Rainfall Analysis

Depth-Area-Duration Analysis (DAD Curve)

For hydrological analysis it is necessary to know the maximum amount of rainfall of various durations occurring over various sizes of areas.

Normally, a storm starts with a heavy downpour and gradually decreases with the increase in time.

Similarly, rainfall may be uniform over a small area but due to variation in rain falling over different parts of a large area, the rainfall in the large area would be lesser than the small area.

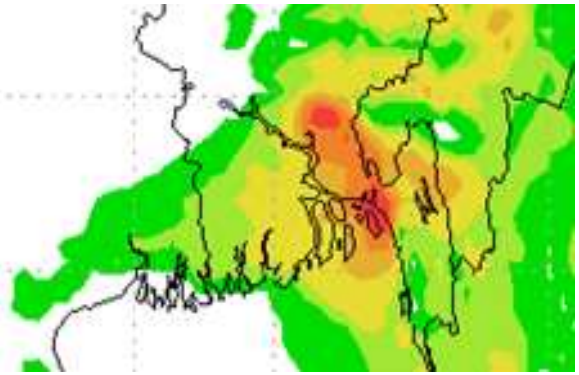
Hence, rainfall depth varies both with the duration and the area of the watershed. The Depth-Area-Duration (DAD) analysis is carried out based on storms of different durations with different areal extent in a watershed.

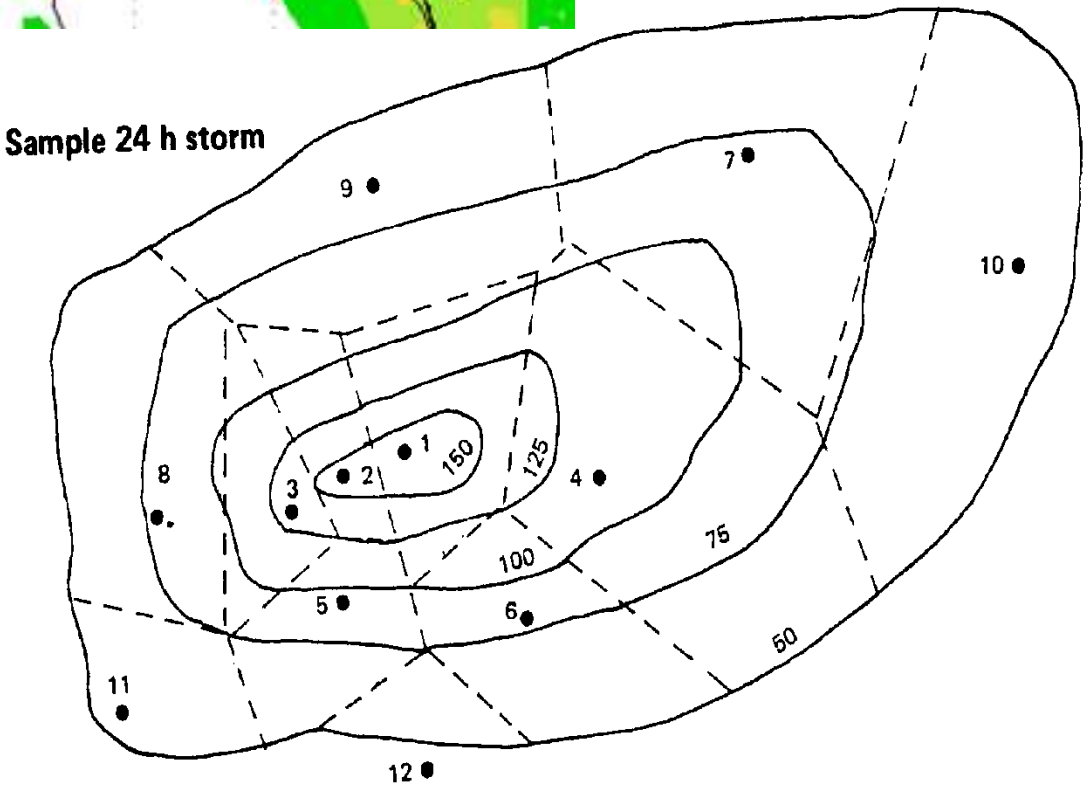
The development of relationships between maximum area-depth-duration for a region is known as DAD analysis.

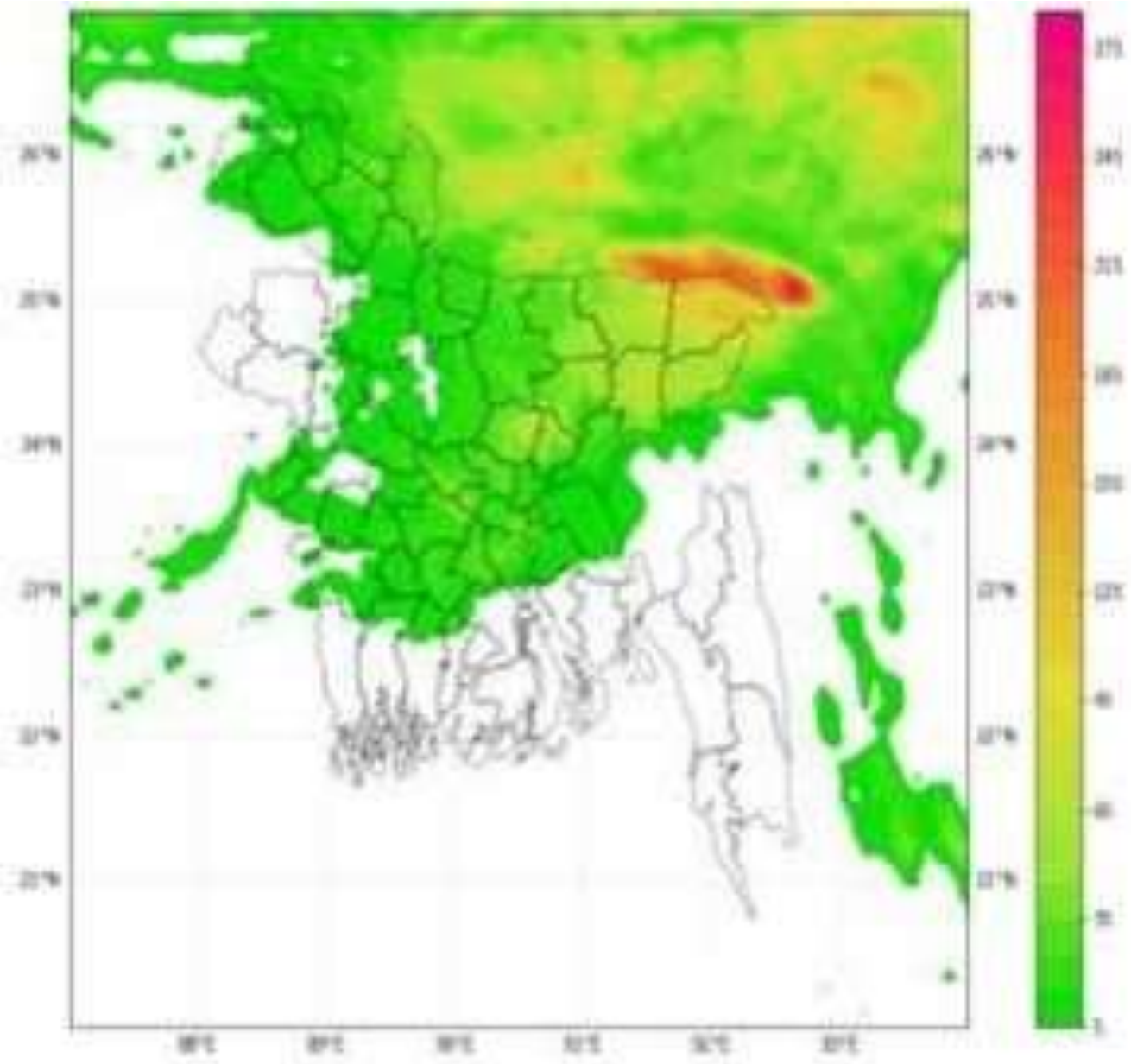
- First the isohyets of the total storm are drawn.
- The areal rainfall depths over the enclosing isohytal areas are determined for the total storm.
- The duration computations then proceed as in the following table, where the area enclosed (10 km^2) by the 150 mm isohyet is considered first. The areal rainfall over the 10 km^2 for the whole storm is 155 mm.
- The computations are continued by repeating the method for the areas enclosed by all the isohyets.

DAD Analysis

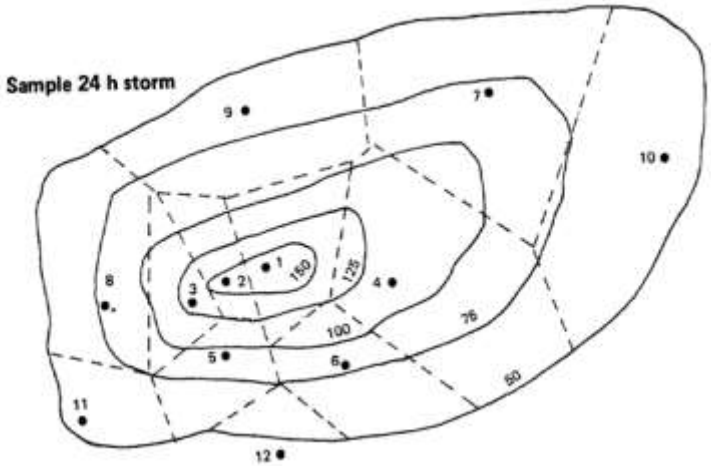
Station	24h
1	160
2	153
3	130
4	114
5	90
6	80
7	78
8	76
9	65
10	60
11	55
12	45







DAD Analysis



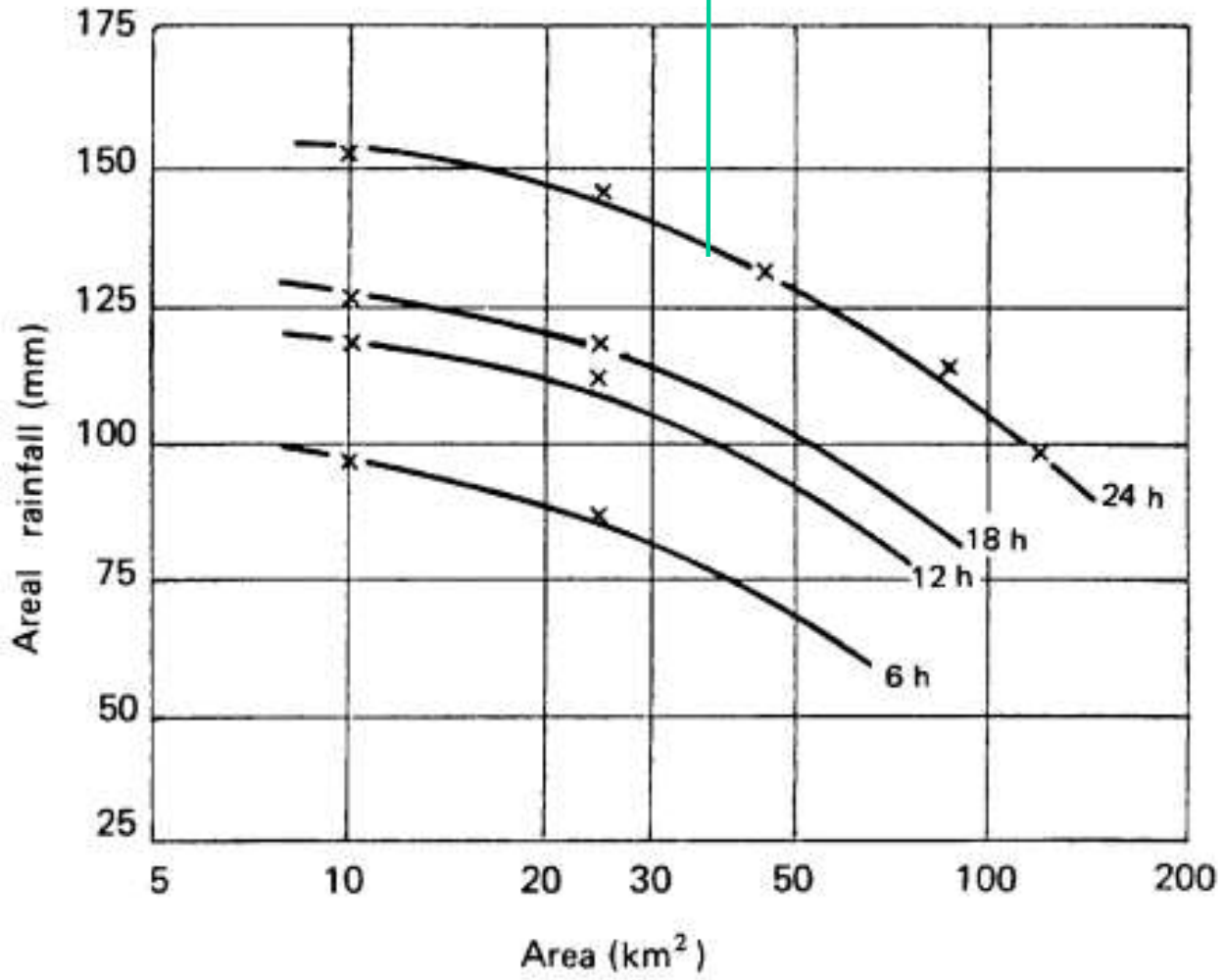
Average of 160 and 150

(1)	(2)	(3)	(4)	(5)= (4)×(3)	(6)	(7)= (6)÷(2)
Isohyet (mm)	Total area enclosed (km^2)	Area between Isohyets	Av. rain between isohyets	Vol. of rain between isohyets	Cumulative volumes.	Areal Rain (mm)
150	10	10	155	1550	1550	155.0
125	25	15	137.5	2062.5	3612.5	144.5
100	45	20	112.5	2250	5867.5	130.4
75	75	30	87.5	2625	8487.5	113 .2
50	110	35	62.5	2187.5	1067.5	97.0

DAD Analysis

(semi-log plot)

24 hour DAD Curve



Rainfall depth – area – duration curves.

DAD Curves

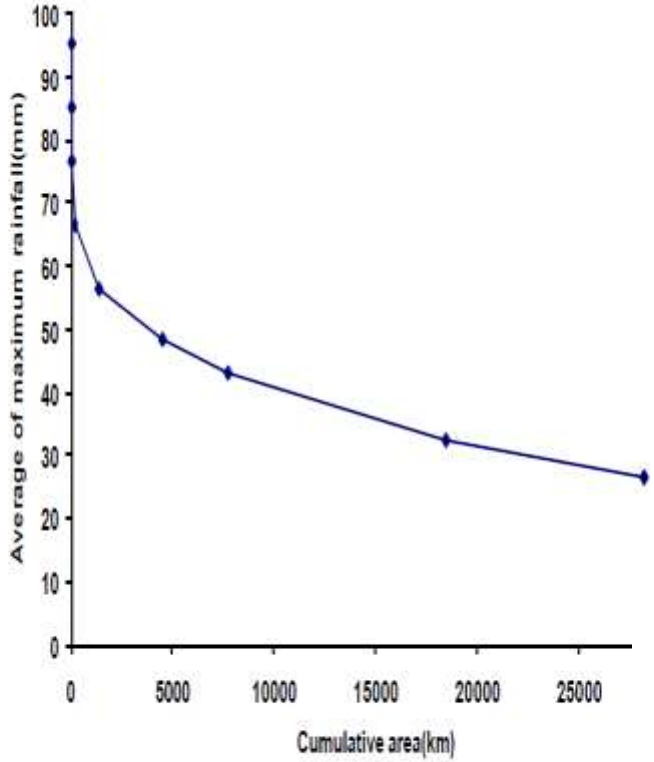


Fig. 5: DAD curve of the 24-hours rainfall of 2/11/1993

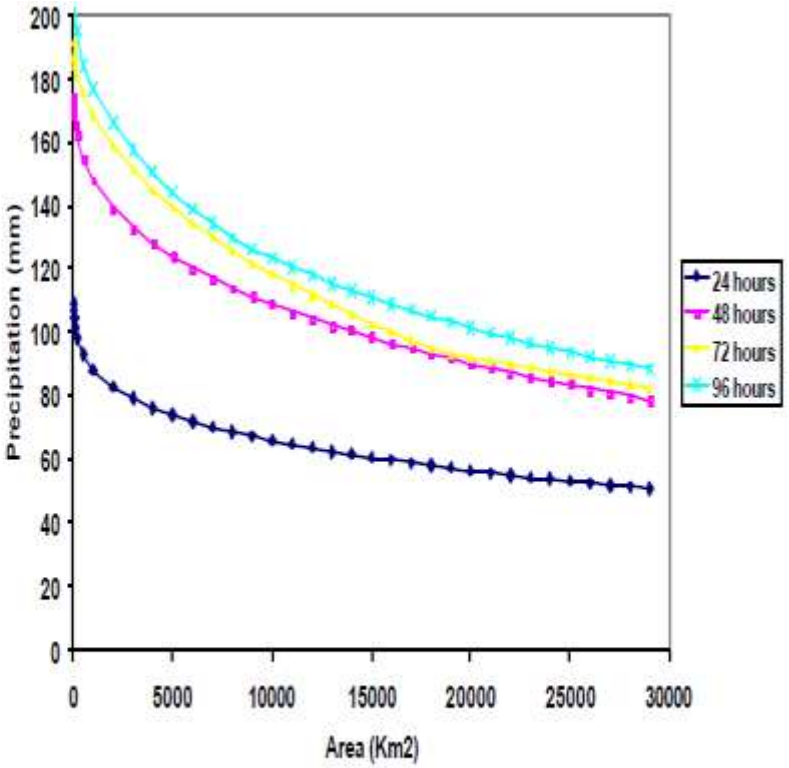


Fig. 6: Final DAD curves of Kurdistan Province

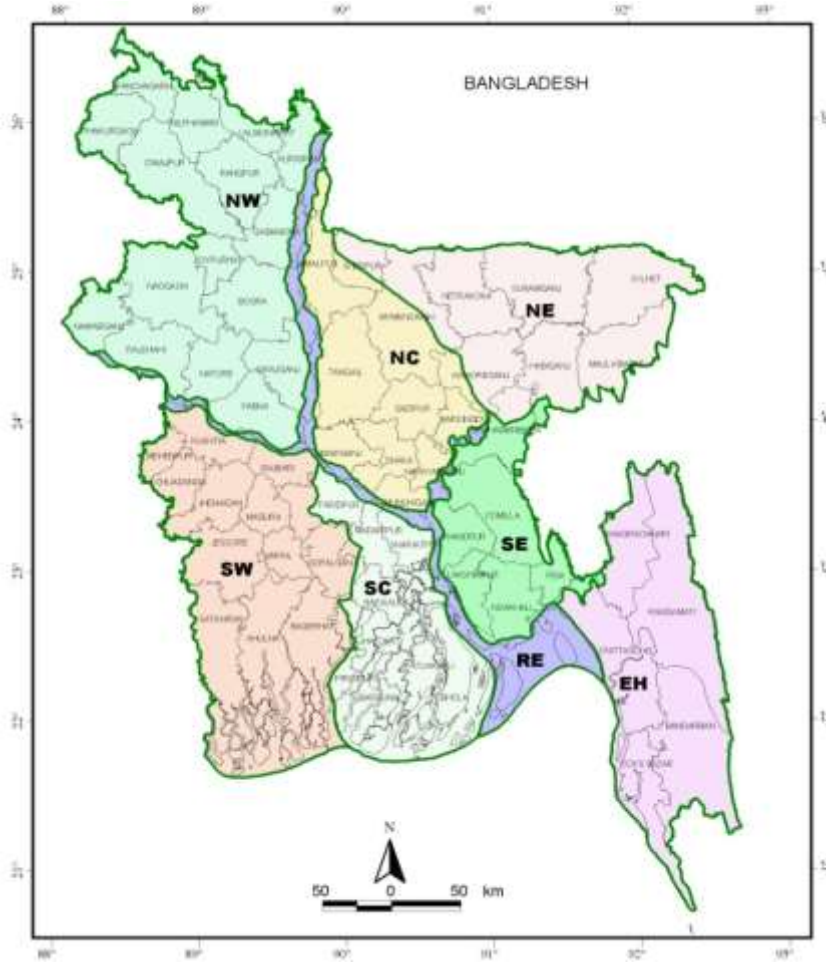
Note the difference between normal and semi-log plots

Rainfall Analysis

Some Characteristics of DAD Curves

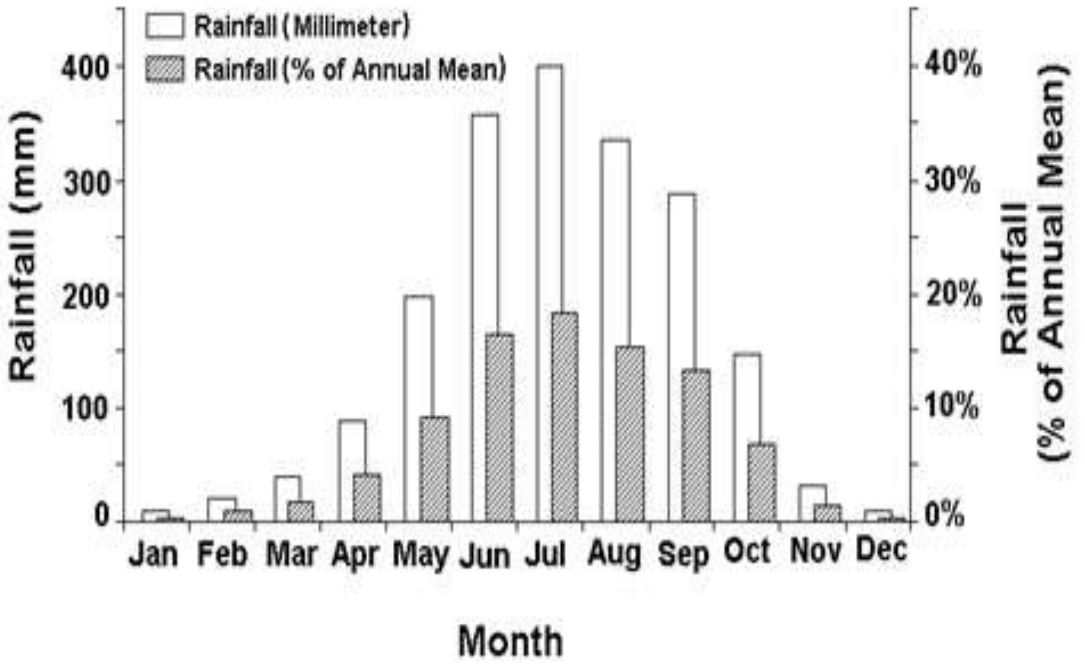
1. Rainfall never occurs uniformly over large areas and variations of total depth and intensity occur from the centre of the storm to the peripheries.
2. The depth of rainfall decreases as the area increases.
3. For a given area the depth of rainfall increases with the increase of the duration.
4. For a given area the intensity of rainfall decreases with the increase of the duration.
5. For a given duration the rainfall amount decreases with increase in area.

Rainfall in Bangladesh

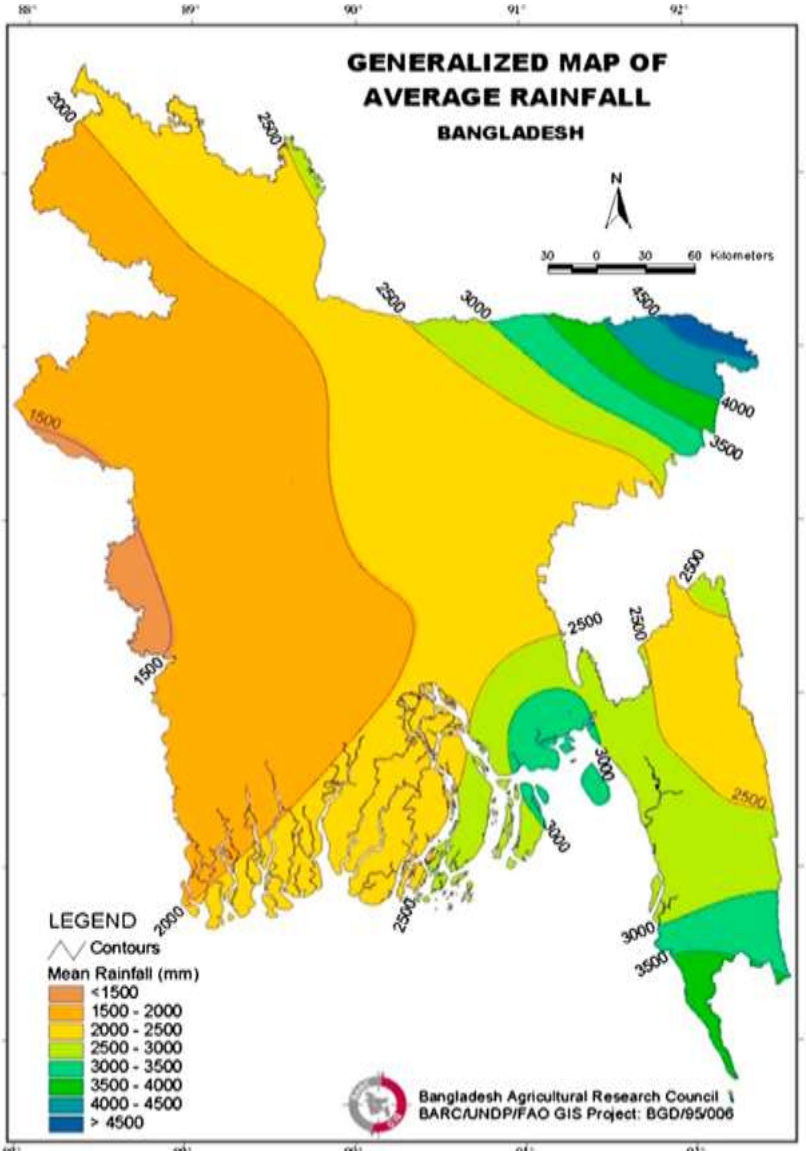


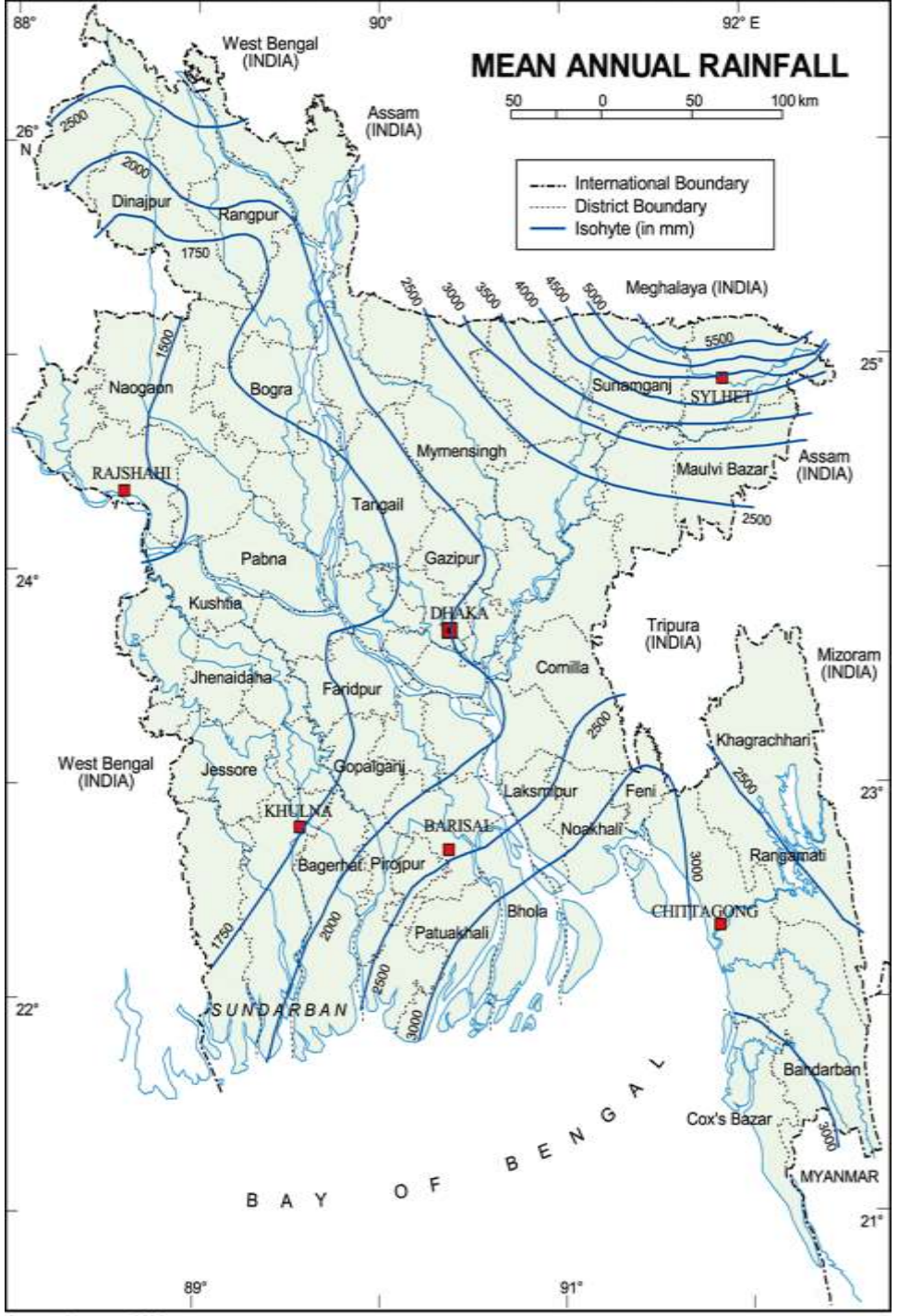
Rainfall, mm/month

Region	J	F	M	A	M	J	J	A	S	O	N	D	Total
SE	6	24	60	157	291	465	521	445	305	172	39	11	2,271
NW	8	11	22	72	214	347	437	319	312	124	12	7	1,739
NC	6	21	40	127	283	380	411	318	290	152	23	11	1,956
RE	6	20	48	130	262	468	561	443	329	171	38	11	2,318
SW	9	23	36	80	176	331	371	340	285	141	31	11	1,665
NE	9	31	82	255	475	661	664	527	457	202	32	13	3,194
SC	7	23	46	115	231	495	531	470	341	179	53	11	2,307
EH	5	17	44	124	251	610	688	488	270	186	59	11	2,445
B'desh	7	20	44	125	265	457	510	405	322	161	33	10	2,360



Rainfall Distribution in Bangladesh





Source: *Brammer, 1996*

Evaporation versus Precipitation

- About equal on a global scale
- Evaporation more prevalent over the oceans than precipitation
- Over land, precipitation exceeds evaporation
- Most water evaporated from the oceans falls back into the ocean as precipitation
- 10% of water evaporated from the ocean is transported over land and falls as precipitation
- Once evaporated, a water molecule spends ~ 10 days airborne.

Evaporation

Evaporation is the process whereby liquid water is converted to water vapour. The process is accompanied by the transfer of energy.

About 90% of the water in the atmosphere comes from evaporation.

The latent heat of vapourization is the heat required in calories to convert 1 gm of water at 1 atmosphere to vapour. The latent heat of vapourization is expressed as:

$$H_V = 597.3 - 0.564\ T \quad \text{(cal/gm)}$$

The latent heat of fusion is heat required to convert 1 gm of ice to water. The latent heat of fusion is 79.7 cal/gm at 0^0C.

The latent heat of sublimation is heat required to convert 1 gm of ice to vapour without passing through water state. The latent heat of sublimation is 677 cal/gm at 0^0C.

The rate of evaporation is dependent on:

1. Vapour pressure of the atmosphere (amount of vapour)
2. Air and water temperatures
3. Wind speed
4. Quality of water
5. Atmospheric pressure
6. Size of water body

Evaporation

Vapour Pressure:

The partial pressure exerted by water vapour is called vapour pressure.

The pressure exerted by the maximum amount of vapour at a given temperature is called saturated vapour pressure.

The relative humidity is the ratio of the actual to the saturated vapour pressure and is expressed in percentage.

Specific humidity is the ratio of the mass of water vapor in air to the total mass of the air (dry air plus water vapor).

The relative humidity is measured by Hygrometers.

The rate of evaporation is proportional to the difference between the saturated and actual vapour pressure in the air. Thus,

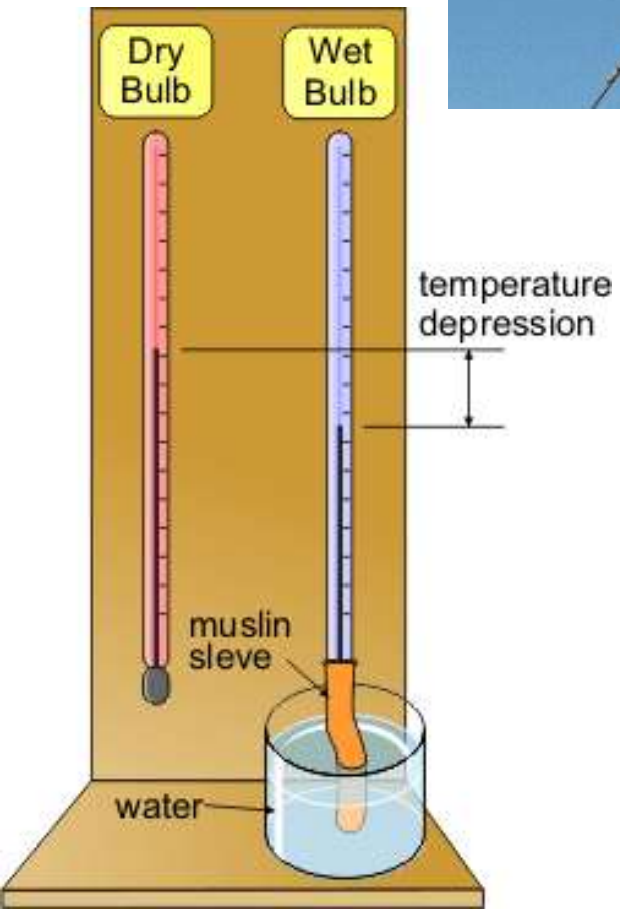
$$E = C (e_s - e_a)$$

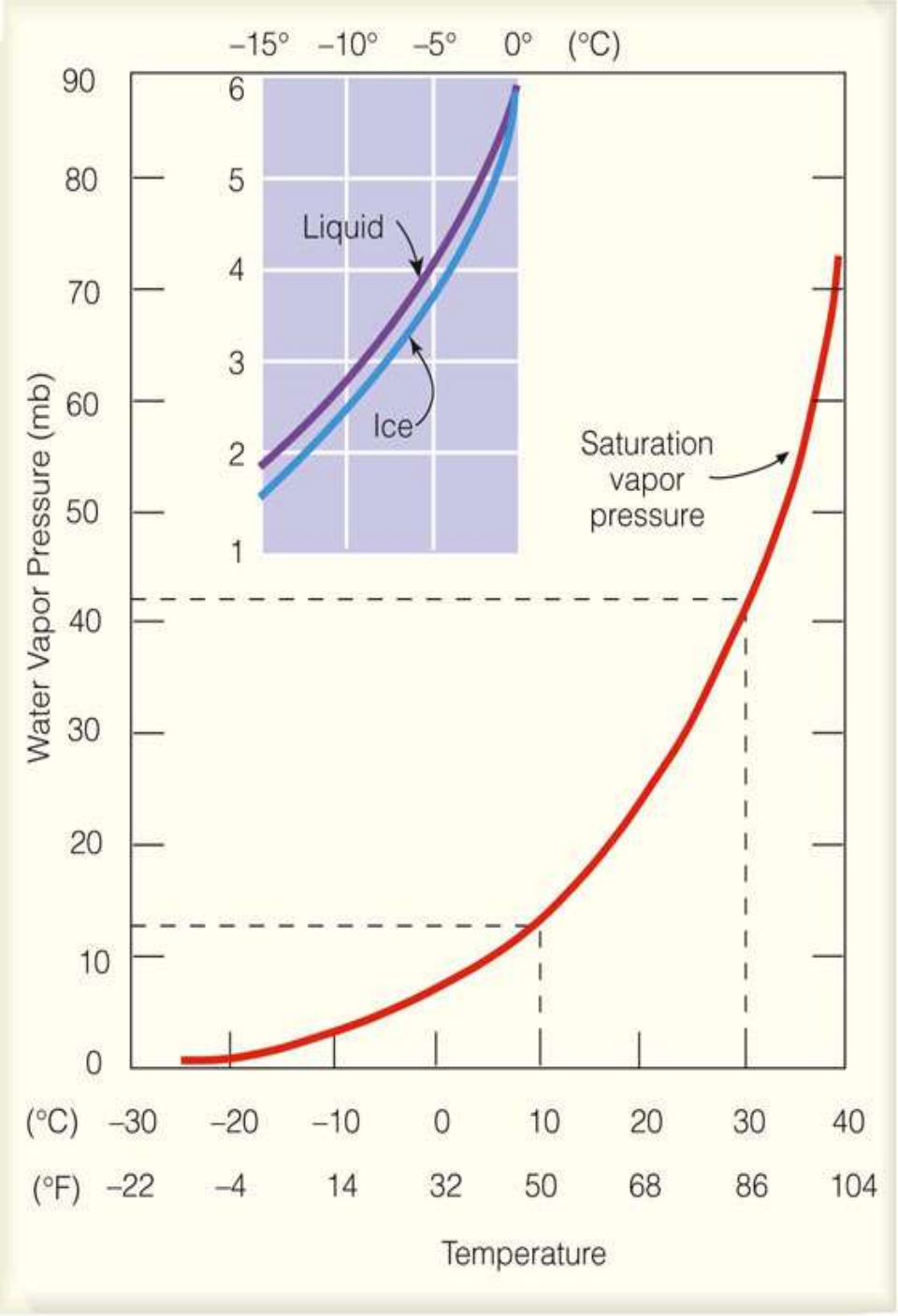
Where, E is the evaporation rate, C is a constant and e_s and e_a are saturated and actual vapour pressures. Evaporation continues till $e_s = e_a$.

Anemometer



Hygrometer





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Air Temp. ↓

Relative Humidity (%)

Dry-Bulb Temperature (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
−20	100	28														
−18	100	40														
−16	100	48														
−14	100	55	11													
−12	100	61	23													
−10	100	66	33													
−8	100	71	41	13												
−6	100	73	48	20												
−4	100	77	54	32	11											
−2	100	79	58	37	20	1										
0	100	81	63	45	28	11										
2	100	83	67	51	36	20	6									
4	100	85	70	56	42	27	14									
6	100	86	72	59	46	35	22	10								
8	100	87	74	62	51	39	28	17	6							
10	100	88	76	65	54	43	33	24	13	4						
12	100	88	78	67	57	48	38	28	19	10	2					
14	100	89	79	69	60	50	41	33	25	16	8	1				
16	100	90	80	71	62	54	45	37	29	21	14	7	1			
18	100	91	81	72	64	56	48	40	33	26	19	12	6			
20	100	91	82	74	66	58	51	44	36	30	23	17	11	5		
22	100	92	83	75	68	60	53	46	40	33	27	21	15	10	4	
24	100	92	84	76	69	62	55	49	42	36	30	25	20	14	9	4
26	100	92	85	77	70	64	57	51	45	39	34	28	23	18	13	9
28	100	93	86	78	71	65	59	53	47	42	36	31	26	21	17	12
30	100	93	86	79	72	66	61	55	49	44	39	34	29	25	20	16

Evaporation

Temperature:

Average, mean and normal are generally used as synonyms but in hydrology average and mean daily temperature is the average of the daily maximum and minimum temperatures.

Normal daily temperature (related to weather) is the average of daily mean temperatures for 30 years.

The mean monthly temperature is the average of the mean monthly maximum and minimum temperatures.

The warmer the water, the more active are the molecules (loose bonding) and the greater is the transfer of molecules from water to air. Moreover, as the temperature increases the moisture holding capacity of the atmosphere also increases. Thus, the evaporation increases with the increase in temperature and it affects evaporation in two ways.

Wind Speed:

Wind has both speed and direction and is generally expressed as m/sec, km/hour or knots (1 knot = 0.514 m/sec).

Wind speed is measured by anemometers (three or four cups).

Evaporation

Wind speed varies greatly with height above the ground and there is no standard level for measurement. For meteorological purposes, the power-law profile is usually used:

$$v/v_1 = (z/z_1)^k$$

Where v is the wind speed at height z and v_1 is the measured wind speed at height z_1 and k is a constant depending upon surface roughness (varying between 0.1 to 0.6).

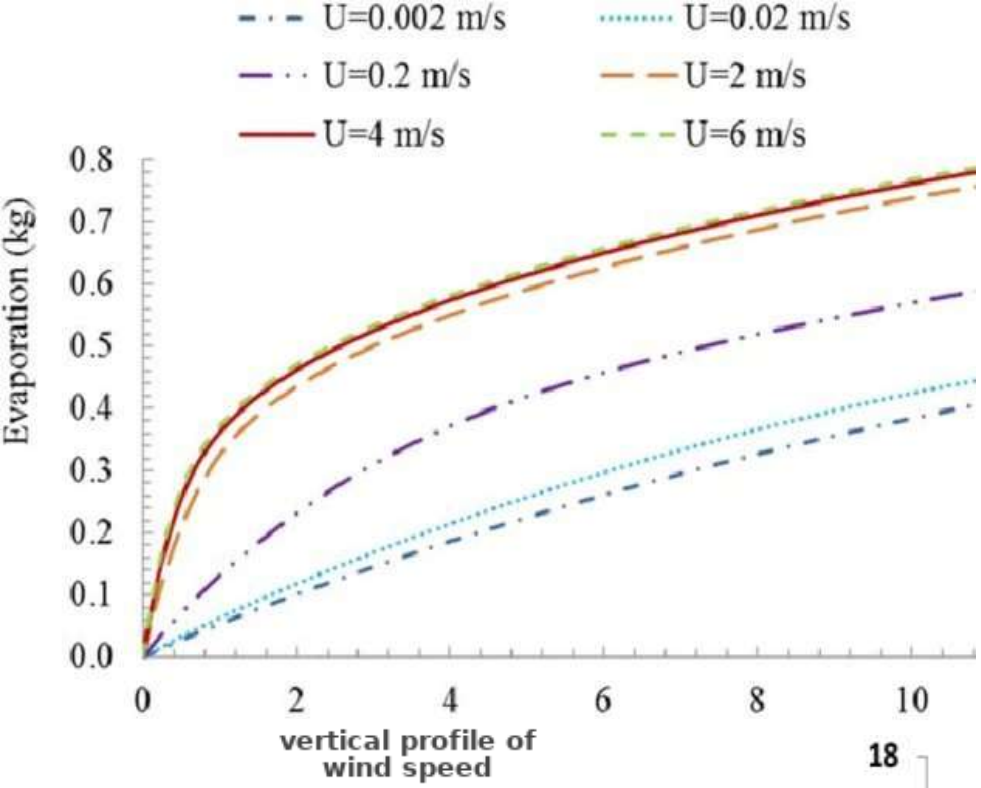
Note: higher wind speed at higher elevation and k increases with roughness.

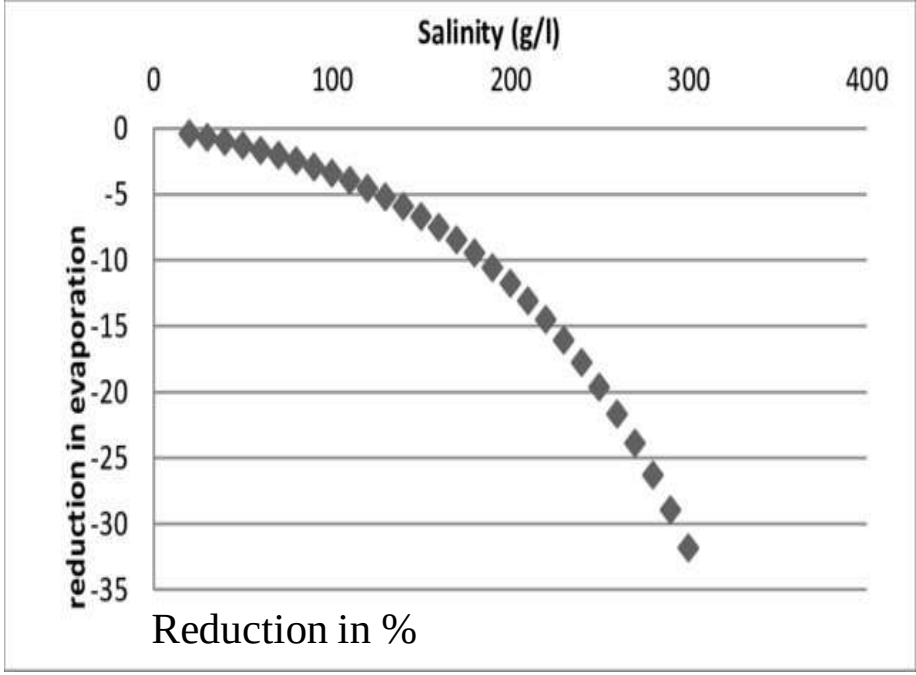
Wind helps in removing the evaporated water and consequently creates the scope of further evaporation. Thus, rate of evaporation increases with the wind speed up to a critical value. The critical value is dependent upon the size of the water body.

Water Quality: Vapour presure of water is reduced when solids are dissolved in water. Pure water has a higher vapour pressure than saline water. Thus, the rate of evaporation is less in saline water than fresh water. The sea water evaporation rate is less than that of freshwater by about 3%.

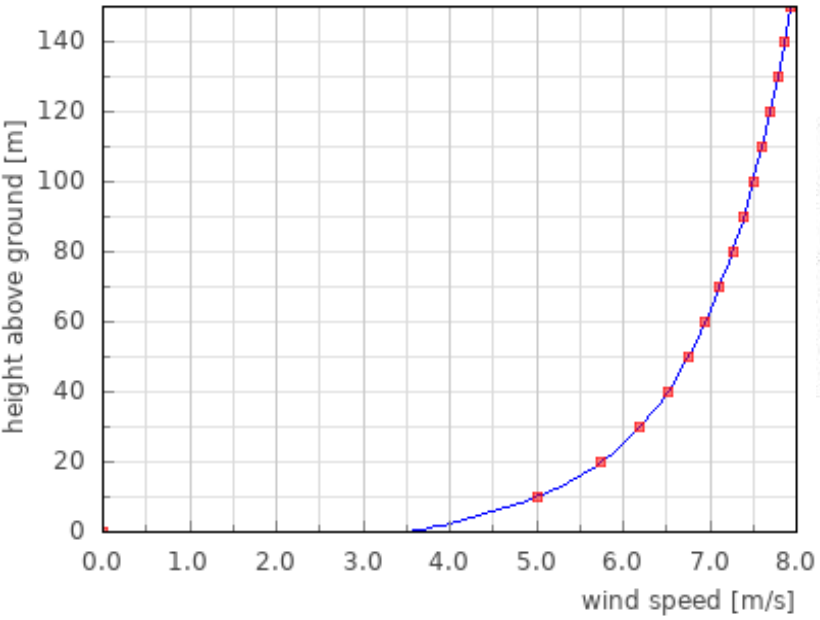
Atmospheric Pressure: Because of fewer air molecules in less dense air (lower atmospheric pressure) the evaporation is greater in lower pressure (at higher altitudes).

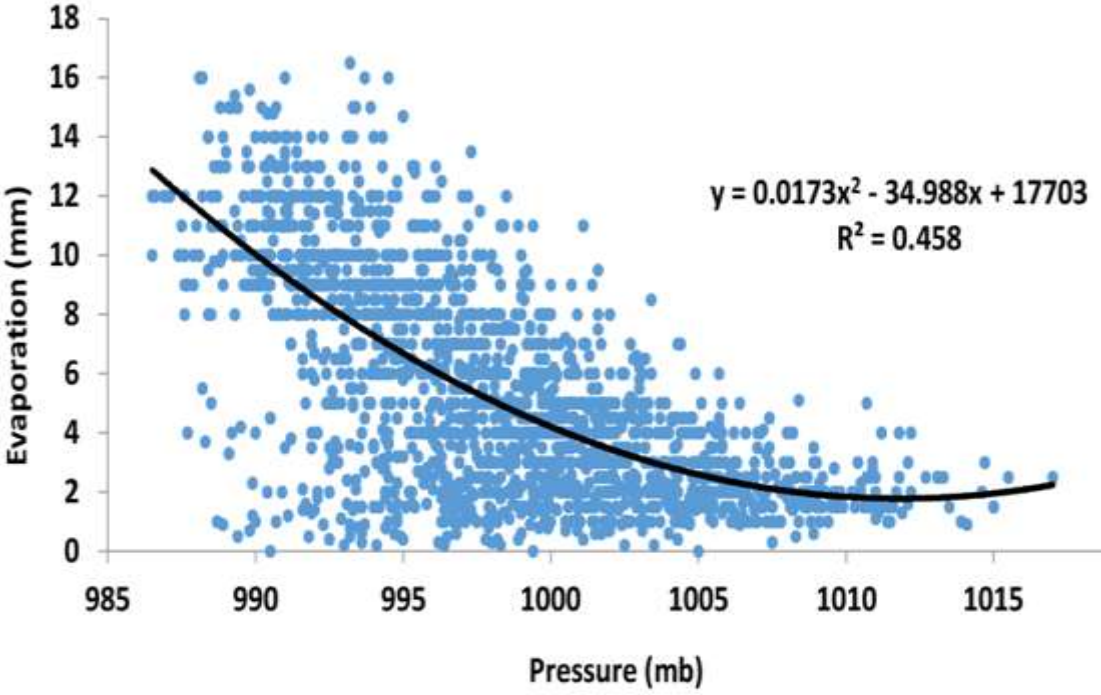
Size of Water Body: Shallow water bodies are more rapidly heated than deep water bodies and therefore evaporate more rapidly.





Reduction in %





Evaporation

Measurement of Evaporation

Evaporation is usually measured by evaporation pan.

The evaporation from pans is affected by the size, depth and location of pans.

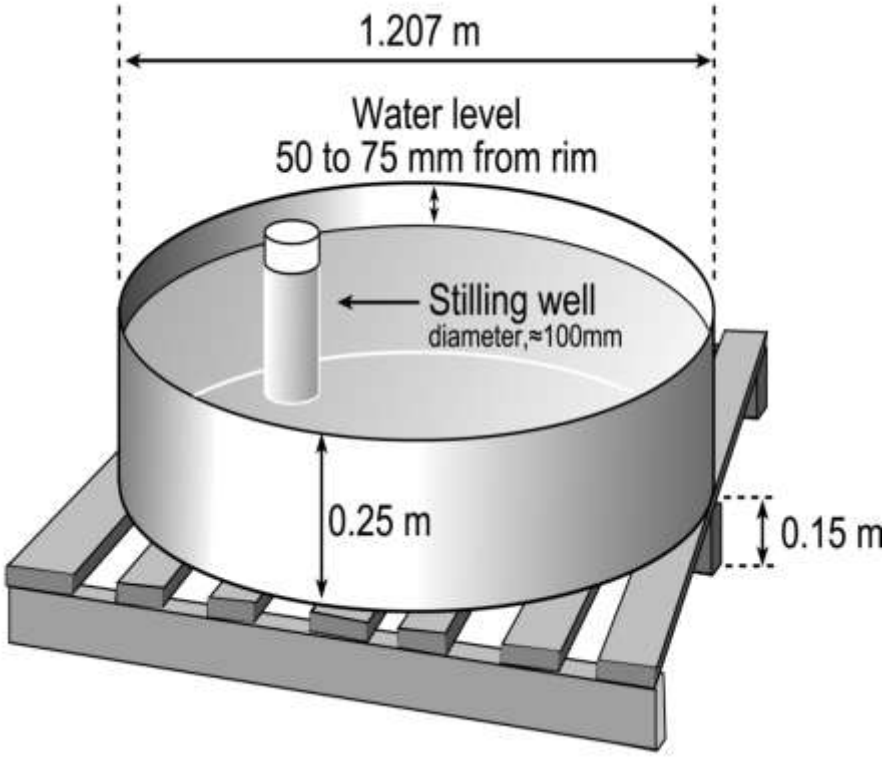
There are three types of pan depending upon installation: sunken, floating and surface.

Surface pans have higher evaporation than both sunken and floating pans because of the side and bottom walls, but are widely used because of economy and ease of installation, operation and maintenance.

Sunken pans eliminate the boundary effects but creates observational problems: collects trash, difficult to install, clean and repair and leakages may remain undetected.

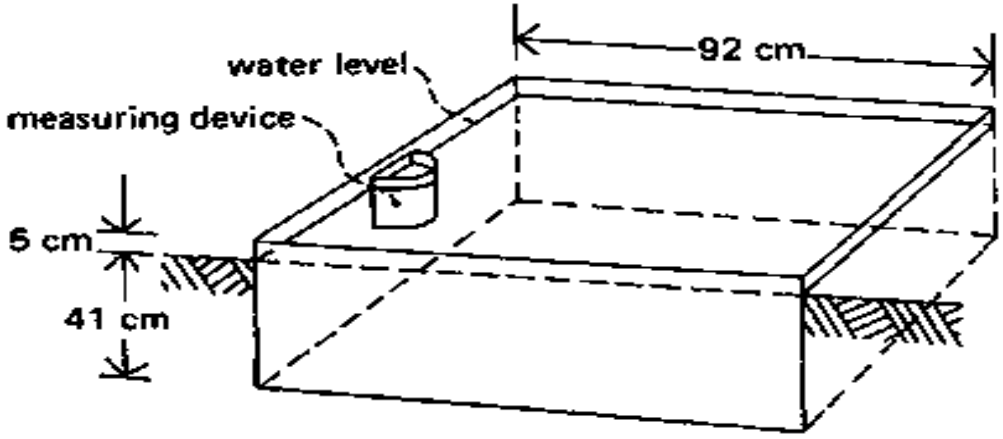
Floating pans have conditions similar to lakes or reservoirs but have observational difficulties like splashing and installation and operation costs are high.

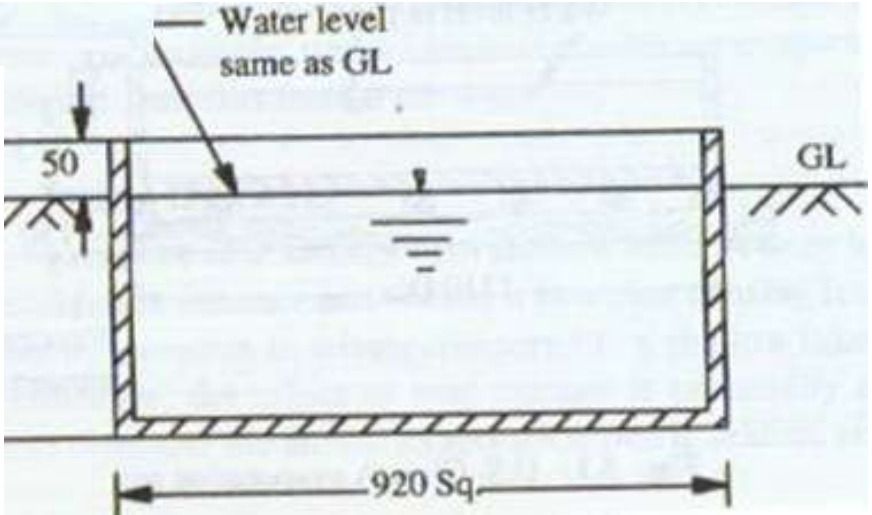
US Class A Evaporation Pan





Sunken Evaporation Pan





Floating Evaporation Pan



Evaporation

The most common pan used for the measurement of evaporation is the US Weather Bureau Class A pan (1.2 m in diameter and 25 cm deep) of unpainted galvanized iron sheet on a wooden frame 15 cm above the ground surface to let air circulate beneath the pan.

The pan is filled with water 5 cm below the top of the pan and not more than 7.5 cm below the top.

The decrease in water level in the pan (generally measured at daily interval), multiplied by the pan coefficient is the amount of evaporation (mm/day). The pan coefficient for Class A pan is 0.7.

As the rate of evaporation of a pan is not the same as that from large water bodies (reservoirs, lakes etc.), pan coefficient is used as the correction factor.

Thus, the volume of water lost due to lake evaporation V_E is:

$$V_E = AC_P E_P$$

Where A is the average reservoir (lake) area, E_P and C_P are pan evaporation and pan coefficient.

Evaporation

Why Pan Coefficient?

1. Heat storing capacity of a water body is much larger than that of a pan (water: 4.19 and iron: 0.44 J/gm ^{0}C) and heat transfer from the sides and bottom of a pan is also different. Generally, pan evaporation is higher (heats up easily due to small amount of water and effects of metallic sides and bottom) than that of large water bodies.
2. The height of the rim of a pan affects the wind action and also casts a shadow over the water surface.
3. The heat transfer characteristics of the pan material is different from that of large water bodies.

As such, evaporation from a pan is corrected by pan coefficient to get the evaporation from a large water body under similar climatic and exposure conditions.

Thus, Actual Evaporation, E = Pan Evaporation x Pan Coefficient

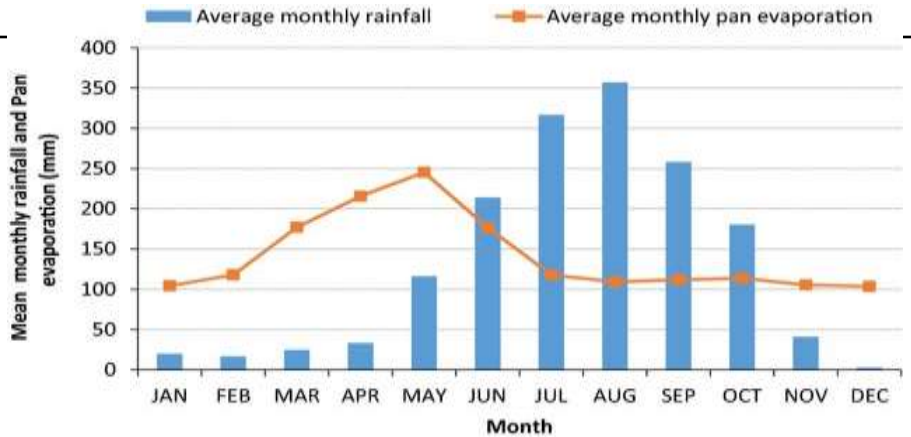
For US Class A weather pan, the pan coefficient is 0.7.

Evaporation of Bangladesh (mm/month)

In Bangladesh, evaporation is measured at 47 stations by BWDB and at 12 stations by BMD. Unlike rainfall, there is little regional variation in ET but, like rainfall, there is wide variation in season.

Region	J	F	M	A	M	J	J	A	S	O	N	D	Total
SE	70	86	132	148	143	113	112	117	107	102	80	65	1,275
NW	67	85	136	164	155	127	118	123	108	105	79	65	1,332
NC	70	87	136	159	150	119	117	120	107	105	80	66	1,316
RE	74	90	136	157	151	119	114	116	109	106	83	70	1,325
SW	76	92	145	173	167	122	114	118	110	108	84	72	1,381
NE	68	85	128	140	135	111	112	113	99	99	78	65	1,233
SC	75	90	135	152	146	112	107	110	104	104	81	71	1,287
EH	85	98	140	153	151	116	112	116	113	109	88	79	1,360
B'desh	73	89	137	158	151	119	114	117	107	105	82	69	1,320





Transpiration

Interception is that part of precipitation which is caught by the vegetation (mainly leaves) and is subsequently evaporated back to the atmosphere. Out of the total rainfall during the plant growing season, the interception loss seldom exceeds 10%.

Transpiration is the process by which the water leaves the plant and reaches the atmosphere as water vapour. Through transpiration the plants utilize the water for their metabolism and growth.

About 10% of the water in the atmosphere comes from transpiration.

Due to osmotic pressure (difference in concentrations of water in roots and soil), water moves from the soil to the roots and then to the leaves.

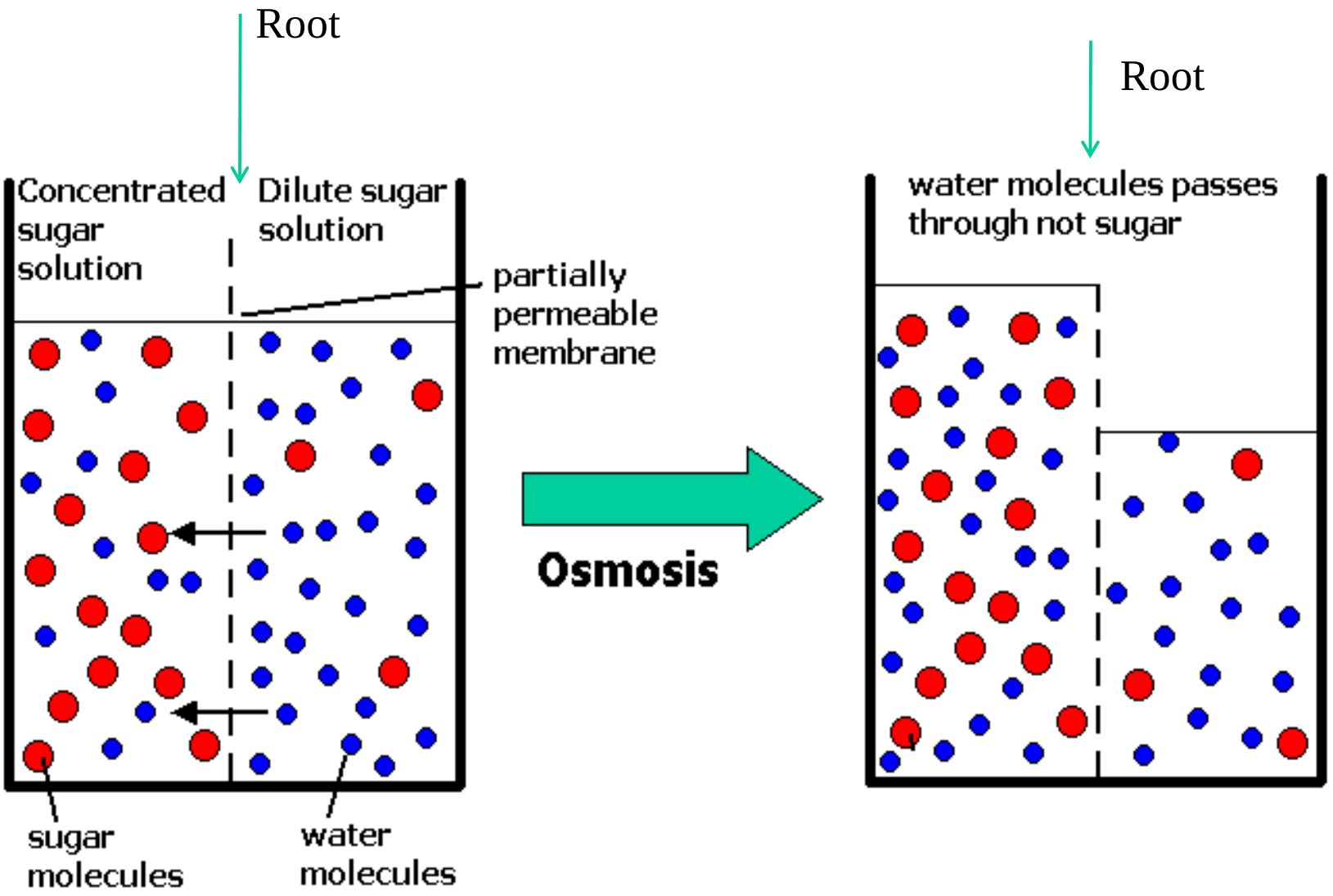
Plant leaves contain stomata (8,000 to 120,000 per cm^2). In presence of light, the stomata opens and CO_2 and HO_2 react to form starch (also known as photosynthesis) which is used in building the plant tissue. In the process, water escapes from the stomata which is known as transpiration.

The transpiration depends upon: 1. Solar radiation 2. Temperature 3. Wind velocity 4. Relative humidity 5. Plant characteristics and 6. Soil water regime.

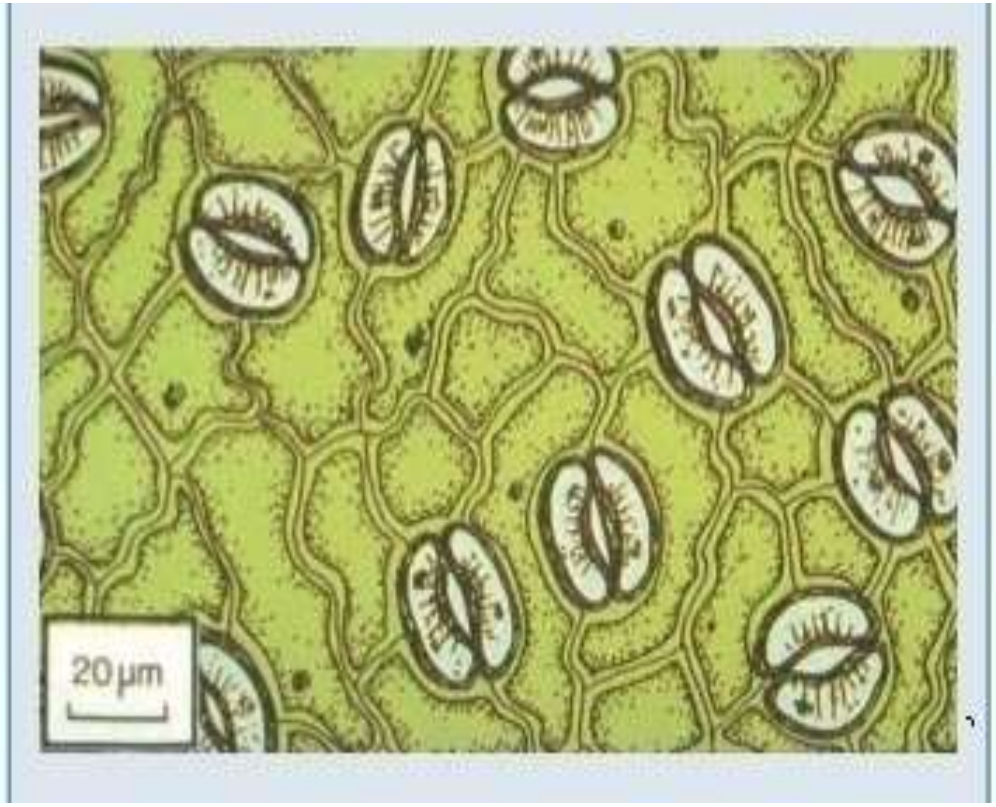
The crop type, variety and development stage should be considered when assessing the transpiration from crops grown in large, well-managed fields. Differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop rooting characteristics result in different ET levels in different types of crops under identical environmental conditions.

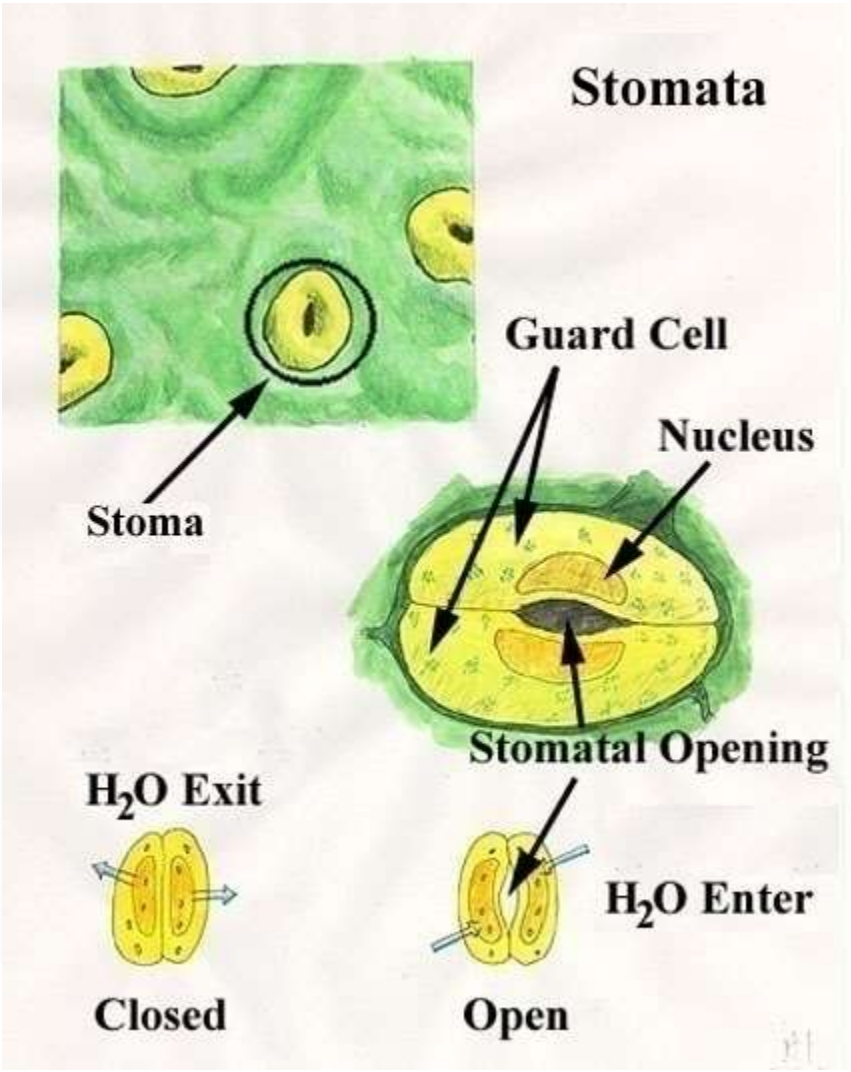
Soil moisture availability also restricts the transpiration.

If two solutions of different concentration are separated by a semi-permeable membrane which is permeable to the smaller solvent molecules but not to the larger solute molecules, then the solvent will tend to diffuse across the membrane from the less concentrated to the more concentrated solution. <u>This process is called osmosis.</u>



Upper Plant Leaf



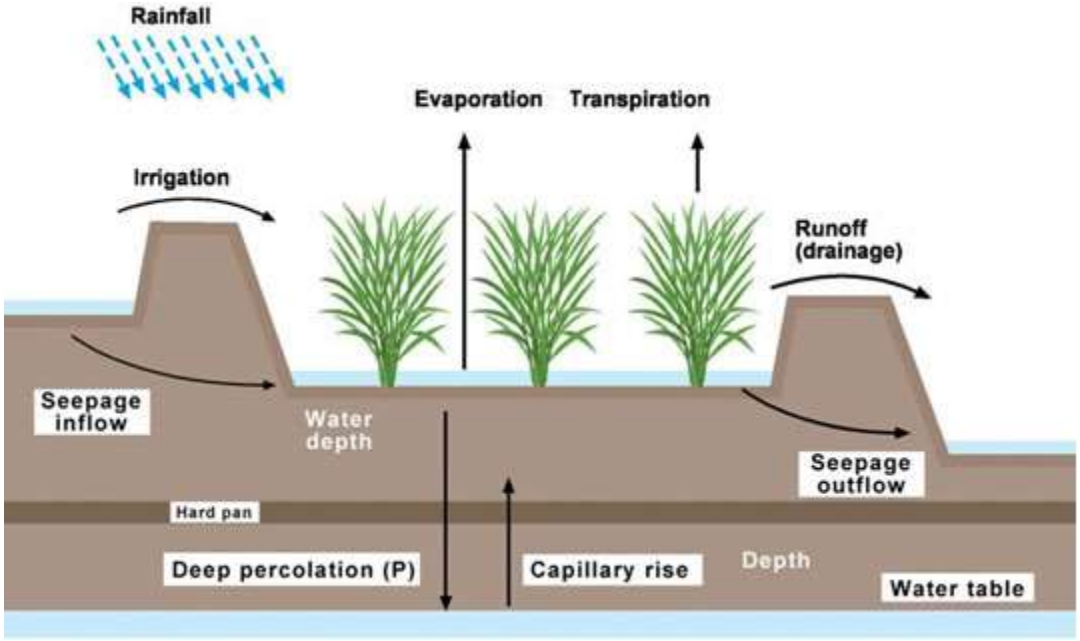


Light

$6H_2O + 6CO_2$ ----------> $C_6H_{12}O_6 + 6O_2$

Evapotranspiration

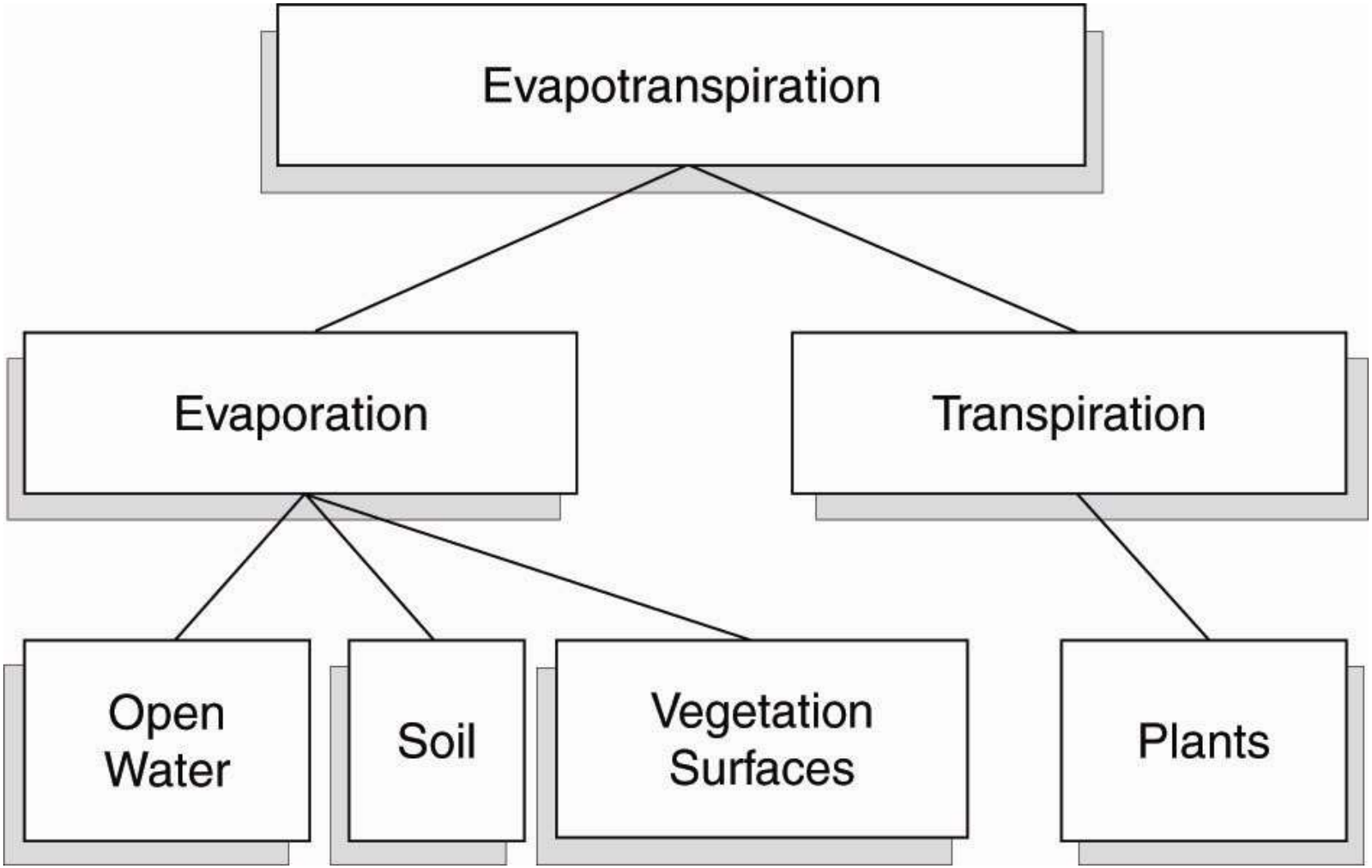
In a farm/agricultural land, evaporation and transpiration take place simultaneously and for all practical purposes, it is necessary to know the total loss due to evaporation and transpiration and not their individual values.



As such, evapotranspiration from a farm/agricultural land is the sum of transpiration from the vegetation and evaporation from the water bodies and soil.

Factors that control evaporation and transpiration, also control evapotranspiration.

Evaporation & Transpiration



Evapotranspiration

Estimation of ET

ET can be measured by Lysimeters but generally ET is estimated by empirical equations.

A **lysimeter** is a measuring device which can be used to measure the amount of actual evapotranspiration which is released by plants.

ET can be calculated by using empirical formulae, from the simple ones needing only temperature, to complicated ones requiring several climatic observations.

The Blaney-Criddle formula:

$$ETo = p\,(0.46\,T + 8)$$

ETo = Reference crop evapotranspiration (mm/day)

T = mean daily temperature (°C)

p = mean daily percentage of annual daytime hours

Lysimeter



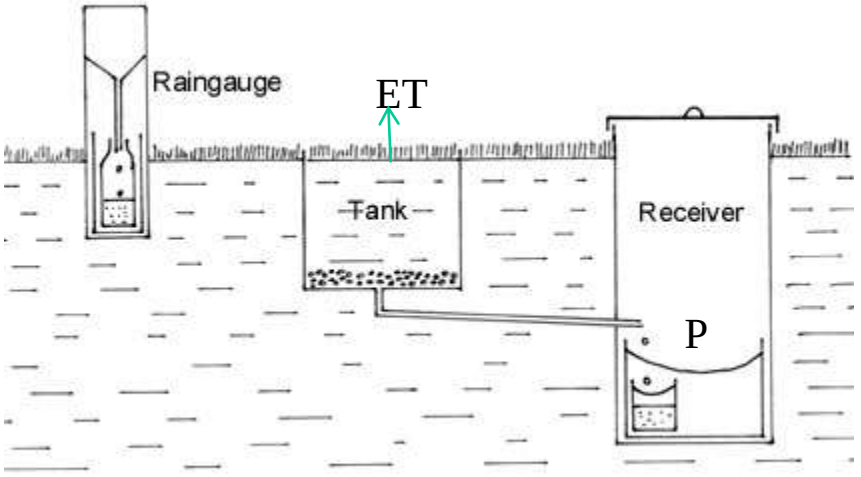


Fig 2. Lysimeter apparatus for measuring evapotranspiration

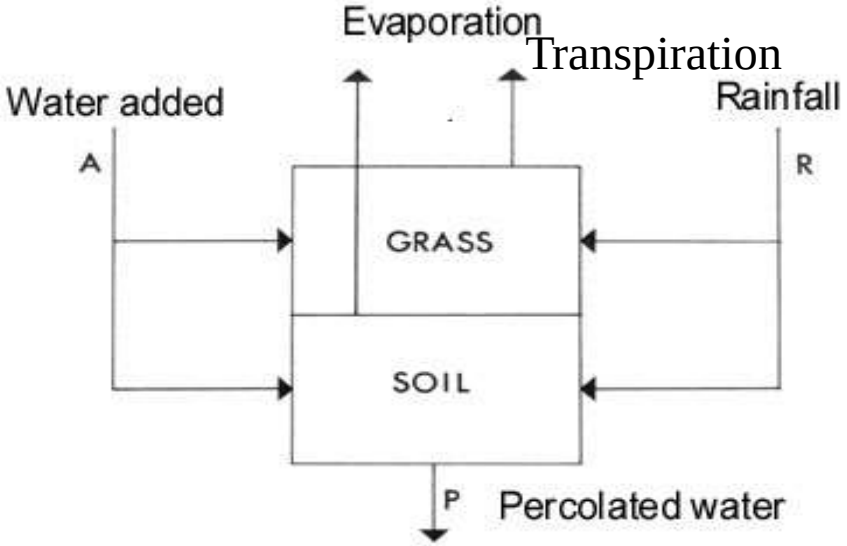


Fig 1. Simplified pathway of water in an evapotranspiration measuring apparatus

$$\Delta S = R + A - P - ET$$

Evapotranspiration

Penman-Monteith Formula:

The Penman-Monteith equation is:

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \dfrac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \dfrac{r_s}{r_a}\right)}$$

where R_n is the net radiation, G is the soil heat flux, (e_s - e_a) represents the vapour pressure deficit of the air, r_a is the mean air density at constant pressure, c_p is the specific heat of the air, D represents the slope of the saturation vapour pressure temperature relationship, g is the psychrometric constant, and r_s and r_a are the (bulk) surface and aerodynamic resistances.

A software called CROPWAT has been developed by FAO to calculate the ET by Penman-Monteith method.

Period	Months	ET_{Aus}	ET_{Boro}	ET_{Wheat}	ET_{Potato}	$ET_{Oil\ seed}$
1980 -	JAN	**	3.84	2.94	3.36	2.94
1990	FEB	**	5.37	0.99	4.19	4.15
	MAR	5.22	**	**	**	1.74
	APR	7.38	**	**	**	**
	MAY	6.27	**	**	**	**
	JUN	4.7	**	**	**	**
	NOV	**	4.22	0.87	1.83	0.87
	DEC	**	3.49	1.79	2.34	1.79

Table: ET values (mm/day) for different crops in Barind area of Rajshahi district.