

### 3.4.4 Spatial Consistency Check

Rainfall data exhibit some spatial consistency and this forms the basis of investigating the observed rainfall values. An estimate of the interpolated rainfall value at a station is obtained on the basis of the weighted average of rainfall observed at the surrounding stations. If the difference between the observed and the estimated values exceed the expected limiting value, such values are considered as suspect and are flagged for further investigation and ascertaining the possible causes of departures.

Spatial consistency checks for rainfall data are carried out by relating the observations from surrounding stations for the same duration with the rainfall observed at the station. This is achieved by interpolating the rainfall at the station under question with rainfall data of neighboring stations. The station being considered is called the test station. The interpolated value is estimated by computing the weighted average of the rainfall observed at neighboring stations. Ideally, the stations selected as neighbors should be physically representative of the area in which the station under scrutiny is situated. The following criteria are used to select the neighboring stations:

- (a) The distance between the test and the neighboring station must be less than a specified maximum correlation distance;
- (b) too many neighboring stations should not be considered for interpolation; and
- (c) to reduce the spatial bias in selection, it is advisable to consider an equal number of stations in each quadrant.

**Example 3.3:** Rainfall reported at a group of five stations (see Fig. 3.7) is as follows.

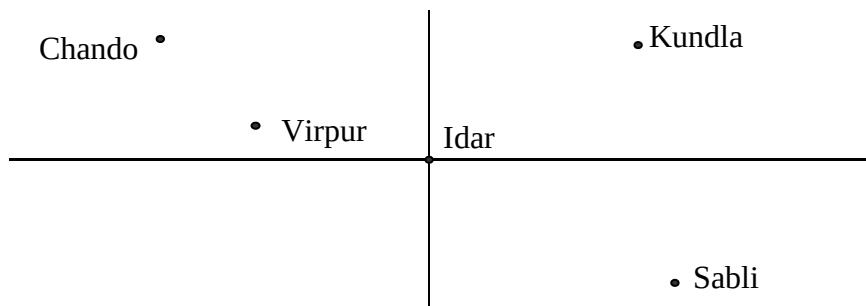


Fig. 3.7 Location of stations for spatial consistency check.

| Station       | Kundla | Idar | Virpur | Chandop | Sabli |
|---------------|--------|------|--------|---------|-------|
| Rainfall (mm) | 132.1  | 12.1 | 103.3  | 125.7   | 149.8 |

During the quality control process, the data at Idar is identified as doubtful. Check this data for spatial consistency.

**Solution:** The rainfall at Idar is estimated using the distance power method and compared with the observed value. From the four quadrants around Idar (Fig. 3.6), the station nearest from each quadrant is selected for estimation of rainfall at Idar. Using the reference coordinate system, the distance of each of the estimator stations from Idar is determined and the rainfall at Idar is estimated.

| S. N. | Station | Distance from Idar $D_i$<br>(km) | $1/D_i^2$              | $R_i/D_i^2$ |
|-------|---------|----------------------------------|------------------------|-------------|
| 1.    | Kundla  | 42                               | $5.67 \times 10^{-4}$  | 0.075       |
| 2.    | Virpur  | 39                               | $6.57 \times 10^{-4}$  | 0.068       |
| 3.    | Sabli   | 75                               | $1.78 \times 10^{-4}$  | 0.027       |
|       | Total   |                                  | $14.02 \times 10^{-4}$ | 0.170       |

$$\text{Rainfall at Idar} = [\sum(R_i/D_i^2)] / [\sum(1/D_i^2)] = 0.17/14.02 \times 10^{-4} = 121.25 \text{ mm.}$$

Since the observed value is very much different from the estimated value, it is rejected and replaced by the estimated value. Note that there is a possibility that the decimal point was wrongly placed while recording the data at Idar.

### 3.5 Spatial Averaging of Rainfall Data

Precipitation observations from gauges are point measurements. However, in the hydrological analysis and design, we frequently require mean areal precipitation over an area. A characteristic of the precipitation process is that it exhibits appreciable spatial variation though the values at relatively short distances may have good correlation.

Numerous methods of computing areal rainfall from point measurements have been developed. While using precipitation data, one often comes across missing data situations. Data for the period of missing rainfall could be filled using various techniques. Due to the spatial structure of precipitation data, some type of interpolation making use of the data of nearby stations is commonly adopted.

Let the precipitation data be available at  $n$  stations, spread over an area and  $P_i$  be the observed depth of precipitation at the  $i^{\text{th}}$  station. Using a linear interpolation technique, an estimate of precipitation over the area can be expressed by

$$P^* = \sum_{i=1}^n P_i W_i \quad (3.7)$$

where  $W_i$  is the weight of the  $i^{\text{th}}$  station. The spatial averaging techniques differ in the method of evaluation of these weights. Weights of an optimal interpolation technique are decided such that the variance of error in estimation is the minimum.

The most commonly used methods are for Spatial Averaging of Precipitation Data:

- (a) Arithmetic average,
- (b) Normal ratio method,
- (c) Distance power method,
- (d) Thiessen polygon method, and
- (e) Isohyetal method.

The choice of the method is depends on the quality and nature of data, importance of use and required precision, availability of time and computer. Some of the commonly used methods are described below.

### 3.5.1 Arithmetic Average

The simplest technique to compute the average precipitation depth over a catchment area is to take an arithmetic average of the observed precipitation depths at gauges within the catchment area for the time period of concern. The average precipitation is:

$$P = \frac{\sum_{i=1}^n P_i W_i}{n} \quad (3.8)$$

where  $P$  is the average catchment precipitation from the data of  $n$  stations,  $P_i$  is the precipitation at station  $i$ , and  $W_i$  is the weight of  $i^{\text{th}}$  station. If the gauges are relatively uniformly distributed over the catchment and the rainfall values do not have a wide variation, this technique yields good results.

### 3.5.2 Thiessen Polygon

The Thiessen Polygon method is based on the concept of proximal mapping. Weights are assigned to each station according to the catchment area which is closer to that station than to any other station. This area is found by drawing perpendicular bisectors of the lines joining the nearby stations so that the polygons are formed around each station (Fig. 3.8). It is assumed that these polygons are the boundaries of the catchment area which is represented by the station lying inside the polygon. The area represented by each station is measured and is expressed as a percentage of the total area. The weighted average precipitation for the basin is computed by multiplying the precipitation received at each station by its weight and summing. The weighted average precipitation is given by:

$$P = \sum_{i=1}^n P_i W_i \quad (3.9)$$

in which  $W_i = A_i/A$ , where  $A_i$  is the area represented by the station  $i$  and  $A$  is the total catchment area. Clearly, the weights will sum to unity.

An advantage of this method is that the data of stations outside the catchment may also be used if these are believed to help in capturing the variation of rainfall in the catchment. The method works well with non-uniform spacing of stations.

A major drawback of this method is the assumption that precipitation between two stations varies linearly and the method does not make allowance for variation due to orography. In this method, the precipitation depth changes abruptly at the boundary of polygons. Also, whenever a set of stations are added to or removed from the network, a new set of polygons have to be drawn. The method fails to give any idea as to the accuracy of the results. If a few observations are missing, it may be more convenient to estimate the missing data than to construct the new set of polygons.

**Example 3.4:** For a catchment, the rainfall data at six stations for July month along with their weights are as given in Table 3.4. Find the weighted average rainfall for the catchment by using the Thiessen polygon method.

**Solution:** Using the observed rainfall and station weight, weighted rainfall at each station is computed. Summation of these values gives the weighted average rainfall for the catchment. The computations are shown in Table 3.1.

Table 3.1 Estimation of the mean areal rainfall by the Thiessen polygon method.

| S. N.                       | Station Name | Station weight | Rainfall (mm) | Weighted rainfall (mm) |
|-----------------------------|--------------|----------------|---------------|------------------------|
| 1.                          | Sohela       | 0.06           | 262.0         | 15.7                   |
| 2.                          | Bijepur      | 0.12           | 521.0         | 62.5                   |
| 3.                          | Padampur     | 0.42           | 177.0         | 74.3                   |
| 4.                          | Paikmal      | 0.28           | 338.0         | 94.6                   |
| 5.                          | Binka        | 0.04           | 158.0         | 16.1                   |
| 6.                          | Bolangir     | 0.08           | 401.6         | 12.6                   |
| Weighted catchment rainfall |              |                |               | 275.8                  |

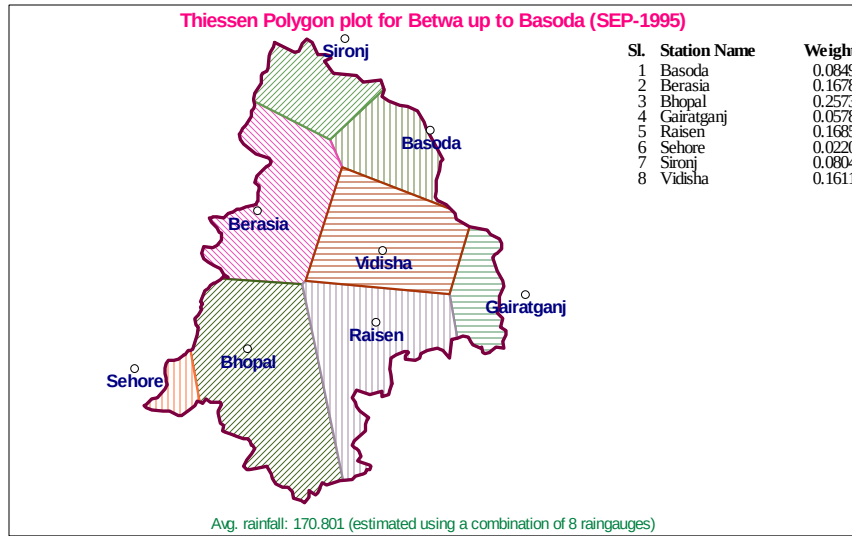


Fig. 3.8 The Thiessen polygon method for computing the mean areal rainfall.

### 3.5.3 Isohyetal Method

The isohyetal method employs the area encompassed between isohyetal lines. Rainfall values are plotted at their respective stations on a suitable base map and contours of equal rainfall, called isohyets, are drawn. In regions of little or no physiographic influence, drawing of isohyetal contours is relatively simple matter of interpolation. The isohyetal contours may be drawn take into account the spacing of stations, the quality, and variability of the data. In regions of pronounced orography where precipitation is influenced by topography, the analyst should take into consideration the orographic effects, storm orientation etc. to adjust or interpolate between station values.

Computers are being used to draw isohyetal maps these days, by using special software. As an example, the isohyetal map for an area is shown in Fig. 3.8. The total depth of precipitation is computed by measuring the area between successive isohyets, multiplying this area by the average rainfall of the two isohyets, and totaling. The average depth of precipitation is obtained by dividing this sum by the total area. The average depth of precipitation ( $P_i$ ) over this area is obtained by:

$$P = \frac{\sum_{i=1}^n P_i A_i}{\sum_{i=1}^n A_i} \quad (3.10)$$

where  $A_i$  is the area between successive isohyets and  $P_i$  is the average rainfall between the two isohyets.

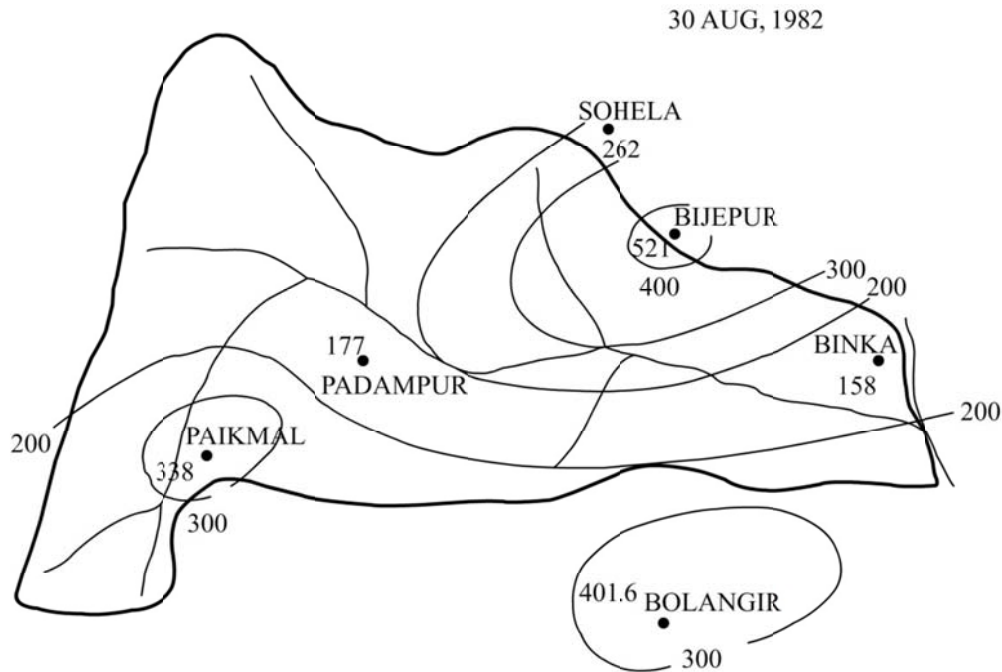


Fig. 3.8 The isohyetal method for computing the mean areal rainfall.

Table. 3.2 Estimation of mean areal catchment rainfall by Isohyetal Method

| Isohyetal range<br>(mm) | Average value<br>(mm) | Area<br>(km <sup>2</sup> ) | Volume<br>(10 <sup>5</sup> m <sup>3</sup> ) |
|-------------------------|-----------------------|----------------------------|---------------------------------------------|
| 521.0 - 500.0           | 510.5                 | 70                         | 357.4                                       |
| 500.0 - 300.0           | 400.0                 | 530                        | 2120.0                                      |
| 338.0 - 300.0           | 319.0                 | 100                        | 319.0                                       |
| 200.0 - 300.0           | 250.0                 | 2080                       | 5200.0                                      |
| 158.0 - 200.0           | 179.0                 | 2820                       | 5047.8                                      |
|                         |                       | <b>5600</b>                | <b>13044.2</b>                              |

$$\text{Average catchment rainfall} = \frac{13044.2}{5600} = 232.9\text{mm}$$

**Example 3.5:** Using the point rainfall data for a catchment, isohyetal lines were drawn as shown in Fig. 3.8. The area enclosed by each isohyet was calculated as given in Table 3.3. Compute the average catchment rainfall.

**Solution:** For each isohyet, the average value is worked out (the maximum observed rainfall was 108 cm and the minimum 38 cm). This, multiplied by the area enclosed by that isohyet gives the volume of rainfall for that isohyet. Now the volumes for different isohyetals are summed and

divided by the area of the catchment to get average catchment rainfall. The computations are shown in Table 3.3.

Table 3.3 Estimation of mean areal rainfall by the isohyetal method.

| Isohyet<br>value (cm)                              | Average<br>value (cm) | Area<br>enclosed<br>(km <sup>2</sup> ) | Net area<br>(km <sup>2</sup> ) | Rainfall<br>volume (km <sup>2</sup> -<br>cm) |
|----------------------------------------------------|-----------------------|----------------------------------------|--------------------------------|----------------------------------------------|
| 105                                                | 106.5                 | 0.79                                   | 0.79                           | 84.14                                        |
| 100                                                | 102.5                 | 1.52                                   | 0.73                           | 74.83                                        |
| 90                                                 | 95                    | 2.57                                   | 1.05                           | 99.75                                        |
| 80                                                 | 85                    | 3.47                                   | 0.90                           | 76.50                                        |
| 70                                                 | 75                    | 4.50                                   | 1.03                           | 77.25                                        |
| 60                                                 | 65                    | 5.18                                   | 0.68                           | 44.20                                        |
| 50                                                 | 55                    | 5.39                                   | 0.21                           | 2.20                                         |
| < 40                                               | 39                    | 5.41                                   | 0.02                           | 0.78                                         |
| Total                                              |                       |                                        | 5.41                           | 459.65                                       |
| Average catchment rainfall = 459.65/5.41= 84.96 cm |                       |                                        |                                |                                              |