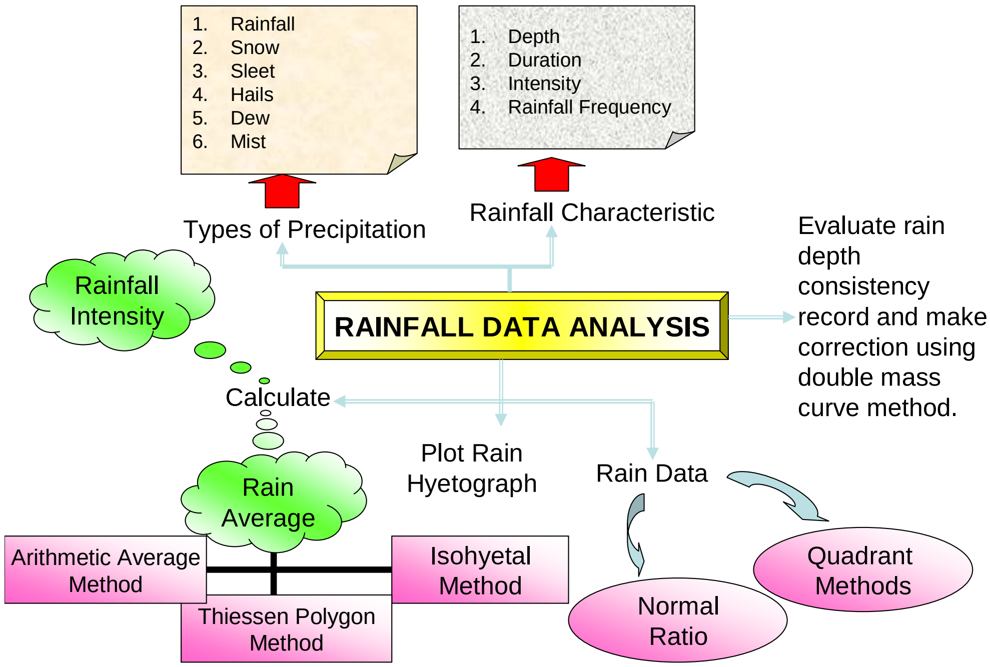


PERCIPITATION

- Precipitation is any dump or deposition in solid or liquid form that originated from the atmosphere.
- Most come from the sea.
- Precipitation occurs when water vapor cools.
- When the air reaches saturation point (also know as condensation point and dew point) the water vapour condenses and forms tiny droplet of water.
- Precipitation form a 0.001% of the world's water resources

TYPES OF PRECIPITATION

Horizontal Precipitation

- Water vapour become frozen near the surface or directly on the surface
- Example : dew and fog

Vertical Precipitation

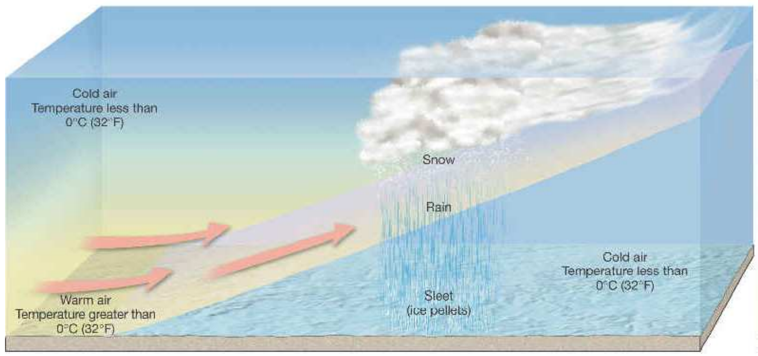
- Water vapour become freezing on the air and fall to the earth
- Example : rain and snow

RAINFALL

- Rain is the major from precipitation in the form of water drops sizes greater than 0.5 mm.
- The maximum sizes of rain drop is about 6mm based on the intensity, rainfall is classified as light rain (>2.5m.5mm/hr), moderate rain (2.5 – 7 mm/hr) and heavy rain (>7.5mm/hr)

SLEET

- Sleet refers to two distinct forms of precipitation:
- Rain and snow mixed snow that partially melts as it falls. (UK, Ireland and Canada)
- Ice pellets, one of three forms of precipitation in a US-style "wintry mix", the other two being snow and freezing rain. (US)



Sleet forms when rain passes through a cold layer of air and freezes into ice pellets. This occurs most often in the winter when warm air is forced over a layer of cold air.

SNOW

- Formed when water vapor through the atmosphere of high level under a temperature less than 0^0C and then fall back to the earth
- Snow is composed of ice crystals, primarily in complex hexagonal form and often aggregated into snowflakes that may have a diameter more than 25mm.

HAIL

- Hail is a form of precipitation which consists of balls or irregular lumps of ice (hailstones).
- Hailstones usually consist mostly of water ice and measure between 5 and 150mm in diameter, with the larger stones coming from severe thunderstorms.
- Hail is only produced by cumulonimbi (thunderclouds), usually at the front of the storm system and is composed of transparent ice or alternating layers of transparent and translucent ice at least 1mm thick.

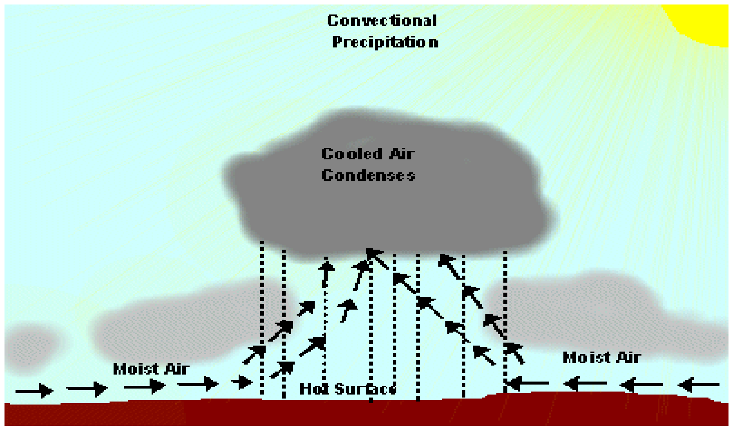
DEW

- Dew is water in the form of droplets that appears on thin, exposed objects in the morning or evening.
- As the exposed surface cools by radiating its heat, atmospheric moisture condenses at a rate greater than that of which it can evaporate, resulting in the formation of water droplets

MIST/ FOG

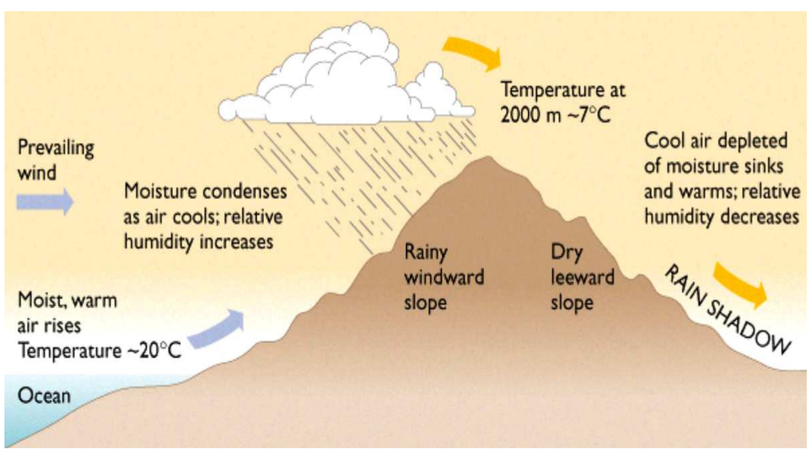
- Fog is a collection of water droplets or ice crystal suspended in the air at or near the earth's surface
- Fog begins to form when water vapor condenses into tiny liquid water droplet in the air.
- Fog normally occurs at a relative humidity near 100%

CONVECTIONAL PRECIPITATION



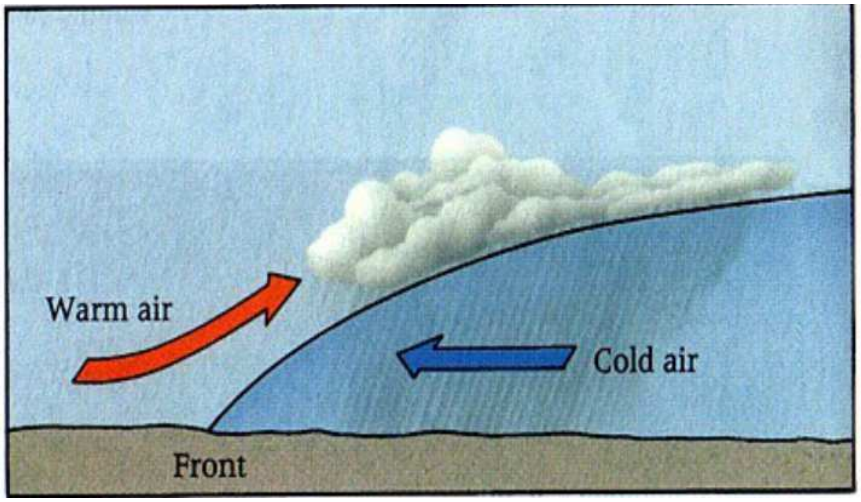
Stage 1	:	The sun heats the ground and warm air rises
Stage 2	:	As the air rises it cools and water vapour condenses to form clouds
Stage 3	:	When the condensation point is reached large cumulonimbus clouds are formed
Stage 4	:	Heavy rain storms occur. These usually include thunder and lightening due to the electrical charge created by unstable conditions.

ORGRAPHIC PRECIPITATION



Stage 1	:	Warm wet air id forced to rise over high land
Stage 2	:	As the air rises it cools and condenses. Clouds form and precipitation occurs.
Stage 3	:	The drier air descends and warms
Stage 4	:	Any moisture in the air (e.g. cloud) evaporates

FRONTAL PERCIPITATION (CYCLONIC)



Stage 1	:	An area of warm air meets and area of cold air
Stage 2	:	The warm air is forced over the cold air.
Stage 3	:	Where the air meets the warm air is cooled and water vapour condenses
Stage 4	:	Clouds form and precipitation occurs

CHARACTERISTICS OF PRECIPITATION

Quantity/ Depth

- Measurements in high-rainfall
- Measured in mm @ cm
- Measured by the hour, day, week, month and year

Intensity

- Depth of rainfall per unit time
- Example: 30 mm in 3 hours; intensity = 10mm/hr

Types of rainfall	Intensity
Light rain	< 2.5mm/hr
Moderate rain	2.5 mm to 7.6 mm/hr
Heavy rain	> 7.6mm/hr

Types of rainfall by intensity

Rainfall Frequency

- The frequency of rainfall occurred
- Repeat for the rain
- This situation can be illustrated by the rainfall that is:
  a) Uniform distribution: suitable for agriculture and reduce erosion
  b) Distribution of single-mode: rainfall in the wet season
  c) Distribution of dual mode

Duration
- The period of time during which rain fell
- Rain time interval fall measured in minutes and hour

Area
- Wide of rain catchment area
- Measured in km^2

Wind Speed Limit And Direction
- Depending on the wind
- Impact on flooding

Size Droplets
- Angle of dip and angle of impact
- Influence of agriculture, erosion, sediment

CALCULATE THE RAIN INTENSITY

- Rainfall intensity equation :

$$i = \frac{\text{Depth rainfall}}{\text{Time}}$$

$$\text{Volume, V} = \text{Area x Depth}$$
$$= m^3 \text{ @ } ka^3$$

Example 2.1

The rain that fall within 4 hours in the depth measure with rain gauge. The average depth is 6 in. Wide this area is 6 acres. Calculate the intensity and volume of rain

Solution

$$i = \frac{\text{Depth rainfall}}{\text{Time}}$$
$$= \frac{6 \text{ in}}{4 \text{ hour}}$$
$$= \mathbf{1.5\ in/hr}$$

$$\text{Volume, V} = \text{area x depth}$$
$$= \left(6 \text{ acres } \times \frac{4046.856 \text{ m}^2}{1 \text{ acres}}\right) \times \left(6 \text{ in} \times \frac{0.0254 \text{ m}}{1 \text{ in}}\right)$$
$$= \mathbf{3,700.24\ m^3}$$

Example 2.2

In one area it rained 20 minutes. 25 mm rain's depth for an area of 2.5 hectares. Calculate the intensity and volume of rain.

Solution

$$i = \frac{\text{Depth rainfall}}{\text{Time}}$$

$$= \frac{25\text{mm}}{20\text{ min}}$$

$$= \mathbf{1.25\ mm/min\ @\ 75mm/hr}$$

$$\text{Volume, V} = \text{Area x Depth}$$

$$= \left(2.5\text{ ha x } \frac{10{,}000\text{m}^2}{1\text{ ha}}\right) \text{ x } \left(25\text{mm x } \frac{1\text{ m}}{1000\text{mm}}\right)$$

$$= \mathbf{625\ m^3}$$

METHODS OF AVERAGING RAINFALL DATA

- There are 3 methods of averaging rainfall data
  - Arithmetic average
  - Theissen polygons
  - Isohyetal method

Although, most of these calculations are done with computer mapping programs, it is still useful to understand these methods.

ARITHMETIC AVERAGE

- This is the simplest of three methods
- Low reliability of data
- Rain gauge stations need to be in the catchment
- However, the station outside the catchment area, but near the watershed should be taken into account (the conditions of the area should be flat and reflects the catchment area)
- This method is used in two circumstances:
  a) The distance between each rain gauge is almost the same
  b) The medium-broad and subtle differences in topography

$$P = \frac{P1 + P2 + P3 + \ldots\ldots\ldots Pm}{n}$$

$$P = \sum Pi / n$$

where:

P = Average depth of rainfall
P_i = Sum of rainfall amounts at individual rain gauge stations
n = Number of rain gauge stations in the area.

Example 2.3

Compute precipitation average below using the arithmetic method

Stations	Rainfall (mm)
A	1.46
B	1.92
C	2.69
D	4.50
E	2.98
F	5.00

Solution

Average rainfall $= \frac{1.46 + 1.92 + 2.69 + 4.50 + 2.98 + 5.00}{6}$

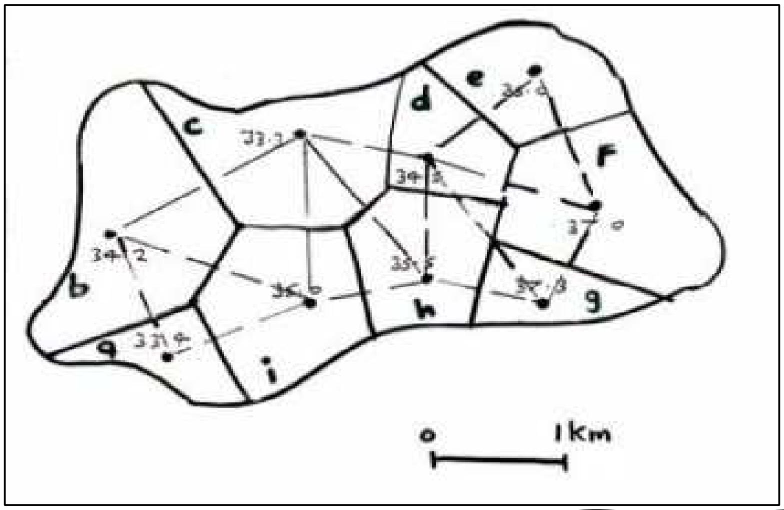
= **3.09mm**

THIESSEN POLYGON

- This method takes its name after A.M Thiessen who suggested it first in 1911.
- This method attempts to allow for non-uniform distribution of gauge by prooviding a weighting factor for each gauge.
- Catchment area is split into sub-area polygons using each station as the center points
- It assume that the precipitation is uniform (not suitables for hilly areas)

THIESSEN POLYGON METHOD FOR MAPPING RAINFALL

- The locations of rain gauges are potted on a scale map of the catchment and surrounding area.
- The locations (stations) are joined with straight lines in order to form a pattern of triangles, preferably with sides of approximately equal length.
- Perpendicular bisectors to the sides of these triangles are drawn to enclose each station within polygon called a Thiessen polygon, (each polygon contains only one rain gauge station.
- Calculate the area of each polygon and the average of precipitation



$$\textbf{Average of rainfall} = \frac{\sum \text{ precipitation x polygon area}}{\sum \text{ polygon area}}$$

$$P = \frac{P_1A_1 + P_2A_2 + P_3A_3}{A_1 + A_2 + A_3}$$

OR BY TABLE

Station	Rainfall (mm)	Area (km^2)	Thiessen weights	Weights average
1	40	4.5	0.23	9.2
2	42	6.75	0.35	14.7
3	49	3.00	0.15	7.35
4	38	5.25	0.27	7.35
		∑ 19.5		**∑ 41.51 mm**

Thiessen weight = $\frac{\text{Area}}{\text{Total area of basin}}$

= $\frac{4.5}{19.5}$

= 0.23

Weight Average = Thiessen weight x rainfall

= 0.23 x 40

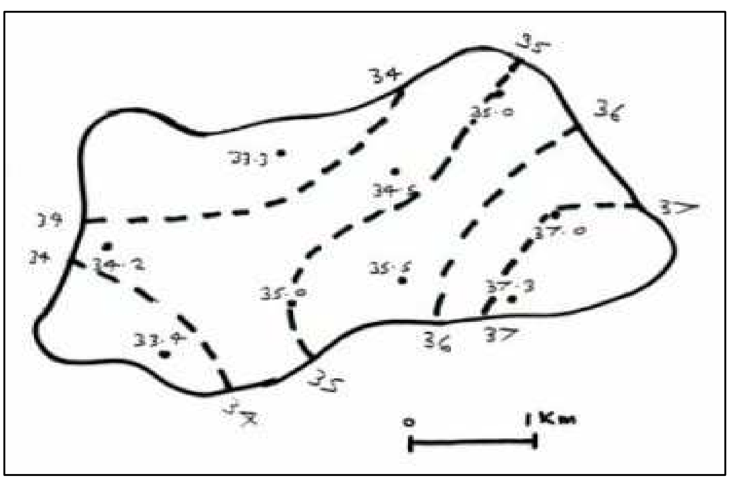
= 9.2 mm

ISOHYETAL METHOD

- Is the best method but requires efficient
- Also known as rain equivalence method of line
- Isohyetal is a line that connects the dots with the same heavy rain. In this method outside of the station catchment area are also taken into account.
- Suitable for the hilly and sloping areas. Also suitable for areas with an area of over 500km^2

ISOHYETAL METHOD FOR MAPPING RAINFALL

- The location of rain gauges are plotted on a scale map of the catchment and surrounding area.
- Each station's rainfall depth is used to draw isohyets throughout the catchment in a manner similar to that used in the preparation of topographic contour maps.
- The mid-distance between two adjacent isohyets is used to delineate the area of influence of each isohyet.



- The average precipitation over catchment is calculated by formula:

$$P = \frac{A_1\left(\frac{P_1+P_2}{2}\right)+A_2\left(\frac{P_2+P_3}{2}\right)+\ldots\ldots\ldots\ldots A_{n-1}\left(\frac{P_{n-1}+P_n}{2}\right)}{\Sigma A}$$

ESTIMATES OF MISSING DATA

- Rainfall data analysis process requires a continuous record of rainfall data precipitation of data inconsistencies caused by:
  a) recorders neglect
  b) recorder equipment damage (rain gauge)
- Thus missing data should be estimated before the analysis is performed
- Data loss can be estimated by using the gauge stations near
- Three methods commonly used in the estimation:
  a) Arithmetic average method
  b) Normal ration method
  c) Quadrant methods

ARITHMETIC AVERAGE METHOD

This method is used if the annual rainfall at each of the index station within 10% of that or station X

$$\mathbf{Px = \frac{1}{M} \times \sum (Pi)}$$

$$\mathbf{= \frac{1}{M} (P1 + P2 + P3 + \ldots\ldots PM)}$$

Example 2.4

In a watershed, there are four rain gauges. One of the gauges has been damaged. Reading for the three stations nearby and normal annual rainfall given as in the table. Estimate the rain gauge readings for precipitation which is damaged.

Reading of rain gauge (mm)	Normal annual rainfall (mm)
37	726
42	752
49	760
X	694

Solution

Normal annual rainfall for the X, Nx = 694mm
10% of Nx = 0.1 x 694
= 69.4mm

The maximum allowable rainfall = 694 + 69.4
= 763.4 mm

As the value of 726, 752 and 760 is less than 763.4mm, so the average method can be used

Annual rainfall station X, Px = 1 / 3 x (37 + 42 + 49 + 49)
= 42.7mm

NORMAL RATIO METHOD

This method use if the normal annual rainfall at any of the index station differs by more than 10% from that station X

$$P_X = \frac{N_A}{n} \sum (P_i / N_i) \text{ @}$$

$$P_X = \frac{N_A}{n} \left(\frac{P_1}{N_1} + \frac{P_2}{N_2} + \ldots\ldots + \frac{P_m}{N_m} \right)$$

where :

N_X = normal annual rainfall for the missing station data
n = number of index stations
P_1, P_2, P_3 = rainfall for the index stations

Example 2.5

In an area placed 4 rain gauges A, B, C & D. After the inspection gauge D is not working. Estimate the annual rainfall station D where the normal annual rainfall and the annual rainfall reading is given as shown in table

Station	Normal Annual Rainfall	Reading of Precipitation
A	1120	107
B	935	89
C	1200	122
D	978	X

Solution

If Nx = 978mm
10 % from Nx = 97.8mm
Normal annual rainfal = 978.8 + 97.8
= 1075.8mm

Due to normal annual rainfall at station A & C exceeding 1075.8mm so the normal ratio method is used
.

$$P_X = \frac{N_A}{n} \quad \frac{P_1}{N_1} + \frac{P_2}{N_2} + \ldots\ldots + \frac{P_m}{N_m}$$

$$= \frac{978}{3} \left(\frac{107}{1120} + \frac{89}{935} + \frac{122}{1200} \right)$$

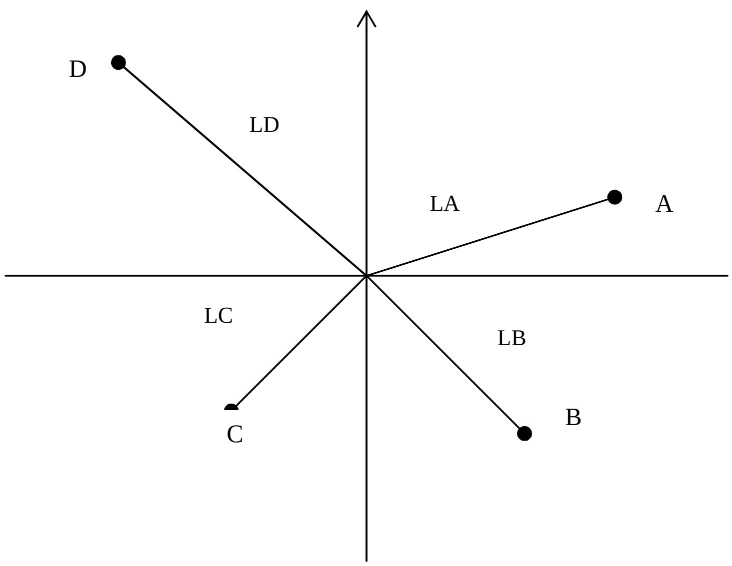
$$= \mathbf{95.4mm}$$

QUADRANT METHOD

- This method is used by U.S National weather service in the studies of river forecasting.
- In this method four quadrant are delineated by north-south and east-west line passing through the rain gauge station where the missing rainfall is to be estimated.

PROCEDUR

- Plot the location of all stations
- Build x-y axis through the gauge which missing data as the origin
- Select the four rain gauge stations from each quadrant and the closest to the origin
- Calculate the distance from each station of origin



Position of station X and index station A, B, C and D

- The procedure is described by the following formula

$$P_X = \frac{\sum_{i=1}^{4} (P_i / L_i^2)}{\sum_{i=1}^{4} (1 / L_i^2)}$$

which

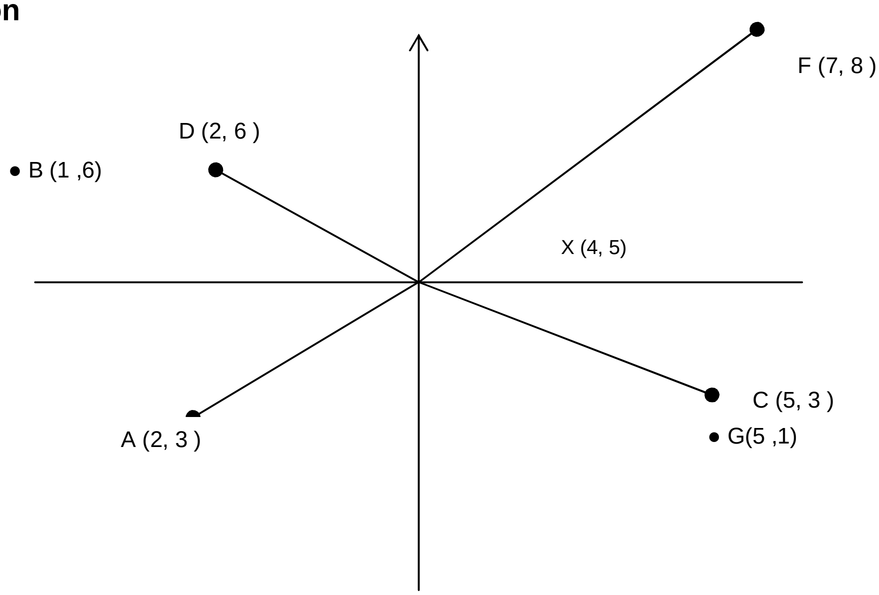
P = Precipitation
L = Distance between index stations and station X
i = Refer to each one of the index station A, B, C and D

Example 2.6

The table below shows rainfall data and the position of rain gauge for a basin. Estimate the rainfall data in station X by using quadrant method.

Station	Rainfall	Coordinates
X	-	4,5
A	100	2,3
B	105	1,6
C	109	5,3
D	110	2,6
E	90	1, -3
F	98	7,8
G	85	5,1

Solution



$$\mathbf{P_X} = \frac{\sum_{i=1}^{4} (P_i / L_i^2)}{\sum_{i=1}^{4} (1/L_i^2)}$$

$$P_X = \frac{\frac{100}{(-2^2 + -2^2)} + \frac{98}{(3^2 + 3^2)} + \frac{109}{(1^2 + -2^2)} + \frac{110}{(-2^2 + 1^2)}}{\frac{1}{8} + \frac{1}{18} + \frac{1}{5} + \frac{1}{5}}$$

$$P_X = \frac{61.74}{0.58}$$

$$= \mathbf{106.45\ mm}$$

Example 2.7

Stations A, B, C, D, E, F is the observation station rainfall data. Record for station A is not complete because of flooding. Rainfall values for the other stations are 40, 45, 37.5,50 and 42.5mm. The quadrant of the four have been drawn, the coordinates for the station is B (4, 2), C (1.6), D (3, 2), E (3.3) and F (2,2). Calculate the amount of rainfall for station A.

Station	Rinfall P	X	Y	$D^2 = X^2 + Y^2$	$W = 1/D^2$	P x W
A	P_A	0	0	0	0	0
B	40	4	2	20	0.050	2
C	45	1	6	37	0.027	1.215
D	37.5	3	2	13	0.077	2.888
E	50	3	3	18	0.056	2.8
F	42.5	2	2	8	0.125	5.313
					∑0.335	**∑14.216**

$$D^2 = X^2 + Y^2 = 4^2 + 2^2 = 20$$

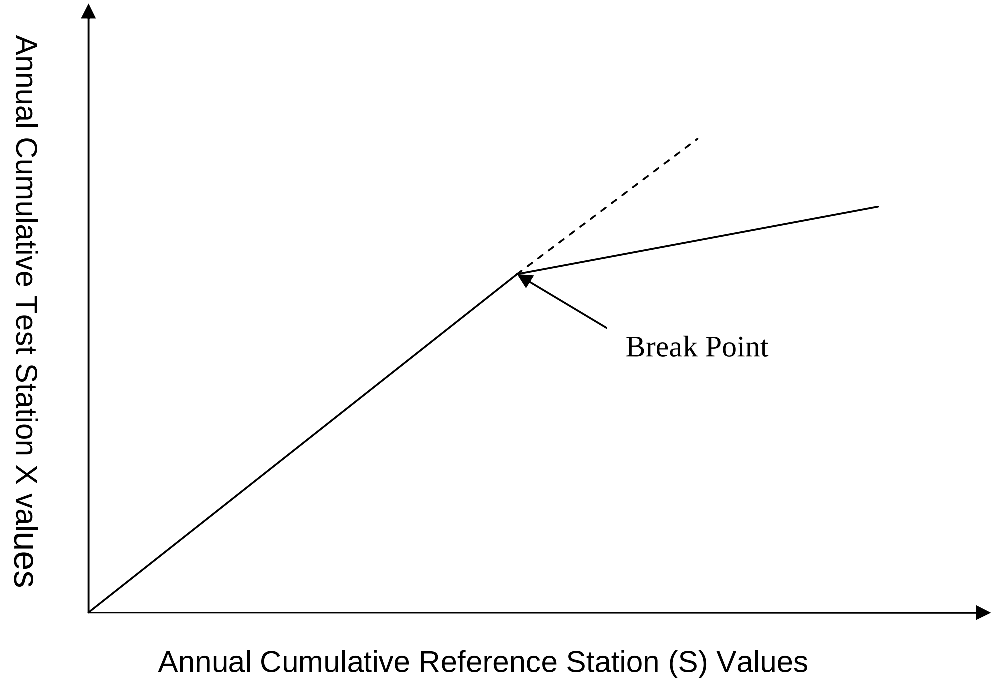
$$P_A = \frac{14.216}{0.335} = 42.436\,\textbf{mm}$$

CHECKING CONSISTENCY DATA

Changes in the location or exposure of rain gauge, significant changes in the station environment and changes in ecosystems due to natural disasters may have a significant effect on the amount of precipitation it measures, leading to inconsistent data (data of different nature within the same record). The consistency of a rainfall record is tested with double mass analysis.

DOUBLE MASS ANALYSIS

- This method compares the cumulative rainfall data stations with a cumulative average annual rainfall of all the surrounding stations
- The cumulative pairs (double mass values) are plotted in a xy arithmetic coordinate system, coordinate system and the plot is examined for trend changes.
- If the plot is essentially linear the record at record at station Y is consistent.
- If the plot shows a break in slope the record at station Y is inconsistent and should be corrected.



- The correction can be done by using the following formula :

$$P_a = \frac{M_a}{M_i} \times P_o$$

P_a = Correction in rainfall data that is observed
P_o = Rainfall data from observation (original)
M_a = slope line of rain's data consistent
M_i = slope line of rain's data inconsisten

TOTURIAL

1) Compute the average depth of rainfall for catchment show in Fig 1.0 with an area of 200 km^2, using the arithmetic and Theissen polygon. The rainfall amounts are indicated in mm at the respective gauge sites. Also compute the volume of rain water in m^3 received by the catchment area in each case.

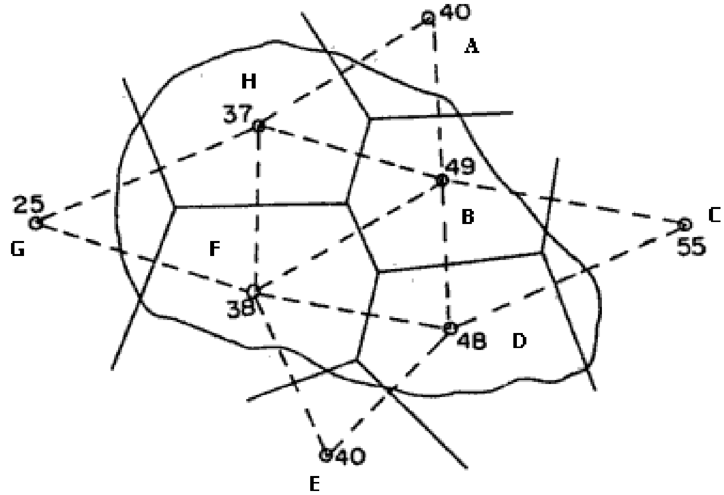


Fig 1 : Theissen polygon

2) The network of 10 stations on and around a river basin has the Thiessen weights of 0.10, 0.06, 0.11, 0.07, 0.08, 0.09, 0.11, 0.12, 0.16 and 0.10 respectively. Stations 2, 4 and 5 lie outside the basin while the remaining is inside. If the rainfall recorded at these gauges during the storm are 150, 168,158,135,156,207,138,162,114 and 132mm respectively. Determine the average depth of rainfall over the basin by arithmetic and Thiessen mean methods.

3) The isohyets drawn for a storm which occurred over a drainage basin of area 950km^2 yielded the following information.

Isohyet interval in mm	85-75	75-65	65-55	55-45	45-35
Area between isohyets in km2	125	236	264	175	150

Determine the average depth of rainfall over the basin

4) Rain gauge station X did not function for a part of a month during a storm occurred. The storm produced rainfalls of 84, 70 and 96mm at three surrounding stations A, B and C respectively. The normal annual rainfalls at the station X, A, B and C are respectively 770,
882, 736 and 944 mm. Estimate the missing storm rainfall at station X.

5) Neighboring rain gauge stations A, B, C, D, E and F have normal annual rainfall of 610,554,468,606,563 and 382mm respectively. During storm, stations B,C,D,D, E and F have reported rainfalls of 22,29,35,13,25mm respectively and station A did not report as it was inoperative. Estimate the missing storm rainfall at A.

6) Station X failed to report the rainfall recorded during a storm. With respect to east-west and north-south axes set up at station X, the coordinated of 4 surrounding gauges, which are the nearest to the station X respective quadrants, are (10,15), (-8 ,5), (-12, -9), and (5,-15) km respectively. Determine the missing rainfall at X, if the storm rainfalls at the four surrounding are 73, 89, 68 and 57mm respectively.

7) Station A failed to report the rainfall during a storm. With respect to east-west and north-south axes set up at station A, the co-ordinates of 4 surrounding gauges which are the nearest to A in the respective quadrant are (7.5,7.5), (-10,15), (-5,-6.5), (12,-8) km respectively. Determine the missing rainfall at A, if the storm rainfalls at the four surrounding gauges are 98, 67, 72 and 53mm.

8) The annual precipitation data at rainfall gauge station X on the Polytechnic of Kota Bharu, were to tested for consistency from 1972 through 1987. Data at eight neighboring gauge stations also were obtained and are presented on the following table.

Year	Precipitation at X (mm)	8- station average (mm)
1972	35	28
1973	37	29
1974	39	31
1975	35	27
1976	30	25
1977	25	21
1978	20	17
1979	24	21
1980	30	26
1981	31	31
1982	35	36
1983	38	39
1984	40	44
1985	28	32
1986	25	30
1987	21	23

a) Test the consistency of station X records. If a change in regime is identified, report the year in which the change occurred
b) Adjust station X records so that the regime before the break is maintained for all values.

9) A water catchments area has a rainfall record from 1976-1992. After five years of data observed at station A start, a project was developed in the area. The project involves felling of trees, equalization of land and buildings. Station A had been transferred to other locations but this affects the consistency of the data. You are asked to review this data and make modifications to existing records.

YEAR	ANNUAL RAINFALL STATION				
	A	B	C	D	E
1976	32.9	39.8	45.7	30.7	37.4
1977	28.1	39.6	38.5	41	30.9
1978	33.5	42	48.3	40.4	42
1979	29.6	41.4	34.6	32.5	39.9
1980	23.8	31.6	45.1	36.7	36.3
1981	54.4	56.5	53.3	62.4	36.6
1982	46.3	48.1	40.1	47.9	38.6
1983	30.8	39.9	29.6	32.7	26.9
1984	46.8	45.4	41.7	36.1	32.4
1985	38.1	44.9	48.1	30.7	41.6
1986	40.8	32.6	39.5	35.4	31.3
1987	37.9	45.9	44.1	39.2	44.1
1988	50.7	46.1	38.9	43.3	50.6
1989	46.9	49.8	41.6	49.9	41.1
1990	50.5	4703	49.7	47.9	39
1991	34.4	37.1	31.9	32.2	34.5
1992	47.6	45.9	38.2	52.4	47.3

10) The cumulative rainfall depth with time during a storm as obtained from a recording rain gauge at a station is given below

Time in hours	10.00	10.30	11.00	11.30	12.00	12.30	13.00	13.30	14.00	14.30	15.00	15.30	16.00
Rainfall (mm)	0	6	11	24	29	38	51	57	61	66	67	67	67

a) Construct the hyetograph of this storm using uniform time interval of 30 minutes and also 2 hours
b) Compute the maximum average intensities of rainfall for duration of 30 minutes, 1 hour, 2 hours, 3 hour and 5 hours in this storm and plot the resulting intensity duration curve.