DESIGN OF METEOROLOGICAL DATA NETWORKS

Dr. N. K. Goel

Professor
Department of Hydrology,
Indian Institute of Technology Roorkee
Roorkee-247 667

1. INTRODUCTION

The design of meteorological data networks is intended to know the number of meteorological stations in the basin under consideration, type of instruments in the observatory i.e. rain gauge, snow gauge evaporation pans, various types of thermometers (minimum, maximum, dry bulb, wet bulb etc.), type of instruments for individual parameters, location of observatories and prioritization of observatories. The number of observatories in a given basin or area under consideration depends on the purpose of observatory e.g. (a) Educational purpose (b) To know the general meteorological characteristics of the area, (c) flood forecasting etc.

It is important to establish few observatories for educational purpose even at school level and college level. In India, a project named 'PROBE' (Participation of Youth in Real time Observation to Benefit Education) was started by Department of Science and Technology in year 2001. Under this project a number of observatories were established in different states like Uttarakhand NCR, Delhi, Orissa etc. In various countries networks of meteorological observatories are developed to know the local and regional meteorological characteristics of the area by the National meteorological agency. The data of selected observatories are shared with other countries through bilateral arrangements, and with World Meteorological Organisation (WMO). Network of meteorological stations and gauge and discharge sites are also developed for specific purposes like flood forecasting for large storage dams, water availability for small hydropower schemes etc.

2. PLANNING

For initial planning of observatories the number is decided on the basis of density recommended by National Meteorological agencies, availability of funds and guidelines given by WMO and availability of funds.

The type of instruments to be installed in any observatory again depends on purpose and availability of funds. The instruments may be classified as follows:

(i) Manual instruments (ordinary)
(ii) Manual instruments (with recording facilities)
(iii) Instruments with data logging facilities
(iv) Instruments with data logging and transmission facilities.

The details of rain gauge network design are available in number of text books. For completeness purpose the details of rain gauge network as given by Subramanya (2008) are given in Annexure – I

A good description for allocation of additional rain gauge is given in lecture notes published by National Institute of Hydrology in year 1987. The same is reproduced in Annexure – II. The rain gauge network design for flood forecasting purpose is explained well in manual on 'Flood Forecasting' published by Central Water Commission in year 1980. The same is reproduced in Annexure – III.

References:

Central Water Commission (1980), 'Manual on Flood Forecasting, pp 15-29.

National Institute of Hydrology (1987). Lecture notes of workshop on 'Processing and Analysis of Precipitation Data', Roorkee.

Subramanya, K. (2008). Engineering Hydrology, Tata McGraw Hill Companies, pp 28-30.

World Meteorological Organisation (1974), 'Guide to Hydrology Practices', WMO NO. 168.

ANNEXURE – I

Source: *Subramanya, K. (2008). Engineering Hydrology, Tata McGraw Hill Companies, pp 28-30.*

1. RAINGAUGE NETWORK

Since the catching area of a raingauge is very small compared to the areal extent of a storm, it is obvious that to get a representative picture of a storm over a catchment the number of raingauges should be as large as possible; i.e. the catchment area per gauge should be small. On the other hand, economic considerations to a large extent and other considerations, such as topography, accessibility, etc. to some extent restrict the number of gauges to be maintained. Hence one aims at an optimum density of gauges from which reasonably accurate information about the storms can be obtained. Towards this the World Meteorological Organisation (WMO) recommends the following densities.

1. In flat regions of temperate, Mediterranean and tropical zones:
   ideal – 1 station for 600-900 km^2,
   acceptable – 1 station for 900-3000 km^2;
2. In mountainous regions of temperature, Mediterranean and topical zones:
   ideal – 1 station for 100-250 km^2,
   acceptable – 1 station for 250-1000 km^2;
3. In arid and polar zones: 1 station for 1500-10,000 km^2 depending on the feasibility.

Ten percent of rain gauge stations should be equipped with self-recording gauges to know the intensities of rainfall.

From practical considerations of Indian conditions, the Indian Standard (IS: 4987-1968) recommends the following densities as sufficient.

1. In plain: 1 station per 520 km^2;
2. In regions of average elevation 1000 m: 1 station per 260-390 km^2; and
3. In predominantly hilly areas with heavy rainfall: 1 station per 130 km^2.

2. ADEQUACY OF RAINGAUGE STATIONS

If there are already some raingauge stations in a catchment, the optimal number of stations that should exist to have an assigned percentage of error in the estimation of mean rainfall is obtained by statistical analysis as

$$N = \left(\frac{C_v}{\varepsilon}\right)^2 \tag{1}$$

Where N= optimal number of stations, ε= allowable degree of error in the estimate of the mean rainfall and C_v = coefficient of variation of the rainfall values at the existing m stations (in per cent). If there are m stations in the catchment each recording values P_1, P_2, …., P_i, …P_m in a known time, the coefficient of variation C_v is calculated as:

$$C_v = \frac{100 \times \sigma_{m-1}}{\bar{P}}$$

Where $\sigma_{m-1} = \sqrt{\left[\frac{\sum_1^m (P_i - \bar{P})^2}{m-1}\right]}$ = standard deviation

P_i = precipitation magnitude in the ith station

$\bar{P} = \frac{1}{m}\left(\sum_1^m P_i\right)$ = mean precipitation

In calculating N from equation 1, it is usual to take ε = 10%. It is seen that if the value of ε is small, the number of raingauge station will be more.

According to WMO recommendations, at least 10% of the total raingauges should be of self-recording type.

Example 1. A catchment has six raingauge stations. In a year, the annual rainfalls 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% error in the estimation of the mean rainfall, calculate the optimum number of stations in the catchment.

Solution: For this data,

$m = 6, \qquad \bar{P} = 118.6, \qquad \sigma_{m-1} = 35.04, \qquad \varepsilon = 10$

$$C_v = \frac{100 \times 35.04}{118.6} = 29.54$$

$N = (\frac{29.54}{10})^2 = 8.7, say\ 9\ stations$

The optimal number of stations for the catchment is 9. Hence three more additional stations are needed.

ANNEXURE – II

RAIN GAUGES NETWORK DESIGN

Source: *National Institute of Hydrology (NIH) (1987-88). Lecture notes of workshop on 'Processing and Analysis of Precipitation Data', Roorkee.*

1. Introduction

A rain gauge (also known as an udometer, pluviometer, or an ombrometer) is used to measure the amount of liquid precipitation over a set period of time. The main purpose of planning the hydro meteorological network is to have a status of the hydrological characteristics of the different river basins in a region. Though this is most vital for hydrological studies, most networks are inadequate. Even in areas with relatively large numbers of long-established stations, there are usually gaps and deficiencies. Since precipitation is the most important factor in the problems relating to hydrological analysis, the concerned authorities need to ensure that the network is adequate for obtaining representative observations of precipitation. Scientific planning is, therefore, necessary for network design, so that the desired results could be achieved with minimum cost.

2. Precipitation Network

A precipitation network can be considered as a system for collection of data with due consideration given to the needs as well as the economy. A network of gauges may be intended to serve one or more of the purposes, such as water availability for water supply, hydroelectric power generation, irrigation, and flood control and water resources management.

2.1. Recommendation for Network Density

The optimum density of precipitation gauge network i.e. the numbers of gauges per unit area depends on the hydrologic purposes to which the observed data are to be put. If gross seasonal precipitation figures are required for comparison with seasonal runoff volumes a relatively coarse network of stations, say one per 500-750 km^2 would usually suffice except where orographically induced variations in precipitation are significant. For accurate measurements of precipitation required for river forecasting and flood analysis, much denser networks are needed.

2.1.1. WMO recommendations

The World Meteorological Organization has recommended the following as minimum network densities for general hydrometeorological practices.

i. For flat regions of temperate, Mediterranean and tropical zones:
ideal – 1 station for 600-900 km^2,
acceptable – 1 station for 900-3000 km^2;
ii. For mountainous regions of temperature, Mediterranean and topical zones:
ideal – 1 station for 100-250 km^2,
acceptable – 1 station for 250-1000 km^2;
iii. In arid and polar zones: 1 station for 1500-10,000 km^2 depending on the feasibility.

Ten percent of rain gauge stations should be equipped with self-recording gauges to know the intensities of rainfall.

2.1.2. BIS standard

From practical considerations of Indian conditions, the Bureau of Indian Standards (IS: 4987-1968) recommends the following densities.

i. In plains: 1 station per 520 km^2; However if the catchment lies in the path of low pressure systems which cause precipitation in the area during their movement, their network should be denser particularly in the upstream.

ii. In regions of average elevation 1000 m: 1 station per 260-390 km^2; and in areas predominantly hilly where very heavy rainfall is experienced care should be taken in the setting up of network of rain gauge stations.

iii. In predominantly hilly areas with heavy rainfall: 1 station per 130 km^2, if however, the catchment is in the rain shadow region of high mountains such dense network may not be necessary.

Since most of the water resources projects are connected with irrigation, flood control and /or power generation, installation of self-recording rain gauges has be to commensurate with the requirement.

2.1.3. Network Density Studies

Interesting and valuable studies using very dense gauge networks have been conducted. Such studies have been used to determine the standard error of average precipitation estimated over various size drainage areas, with various rain gauge network densities. Linsely, Kohler and Paulhus (1947) have presented a US Weather Bureau graph which suggested that the standard error of estimate of storm rainfall over an 8000 $mili^2$ basin (Muskingum in Ohio) is about 6 % for a network of 100 sq. mi per gauge and about 14 % for 500 sq. mi per gauge.

A similar study of areal variability of rainfall in a region characterized by thunderstorm activity was undertaken by Huff and Neill (1957) for Illinois state water survey which indicated for a 100 sq. mi per gauge network a measured rainfall of 2.0 in could be either 1.5 in or 2.5 in. with a 95% confidence, i.e. within ± 26 percent.

Similar studies have been carried out for the Vidarbha region of Maharashtra by Mooley and Mohamed Ismail (1981).

3. Types of Network

In the case of project areas where already some gauges are in operation it may be essential to review density to ascertain whether it is optimum saturated or otherwise. In order to determine whether the existing network is saturated and to estimate the optimum and minimum network requirement BIS has recommended certain procedures.

3.1. Saturated Networks

Rainfall in the area for a few storms should be estimated by taking into account all the rain gauges (100 percent) in the catchment, 80 percent of the rain gauges, 60 percent of the rain gauges etc. Care should be taken to see that the rain gauges selected are evenly distributed in the area. A graph between the number of rain gauges considered and the storm rainfall should be drawn separately for each storm. If it is noticed that the assessed storm rainfall does not change appreciably with decrease in the number of rain gauges, the network is considered to be saturated and some of the gauges could be dispensed with. If, however, the estimated storm rainfall change appreciably with the decrease in the number of gauges considered, it indicates what the network is not saturated.

3.2.Optimum Network Design

The optimum network, the purpose of rain gauge network design is to know the spatial and temporal characteristics of rainfall over the area.

4. Network Design

Rain gauge network design is intended for the following:

4.1.Number of rain gauges

Estimation of the number and location of the rain gauge stations which will provide sufficient information regarding rainfall falling over the catchment is referred as Optimal Network Design. For development of a flood forecasting technique it is desirable that data from all these stations are collected. However for operational purpose the real time collection of rainfall data from all these station may not be possible because of many factors such as transmission factors, lack of time, etc. It is therefore desirable that the number of rain gauge station be reduced to the minimum without sacrificing much accuracy in computation of areal average rainfall. These rain gauge stations constitute key or representative rain gauge stations.

Some simple and complex statistical techniques have been developed for the estimation of number of gauges required.

For estimation of adequacy of rain gauges two techniques namely coefficient of variation based technique and method suggested by Kaya and Rodda ( ) are in vogue. These techniques are explained is subsequent relations:

i. C_v based technique

For the area where some rain gauges already exist, the optimal rain gauge network can be designed by using the coefficient of spatial variation of the rainfall. The optimum number 'N' of rain gauge is obtained by using the following relation.

$$N = (C_v/p)^2$$

Where C_v = coefficient of variation of rainfall based on existing rain gauge station; and p = percentage error in the estimate of basic rainfall.

4.2 Allocation of Additional Rain gauges

While allocation the additional rain gauges determined by the procedures in Section 4.0, not only the spatial distribution of the existing rain gauges but also the climatology, rainfall pattern and rainfall variability of the place need to be kept in view. Since the limitations of accessibility and facilities for installation of the rain gauge may be constraints, great care is to be exercised while allocation the gauges so that the planes development of network would contribute to the realistic assessment of water resources and help in the flood estimation and control measures. The allocation of additional gauges is illustrated in Example 5.1.

Example 1

Consider the catchment of Malaprabha up to Naviluteerth. There are four long term stations Khannapur, Bail Hongal and Saundatti within the catchment and Belgaum is outside to the north of the catchment. Besides, there are 13 rain gauges maintained by WRDO, Karnataka which have a short period of record.

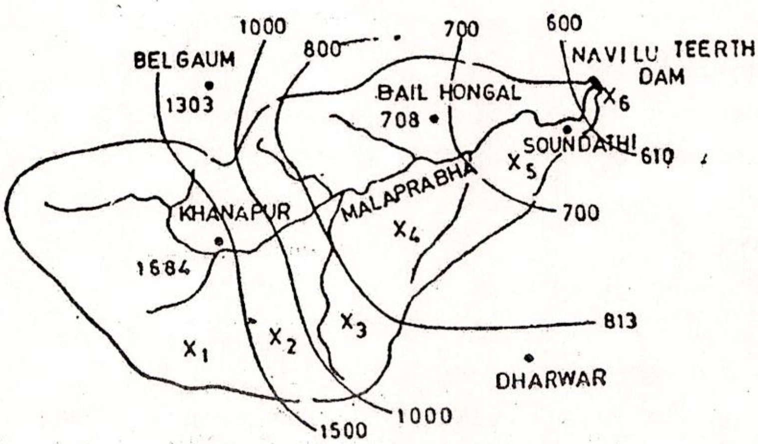

Figure 1. Malaprabha catchment up to Naviluteerth

The normal annual rainfall (1901-50) of the four stations is listed below:

Khanapur : 1613.6 mm
Bail Hongal : 708.8 mm
Belgaum : 1303.2 mm
Soundatti : 610.4 mm

The coefficient of variation of the rainfall in space is $C_v = 50.3$. Considering a percentage permissible error of 10% the number of rain gauges required in the catchment would be

$N = (50.3/10)^2 = 25.3$ Say = 25

Thus the existing four rain gauges are not sufficient and an additional 8 rain gauges need to be provided in the catchment. For allocating the additional number of rain gauges in the catchment, the steps given below are followed.

Step 1: Isohyets are drawn at equal intervals taking into consideration rainfall at stations outside the catchment.

Step 2: The area bounded by two consecutive isohyets is planimetered and expressed as a ratio to that of the total catchment area.

Step 3: The optimum number of gauges are allocated to each of the isohyetal zones in proportion to their areas.

Step 4: The additional rain gauges to be located in each zone are determines as follows.

	Zone	X_1	X_2	X_3	X_4	X_5	X_6	Total
(i)	Proportion of catchment area	.28	.12	.15	.25	.15	.05	
(ii)	Existing Raingauges a) Long term	1	1	0	1	1	0	4
	b) Short term	3	1	4	3	1	1	13
(iii)	Total required	7	3	4	6	4	1	25
(iv)	Additional required	3	1	0	2	2	0	8

ANNEXURE – III

Source: *Central Water Commission (1980), 'Manual on Flood Forecasting, pp 15-29.*

1. RAINGAUGE NETWORK

Rainfall is one of the basic data required for flood forecasting purposes, Even in case of a long river where the forecasting methods are essentially based on gauge and discharge data, the rainfall data from various stations in the intermediate catchment/catchments are very essentially used as a parameter resulting in marked improvement. So far forecasting in small and flashy rivers is concerned, the techniques of requires rainfall data from sufficient number of stations in the catchment. The number of rain gauge stations in the basin should be such that:

a) The areal rainfall in the catchment can be estimated with desired accuracy, and

b) The variation in the areal distribution as well as time distribution can be identified.

Estimation of the number and location of the rain gauge stations which will provide sufficient information regarding rainfall falling over the catchment is referred as Optimal Network Design. For development of a flood forecasting technique it is desirable that data from all these stations are collected. How-ever for operational purpose the real tie collection of rainfall data from all these station may not be possible because of many factors such as transmission factors, lack of time, etc. It is therefore desirable that the number of rain gauge station be reduced to the minimum without sacrificing much accuracy in computation of areal average rainfall. These rain gauge stations constitute key or representative rain gauge stations.

The detailed procedure for design of optimal Network as well as key Network are discussed below.

1.1. Design of optimal rain gauge network:

The design of Optimal Rain gauge Network is intended:

i. To find out the number of rain gauge stations required for the purpose; and
ii. To suggest suitable locations for these stations in the concerned river basins.

For the area where some rain gauge already exist, the optimal rain gauge network can be designed by using the coefficient of spatial variation of the rainfall. The optimum number 'N' of rain gauge is obtained by using the following relation.

$$N = (C_v/p)^2$$

Where C_v = coefficient of variation of rainfall based on existing rain gauge station; and p = percentage error in the estimate of basic rainfall

Alternatively, the existing coefficient of variation of rainfall and the required coefficient of variation can also be utilized for determining the optimal network. If C_{ve} and C_{vr} are the existing coefficient and the required coefficient of variation and 'n' and 'N' are the existing and required number of rain gauges, then

$$N = n\frac{C_{ve}}{C_{vr}}$$

Example 1: In a particular catchment, there are six raingauge stations as shown in the fig. 1.

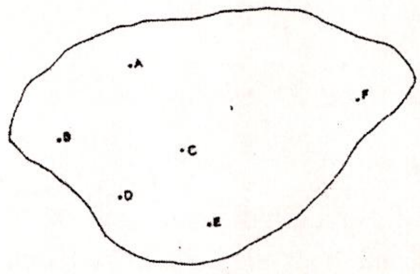

Figure 1

The average annual precipitation at the various stations are given below:-

Station	Rainfall
A	700
B	830
C	650
D	710
E	600
F	400

Estimate the optimal number of raingauge station in the rain. The allowable error maybe taken as 5%.

Solution: $\overline{P}$ = Mean of the rainfall $= \frac{\Sigma P}{n}$

$= \frac{700+830+650+710+600+400}{6}$

$= \frac{3890}{6} = 648$

σ = Standard deviation

$\sigma = \sqrt{\frac{\Sigma(P-\overline{P})^2}{n-1}} = \sqrt{\frac{103484}{6-1}} = 143.86$

C_v = Coefficient of variation

$= \frac{\sigma}{\overline{P}} = \frac{143.86}{648} = 0.222$

Therefore $N = (\frac{0.222}{0.05})^2 = (4.44)^2 = 19.7$ Say 20.

And hence 20 No. rain gauge stations should be provided in the catchment if an accuracy up to 5% is desired.

1.1.1. Location of rain gauge stations

In order to locate the station in the catchment the following procedure is adopted:-

i. Draw isohyets as shown in figure 2.2. It may be seen that various isohyets divided the whole basin areas into ten zones.
ii. The location of rain gauges will be such that equal number of rain gauge station are located in each zone i.e. 20/10=2 Rain gauge stations in each zone e.g. in zone (I), one rain gauge station already exist and hence only one more is to be established in this zone.

In this case of zone (II), 2 rain gauge stations are to be established. Similarly the requirement of rain gauge in various zones will be determined.

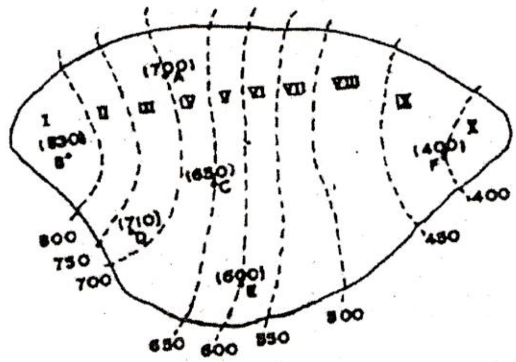

Figure: 2

iii. The exact location should be decided keeping in view the following points:
   a) The rain gauge station should be located near a village or town.
   b) The site should be accessible throughout the year.
   c) The distribution as a whole should be uniform over the catchment area.
   d) As far as possible each of the sub-catchment should be proportionate to the number of rain gauge stations.

1.2. DETERMINATION OF KEY STATION NETWORK

One of the most rational method for determination of the key station network is as suggested by Hall (1972). The procedure used for the determination of Key Station network is discussed here.

If P_a be the rainfall required to be estimated from the observed record at selected station $X_1, X_2, X_3, X_4 \ldots\ldots\ldots\ldots X_n$ then P_a can be determined by

$$P_a = C+A_1X_1+A_2X_2+\ldots\ldots\ldots\ldots\ldots\ldots+A_nX_n$$

Where, A_1 $A_2 \ldots\ldots\ldots A_n$ are called the regression coefficients and C is a constant, known as intercept.

The method involves a gradual process of elimination of stations. The steps are as follows:

As first correlation coefficients between the average of the storm rainfall and the individual station rainfall are found the stations are then arranged in order of their decreasing correlation coefficient and the stations exhibiting higher correlation coefficient are considered for further analysis. The next step is determine the independent order of correlation coefficient among the stations considered is called the first key station and its data removed for the determination of second key station. The procedure is repeated by considering the average rainfall of the reaming stations. The station showing the highest correlation coefficient after moving the data of first station is called the second key station. Similarly, the third and further key stations are selected after removing the data of already selected key stations.

As each station gets added to the key station network the total amount of variance which is accounted for by the network at that stage is determined. This would provide a basis for determining the number of stations required for achieving an acceptable degree of error in the areal estimate.

The multiple correlation coefficient increases with the increase of the number of station in the combination and the sum of the squares of the deviations of the estimated values of average rainfall from actual as well as the minimum deviation decreases. A stage will then be reached when improvement in either the multiple correlation coefficient or the sum of the square of deviations will be little. The corresponding number of rain gauges at that stage will be taken as the representative network for the purposes of determining areal estimates of rainfall. The next step is to test several combinations of the number of key stations which gives a satisfactory estimate of the areal rainfall. Thus a number of alternative key stations network are determined which may be employed to give estimated of areal rainfall taking in to consideration, the possibility of any of the stations in the best combination not reporting the rainfall data.

Alternatively, the key rain gauge network can be established by the simple correlation analysis where the rainfall data from the various stations in and around the catchment are correlated with the total runoff, if the correlation coefficient 'r' is less than 0.60, it is best to reject the station as it will reduce the reliability relationship. In case all of the stations exhibit a low correlation coefficient it means that none of the methods for determining the areal estimate of rainfall will work very well. In such a situation it will be desirable to relocate the rain gauges.

Various steps, involved in the analysis, are illustrated in Example 1 and 2.

Table 1 Table Showing the total R.F. In different Storm: All R.F. in mm.

SI. No.	Name of R.F. Station	Storm No.												
		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Panposh	141.5	136.6	55.6	160.0	49.0	123.6	100.7	42.2	120.8	20.8	26.6	12.4	44.2
2	Bonaigarh	199	180	103.5	109.0	122	52.5	73.0	92.5	10.0	56.0	71.5	10.5	42.0
3	Chhedipada	87.7	150.0	56.0	51.0	0.0	15.0	46.0	84.0	25.0	84.0	15.5	178.0	60.5
4	Pallahara	80.0	176.3	80.3	288.0	57.0	46.0	82.8	227.5	63.0	106.7	89.0	71.0	136.0
5	Kamakhya Nagar	24.4	158.0	22.0	99.0	4.1	50.0	33.4	51.0	19.8	80.7	37.4	122.4	69.0
6	Talcher	23.4	241.8	60.3	80.7	10.1	36.10	32.7	119.3	30.4	161.4	12.1	210.9	79.7
7	Dhenkanal	83.2	170.2	74.7	91.9	5.6	50.5	21.5	49.1	53.3	126.3	107.9	163.8	38.1
8	Sukinda	55.3	77.0	27.8	98.8	4.8	49.5	35.5	95.3	48.7	28.9	19.0	137.5	50.0
9	Deogarh	216.0	121.4	61.5	83.4	26.2	26.2	25.8	93.1	33.2	28.8	90.6	19.0	201.6
10	Raemal	59.5	138.2	102.2	78.0	2.5	16.5	59.0	194.0	69.0	36.0	61.0	110.6	77.0
11	Lohardaga	27.4	11.4	182.4	84.6	13.0	171.8	61.6	26.2	87.8	77.0	136.2	26.0	235.0
12	Manoharpur	139.0	100.0	16.6	186.6	48.0	139.0	322.0	26.5	62.0	55.0	43.8	25.5	54.0
13	Angul	19.6	138.2	73.0	32.2	4.6	27.0	46.0	137.1	44.9	70.6	8.4	172.2	28.2
Total R.F. (in m.m.s)		1156.2	1799.1	915.9	1443.2	346.9	80.37	940.0	1237.8	676.4	932.2	719.0	1259.6	1145.3
Average R.F.		88.938	138.392	70.438	111.0	26.68	61.82	72.30	95.21	51.41	71.70	55.30	96.89	88.1

Example 2: For the catchment of river Brahmani up to Talcher the various storms were analysed and the rainfall observed during these storms at various stations is given in table (1). Out of the 12 rain gauges stations whose data are given above, select Key rain gauge stations by using the method suggested by Hall.

Solution: The key rain gauge stations will be determined by using the technique as discussed above. The various steps are explained below:

Step No. 1: Calculate the average rainfall for each storm i.e. for each storm add the rainfall data of all the 13 stations and divide by 13, the values are given in the last row of table 1.

Step No. 2: Compute the coefficient of correlation between the rainfall data of Panposh (Row no. 1) and the average rainfall (last row). The coefficient of correlation works out to be 0.3296. Similarly compute the correlation coefficient between rainfall data of other stations and the average rainfall.

Table 2 gives the coefficient of correlation between the data for various stations and the average rainfall.

Table 2

Sl. No.	Rain gauge station	Coefficient of Correlation
1	2	3
1.	Panposh	0.3296
2.	Bonaigarh	0.3589
3.	Chhendipada	0.7647
4.	Pallahara	0.6747
5.	Talcher	0.7313
6.	Kamakhya Nagar	0.8304
7.	Dhenkanal	0.6224
8.	Sukinda	0.7131
9.	Deogarh	0.4305
10.	Reamal	0.6711
11.	Lohardaga	0.2095
12.	Manoharpur	0.1426
13.	Angul	0.6608

From above it may be seen that the best correlation is Kamakhya Nagar (0.8304), therefore this station is the first key station of the network.

Step No. 3

Delete the data of this station from table 1 and calculate the average rainfall on the basis of remaining 12 stations and the earlier values of the mean rainfall as given in the last row of table 1 is replaced by respective average values.

Step No. 4

Again calculate the coefficient of correlation between rainfall of each station and the average rainfall as in step No. 2.

The values of respective correlation coefficient are given below:

Sl. No.	Rain gauge station	Coefficient of Correlation
1.	2	3.
1.	Panposh	0.3544
2.	Bonaigarh	0.3905
3.	Chhendipada	0.7454
4.	Pallahara	0.6831
5.	Talcher	0.6902
6.		
7.	Dhenkanal	0.5838
8.	Sukinda	0.6999
9.	Deogarh	0.4668
10.	Reamal	0.6863
11.	Lohardaga	(-) 0.2038
12.	Manoharpur	0.1604
13.	Angul	0.6083

Now it may be seen that Chhendipada has the highest correlation coefficient (0.7454) with the average rainfall. This is then the second key rain gauge station.
Similarly the 3rd, 4th and 5th & so N key stations are found out.

<u>Step No. 5.</u>

Now arrange the stations determined in step 3 and 4 serially in the order as they are found as given below.

Table 3

COEFFICIENT OF THE REGRESSION EQUATION

Various combination	Kamakhya Nagar	Chhendipada	Pallahara	Sukinda	Talcher	Deogarh	Panposh	Intercept	MCC
1	2	3	4	5	6	7	8	9	10
1	0.5277	-	-	-	-	-	-	47.78	0.81
2	0.3787	0.1653	-	-	-	-	-	45.94	0.82
3	0.1594	0.2571	0.1756	-	-	-	-	32.45	0.93
4	0.1593	0.2788	0.1837	(-) 0.0462	-	-	-	32.68	0.91
5	0.4211	0.5297	0.1985	(-) 0.1596	(-) 0.2847	-	-	29.49	0.93
6	0.3714	0.3936	0.1645	(-) 0.0772	(-) 0.1891	0.5628	-	28.10	0.93
7	0.2152	0.3361	0.1436	(-) 0.0678	(-) 0.0541	0.0614	0.1246	21.26	0.95
8.	0.2293	0.1001	0.1366	0.1031	-	-	-	28.41	0.93
9.	0.1763	0.2585	0.1255	0.0786	0.1283	-	-	20.73	0.97
10.	0.2486	0.1633	0.0729	0.3254	0.1395	0.1078	-	19.21	0.97
11.	0.2748	0.1367	0.5601	0.0954	0.0905	0.1413	0.0489	17.11	0.98

Sl. No.	Key Station
1	Kamakhaya Nagar
2	Chhendipada
3	Pallahara
4	Sukinda
5	Talcher
6	Deogarh
7	Panposh
8	Reamal
9	Marioharpur
10	Dhenkanal
11	Lohardaga
12	Boniagarh
13	Angul

Step No. 6

Now the various combinations of stations is $1^{st} + 2^{nd}$, $1^{st} + 2^{nd} + 3^{rd}$, $1^{st} + 2^{nd} + 3^{rd} + 4^{th}$, etc. are considered to constitute the key network and Multiple correlation coefficient (MCC) are found out in each case. Table 3 gives the MCC is for different combinations of stations along with the coefficient of the respective regression equations and their intercept.

It may be seen from Table 3 that the Multiple correlation coefficient (MCC) more or less increases with addition of R.G. Station to the key network. It is seen that the coefficient in respect of stations Sukinda and Talcher are always negative which is physically not justified and hence if these two stations are omitted, then the MCC improves considerably as is indicated in Table 3.

From table 3 it may be seen that MCC in case of combination 9 is 0.97 and there is not much improvement in the MCC by further increasing the number of stations.

Hence the rain gauge stations in combination 9 i.e. Kamakhaya Nagar, Chhendipada, Pallahara, Deograh and Panposh (5 Nos.) may be considered to form key rain gauge network.

Example 3.

The simple correlation between the total rainfall and runoff has been used to select representative key rain gauges stations for Baitarani basin. Rainfall from twelve different raingauge stations in and around the catchment have been used for the analysis. They are Anandpur, Swanpatna, Champura, Ghatgaon, Karanjai, kheonjhar, Thakurmunda, Chandbali, Udala, Kaptipada, Bariapada and Pallahara (Fig. 3). The total rainfall (in) recorded at each of the 12 stations during the monsoon period for the years 1973 to 1978 have been computed and are tabulated in table 4.

The total runoff, (in mm) at Anandpur during monsoon period has been computed for all the years with the help of discharge data. The correlation between the runoff and the rainfall has been worked out for each of the rainfall stations and listed in table 4.

Based on the correlation coefficients thus obtained, the following rainfall stations may be included in the forecast development programme.

Rain gauge stations	Correlation coefficient
Anandpur	(0.931)
Udala	(0.922)
Swampatna	(0.895)
Thakurmunda	(0.833)
Keonjhar	(0.827)
Champua	(0.822)
Karanjia	(0.874)
Baripada	(0.866)

It I observed from the table 4 that Ghatgon, (r=0.35) is so poorly correlated that the station may be abandoned, as serving no useful purpose.

TABLE 4

Sl. No.	Name of Rainfall Station	Rainfall during Monsoon period in mm						Correlation Coefficient (No. years Date)		
1	2	3	4	5	6	7	8	9	10	11
1.	Swampatna	1893	1275	1233	702	855	1175	.895	-	-
2.	Anandpur	2102	1068	1433	973	1354	1228	.931	-	-
3.	Champua	-	910	1200	915	1128	1112	-	.822	-
4.	Ghatgaon	1082	1112	1418	927	968	1195	.354	-	-
5.	Karanjia	1743	1183	-	819	948	1002	-	.859	-
6.	Keonjhar	1515	816	606	671	508	920	.827	-	-
7.	Thakurmunda	1859	1191	11809	983	1252	1228	.835	-	-
8.	Chandbali	1622	1071	1550	1102	1036	1015	.725	-	-
9.	Udala	1906	1148	1394	1140	1446	1699	.922	-	-
10.	Kaptipada	-	1121	1580	1105	1485	-	-	-	.876
11.	Baripada	2269	1223	1724	1149	1903	1774	.866	-	-
12.	Pallahara	2209	1178	700	856	1563	-	-	.700	-
Runoff at Anandpur		**919**	**433**	**615**	**352**	**473**	**637**			

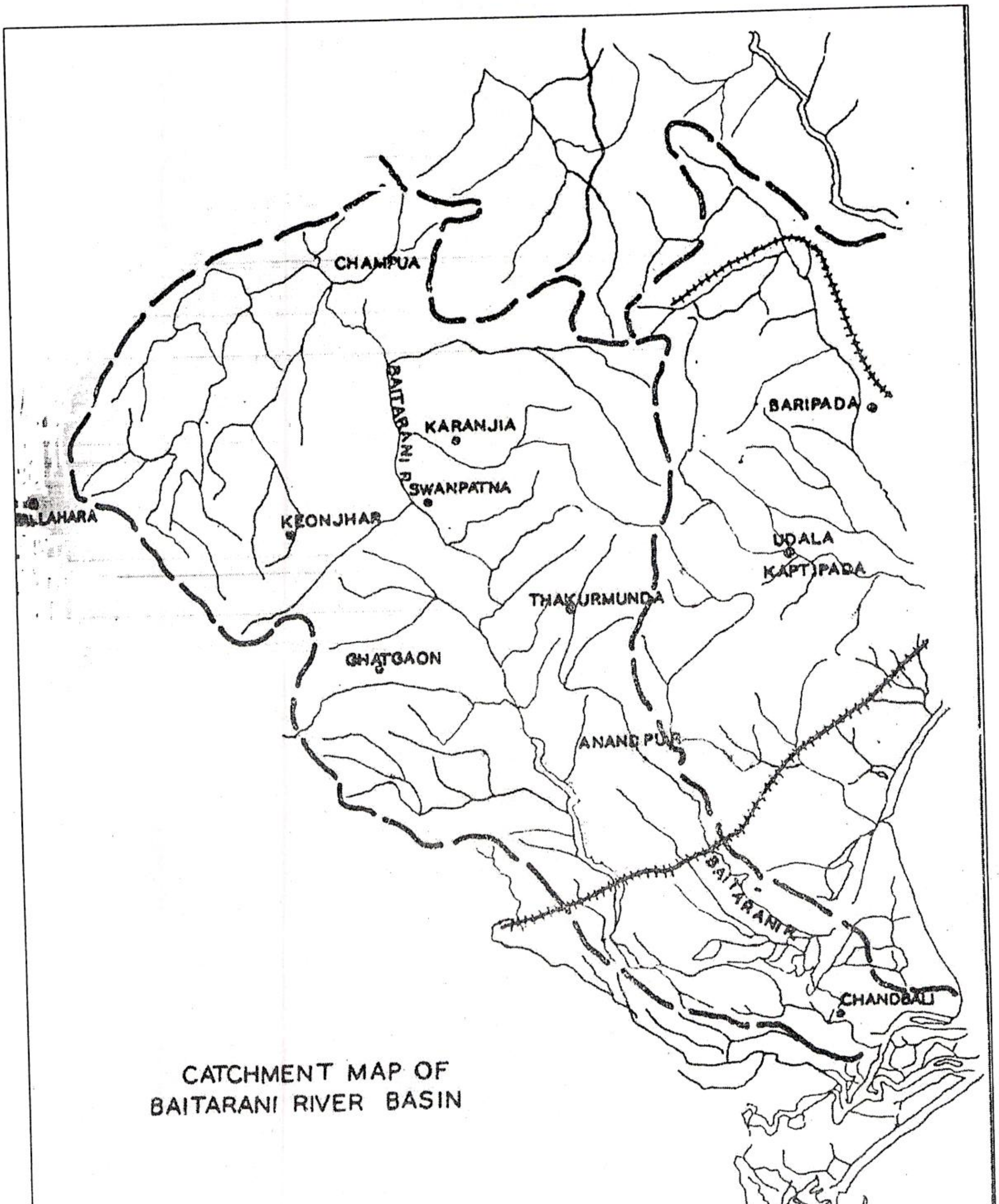
CHAMPUA
BAITARANI R.
KARANJIA
SWANPATNA
BARIPADA
KEONJHAR
UDALA
KAPTIPADA
THAKURMUNDA
GHATGAON
ANANDPUR
BAITARANI R.
CHANDBALI
CATCHMENT MAP OF
BAITARANI RIVER BASIN

Figure 3