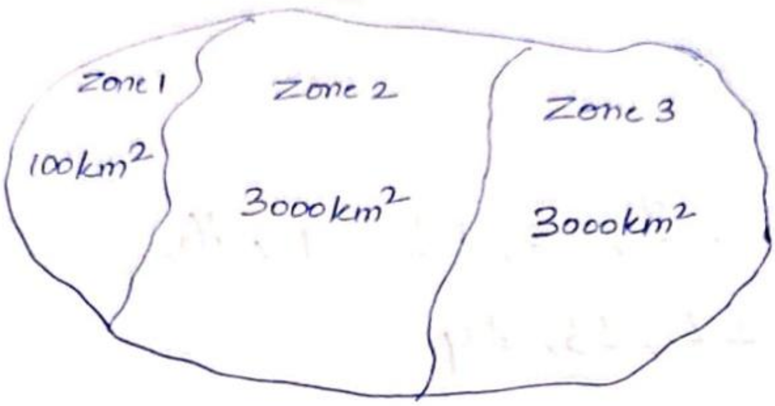


Typical DAD Curves

1. A catchment is divided into 3 zones with area of each zone as 100 km2, 3000 km2 and 3000 km2. Cumulate average rainfall (in mm) in different zones is given as

Time (hrs)	Zone 1	Zone 2	Zone 3
2	8	5	2
4	14	11	7
6	23	18	12
8	35	28	21
10	48	40	30

Draw the maximum average depth vs area plot for the duration of 2hrs, 4hrs and 6hrs.



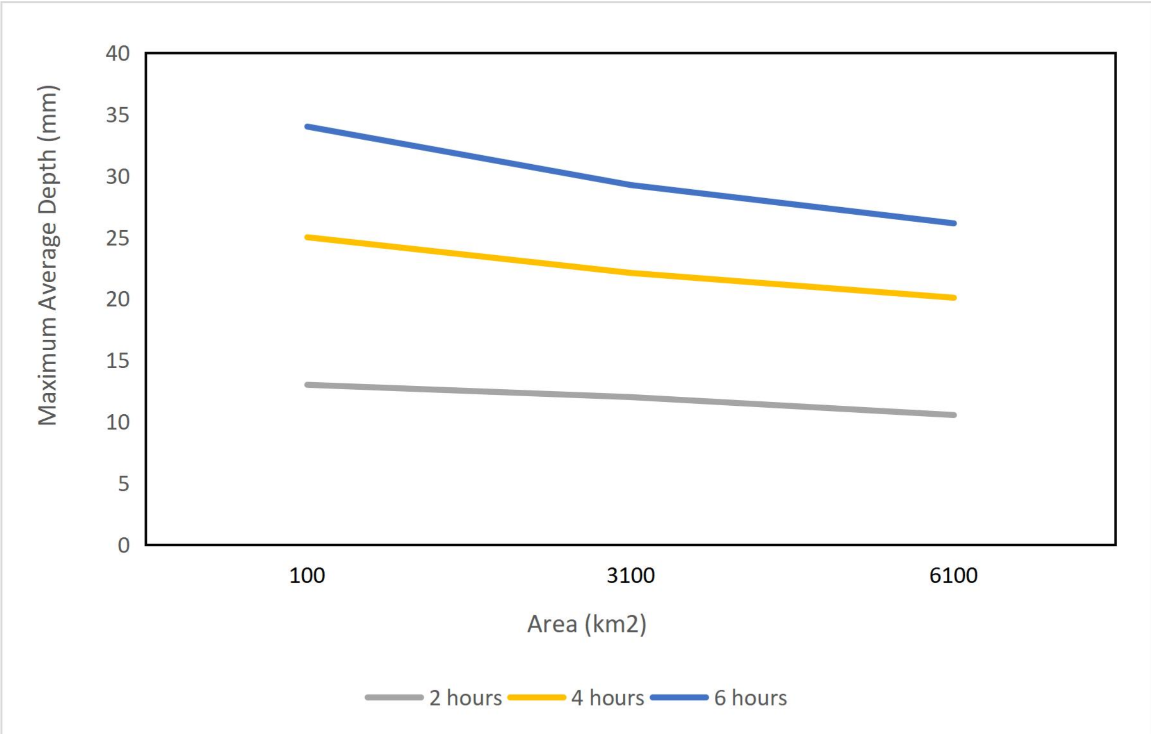
The Depth of Rainfall is calculated as below

Time	Zone - 1	Zone - 2	Zone - 3
2	$= \frac{8 \times 100}{100}$ $= 8$	$= \frac{(8\times100)+(5\times3000)}{100+3000}$ $= 5.09$	$= \frac{(8\times100)+(5\times3000)+(2\times3000)}{100+3000+3000}$ $= 3.57$
4	$= \frac{14\times100}{100}$ $= 14$	$= \frac{(14\times100)+(11\times3000)}{100+3000}$ $= 11.09$	$= \frac{(14\times100)+(11\times3000)+(7\times3000)}{100+3000+3000}$ $= 9.08$
6	$= \frac{23\times100}{100}$ $= 23$	$= \frac{(23\times100)+(18\times3000)}{100+3000}$ $= 18.16$	$= \frac{(23\times100)+(18\times3000)+(12\times3000)}{100+3000+3000}$ $= 15.13$
8	$= \frac{35\times100}{100}$ $= 35$	$= \frac{(35\times100)+(28\times3000)}{100+3000}$ $= 28.26$	$= \frac{(35\times100)+(28\times3000)+(21\times3000)}{100+3000+3000}$ $= 24.67$
10	$= \frac{48\times100}{100}$ $= 48$	$= \frac{(48\times100)+(40\times3000)}{100+3000}$ $= 40.26$	$= \frac{(48\times100)+(40\times3000)+(30\times3000)}{100+3000+3000}$ $= 35.21$

The maximum average depth of Rainfall is calculated as below

Duration	Area		
	$100 km^2$	$3100 km^2$ (100 + 3000)	$6100 km^2$ (100+3000+3000)
2hr.	Max of 14 - 8 = 6 23 - 14 = 7 35 - 23 = 12 48 - 35 = 13 = 13	Max of 11.01 - 5.10 = 5.91 18.16 - 11.01 = 7.15 28.28 - 18.16 = 10.10 40.26 - 28.26 = 12 = 12	Max of 9.08 - 3.57 = 5.51 15.13 - 9.08 = 6.05 24.67 - 15.13 = 9.54 35.21 - 24.67 = 10.54 = 10.54
4hr.	23 - 8 = 15 35 - 14 = 21 48 - 23 = 25 25	18.16 - 5.10 = 13.06 28.26 - 11.01 = 17.25 40.26 - 18.16 = 22.10 = 22.10	15.13 - 3.57 = 11.56 24.67 - 9.08 = 15.59 35.21 - 15.13 = 20.08 = 20.08
6hr.	35 - 8 = 27 48 - 14 = 34 = 34	28.26 - 5.10 = 23.16 40.26 - 11.01 = 29.25 = 29.25	24.67 - 3.57 = 21.10 35.21 - 9.08 = 26.13 = 26.13

Depth Area Duration Curve



<u>Probable Maximum Precipitation (PMP)</u>

- The probable maximum precipitation is the maximum possible precipitation that can be reasonably expected at a given location.
- PMP is defined as the greatest (or) extreme rainfall for a given duration i.e., physically possible over a station (or) basin.
- PMP can be statically estimated as

$$\mathrm{PMP} = \overline{P} + K\sigma$$

Where,

P = Mean of angular rainfall series

σ = Standard deviation

K = Frequency factor which depend upon the statically distribution

<u>World Greatest Observed Rainfall Data</u>

A list of world greatest observed rainfall data is made with the available data and plotted a logarithmic scale.

The data seems to be in line can be used for other data also

$$\boxed{P_m = 42.16\, D^{0.475}}$$

Where,

P_m = Extreme rainfall depth in cm, D = Duration in hours

Index of Wetness

The ratio of the actual rainfall in a given year at a given place to the average annual rainfall at a given place is known as "Index of wetness"

Index of Wetness = Actual rainfall in a given year at a given place/Average annual rainfall at a given place