```
•	print ("*********************************************")
•	print ("**********************FTW 2016**********************")
•	print  ("This code uses water budget equation to compute change in storage")
•	print ("*********************************************")
•	from  decimal import Decimal

•	print("please input the precipitation  (m3);")
•	pcp=float (input ())
•	print( "please input the evapotranspiration(m3):")
•	et=float (input  ())
•	print ("please input any inflow in to the system  (m3):")
•	vin=float (input ())
•	print  ( "please input any outflow from the system(m3):")
•	vot=float (input ())
•	print("please input the infiltration volume (m3):")
•	inf=float (input ())
•	print("please input any otherloss from the system(m3):")
•	ot=float (input ())
•	cs0=Decimal (pcp+vin-vot-et-ot-inf)
•	cs=round (cs0,3)
•	print ("*********************************************")
•	if cs <0:
•	 print ("the initial storage has decreased by",cs,"m3")
•	elif cs==0:
•	 print ("no change in the storage volume")
•	else:
•	 print ("the initial storage has incresaed by",cs ,"m3")
•	print ("*********************************************")
```

PRECIPITATION

Chapter -2

- **PRECIPITATION** is all forms of water that reach the earth from the atmosphere.
- The magnitude of precipitation varies with time and space
- The detail study of precipitation is called **hydrometeorology**

Forms of Precipitation

- **Drizzle:** very small (they appear to float in the air) size less than 0.5mm and intensity less than 1mm/h
- **Rain:** The term rainfall is used to describe precipitation in the form of water drops of sizes 0.5mm to 6mm
- **Hail**: It is a showery precipitation in the form of irregular pellets or lumps of ice of size more than 8mm
- **Snow:** Snow consists of ice crystals which usually combine to form flakes. average density of 0.1gm/cm^3**.**
- **Glaze/Frost:** When rain or drizzle comes in contact with cold ground at around 0^{0}C**, the water drops freeze to form an** ice coating called glaze or freezing rain.
- **Sleet:** It is frozen raindrops of transparent grains which form when rainfalls through air at subfreezing temperature. Sleet in many places denotes precipitation of snow and rain simultaneously.

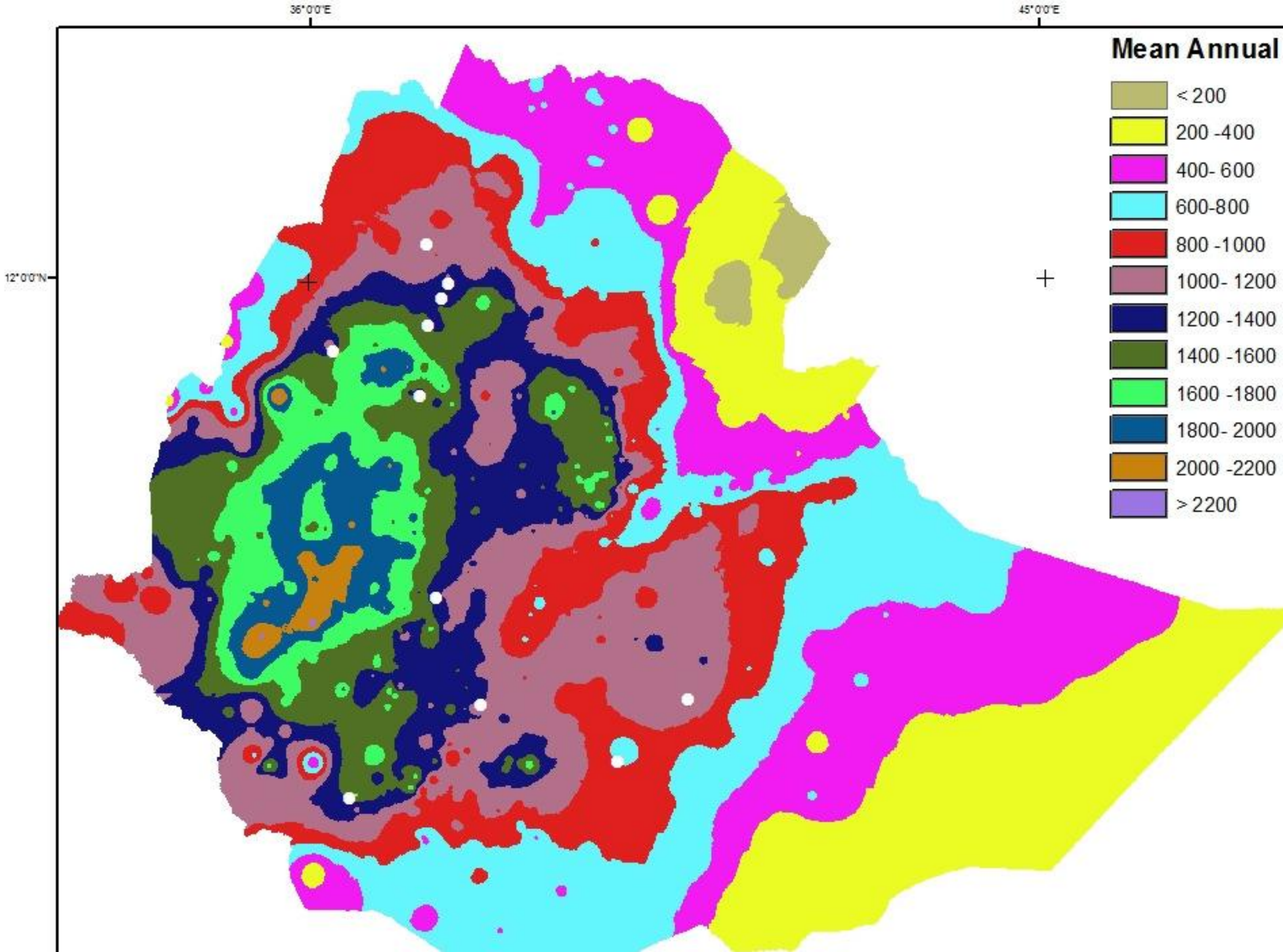

36°0'0"E
45°0'0"E
12°0'0"N
Mean Annual
< 200
200 -400
400- 600
600-800
800 -1000
1000- 1200
1200 -1400
1400 -1600
1600 -1800
1800- 2000
2000 -2200
> 2200

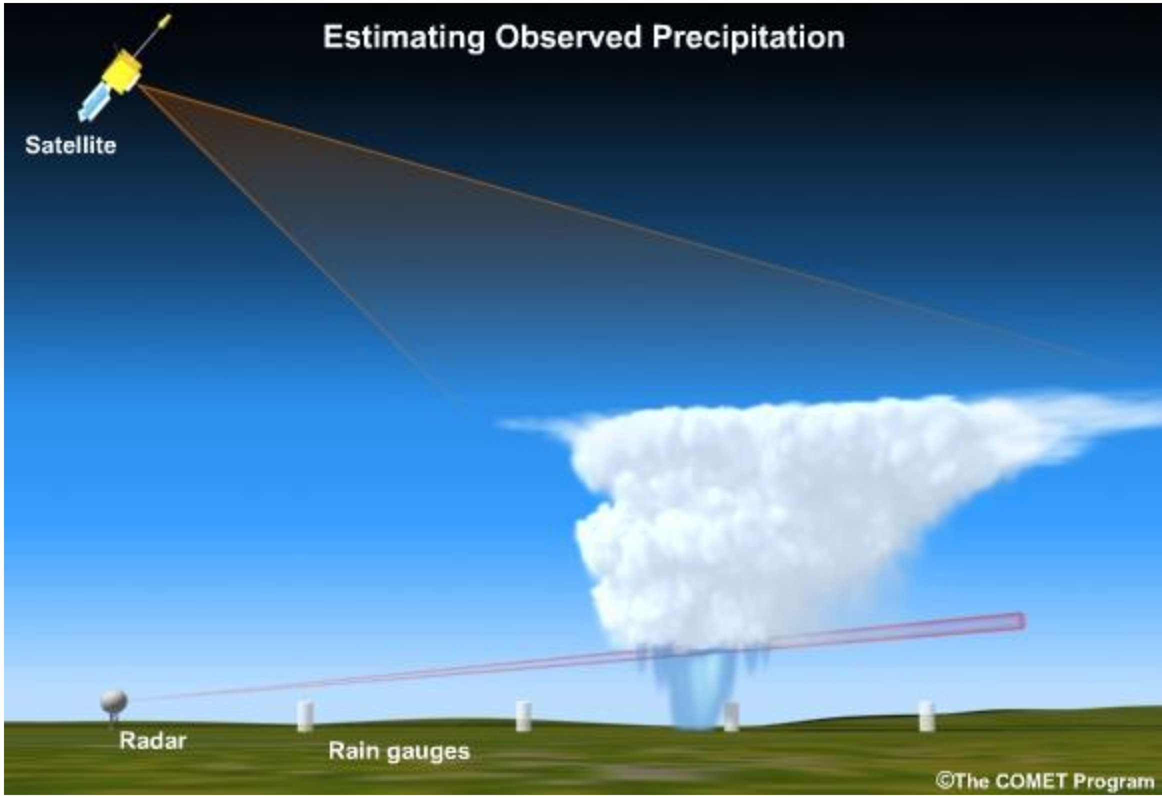
Fig. 2.1 - The Rainfall Regimes of Ethiopia

Causes of precipitation

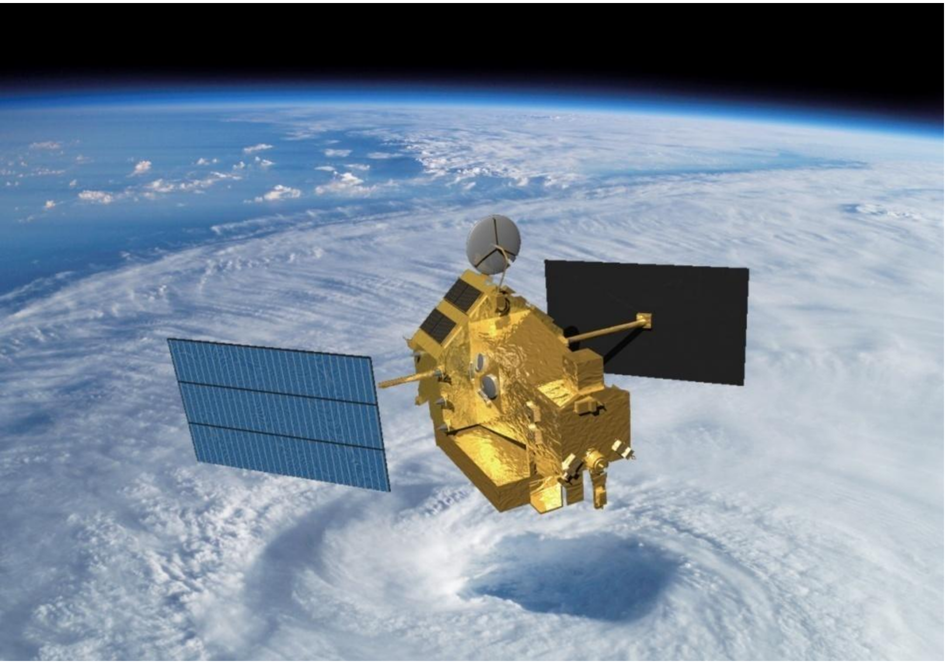
- Weather conditions must be good for condensation of water vapor to take place
- The atmosphere must have moisture
- There must be sufficient nuclei present to aid condensation
- The products of condensation must reach the earth

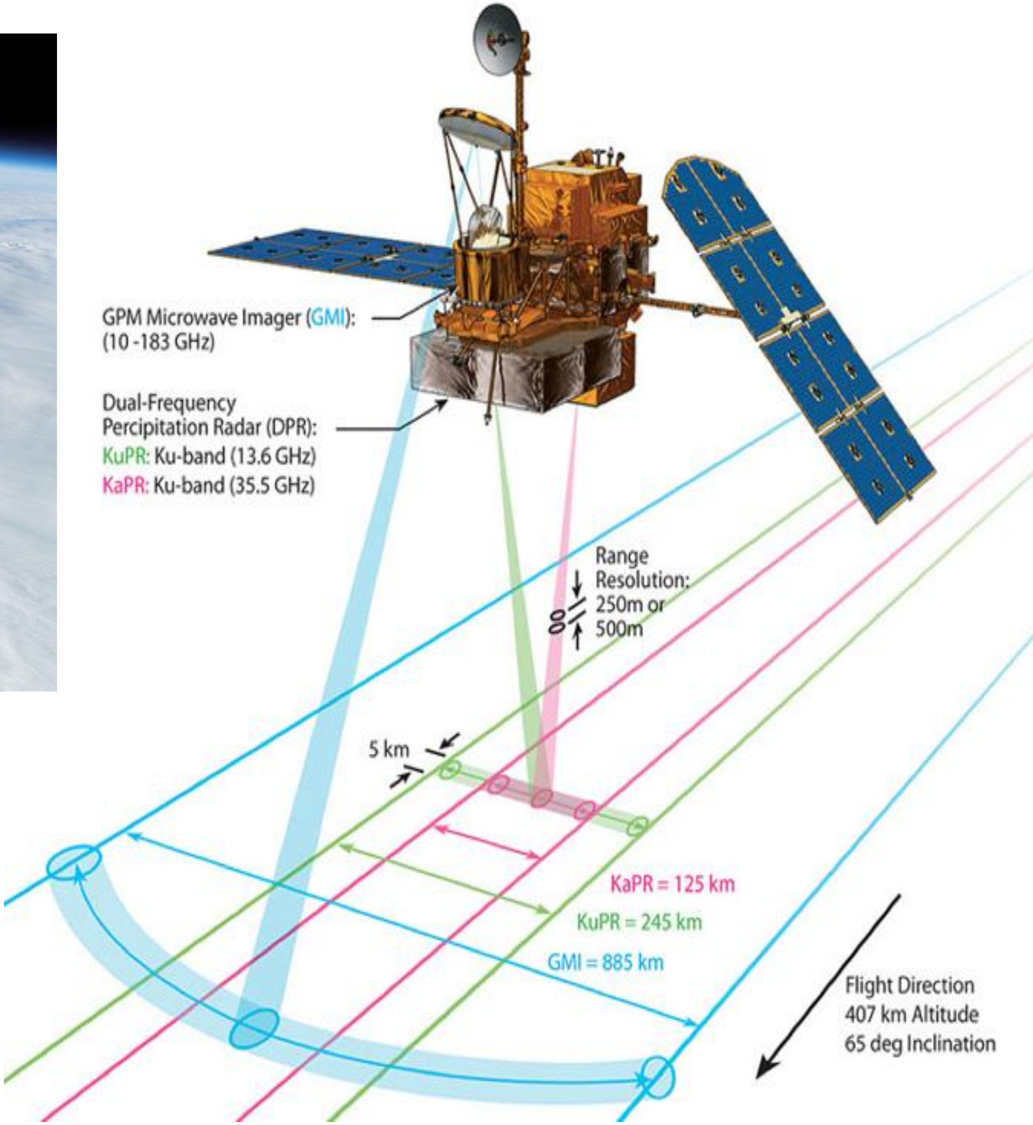
Measurement of Rainfall

- *Measurement of magnitude, intensity, location, patterns of Rainfall.*
- *Measured by:*
  - Rain gauge
  - RADAR
  - Satellite

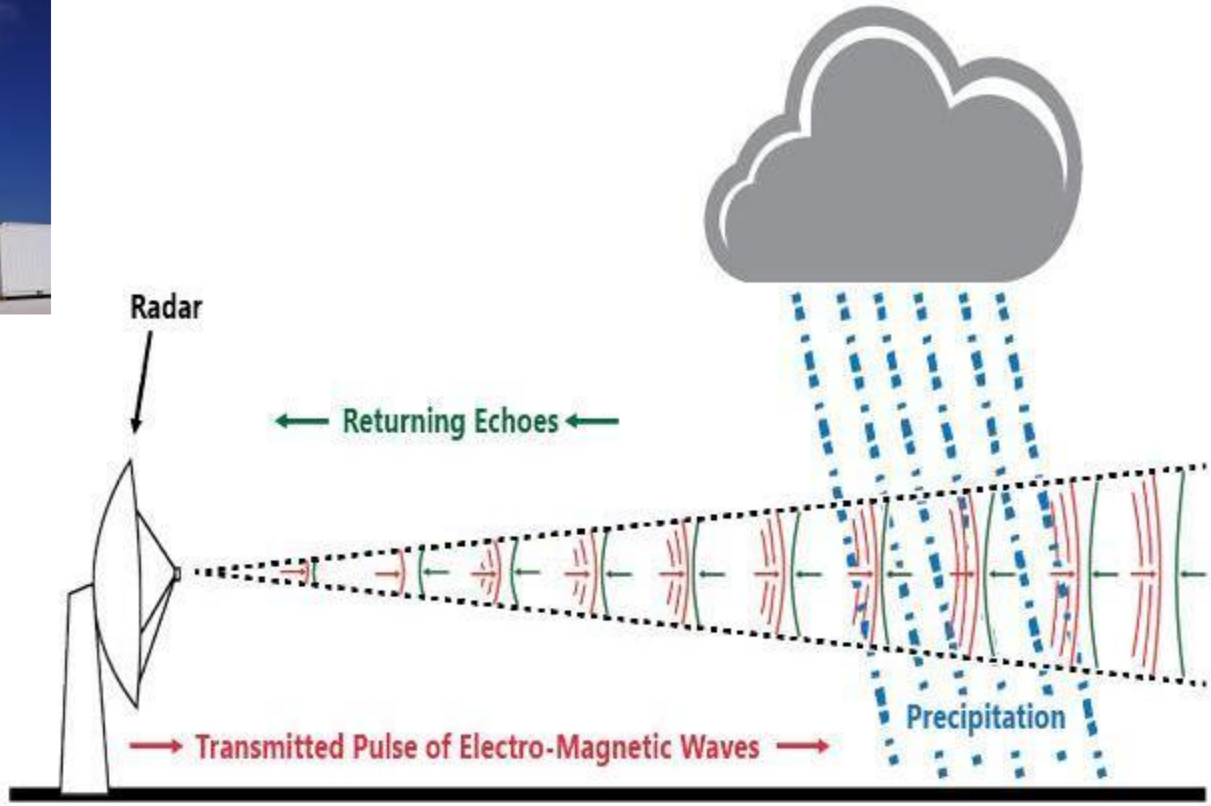


Satellite




GPM Microwave Imager (GMI):
(10 -183 GHz)
Dual-Frequency
Percipitation Radar (DPR):
KuPR: Ku-band (13.6 GHz)
KaPR: Ku-band (35.5 GHz)
Range
Resolution:
250m or
500m
5 km
KaPR = 125 km
KuPR = 245 km
GMI = 885 km
Flight Direction
407 km Altitude
65 deg Inclination

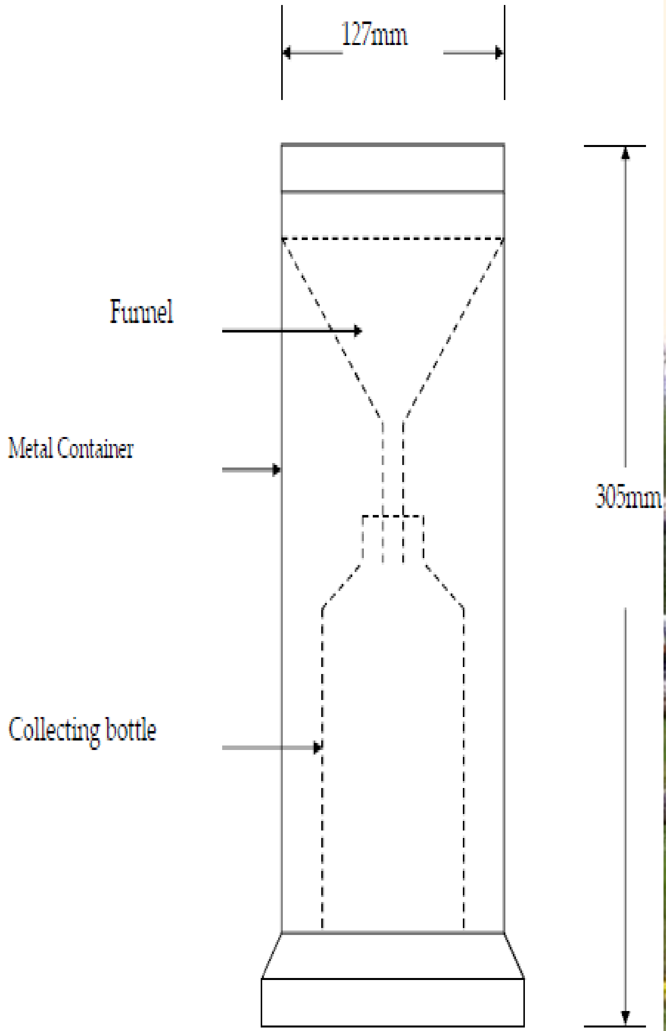
RADAR


Radar
Returning Echoes
Precipitation
Transmitted Pulse of Electro-Magnetic Waves

Rain gauges

- Measures the amount (depth) of rainfall at a single point.
- SI Standard
  - 127mmdiameter (5 inches)
  - 1.2 m height above ground (4 feet)
- Requirements
  - Sharp edge
  - Rim falls away vertically
  - Prevent splashing
  - Narrow neck prevents evaporation

Rain gauges



Types of Rain gauges

- **Non-recording and Recording rain gauges**
  – A non-recording rain gauge is typically a catchment device calibrated to provide visual observation of rainfall amounts
  – Recording gauges are equipped with paper charts and/or data logger equipment

Non - Recording Rain gauges

- Measure with calibrated flask or dipstick
- Flask usually tapered to allow accuracy if little rain
- Evaporation losses high and its prevented by

– oil film

– small exposed surface area

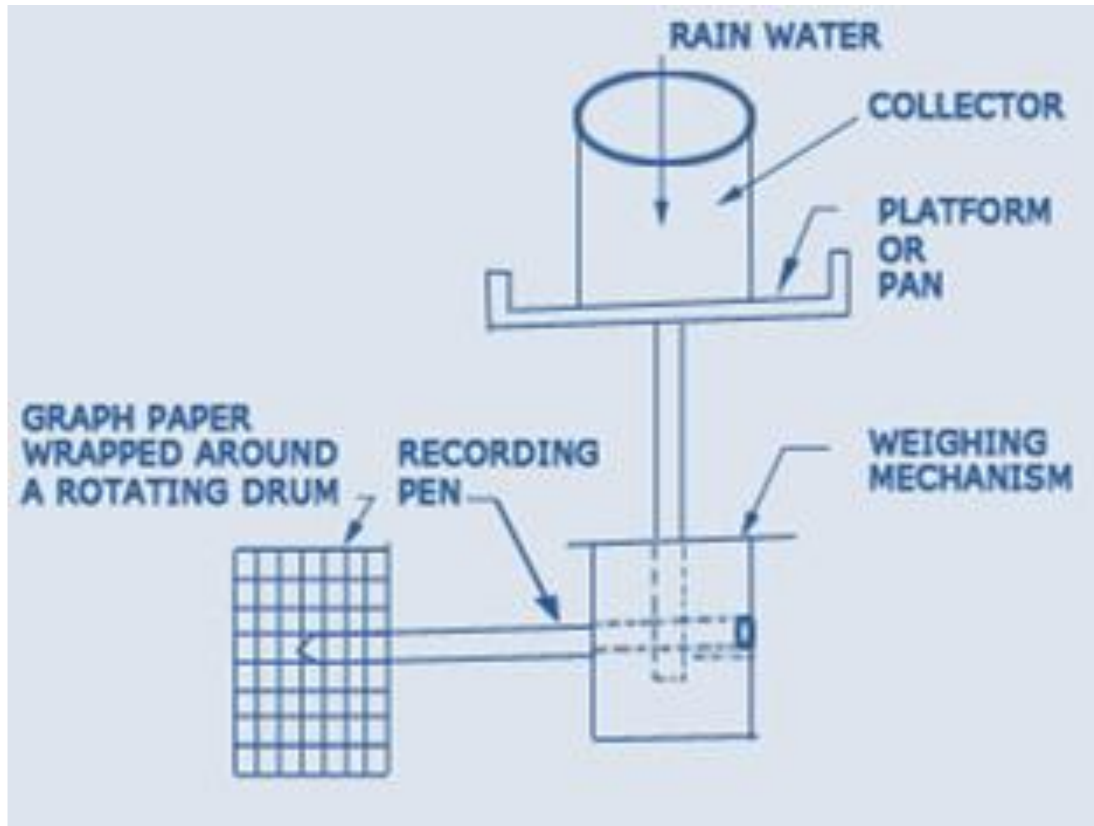
– poor ventilation

– low internal temperature

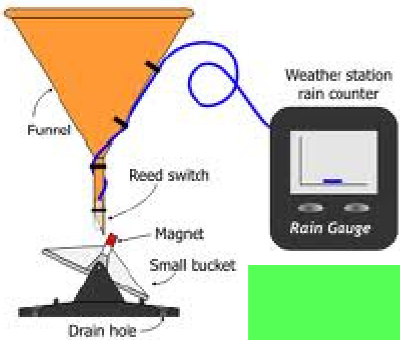
Recording Rain gauges

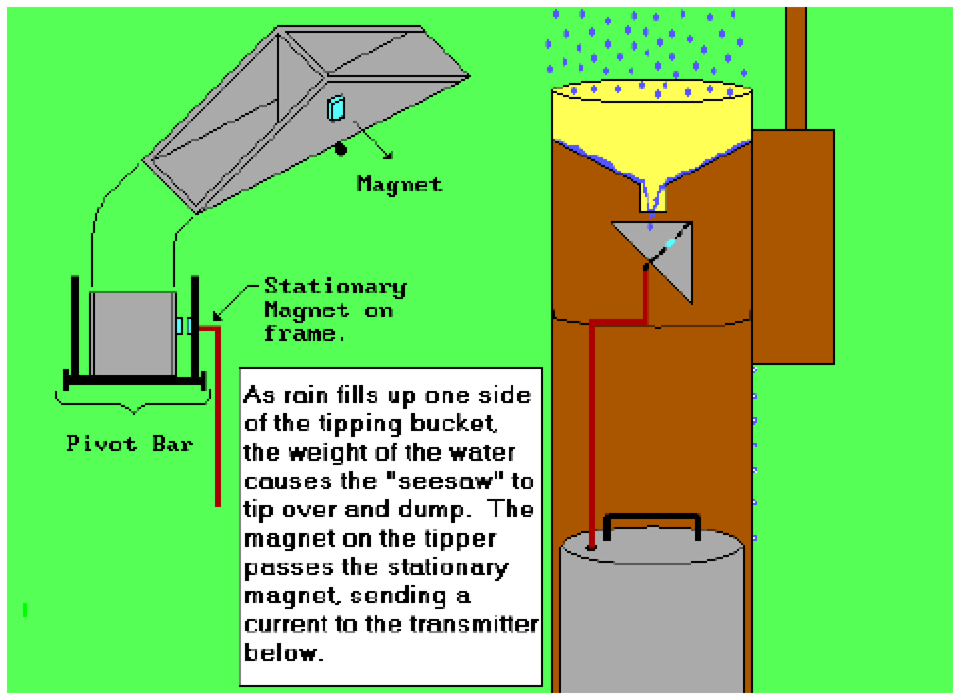
- **Analogue Devices**
  – Weighing Bucket Rain Gauge
  – Float Type Rain Gauge
- **Digital Devices**
  – Tipping Bucket Rain Gauge
  – Optical Rain Gauge

Weighing Bucket Rain Gauge

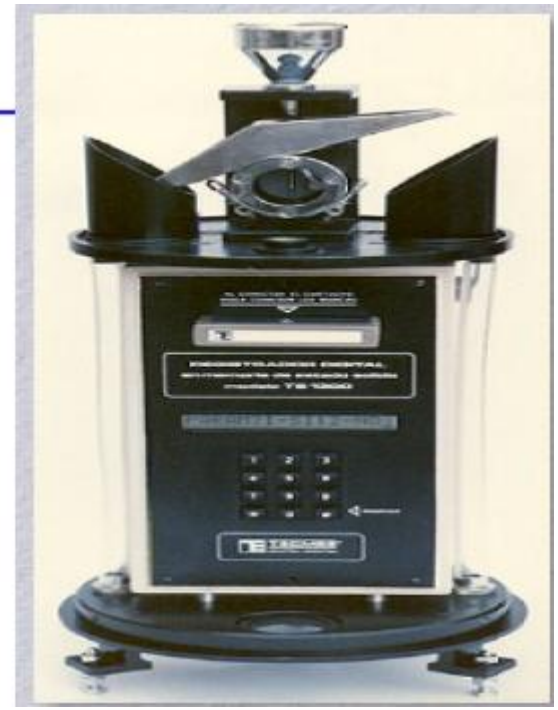


Tipping Bucket Rain Gauge

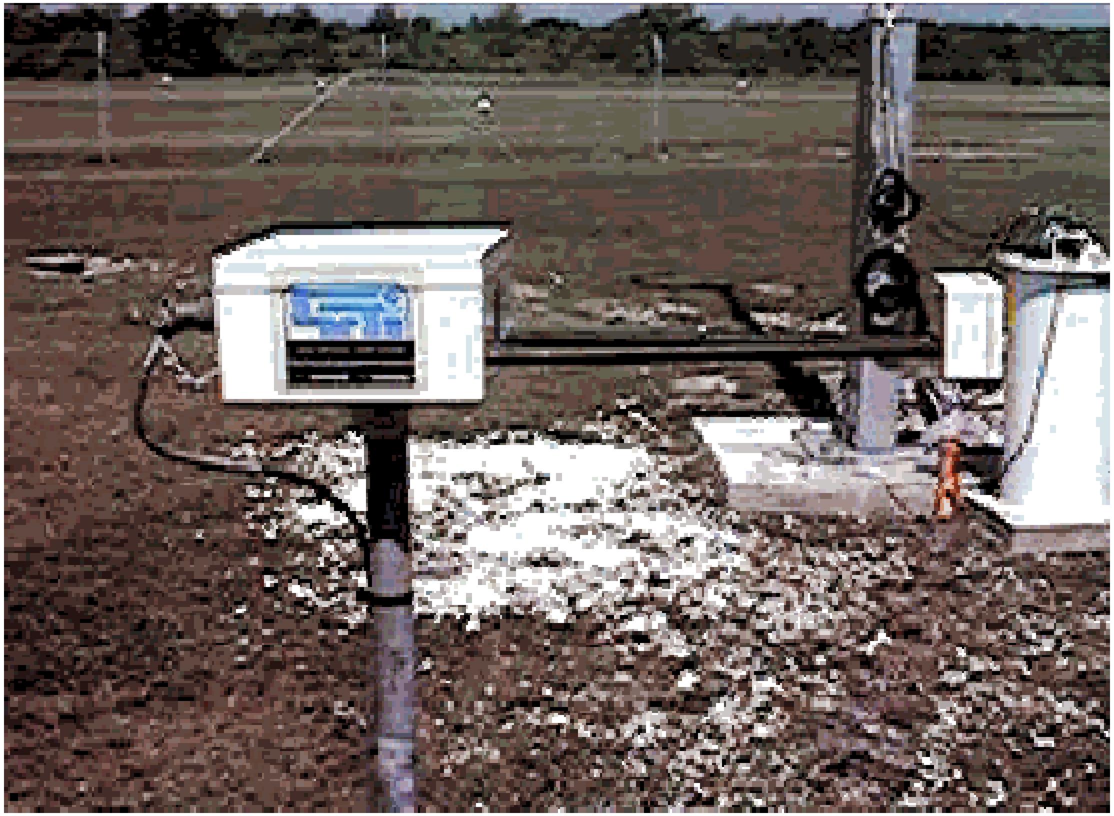




Tipping Bucket Rain Gauge



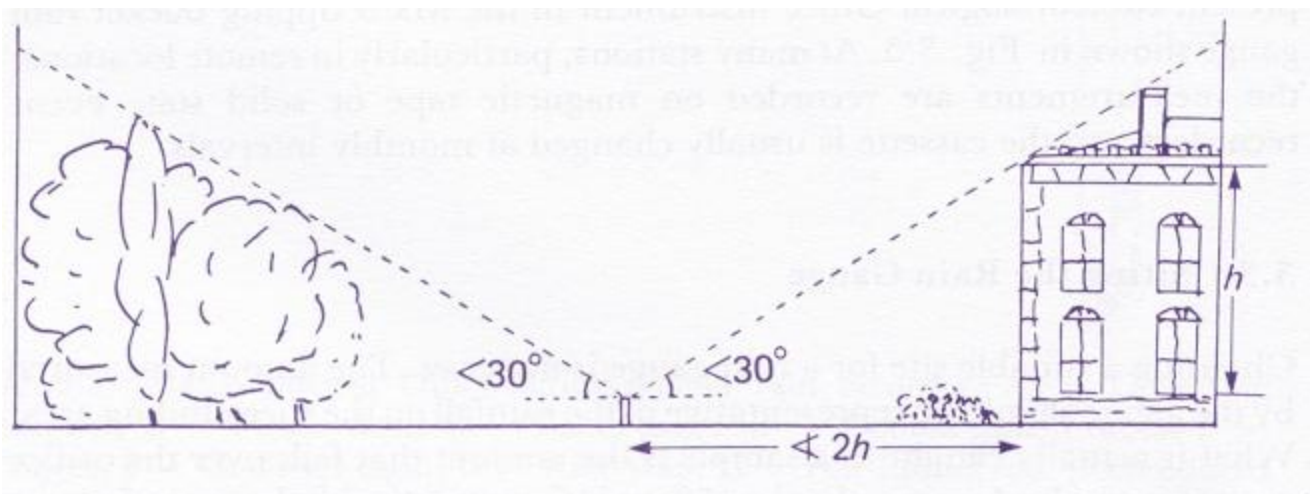
Optical Rain Gauge (ORG)



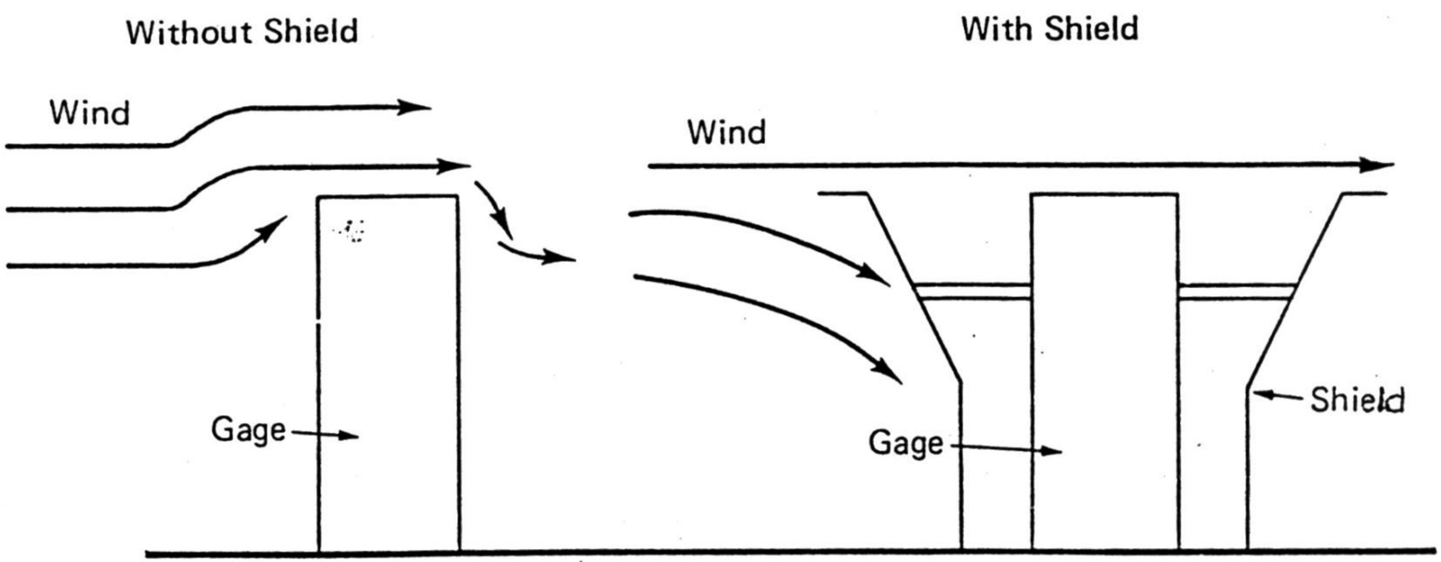
SMET ORG - Optical Rain Gauge

Consideration to set rain gauge

- The ground must be level and in the open air and the instrument must be fixed on a horizontal catch surface.
- The gauge must be set as near the ground as possible to reduce wind effects but it must be sufficiently high to prevent splashing, flooding
- The instrument must be surrounded by an open fenced area of at least 5.5m x 5.5m. No object should be nearer to the instrument less than 30^{o} or twice the height of the obstruction.
- Ideally, the gauge should be sited with some shelter, but not over-sheltered
- Windshields may reduce the loss due to turbulence(eddies) around the gauge



<30°
<30°
h
∢ 2h



Without Shield
With Shield
Wind
Wind
Gage
Gage
Shield

Rain Gauge Network

- Precipitation varies both in time and space
- Sound hydrologic/hydraulic designs require adequate estimation of temporal/ spatial precipitation patterns

The density of rain gauge network depends on

(1) purpose of the study;

(2) geographic configuration of the study region;

(3) economic consideration

- A minimum density for precipitation gauge network: (at least 10% are automatic recording gauges)

Region Type	Range of norms for min network [km²/gauge]	Range of provisional norms in difficult conditions [km²/gauge]
I	600 – 900	900 – 3000
IIa	100 – 250	250 – 1,000
IIb	25	
III	1500 – 10,000	

I: Flat region of temperature, Mediterranean & tropical zones;

IIa: Mountain region of temperate, Mediterranean & tropical zones

IIb: Small mountains island with very irregular precipitation requiring very dense hydrographic network

III: Arid and polar zones

Adequacy of rain gauge stations

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

N – Optimal number of stations

Cv– coefficient of variation of the rainfall values at the existing *m* stations (in percent)

ε – Allowable degree of error in the estimate of the mean rainfall

$$C_v = \frac{\sigma_{m-1}}{\overline{p}} \times 100 \qquad \sigma_{m-1} = \sqrt{\frac{\sum_1^m \left(P_i - \overline{P}\right)^2}{m-1}}$$

$$\overline{P} = \frac{1}{m}\left[\sum_1^m P_i\right]$$

σ_{m-1} – Standard deviation

P_i – Precipitation magnitude in the i^{th} station

m – number of existing stations

Errors Precipitation Measurement

1. **Human Error**: scale reading and water displacement (if a dip stick is used)
2. **Instrumental Defect**: water to moisten the gauge; speed at which mechanical devices work (such as tipping bucket gages); and inadequate use of wind shield
3. **Improper sitting**: height above ground of the gage orifice; exposure angle; and regionalization techniques

Example 2-1

- A catchment's has six rain gauge stations. In a year, the annual rainfall recorded by the gauges are as follows:

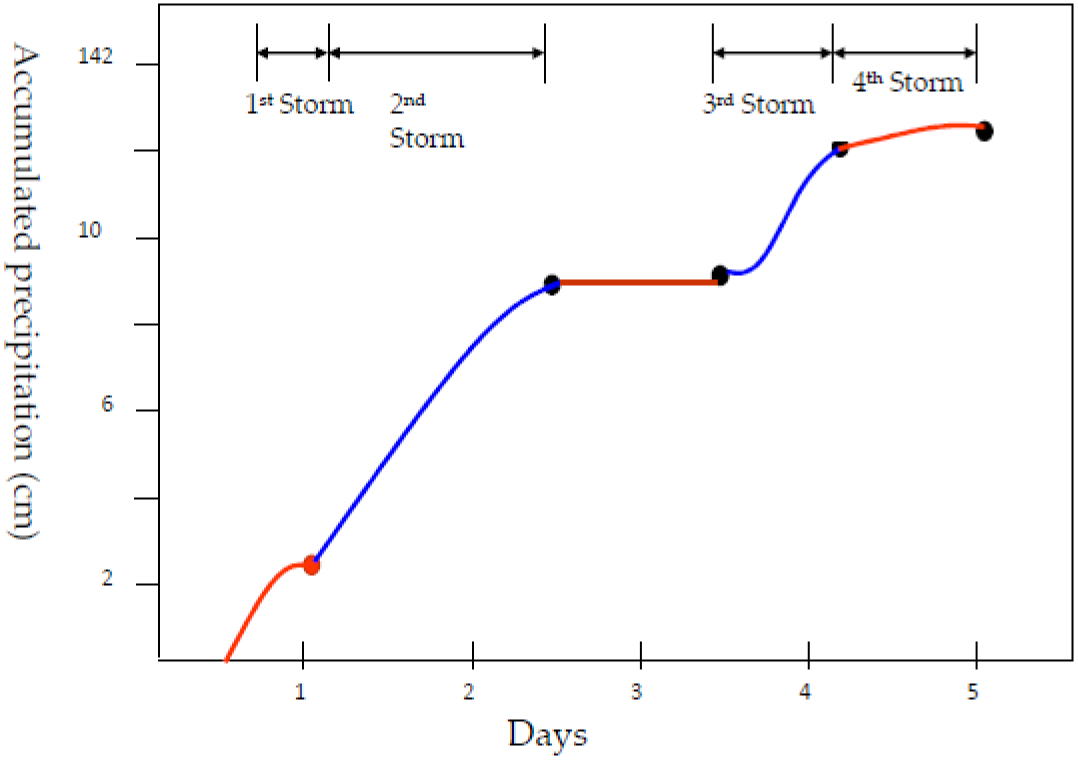
Station	A	B	C	D	E	F
Rainfall (cm)	82.6	102.9	180.3	110.3	98.8	136.7

- For a 10% allowable error in the estimation of the mean rainfall, calculate the optimum number of stations in the catchment's

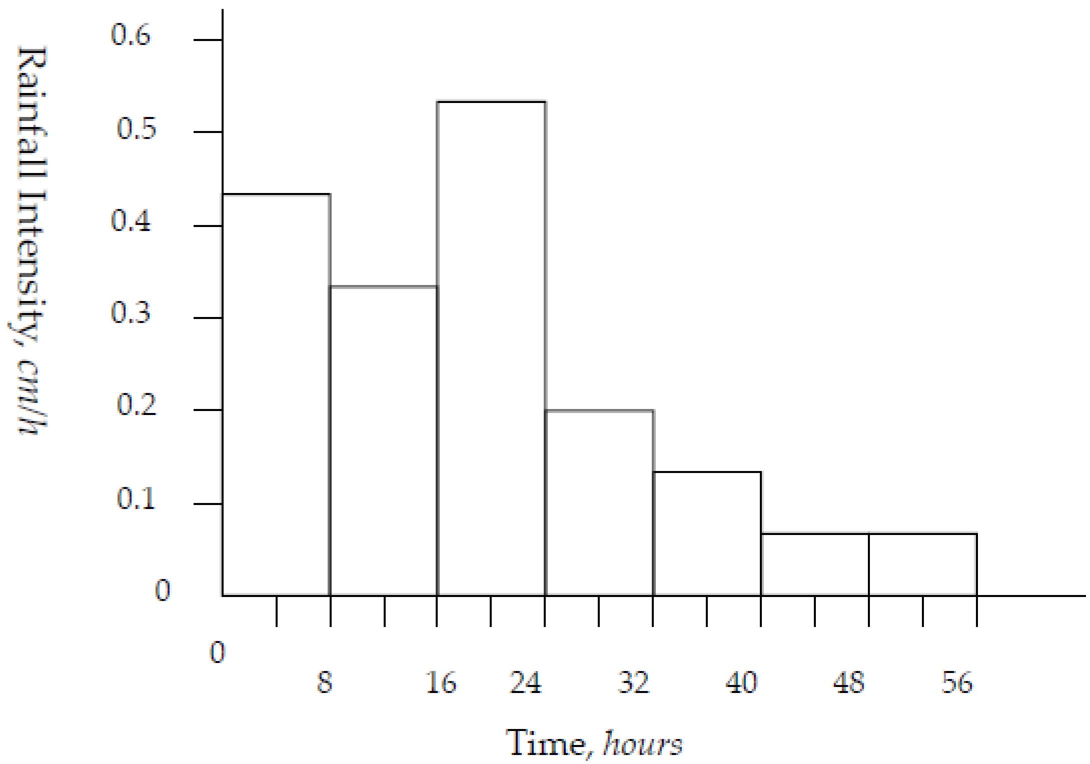
Rainfall Data Processing

- *Hourly Rainfall :* ***the rainfall depth in*** *each hour*
- *Daily Rainfall* ***: depth of Rainfall in*** *24 hour*
- *Decadal Rainfall* ***: sum of*** *10 days* ***rainfall***
- *Monthly Rainfall* ***:*** *sum* ***of*** *daily* ***rainfall of days*** *in* ***a*** *month*
- *Annual Rainfall* ***: sum of monthly rainfall in a*** *year*
- *Mean Daily Rainfall****: The*** *average daily* ***rainfall over long year***
- *Mean monthly Rainfall* ***: the*** *average monthly* ***rainfall over the long year***
- *Mean annual Rainfall****: the*** *average of annual* ***rainfall over the long year***
- *Maximum Daily Rainfall****: the*** *maximum of the daily* ***rainfall over the specified period /decadal, monthly, Annual ?***

- **Rainfall Mass Curve: A plot showing the cumulative rainfall** depth over the storm duration



- **Rainfall Hyetogragh: A plot of rainfall depth or intensity with** respect to time



- **Instantaneous Rainfall Intensity, (slope of the mass curve)** $\mathrm{i(t)} = \frac{\mathrm{dP(t)}}{\mathrm{dt}}$
- **Average Intensity in (t, t + Δt) is**

$$\bar{i}_t = \frac{\Delta P}{\Delta t} = \frac{P(t + \Delta t) - P(t)}{\Delta t}$$

Estimation of Missing data

Reasons for missing data

- Instrument failure
- The failure of the observer to make the necessary visit to the gage
- Miss typing of the data on the sheet

Estimation of Missing data

Methods for estimating missing rainfall data.

– The Arithmetic mean method

– The normal-ratio

– The isohyetal method

– Distance inverse method

Arithmetic Mean Method

- the variation among the normal annual precipitation of the stations is less than 10%.

$$P_x = \frac{1}{M}\left[P_1 + P_2 + P_3 .... + P_m\right]$$

Normal-Ratio Method

- the variation among the normal annual precipitation of the stations is grater than 10%.

$$P_x = \frac{N_x}{M}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} \ldots\ldots + \frac{P_m}{N_m}\right]$$

Inverse Distance Method

- The Inverse Distance Method is an alternative in which the estimation of Px is a weighted average of annual rainfalls at other gages with considering their distance

$$Px = \sum_{1}^{n} w_i p_i$$

$$w_i = \frac{1/d_i^2}{\sum_{1}^{4} 1/d_i^2}$$

Example

- With five gauge station network in the catchment, Station E did not operative in the year 1975. The data and their location of other four rain gauge stations are given in the following table, Estimate the missing rainfall of station E ?

A. using Arithmetic mean method ?

B. Using normal ratio method , If the normal annual rainfall at stations A, B, C, D and E are 920.1, 675.9, 809.7, 762.8, and 722.3

C. Using inverse distance method

Station	Coordinate		P(mm) @1975
	N-S	E_W	
A	4	6	939.8
B	-8	11	708.0
C	-5	-10	762.8
D	19	-21	675.9

Test for Consistency of Record

- A second problem occurs when the rainfall at rain gages is inconsistent over a period of time, which need adjustment of the measured data to be consistent record.

reasons for inconsistency

– Shifting of the rain gauge to new location

– Changes in the ecosystem due to calamites, such as forest fires, landslides…

– Occurrence of observational error from a certain data

- Adjusting for gauge consistency involves the estimation of an **effect rather than a missing value.**
- The checking for inconsistency of a record is done using **Double mass- curve technique.** The technique is based on the concept that each record data comes from the same parent population, they are consistent.
- A *double-mass curve is a graph of the cumulative rainfall at rain* gage of interest versus the cumulative rainfall of one or more gauges in the region that has been subjected to similar hydro meteorological occurrences and is known to be consistent.

Test for Consistency of Record

Procedure

1. The data of the annual (or monthly mean) rainfall of the station X and the average rainfall of the base stations covering a long period is arranged in the reverse chronological order (i.e., the latest record as the first entry and the oldest record as the last entry)

2.The accumulated rainfall of the station X (i.e., ΣPx) and the accumulated values of the average of the base stations (i.e., ΣPav) are calculated starting from the latest record.

3. Plot the accumulated values of Station X against the accumulated value of base stations

4. A break in the slope of the resulting plot indicates a change in the precipitation regime of station X.

5. The precipitation values at station X beyond the period of change of regime is corrected by using the relation. where Pcx = corrected rainfall at time period t1 at station X

$$P_{cx} = P_x \frac{M_c}{M_a}$$

Px = original recoded precipitation at time t1 at station X

Mc = corrected slope of the double mass curve

Ma = original slope of the mass curve

Example

- Test the consistency of the 10 year data of annual rainfall measured at station A. Rainfall data for the station A and the average annual rainfall measured at group of Eight stations located in the meteorologically homogonous region are given below in the table

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Annual Rainfall for Station A. (mm)	1880	1850	1720	1550	1480	1420	1400	1300	1370	1300	1630
Avg. Annual Rainfall for 8 stations in the basin (mm)	1640	1550	1430	1150	1350	1580	1550	1430	1500	1450	1610

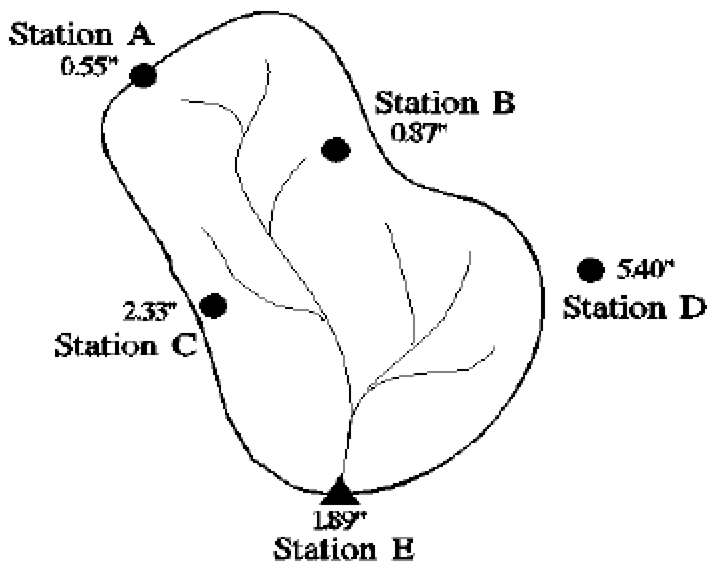
Areal Rainfall

- Three common methods to do mean areal rainfall
  - Arithmetic mean
  - Thiessen polygon
  - Isohyetal

Arithmetical – Mean Method

$$\overline{P} = \frac{P_1 + P_2 + \ldots\ldots\ldots\ldots P_i + \ldots\ldots + P_n}{N} = \frac{1}{N}\sum_{i=1}^{N} P_i$$

Example

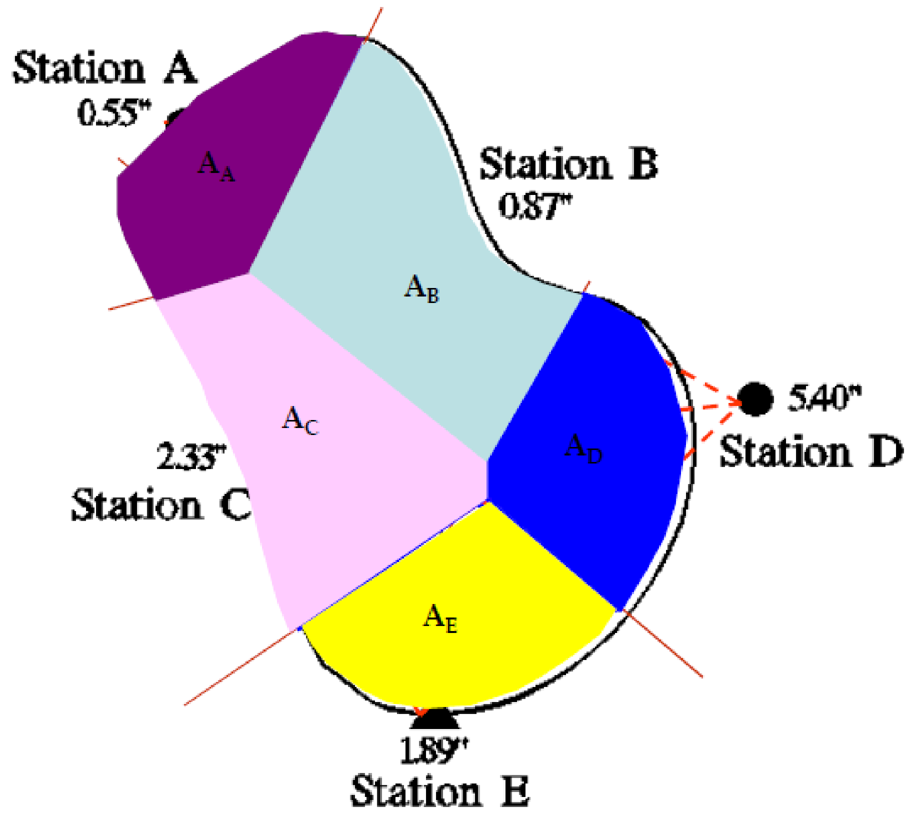


Ans. 2.208″

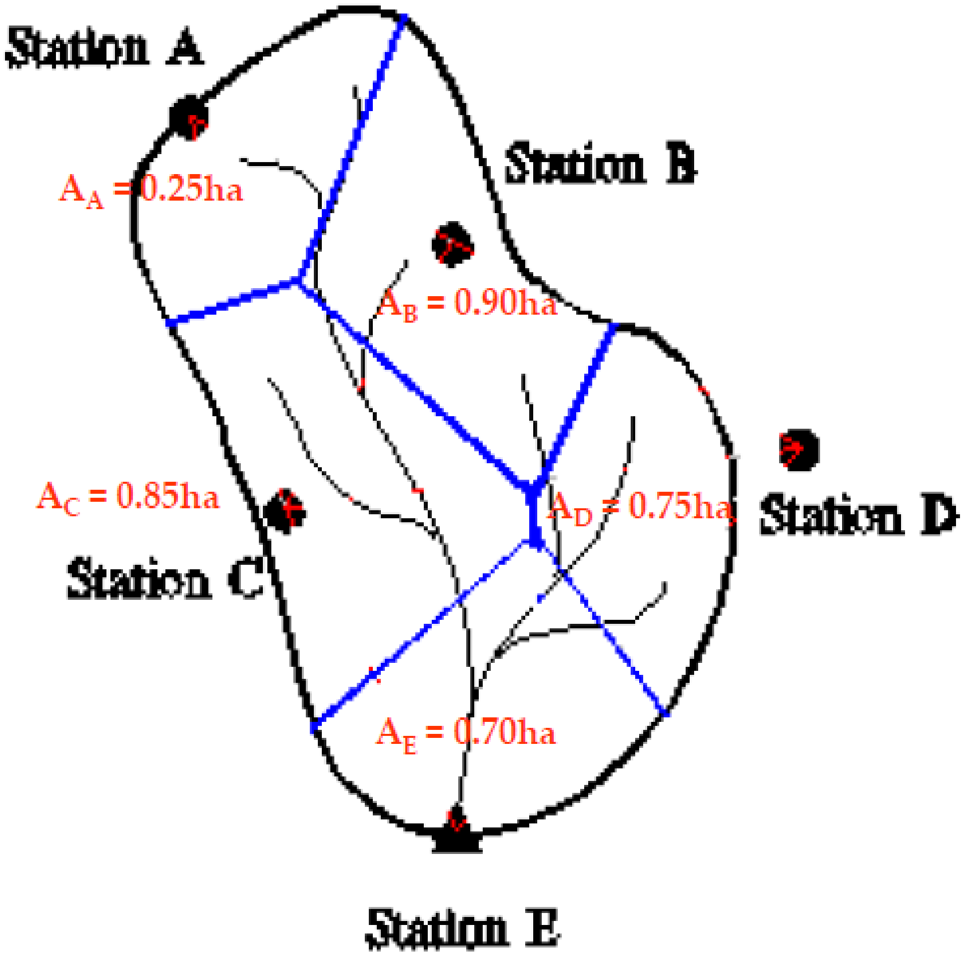
Thiessen – Mean Method

$$\overline{P} = \frac{P_1 A_{1A} + P_2 A_2 + \ldots + P_i A_i + \ldots + P_n A_n}{(A_1 + A_2 + \ldots + A_i + \ldots + A_n)}$$

$$= \frac{\sum_{i=1}^{M} P_i A_i}{A} = \sum_{i=1}^{M} P_i \frac{A_i}{A}$$



Example

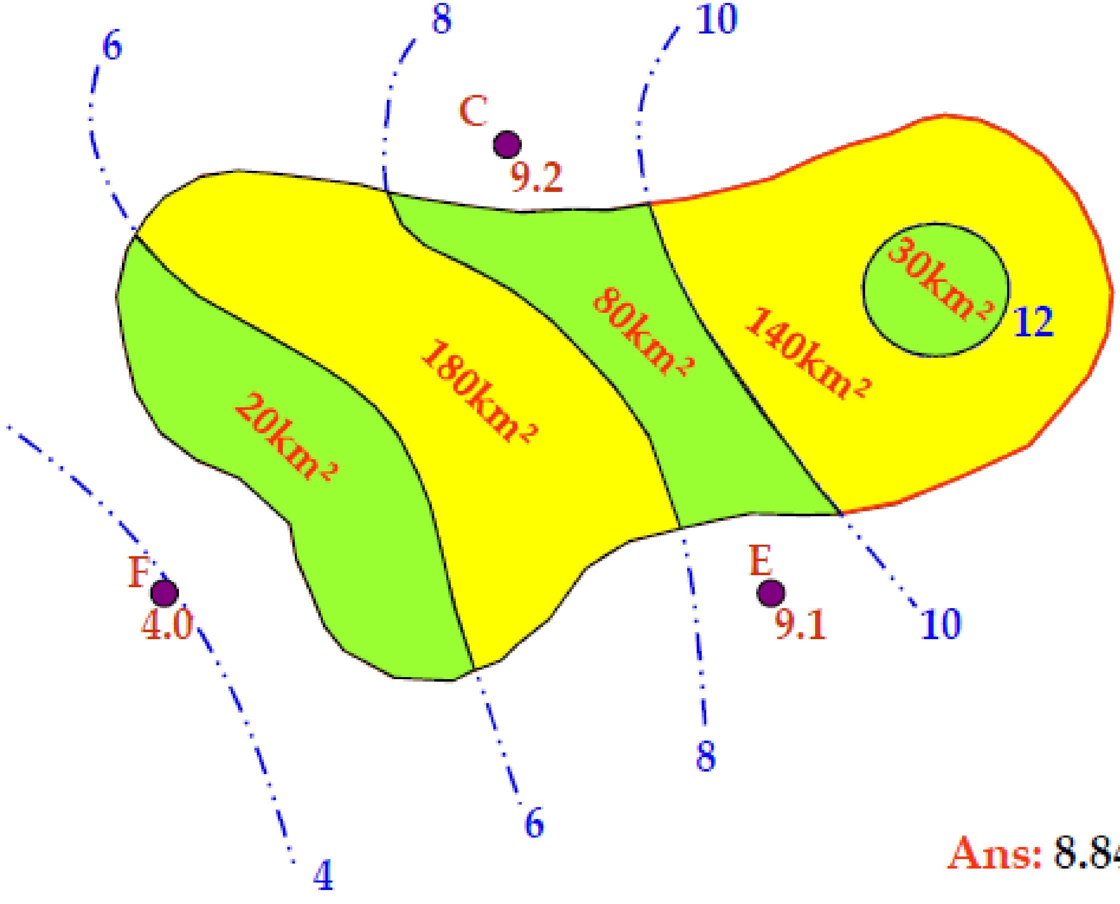


Ans: 2.398″

Isohyetal Method

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

- Thiessen and Isohyetal methods give more accurate information than the simple arithmetic mean.
- The isohyets method is superior to the other two methods especially when the stations are large in number



Ans: 8.844cm

Frequency of Point Rainfall

- occurrence of a particular extreme rainfall
- Annual data series is the common data use in frequency analysis

Terminologies used in Frequency Analysis

- **Probability of occurrence**: the probability of occurrence of an event (rainfall) whose magnitude is equal to or excess of specified magnitude X is denoted by P.
- **Recurrence interval /return period/** : represent the average interval between the occurrence of a rainfall of magnitude equal or greater than X defined as $T = 1/P$

Procedure of the simple empirical technique

- Arrange the given annual extreme series in descending order
- Assign an order/rank/ number m, start from the first to the last, which m=N= number of years of record
- The probability P of an event equaled to or exceeded is given by plotting position, for Weibull formula

$$p = \frac{m}{N+1}$$

- The recurrence interval T = 1/P= (N+1)/m

Intensity – Duration -Frequency

- Intensity of storms decreases with the increase in storm duration

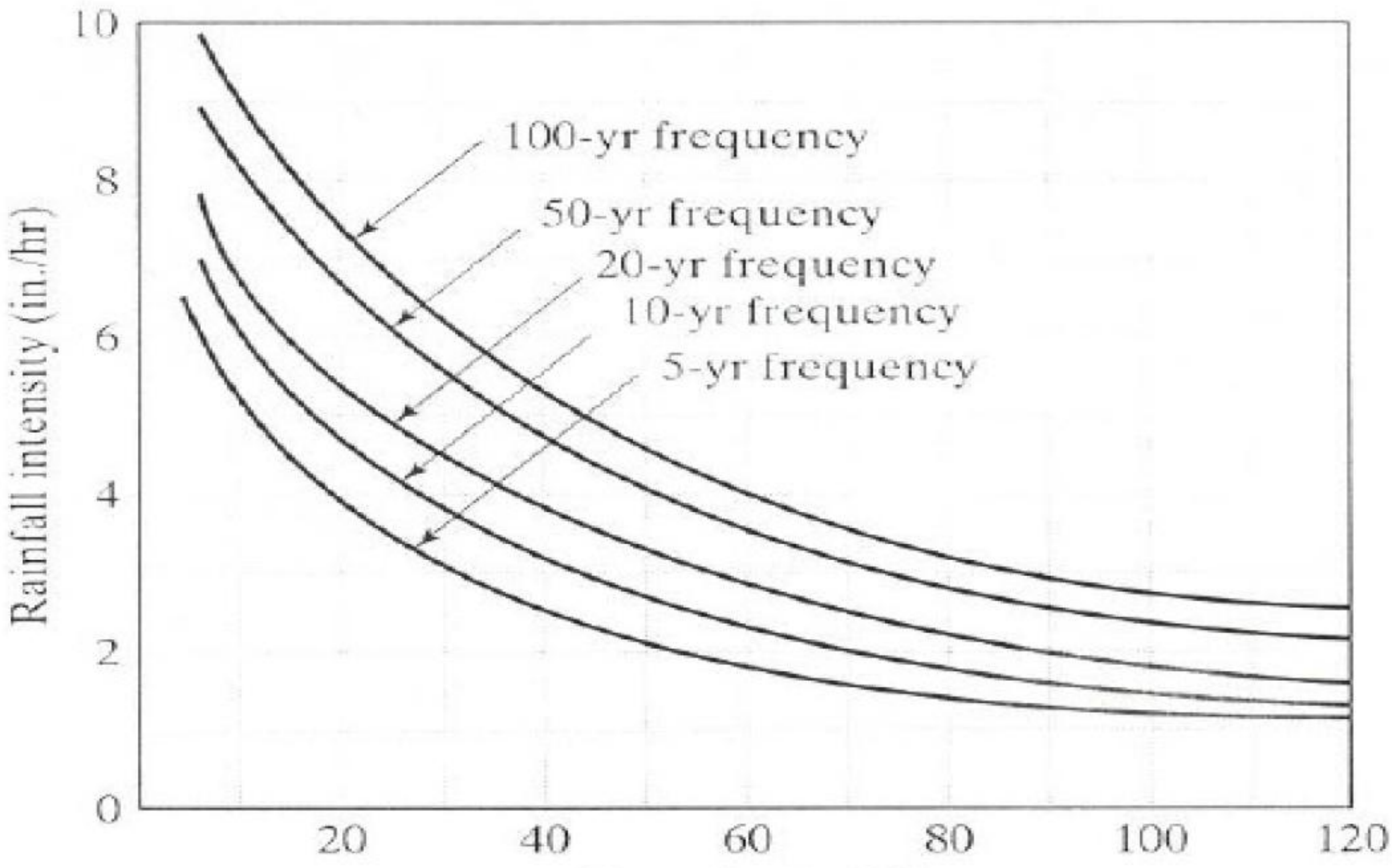
  A storm of any given duration will have a large intensity if its return period is large

- The inter-dependency among intensity (i cm/hr), duration (D hr.) and return period (T years) is commonly expressed in a general formula

$$i = \frac{KT^x}{(D+a)^n}$$

- where k, x, a, and n are constant for a given catchment

Plot



10
8
6
4
2
0
Rainfall intensity (in./hr)
100-yr frequency
50-yr frequency
20-yr frequency
10-yr frequency
5-yr frequency
20
40
60
80
100
120

Example

For a station A, the recorded annual 24h maximum rainfall are given below

A. Estimate the 24hr maximum rainfall with return periods of 13 and 50 years

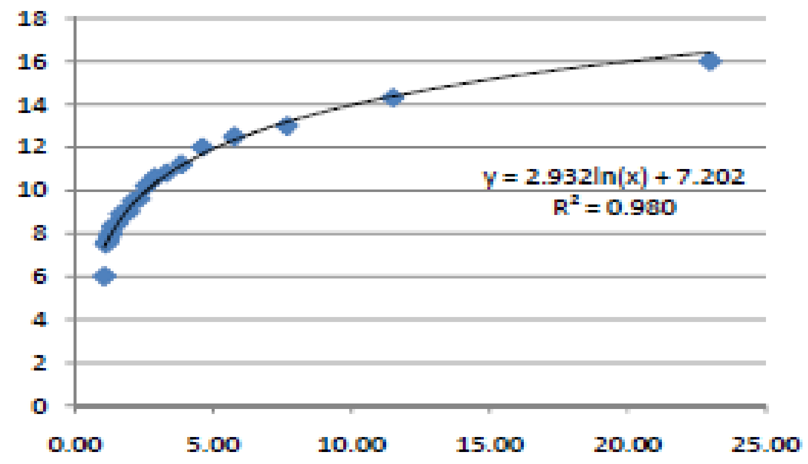
B. What would be the probability of the rainfall of magnitude equal to or exceeding 10cm occurring in 24hr at station A.

C. If the constant k, x, a and n of the area is 6.93, 0.189, 0.50 and 0.878 respectively develop Intensity-duration-frequency curve of the area.

year	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
24hr max. Rainfall (cm)	13	12	7.6	14.3	16	9.6	8	12.5	11.2	8.9	8.9
year	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
24hr max. Rainfall (cm)	7.8	9	10.2	8.5	7.5	6	8.4	10.8	10.6	8.3	9.5

Solution

Year	P(mm)	rank(m)	p=m/(N+1)	T= 1/P	P(mm)
1954	16	1	0.043	23.00	16
1953	14.3	2	0.087	11.50	14.3
1950	13	3	0.130	7.67	13
1957	12.5	4	0.174	5.75	12.5
1951	12	5	0.217	4.60	12
1958	11.2	6	0.261	3.83	11.2
1968	10.8	7	0.304	3.29	10.8
1969	10.6	8	0.348	2.88	10.6
1963	10.2	9	0.391	2.56	10.2
1955	9.6	10	0.435	2.30	9.6
1971	9.5	11	0.478	2.09	9.5
1962	9	12	0.522	1.92	9
1959	8.9	13	0.565	1.77	8.9
1960	8.9	14	0.609	1.64	8.9
1964	8.5	15	0.652	1.53	8.5
1967	8.4	16	0.696	1.44	8.4
1970	8.3	17	0.739	1.35	8.3
1956	8	18	0.783	1.28	8
1961	7.8	19	0.826	1.21	7.8
1952	7.6	20	0.870	1.15	7.6
1965	7.5	21	0.913	1.10	7.5
1966	6	22	0.957	1.05	6



year	P
13	14.72
50	18.67

Assigment-2

For Assignment one Given 5 years daily data for 5 stations

- Compute the mean monthly rainfall from the given daily data for 5 stations
- Compute the mean Annual rainfall and the daily maximum rainfall (with return period)
- Compute the areal pcp using one of the methods
- Link the areal pcp with the water budget equation