CE 15015

WATER RESOURCES ENGINEERING

LECTURE NOTES

MODULE-I

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Course Contents

Module-I

Hydrologic cycle, availability of water on earth, importance of hydrology and its applications in engineering.

Precipitation: Forms & types, measurement of rainfall, optimum number of rainguage stations, consistency of rainfall data, presentation of precipitation data, mean aerial rainfall, depth–area-duration curve, design storm, lossess from precipitation, evaporation, infiltration..

Lecture Note 1

Introduction

1.1 Introduction

Water on the surface of earth is available in the atmosphere, the oceans, on land and within the soil and fractured rock of the earth's crust. Water molecules from one location to another are driven due to the solar energy transmitted to the surface of the earth from Sun. Moisture circulates from the earth into the atmosphere through evaporation and then back into the earth as precipitation.

1.2 Hydrological cycle

1. The hydrologic cycle describes the **continuous re-circulating** transport of the waters of the earth, linking atmosphere, land and oceans.
2. Water evaporates from the ocean surface, driven by energy from the **Sun**, and joins the atmosphere, moving inland as clouds. Once inland, atmospheric conditions act to condense and precipitate water onto the land surface, where, driven by **gravitational forces**, it returns to the ocean through river and streams.
3. The process is quite **complex**, containing many sub-cycles.
4. Engineering Hydrology takes a **quantitative** view of the hydrologic cycle.
5. The quantification of the hydrologic cycle which is an open system can be represented by a **mass balance equation**, where inputs minus outputs are equal to the change in storage.
6. It is a basic Hydro-logic Principle or equation that may be applied either on global or regional scale.

$$I - O = \Delta S$$

The water holding elements of the hydrological cycle are:

1. Atmosphere
2. Vegetation
3. Snow packs
4. Land surface
5. Soil
6. Streams, lakes and rivers
7. Aquifers
8. Oceans

1.3 Hydrological Processes

1. Precipitation
2. Evaporation
3. Transpiration
4. Infiltration

5. Overland flow
6. Surface Runoff
7. Groundwater outflow

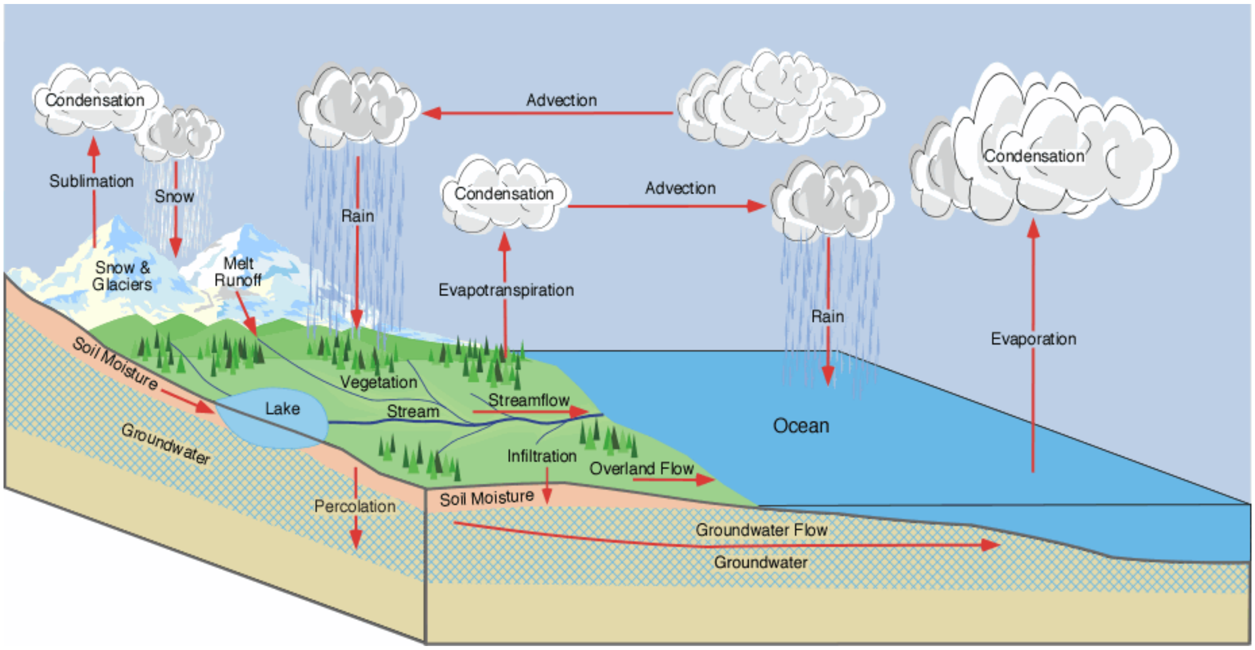


Fig 1(a) Hydrological Cycle

The hydrologic cycle consists of four key components
1. Precipitation
2. Runoff
3. Storage
4. Evapotranspiration

The hydrologic cycle is a model of the movement of water through the Earth system. It also is a pathway through which energy is transferred between the surface of the earth and the atmosphere.

1.4 Water-Budget Equation

The water-budget equation is simple, universal, and adaptable because it relies on few assumptions on mechanisms of water movement and storage. A basic water budget for a small watershed can be expressed as:

$$P + Q_{in} = ET + \Delta S + Q_{out} \quad \ldots \quad \ldots \qquad (1)$$

Where

P is precipitation,

Q_{in} is water flow into the watershed,
ET is evapotranspiration (the sum of evaporation from soils, surface-water bodies, and plants),
ΔS is change in water storage, and
Q_{out} is water flow out of the watershed.

1.5 Applications in Engineering

- Hydrology is used to find out maximum probable flood at proposed sites e.g. Dams.
- The variation of water production from catchments can be calculated and described by hydrology.
- Engineering hydrology enables us to find out the relationship between a catchment's surface water and groundwater resources
- The expected flood flows over a spillway, at a highway Culvert, or in an urban storm drainage system can be known by this very subject.
- It helps us to know the required reservoir capacity to assure adequate water for irrigation or municipal water supply in droughts condition.
- It tells us what hydrologic hardware (e.g. rain gauges, stream gauges etc) and software (computer models) are needed for real-time flood forecasting
- Used in connection with design and operations of hydraulic structure
- Used in prediction of flood over a spillway, at highway culvert or in urban storm drainage
- Used to assess the reservoir capacity required to assure adequate water for irrigation or municipal water supply during drought
- Hydrology is an indispensable tool in planning and building hydraulic structures.
- Hydrology is used for city water supply design which is based on catchments area, amount of rainfall, dry period, storage capacity, runoff evaporation and transpiration.
- Dam construction, reservoir capacity, spillway capacity, sizes of water supply pipelines and affect of afforest on water supply schemes, all are designed on basis of hydrological equations.

Lecture Note 2

Precipitation

2.1 Introduction

Precipitation is any form of solid or liquid water that falls from the atmosphere to the earth's surface. Rain, drizzle, hail and snow are examples of precipitation. In India, rain is the most common form of precipitation.

2.1.1 Causes of precipitation

For the formation of clouds and subsequent precipitation, it is for necessary that the moist air masses to cool in order to condense. This is generally accomplished by adiabatic cooling of moist air through a process of being lifted to higher altitudes. The precipitation types can be categorized as.

- **Frontal precipitation**

This is the precipitation that is caused by the expansion of air on ascent along or near a frontal surface.

- **Convective precipitation**

Precipitation caused by the upward movement of air which is warmer than its surroundings. This precipitation is generally showery nature with rapid changes of intensities.

- **Orographic precipitation**

Precipitation caused by the air masses which strike the mountain barriers and rise up, causing condensation and precipitation. The greatest amount of precipitation will fall on the windward side of the barrier and little amount of precipitation will fall on leave ward side.

For the Indian climate, the south-west monsoon is the principal rainy season when over 75% of the annual rainfall is received over a major portion of the country. Excepting the south-eastern part of the Indian peninsula and Jammu and Kashmir, for the rest of the country the south-west monsoon is the principal source of rain.From the point of view of water resources engineering, it is essential to quantify rainfall over space and time and extract necessary analytical information.

2.1.2 Regional rainfall characteristics

Rain falling over a region is neither uniformly distributed nor is it constant over time. You might have experienced the sound of falling rain on a cloudy day approaching from distance. Gradually, the rain seems to surround you and after a good shower, it appears to recede. It is really difficult to predict when and how much of rain would fall. However it is possible to measure the amount of rain falling at any point and measurements from different point gives an idea of the rainfall pattern within an area.

In India, the rainfall is predominantly dictated by the monsoon climate. The monsoon in India arises from the reversal of the prevailing wind direction from Southwest to Northeast and results in three distinct seasons during the course of the year. The Southwest monsoon brings heavy rains over most of the country between June and October, and is referred to commonly as the 'wet' season. Moisture laden winds sweep in from the Indian Ocean as low-pressure areas develop over the subcontinent and release their moisture in the form of heavy rainfall. Most of the annual rainfall in India comes at this time with the exception of in Tamil Nadu, which receives over half of its rain during the Northeast monsoon from October to November.

The retreating monsoon brings relatively cool and dry weather to most of India as drier air from the Asian interior flows over the subcontinent. From November until February, temperatures remain cool and precipitation low. In northern India it can become quite cold, with snow occurring in the Himalayas as weak cyclonic storms from the west settle over the mountains. Between March and June, the temperature and humidity begin to rise steadily in anticipation of the Southwest monsoon. This pre-monsoonal period is often seen as a third distinct season although the post-monsoon in October also presents unique characteristics in the form of slightly cooler temperatures and occasional light drizzling rain. These transitional periods are also associated with the arrival of cyclonic tropical storms that batter the coastal areas of India with high winds, intense rain and wave activity.

Rainfall and temperature vary greatly depending on season and geographic location. Further, the timing and intensity of the monsoon is highly unpredictable. This results in a vastly unequal and unpredictable distribution over time and space. In general, the northern half of the subcontinent sees greater extremes in temperature and rainfall with the former decreasing towards the north and the latter towards the west. Rainfall in the Thar Desert and areas of Rajasthan can be as low as 200mm per year, whereas on the Shillong Plateau in the Northeast, average annual rainfall can exceed 10,000 mm per year. The extreme southern portion of the country sees less variation in temperature and rainfall. In Kerala, the total annual rainfall is of the order of 3,000 mm.

2.1.3 Measurement of rainfall

One can measure the rain falling at a place by placing a measuring cylinder graduated in a length scale, commonly in mm. In this way, we are not measuring the volume of water that is stored in the cylinder, but the 'depth' of rainfall. The cylinder can be of any diameter, and we would expect the same 'depth' even for large diameter cylinders provided the rain that is falling is uniformly distributed in space.

Now think of a cylinder with a diameter as large as a town, or a district or a catchment of a river. Naturally, the rain falling on the entire area at any time would not be the same and what one

would get would be an 'average depth'. Hence, to record the spatial variation of rain falling over an area, it is better to record the rain at a point using a standard sized measuring cylinder.
In practice, rain is mostly measured with the *standard non-recording rain gauge* the details of which are given in Bureau of Indian Standards code IS 4989: 2002. The rainfall variation at a point with time is measured with a *recording rain-gauge*, the details of which may be found in IS 8389: 2003. Modern technology has helped to develop Radars, which measures rainfall over an entire region. However, this method is rather costly compared to the conventional recording and non-recording rain gauges which can be monitored easily with cheap labour.

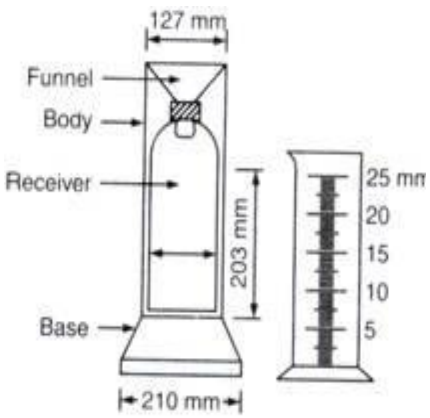


Fig (1)Symons non-recording rain gauge

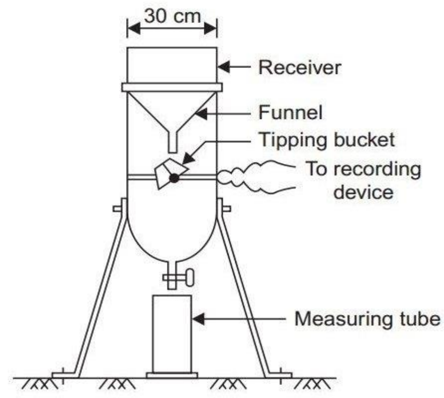


Fig (2) Recording Rain gauge

2.1.4 Variation of rainfall

Rainfall measurement is commonly used to estimate the amount of water falling over the land surface, part of which infiltrates into the soil and part of which flows down to a stream or river. For a scientific study of the hydrologic cycle, a correlation is sought, between the amount of water falling within a catchment, the portion of which that adds to the ground water and the part that appears as streamflow. Some of the water that has fallen would evaporate or be extracted from the ground by plants.

2.1.5 Average rainfall depth

The time of rainfall record can vary and may typically range from 1 minute to 1 day for non – recording gauges, Recording gauges, on the other hand, continuously record the rainfall and may do so from 1 day 1 week, depending on the make of instrument. For any time duration, the average depth of rainfall falling over a catchment can be found by the following three methods.
• The Arithmetic Mean Method
• The Thiessen Polygon Method
• The Isohyetal Method

- **Arithmetic Mean Method**

Assumed recorded value of rainfall depth have been shown in the table:

		Time (in hours)				Total
		First	Second	Third	Fourth	Rainfall
Rain(mm)	A	15	10	3	2	30
	B	12	15	8	5	40
	C	8	10	6	4	28
	D	5	8	2	2	17

Average rainfall as the arithmetic mean of all the records of the four rain gauges, as shown below:

$$\frac{15+12+8+5}{4} = 10mm$$

- **The Theissen polygon method**

This method, first proposed by Thiessen in 1911, considers the representative area for each rain gauge. These could also be thought of as the areas of influence of each rain gauge.

These areas are found out using a method consisting of the following three steps:

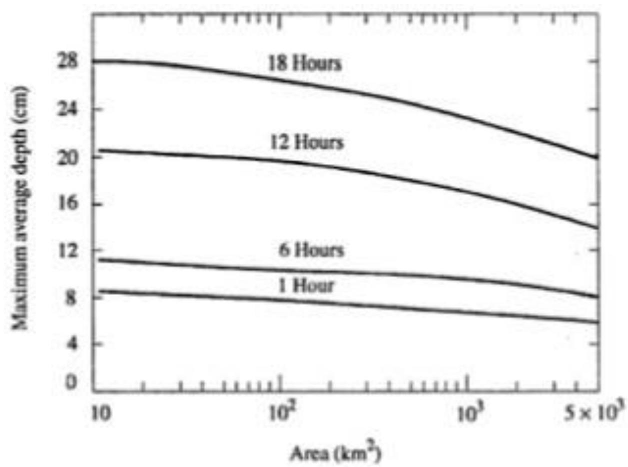
1. Joining the rain gauge station locations by straight lines to form triangles
2. Bisecting the edges of the triangles to form the so-called "Thiessen polygons"
3. Calculate the area enclosed around each rain gauge station bounded by the polygon edges (and the catchment boundary, wherever appropriate) to find the area of influence corresponding to the rain gauge.

- **The Isohyetal method**

This is considered as one of the most accurate methods, but it is dependent on the skill and experience of the analyst. The method requires the plotting of ***isohyets*** as shown in the figure and calculating the areas enclosed either between the isohyets or between an isohyet and the catchment boundary. The areas may be measured with a ***planimeter*** if the catchment map is drawn to a scale.

2.1.6 Depth-Area-Duration curves

In designing structures for water resources, one has to know the areal spread of rainfall within watershed. However, it is often required to know the amount of high rainfall that may be expected over the catchment. It may be observed that usually a storm event would start with a heavy downpour and may gradually reduce as time passes. Hence, the rainfall depth is not proportional to the time duration of rainfall observation. Similarly, rainfall over a small area may be more or less uniform. But if the area is large, then due to the variation of rain falling in different parts, the average rainfall would be less than that recorded over a small portion below the high rain fall occurring within the area. Due to these facts, a Depth-Area-Duration (DAD) analysis is carried out based on records of several storms on an area and, the maximum areal precipitation for different durations corresponding to different areal extents.



Typical DAD curves (Subramanya, 1994)

2.1.7 Intensity-Duration-Frequency curves

The analysis of continuous rainfall events, usually lasting for periods of less than a day, requires the evaluation of rainfall intensities. The assessment of such values may be made from records of several part storms over the area and presented in a graphical form as shown in Figure 1.

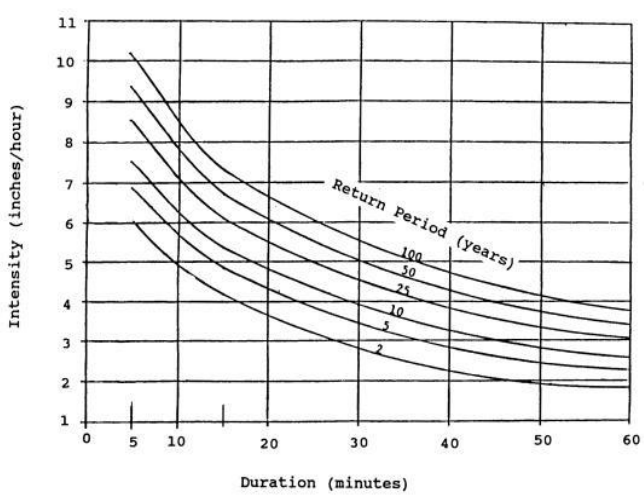


Fig (1)

Two new concepts are introduced here, which are:

- **Rainfall intensity**
  This is the amount of rainfall for a given rainfall event recorded at a station divided by the time of record, counted from the beginning of the event.
- **Return period**
  This is the time interval after which a storm of given magnitude is likely to recur. This is determined by analyzing past rainfalls from several events recorded at a station. A related term, the frequency of the rainfall event (also called the storm

event) is the inverse of the return period. Often this amount is multiplied by 100 and expressed as a percentage. Frequency (expressed as percentage) of a rainfall of a given magnitude means the number of times the given event may be expected to be equaled or exceeded in 100 years.

2.1.8 Analysis for anomalous rainfall records

Rainfall recorded at various rain gauges within a catchment should be monitored regularly for any anomalies. For example of a number of recording rain gauges located nearby, one may have stopped functioning at a certain point of time, thus breaking the record of the gauge from that time onwards. Sometimes, a perfectly working recording rain gauge might have been shifted to a neighborhood location, causing a different trend in the recorded rainfall compared to the past data. Such difference in trend of recorded rainfall can also be brought about by a change in the neighborhood or a change in the ecosystem, etc. These two major types of anomalies in rainfall are categorized as

- Missing rainfall record
- Inconsistency in rainfall record

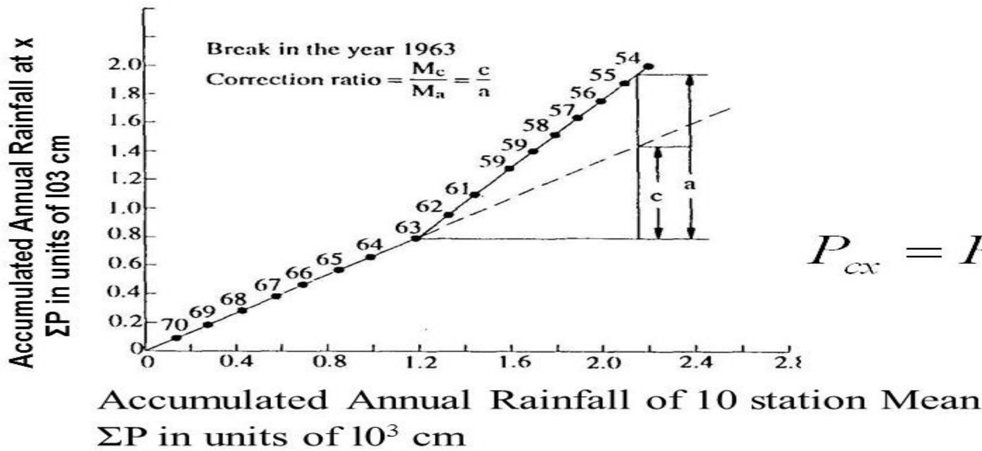
Missing rainfall record
The rainfall record at a certain station may become discontinued due to operational reasons. One way of approximating the missing rainfall record would be using the records of the three rain gauge stations closet to the affected station by the “Normal Ratio Method” as given below:

$$P_5 = \frac{1}{4}[\frac{N_5}{N_1}P_1 + \frac{N_5}{N_2}P_2 + \frac{N_5}{N_3}P_3 + \frac{N_5}{N_4}P_4]$$

Where P5 is the precipitation at the missing location, N1, N2, N3, N4 and N5 are the normal annual precipitation of the four stations and P1, P2, P3 and P4 are the rainfalls recorded at the three stations 1, 2, 3 and 4 respectively.

Inconsistency in rainfall record
This may arise due to change in location of rain gauge, its degree of exposure to rainfall or change in instrument, etc. The consistency check for a rainfall record is done by comparing the accumulated annual (or seasonal) precipitation of the suspected station with that of a standard or reference station using a double mass curve.

Test for Consistency of Record



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

2.1.9 Probable extreme rainfall events

Two values of extreme rainfall events are important from the point of view of water resources engineering. These are:

- **Probable Maximum Precipitation (PMP)**

This is the amount of rainfall over a region which cannot be exceeded over at that place. The PMP is obtained by studying all the storms that have occurred over the region and maximizing them for the most critical atmospheric conditions. The PMP will of course vary over the Earth's surface according to the local climatic factors. Naturally, it would be expected to be much higher in the hot humid equatorial regions than in the colder regions of the mid-latitudes when the atmospheric is not able to hold as much moisture. PMP also varies within India, between the extremes of the dry deserts of Rajasthan to the ever humid regions of South Meghalaya plateau.

- **Standard Project Storm (SPS)**

This is the storm which is reasonably capable of occurring over the basin under consideration, and is generally the heaviest rainstorm, which has occurred in the region of the basin during the period of rainfall records. It is not maximized for the most critical atmospheric conditions but it may be transposed from an adjacent region to the catchment under considerations.

2.1.10 Lossess from precipitation

For a surface water resource engineer, precipitation – runoff =losses
Precipitation – surface runoff = total losses
Total losses = Evaporation + Transpiration + Interception + Depression storage + Infiltration

Interception

Interception is the part of the rainfall that is intercepted by the earth's surface and which subsequently evaporates. The interception can take place by vegetal cover or depression storage in puddles and in land formations such as rills and furrows. Interception can amount up to 15-50% of precipitation, which is a significant part of the water balance.

Depression storage

Depression storage is the natural depressions within a catchment area which store runoff. Generally, after the depression storage is filled, runoff starts. A paved surface will not detain as much water as a recently furrowed field. The relative importance of depression storage in determining the runoff from a given storm depends on the amount and intensity of precipitation in the storm.

Infiltration

The process by which water on the ground surface enters the soil. The rate of infiltration is affected by soil characteristics including ease of entry, storage capacity, and transmission rate through the soil. The soil texture and structure, vegetation types and cover, water content of the soli, soil temperature, and rainfall intensity all play a role in controlling infiltration rate and capacity.

Factors affecting infiltration

Soil Type : Sand with high porosity will have greater infiltration than clay soil with low porosity.

Surface of Entry : If soil pores are already filled with water, capacity of the soil to infiltrate will greatly reduce. Also, if the surface is covered by leaves or impervious materials like plastic, cement then seepage of water will be blocked.

Fluid Characteristics : Water with high turbidity or suspended solids will face resistance during infiltration as the pores of the soil may be blocked by the dissolved solids. Increase in temperature can influence viscosity of water which will again impact on the movement of water through the surface.

Evaporation and its estimation :-

- Continuous natural process by which a substance changes from liquid to gaseous state.
- In arid regions, 90% loss is due to evaporation.
- So evaporation may otherwise be defined as loss of water to the atmosphere over the period under consideration.
- The main source of evaporation is solar radiation.
- 1 gm of water requires about 597cal of heat at 0^0c or 1gm of ice at 0 ^{0}c requires about 677cal for vaporization. This heat is latent heat of water and supplied by sun.
- Equivalent molar wt. Of air = 28.95,water vapour is = 18 So water vapor is 62% lighter than air.
- Due to heat radiation, KE of water surface molecules increases . The surface tension and cohesion force can’t hold the water molecules .They project into the atmosphere

and due to lighter weight than air ,they can rise up to height where they condense .

- The net evaporation takes place during warm periods.
- Therefore the temperature of water surface is maintained at lower level.
- In a hydrologic cycle, evaporation takes place from all stages , even from the falling raindrops .
- Average annual rainfall in India is about 1120mm which is equal to 370 million hector-m of water.
  Total runoff by all the rivers of the country = 170 million hector-m Ground water recharge = 37 million hector-m
  So loss due to evaporation and transpiration = 163 million hector-m

Factors responsible for evaporation :-

1. Meteorological factors :

A) Vapour pressure
B) Solar radiation
C) Air temperature
D) Wind velocity
E) Atmospheric pressure

2. Nature of evaporating surface (Heat storage in water bodies)
3. Quality of water (Presence Soluble salts)

Vapour pressure: The rate of evaporation is proportional to the difference between the saturation vapour pressure at the water temperature, ew and the actual vapour pressure in the air ea.

EL = C (ew - ea) EL = rate of evaporation (mm/day); C = a constant ; ew and ea are in mm of mercury; The above equation is known as Dalton's law of evaporation. Evaporation takes place till ew > ea, condensation happen if ew < ea

Temperature: The rate of evaporation increase if the water temperature is increased. The rate of evaporation also increase with the air temperature.

Heat Storage in water body: Deep bodies can store more heat energy than shallow water bodies. Which causes more evaporation in winter than summer for deep lakes.

Wind: Wind helps in removing evaporated water vapour from the zone of evaporation and creates more scope for further evaporation. But it continues up to a certain increase in wind speed i.e critical speed beyond which no effect on evaporation. If the water surface is having larger area ,then high speed turbulent winds are required for maximum evaporation.

Evaporimeters

Evaporation is estimated by

- Measurement using evaporation pans
- Empirical equations

- Analytical methods
- Water balance method
- Energy budget method
- Mass transfer method

Types of Evaporimeter

- Class A evaporation pan
- ISI standard Pan
- Colorado sunken pan
- US geological survey floating pan.

Class A evaporation pan :

- Pan is normally made up of unpainted galvanized iron sheet.
- Evaporation is measured by measuring the depth of water with a hook gauge in a stilling well.
- Top surface is open to atmosphere.
- Due to absence of top wire mesh, evaporation is 14% extra.

ISI Standard Pan (Modified Class A Pan):-

- Made up of copper sheet, tinned inside and painted white outside.
- Paint gauge is used for water level measurement.
- Calibrated cylindrical measure is used to add or remove water maintaining the water level in the pan.
- Top surface is covered with a hexagonal wire netting of galvanized iron to protect the water in the pan from birds.
- Due to presence of wire mesh, evaporation is 14% less than that of class A pan.

Colorado Sunken pan:-

- Its size is less than the above two pans.
- It is made up of unpainted galvanized iron sheet and buried into the ground within 100m from top.

Advantages:-

Its major advantage is that its radiation and aerodynamic characteristics are similar to those of lake.

Disadvantage:-

- It is very difficult to detect any leak.
- Extra care is required to keep the surrounding free from tall grass, dust etc.
- It is very expensive to install.
- Atometer is sometimes used for measuring evaporation
- It consists of a porous bulb drawing water from a container.
- Evaporation takes place from the bulb.
- A coefficient when multiplied to the depth of evaporated water from the porous bulb gives the required evaporation data of the data.

Evaporation recorded by a pan differs from that of a lake or reservoir due to:-

- Depth of exposure of pan above ground.

- Colour of the pan.
- Height of the rim.
- Heat storage and heat transfer capacity with respect to reservoir.
- Pan diameter
- Variation in vapour pressure, wind speed, water temperature.

We have to reduce the evaporation recorded by pan to that of the lake or reservoir by multiplying a pan coefficient between 0.6 to 0.8.
Lake Evaporation=Cp* Pan Evaporation
Where Cp=Pan co-efficient.

Type of pan	Range of **Cp**	Average value **Cp**
Class A land pan	0.60-0.80	0.70
ISI pan	0.65-1.10	0.80
Colorado sunken pan	0.75-0.86	0.78
USGS Floating pan	0.70-0.82	0.80

Source: Subramanya, 1994

EMPERICAL EQUATION:

a) **General equation:**

$E_L = K\, f(u)\, (e_w - e_a)$

E_L=Lake evaporation (mm /day) e_w=saturated vapour pressure of water e_a= actual vapour pressure of air f(u)=wind speed correction function K=coefficient

b) **Meyer's formula:**

$E_L = K_M (e_w - e_a)(1+u_9/16)$

U_9 = monthly mean wind speed at kmph at 9m above ground K_M = 0.36 for large deep lakes

0.50 For small shallow lakes

c) **Rhower's formula:**

$E_L = 0.771(1.465-0.000732P_a)(0.44+0.0733u_0)(e_w-e_a)$

P_a=mean barometric reading in mm Hg

U_0=mean wind velocity in kmph at ground level=velocity at 0.6 m height above the ground

- In the lower part of atmosphere, up to a height of about 500m above the ground level , the wind velocity can be assumed to follow the 1/7 power law as $U_h = CH^{1/7}$

U_h=wind velocity at height h above ground C=constant

If u_h is given then this equation can be used to determine velocity at any desire level.

Evapotranspiration

Transpiration + Evaporation

- This phenomenon describes transport of water into the atmosphere from surfaces, including soil

(soil evaporation), and vegetation (transpiration).

- Hydrologic Budget equation for Evapotranspiration:

$$P - Rs - Go - Eact = del\ S$$

P= precipitation; Rs= Surface runoff; Go= Subsurface outflow; Eact = Actual evapotranspiration; del S = change in the moisture storage.

REFERENCES

1.Engineering Hydrology by K. Subramanya. Tata Mc Graw Hill Publication

2. Elementary Hydrology by V.P. Singh, Prentice Hall Publication

3 Hydrology by P. Jayarami Reddy

4. Handbook of applied hydrology, V.T. Chow, Mc Graw Hill.