Chapter 8: Mean Precipitation Over an Area

Introduction

Precipitation is a key component of the hydrological cycle and plays a crucial role in the planning and design of various water resources projects such as dams, reservoirs, and drainage systems. However, in practical applications, it is seldom sufficient to know the precipitation at a single point. Engineers and hydrologists often require an estimate of **mean precipitation over an area**, especially for catchments or watersheds. Since precipitation is spatially variable, it becomes important to use techniques that can convert point rainfall measurements at various rain gauge stations into a representative areal mean.

This chapter discusses the different methods of estimating mean precipitation over a given area, their mathematical formulations, applicability, advantages, and limitations. The accuracy of these methods greatly influences flood forecasting, water balance computation, and hydrological modeling.

8.1 Need for Estimating Areal Mean Precipitation

- Precipitation recorded at rain gauge stations represents point data.
- Hydrological models and water balance studies require areal averages.
- Areal precipitation is used in:
  - Estimation of runoff volumes.
  - Flood forecasting and reservoir design.
  - Irrigation planning and drought assessment.
- Due to topographic, climatic, and spatial variability, a uniform distribution of rainfall over a large area is unlikely.

8.2 Factors Affecting Areal Distribution of Rainfall

Several factors influence the spatial distribution of precipitation:

- **Topography**: Mountains and valleys affect orographic lifting and precipitation concentration.
- **Wind patterns and direction**: Influence the location and intensity of storms.
- **Storm characteristics**: Duration, intensity, and movement determine precipitation patterns.

- **Rain gauge network density and placement**: Sparse or uneven networks lead to inaccurate estimates.

8.3 Methods for Estimating Mean Precipitation

There are three principal methods commonly used for estimating the mean precipitation over an area:

8.3.1 Arithmetic Mean Method

This is the simplest method and is suitable when rainfall is fairly uniform over the area.

Formula:

$$P_{mean} = \frac{1}{n} \sum_{i=1}^{n} P_i$$

Where:

- P_i = Rainfall at station i
- n = Number of rain gauge stations

Advantages:

- Simple and quick.
- Requires minimal data processing.

Limitations:

- Not reliable when rainfall varies significantly across the area.
- Does not account for the spatial arrangement of stations.

8.3.2 Thiessen Polygon Method

This is a weighted average method based on the proximity of each rain gauge station to different areas of the basin.

Steps Involved:

1. Plot the location of all rain gauge stations on a map.
2. Connect adjacent stations to form a network of triangles.
3. Draw perpendicular bisectors of each side to form polygons.
4. Each polygon area is assumed to be represented by the station it contains.
5. Compute the weighted average based on polygon area.

Formula:

$$P_{mean} = \sum_{i=1}^{n} w_i P_i$$

Where:

- w_i = Weight = Area of polygon around station i / Total area
- P_i = Rainfall at station i

Advantages:

- Accounts for spatial location of rain gauges.
- More accurate than the arithmetic mean in non-uniform rainfall.

Limitations:

- Assumes rainfall is uniform within a polygon.
- Laborious to construct manually for many stations.

8.3.3 Isohyetal Method

This is the most accurate and widely used method, especially for regions with high spatial variability in precipitation.

Steps Involved:

1. Plot the rainfall values on a map.
2. Draw isohyets (lines of equal rainfall) through interpolation.
3. Divide the area between successive isohyets.
4. Compute the average precipitation in each belt between isohyets.
5. Multiply each average by the area it represents and sum them.

Formula:

$$P_{mean} = \frac{1}{A} \sum_{i=1}^{m} A_i \cdot P_i$$

Where:

- A_i = Area between two isohyets
- P_i = Average precipitation in that area
- A = Total area
- m = Number of isohyetal zones

Advantages:

- Most accurate among all methods.
- Considers both magnitude and spatial variation of rainfall.

Limitations:

- Requires considerable data and mapping skill.
- Time-consuming and requires topographical interpretation.

8.4 Selection of Method

Condition	Preferred Method
Uniform rainfall and evenly distributed gauges	Arithmetic Mean
Uneven distribution of gauges, moderate variation	Thiessen Polygon
High variability in rainfall, complex terrain	Isohyetal Method

Factors to consider while choosing a method:

- Size and topography of the area.
- Distribution and number of rain gauges.
- Availability of contour data and rainfall records.

8.5 Optimum Number of Rain Gauges

The accuracy of estimating mean precipitation over an area increases with the number of rain gauges. However, installing and maintaining gauges involves cost. Hence, an optimum number of rain gauges must be determined.

8.5.1 Formula for Optimum Number of Gauges

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

Where:

- N = Optimum number of gauges
- C_v = Coefficient of variation (standard deviation/mean of rainfall)
- E = Allowable percentage error

This helps in designing a balanced and efficient rain gauge network.

8.6 Double Mass Curve Technique

This technique is used to check the consistency of rainfall records before using them in areal mean calculations.

Steps:

1. Plot cumulative rainfall at a target station against the average of neighboring stations.
2. A straight-line trend indicates consistent data.
3. A change in slope suggests inconsistency, possibly due to changes in station location or equipment.

Use:

- Corrects data inconsistencies.
- Ensures reliability of long-term rainfall data.

8.7 Application of Areal Rainfall in Hydrologic Studies

- **Runoff estimation** using rainfall-runoff models.
- **Water balance analysis** for catchment studies.
- **Design of hydraulic structures** such as spillways and culverts.
- **Drought analysis** and crop planning.
- **Flood frequency analysis**.

8.8 Practical Considerations and Errors

- Gauge error: Faulty readings or malfunction.
- Spatial variability: Actual rainfall can differ significantly even over small areas.
- Human error: Data entry, drawing isohyets inaccurately.
- Storm movement: Some methods may not account for dynamic movement of storms.
