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Hydrometeorological Observation Systems in India and need for Improvement and Research

By

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HYDROMETEOROLOGICAL OBSERVATION SYSTEMS IN INDIA AND NEED FOR IMPROVEMENT AND RESEARCH

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ABSTRACT

In the field of hydrometeorology, India Meteorological Department (IMD) has done some pioneering work in the country. It continues to render operational services in design storm evaluation, flood and drought prediction, snow cover monitoring and basin water management.

Every observational system relies around the optimum utilisation of its network. Different densities of precipitation network are required for different purposes. For instance, for climatological purposes the network may bear a long series of data. Correlation structure of the precipitation field is discussed to know the spatial and temporal requirements of the network.

Analysis of precipitation data include evaluation of spatial and temporal variability of rainfall which is crucial not only in providing designs for various structures both large and small. Trends and fluctuations are demarcated in the spectrum analysis of the series in the precipitation regimes.

Errors involved in the present day observational systems both in the conventional and remote sensing techniques used are discussed.

1.0 INTRODUCTION

Hydrometeorology is data based science. The development of scientific methods started early this century when systematic observational networks were set up worldwide and hydrometeorology also gained ground. With the establishment of India Meteorological Department (IMD) in 1875, the growth of precipitation gauge network in India accelerated. In August, 1890, a rainfall resolution was enforced to improve the system of rainfall registration throughout India. By 1947, about 2800 rain gauges were set up and today this number exceeds 10,000. But these rain gauges belong to numerous agencies and institutions with varied objectives. They do not report data to a single agency on a real time basis. Further more, their spatial distributions are not uniform. Hence, in spite of being a large number, these stations do not form scientifically an adequate network for rainfall monitoring and analysis. The meteorological seasons, time of observations, type of rain gauges and the procedure of recording were standardized. It was also decided that monthly returns of rainfall to be published by each local (state) government and supply to IMD for compilation of Annual Rainfall Volumes of India. However, the system is not working well at present and needs to be reinforced towards compilation of rainfall data.

Although India receives 117 cm of rainfall annually (more than the global normal of 113 cm), but its distribution in space is erratic. Each year some parts experience floods while some other parts reel under drought. In other words, our monsoons are good producer of fresh water but a poor distributor. The sub-division wise normal rainfall are given in Table-I.

The other important component of the water cycle is evaporation. The evaporation losses from water and soil surfaces are about 60 percent of the total precipitation falling on ground. Map showing annual evaporation over India is brought out in Fig.1.

The water resources of the planet spreading over the surface, under the ground and in the atmosphere occupies a volume of 1400 million Cubic Km. However, 35 million Cubic km is fresh water of which 24 is in the form of snow and ice. India receives about 3800 Cubic Km of water as rain and 200 Cubic km as snow and ice every year. Although quantity wise snow melt is a poor producer but it is a good distributor of fresh water as it feeds to 22 major Indian rivers originating from the Himalayas. Hence, precipitation network over the Himalayas is very important for assessing variabilities in water resources Map showing annual mean precipitation over the Himalayas is given in Fig.2. Correlation structure and error estimating of areal precipitation are discussed in Section 2.0 below. IMD has impressive network of parameters involving hydrometeorology and is outlined in Section 3.0. The analysis of precipitation which forms the backbone of hydrometeorology is discussed in Section 4.0 and is followed by the errors so frequently met during the observational work in Section 5.0.

2.0 NETWORK DESIGN FOR PRECIPITATION GAUGES

The different densities for precipitation network are required to meet different purposes. For climatological studies a

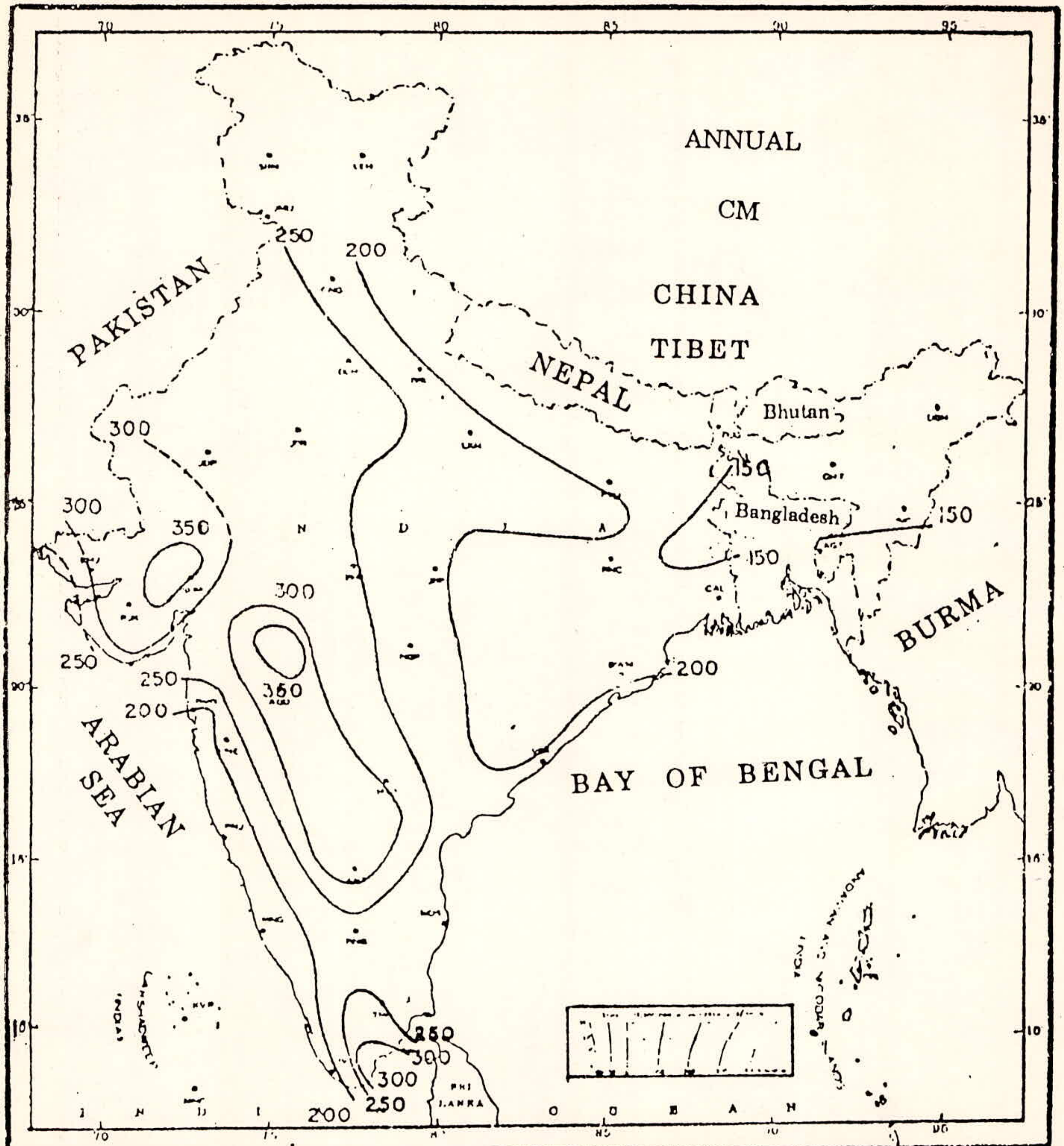
Table - I Seasonal and Annual Rainfall Normals and Co-efficient of variability (Based on 1950 normals)

S.No.	Sub-Division	Total area in Sq. Km.	Jan-Feb	Mar-May	Jun-Sep	Oct-Dec	Annual (mm)	CV (%)
1.	Arunachal Pradesh	83,578	106.1	621.2	2084.6	182.6	2,996.5	11
2.	Assam & Meghalaya	1,01,012	56.4	638.1	1623.8	178.9	2,497.2	11
3.	Nagaland, Manipur, Mizoram & Tripura	70,447	51.6	545.2	1507.9	209.2	2,313.9	11
4.	Bay Islands	8,295	135.1	504.4	1587.8	708.4	2,935.7	11
5.	Sub-Himalayan West Bengal & Sikkim	28,924	28.2	411.6	2172.4	166.6	2,778.5	15
6.	Gangetic West Bengal	66,228	38.9	175.5	1078.5	136.0	1,428.9	15
7.	Orissa	1,55,782	39.3	125.5	1142.9	176.4	1,484.1	14
8.	Bihar Plateau	79,638	52.4	89.8	1124.6	103.7	1,370.5	13
9.	Bihar Plains	94,238	34.1	74.1	1023.5	71.8	1,203.5	16
10.	Uttar Pradesh East	1,46,509	34.6	30.7	893.3	55.6	1,014.2	20
11.	Plains West Uttar Pradesh	96,782	41.7	30.7	726.0	37.2	835.6	16
12.	Hills West Uttar Pradesh	51,122	130.9	127.8	1408.9	82.3	1,749.6	27
13.	Punjab	50,362	60.4	51.2	467.3	31.6	610.5	34

14.	Haryana, Delhi & Chandigarh	45,821	38.4	31.3	462.6	23.2	555.5	28
15.	Himachal Pradesh	55,673	182.8	202.0	9993.1	139.9	1,517.8	21
16.	Jammu & Kashmir	2,22,236	193.7	246.8	458.1	97.9	996.5	22
17.	Rajasthan East	1,47,128	14.7	16.8	646.6	22.0	700.1	23
18.	Rajasthan West	1,95,086	11.2	15.2	275.3	8.2	309.9	40
19.	Madhya Pradesh West	2,29,550	22.6	21.4	945.1	53.5	1,04.6	20
20.	Madhya Pradesh East	2,13,291	43.8	49.1	1,227.3	77.8	1,398.0	15
21.	Gujarat Region	86,597	4.3	10.5	920.0	32.4	967.2	29
22.	Saurashtra & Kutch	1,89,990	3.6	9.2	479.4	23.1	515.3	37
23.	Kokan & Goa	34,095	3.3	36.7	2,705.2	135.8	2,881.0	18
24.	Madhya Maharashtra	1,15,306	6.5	38.9	788.2	106.7	940.3	23
25.	Marathwada	64,525	11.0	36.1	660.1	86.4	793.6	25
26.	Vidarbha	97,537	30.0	35.2	960.3	86.6	1,102.1	19
27.	Coastal Andhra Pradesh	93,045	23.1	87.5	572.6	324.6	1,007.8	18
28.	Talangana	1,14,726	18.9	57.6	759.1	94.9	930.5	21
29.	Rayalseema	69,043	15.0	76.4	367.0	217.3	675.7	20

30.	Tamil Nadu & Pandicheri	1,30,549	53.1	147.1	330.7	475.8	1,006.7	14
31.	Coastal Karnataka	18,717	4.3	148.7	2,886.3	252.6	3,291.9	15
32.	North Interior Karnataka	79,895	5.8	87.7	447.1	144.1	684.7	19
33.	South Interior Karnataka	93,161	9.9	162.7	868.2	230.2	1,271.0	20
34.	Kerala	38,864	38.6	413.6	1,977.9	547.6	2,977.7	14
35.	Lakshadweep	32	32.8	155.4	1,001.2	357.1	1,546.5	14

EVAPORATION



(Note : Quoted from Agroclimatic Atlas of India, I.M.D., 1978)

Fig. 1

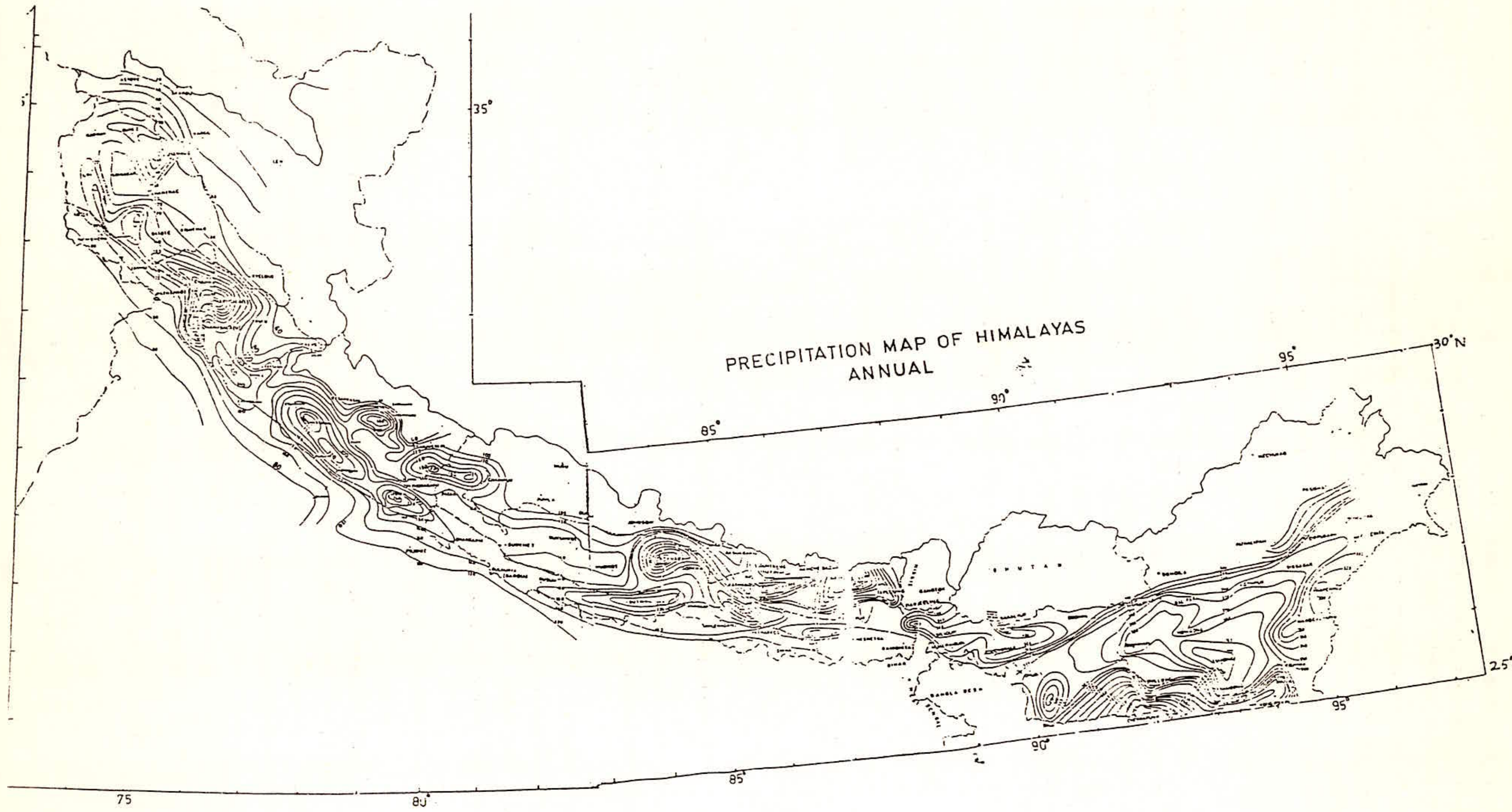

PRECIPITATION MAP OF HIMALAYAS
ANNUAL
35°
30°N
25°
75
80°
85°
90°
95°
BHUTAN

Fig. 2

network based on WMO criterion (at least 1 rain gauge for 600-900 sq km in plains and 100-250 sq km in hilly terrain) may be adequate. But for flood forecasting a denser network is desirable because it requires estimating areal precipitation for each storm. A network for cloud seeding experiments should be much denser. Since radar and satellite data are being used for precipitation estimation with limited accuracy as yet, their networks should be judiciously integrated with the conventional network for deriving maximum benefit.

Designing an optimum network for a specific purpose consists of deriving an expression for the variance of areal precipitation estimate (P_A) as a function of location vector (q), number of stations (n) and the station weight (w). The minimisation of this function F (n, q, w) may be carried out in two stages.

i. Keep w constant and obtain the optimum values say $n = n^*$ and $q = q^*$

ii. Optimise the function $F'(n^*, q^*, w)$ for weights W by solving the set of equations

$$\frac{dF'}{dw_c} = 0 \text{ for } i = 1,2,\ldots\ldots\ldots\ldots\ldots n$$

Alternatively, the error of estimate of P_A, $[\sum(P_A - \bar{P}_A)^2]$ can also be optimised by the numerical techniques of quadratic programming.

Many researchers are using the concept of correlation structure of the precipitation field in determining the network as well as the error in estimation of areal precipitation. This concept is illustrated below.

a. Correlation structure of precipitation field

Let there be n points of observation in a catchment of area A. Let us form the series of seasonal or annual precipitation, for T years for each point and compute the product moment correlations between all possible (${}^{n}C_2$) pairs of series. If the values of r_i are plotted against the distance between the stations (s_i) the curve is expected to exhibit a decreasing trend ($\partial r/\partial s < 0$). This type of curve is generally known as the correlation structure of seasonal/annual precipitation in the catchment (Kaur et al 1987).

Most of the authors have suggested the exponential structure to capture the above trend which is

$$r(s) = r_0 e^{-b\ s} \quad (1)$$

whereas in some cases, where the rate of decrease is smaller, a modified Bessel function

$$r(s) = \qquad sbl\ (sb) \quad (2)$$

has been observed as a best fit. The distance 's' may be regarded as a random variable as it may assume different values between zero (close to it) and D (maximum possible distance between any two points in the basin) with frequency function p(s). Form of p(s) depends on the shape of the catchment. For instance, for a circular area (Erik Erihsen 1972),

$$p(s) = 2\ s\ /R^2 \qquad 0 \ll s \ll R \quad (3)$$

b. Errors in estimation of areal precipitation

(I) For long term areal precipitation

In the studies by Iturbe (1974) and Ramanathan et. al. (1981), it has been indicated that the variance of long term areal precipitation can be split into 3 multiplicative components namely;

(i) the variance of point rainfall process (σ^2)
(ii) temporal reduction factor f(T) which depends on period of the data used for estimation of P_A and
(iii)spatial reduction factor $\psi(n,r)$ which depends on the number of stations 'n' used for estimation of P_A. Thus,

$$V\ (P_A) = \sigma^2\ f\ (T)\ \psi\ (n,r)(4) \quad (4)$$

In a time series, with significant auto correlation lag 1(P), f(T) may be evaluated from

$$f(T) = \frac{1}{T} \quad \frac{1+P}{1-P} \quad (5)$$

$\psi(n, r)$ is a function of n and r; it may be shown that

$$\psi(n, \bar{r}) = \frac{1+(n-1)\bar{r}}{n} = \frac{1-\bar{r}}{n} + \bar{r} \quad (6)$$

(II) For a rainfall event

if P_i (i=1,2,3,.........n) are the rainfall amounts recorded at n points during a rainfall event and the areal mean is expressed by :

$$P_A = \frac{1}{n} \sum_{1}^{n} P_i \quad (7)$$

the variance of P is subjected to only spatial reduction factor, therefore :

$$V(P_A) = \sigma^2 \psi (n, \bar{r}) = \sigma^2 \left(\frac{1-\bar{r}}{n} \right) \quad (8)$$

A case study : Beas Catchment

In the present study, about 18 years' precipitation data (1952-69) has been utilised for the ten selected stations.

The bivariate frequency distribution f(r,s) of different correlations(r) and distances(s) are computed from these ten precipitation series.

The mean correlations for various distances are

s(km)	10	30	50	70	90	110	130	150
r	0.75	0.61	0.34	0.42	0.28	0.37	0.20	0.20

The exponential form fitted to the above data of s and r is as shown in eq.(1).

The estimates of 'b' and r_o have been worked out and are given as :

$$r_o = 0.84 \text{ and } b = 0.0098 \text{ km}^{-1} \quad (9)$$

Therefore,

$$r(s) = 0.84\, e^{-0.0098\, s} \quad (10)$$

3.0 EXISTING OBSERVATIONAL NETWORK OF IMD

1. Surface Observatories (558) - measures surface pressure, temperature, humidity, wind, cloud, rainfall etc., at synoptic hours every day.

2. Upper air observatories (35 - Radiosonde, 34 - Radio wind and 62 - Pilot balloon) measure upper air temperature, pressure, wind and humidity.

3. Agromet observatories (223) which measure soil temperature, dew, radiation, evaporation and grass minimum temperature. Also there are 39 evapotranspiration stations and 52 soil moisture recording stations.

4. Hydrometeorological stations (600) measure only precipitation.

5. Aeronautical observatories (76) to maintain weather watch at airdromes etc.,

6. Seismological Observatories (57)

7. Radiation Observatories (45)

8. Radar stations 15 X band (3 cm wavelength) for convective cloud measurement and 105 band for cyclone detection.

9. Satellite data receiving centers (7), One Met. Data Utilization Center (MDUC) and 100 Data Collection Platform (DCP).

10. Marine Met. Observatories (Ship observation) - such observational fleet (221 ships) maintain liaison with port Met. stations.

4.0 ANALYSIS OF PRECIPITATION DATA

Procedure of analysis depends on its objective. For climatological analysis we need to work out normals (long term averages) spatial and temporal variability, trends and fluctuations where various methods of descriptive statistics & spectral analysis are applicable.

For water budget evaluation point to areal precipitation is to be estimated in which isohyetal and other area weighted averages, interpolation techniques and error analysis are useful.

For small catchment structures & drainage designs frequency analysis of extreme rainfall series is required to compute T-year rainfall over a point or an area, while for large structures design storm study is undertaken to evaluate Probable Maximum Precipitation which involves selection of heaviest storm, its transposition over project basin, Depth- Area- Duration analysis of storm and evaluation of maximising and other adjustment factors. For Quantitative Precipitation Forecast (QPF) past rainfall cases have to be analysed to work out analogues for each type of synoptic situations causing rainfall over the basin in question. For a dynamic approach to QPF moisture analysis and estimation of large scale vertical motion is to be carried out over a 3 dimensional grid system by numerical methods.

Some illustrations are provided below :

(a) Depth - area relationship

Earlier researchers attempted to establish areal rainfall as a function of central rainfall (R_0) and the area (A) e.g. according to Fruhling (1961)

$$\bar{R} = R_0 \, (1 - 0.14 \, A_i^{0.25})$$

where $\bar{R}_i$ =Areal rainfall with isohyet,

R_0 =Maximum point measurement and

A = Area within isohyet

Some authors suggest that

$$\frac{R_A}{R_0} = f (\bar{r})$$

Where $\bar{r}$ is mean correlation of precipitation field over an area A. Upadhyay et al (1984) illustrated that

$$\frac{R_A}{R_0} = a \exp(b \, \bar{r})$$

The values of a and b depend on type of storms.

Isohyetal analysis of various storms over Maharashtra and Gujarat region exhibit that we may classify them in three categories with regard to areal reduction of their rainfall pattern.

I. Those having fairly uniform rainfall distribution over a large area.

In such cases reduction curve has very small slope. For an example, we refer to the storm of 12 Sept.'45 with center at Patur (Akola) where the rainfall distribution was as follows :

Area (Sq Km) :	250	500	1000	1500	2000	3000	4000	5000
P_A/P_O	0.99	0.98	0.97	0.96	0.94	0.92	0.89	0.87

II. Those having moderate areal reductions as in the case of Nanpur/Dhulia storm of 6 June 1925 shown below :

Area (Sq Km) :	250	500	1000	1500	2000	3000	4000	5000
P_A/P_O	0.98	0.96	0.92	0.89	0.86	0.80	0.74	0.70

III. Those having steep gradient of the reduction curve. As an example, the storm of Roti (Ahmednagar) recorded on 28 August 1965.

Area (Sq.Km):	250	500	1000	1500	2000	3000	4000	5000
P_A/P_O	0.95	0.92	0.86	0.79	0.74	0.65	0.58	0.53

Correlation studies upto an area of 5000 Sq.Km show the following values of $\bar{r}$ mean correlation of rainfall series between the stations.

Area (Sq Km):	250	1000	2000	5000
$\bar{r}$:	0.64	0.61	0.59	0.55

Using these values of the depth area relationship given by P_A/P_O equation has been computed. The values of constants a and b for the three types of storms are as follows :

Type of storm	a	b
I	0.369	1.569
II	0.073	4.123
III	0.0095	7.306

The areal reduction factors for these three type of storms computed by the method proposed in D.S. Upadhyay et al, 1984 are tabulated below:

TABLE - II

Area	I	II	III
250	0.99	0.99	0.98
500	0.98	0.94	0.89
1000	0.96	0.90	0.82
1500	0.95	0.87	0.77
2000	0.93	0.83	0.71
3000	0.92	0.80	0.66
4000	0.90	0.76	0.61
5000	0.87	0.70	0.53

(b) Rainfall frequency analysis

Although Gumbel's EV1 distributions being used for frequency analysis of various meteorological variables, it fails to provide a satisfactory fit to the observed series in cases of outliers or when the highest values of the series do not exhibit adequate increase (Upadhyay et, 1990). These difficulties have been experienced by the operational researchers in this field. A linear combination of EV1 with EV2 or EV3 distribution is being prescribed in these two cases respectively.

If $E_1(x)$ and $E_2(x)$ are two distribution functions, a linear combination may be defined as:

$$E_\theta(x) = \left(\frac{1}{2} + \theta \right) E_1(x) + \left(\frac{1}{2} - \theta \right) E_2(x)$$

where $-1/2 \leq \theta \leq 1/2$

$$\therefore \theta = \frac{E_\theta(x) - \frac{1}{2} \left[E_1(x) + E_2(x) \right]}{E_1(x) - E_2(x)}$$

As the nature of prior information about $E_\theta(2)$ is generally not known, it may be estimated by empirical distributions function $E_n(x)$ of the observed sample $(x_1, x_2, \ldots x_n)$. An estimator for θ is:

$$\hat{\theta} = \frac{E_n(x) + \frac{1}{2}[E_1(x) + E_2(x)]}{E_1(x) - E_2(x)}$$

$\hat{\theta}$ provides unbiased and consistent estimate of θ with variance of order 1/n . However, when $\hat{\theta}$ lies outside the interval (-1/2, 1/2), we may truncate the values going beyond -1/2 or 1/2, although by doing so unbiasedness of the estimator is lost.

It may be seen that the sample observations from a discrete series $E_n(x)$ represents a step deviation function whereas $E_1(x)$ and $E_2(x)$ from continuous curves. A mean curve for $E_n(x)$ should be estimated for obtaining $\hat{\theta}$.

$E(x) - 0.6 E_1(x) - 0.4 E_2(x)$, has been applied for the frequency analysis of 24 hourly maximum rainfall series of Alipore which contains an outlier more than 5 times the medium value.

(c) Design storm study

For designing water management structures, it is desirable to know the time and magnitude of future hydrologic events. But we can not predict them. However, using past data it is possible to work out probability or frequency with which a given magnitude of flow rate or rainfall (X_T) will be equaled or exceeded once on an average in T-year. The selection of T involves a calculated risk (R) depending on cost and policy of construction. R is given by

$$R = 1 - \left(1 - \frac{1}{T}\right)^n$$

R - Prob. that $\hat{X}_T$ is equaled or exceeded at least once in n years.

n is the expected design life of the structure.

Rainfall data are generally available in more points and for longer duration and the stream flow observations. Hence, the analysis of rainfall data are normally used for estimating stream flow and other hydrologic quantities.

The probability (or frequency) of short duration high intensity rainfall are important for small catchment projects like designing bridges, drainage structure and water supply system. For this purpose statistical frequency analysis approach is considered appropriately. This involves selecting annual extreme series of

1,3,6,12 or 24 hours rainfall or daily discharge and applying some standard statistical distribution to work out X_T , T year vary. If the distribution function ot F (x) then return period T is given as:

$$T = \frac{1}{1- F(x)}$$

Most commcnly used distributions are EV1 (Gumbel distribution) or log. Pearsons Type III distribution, where data series consist of less than 10 to 15 years of records partial duration series in a better choice where all observations above an assured value are taking to form the series. This series essentially followed an exponential distribution.

The frequency of major rainfall events of 1-day, 2-day or 3-day durations are required for the designing major structures like dams, barrages, flow control structures and other multi-purpose projects. For these types of analysis, physical approach is considered more appropriately. The approach involves selecting a heaviest rainstorm of the appropriate division which has occurred over the project area or in the homogeneous vicinity during past 50 or 100 years, transposing it to the project catchments carrying out depth area duration analysis, estimating maximum observed rainfall for a given area (Standard Project Storm) and maximising spheres for moisture catchments (Probable Maximum Precipitation).

Some challenging problems - Generalised Frequency Analysis

- **Take a homogeneous area with good network of SRRG stations and prepare areal extreme annual rainfall series for t (1,3,6,12, and 24) hrs. duration.**

- **Obtain the empirical relations for a fixed area between T yr. rainfall of t hr. duration with 10-yr. rainfall of 1 hr. duration is**

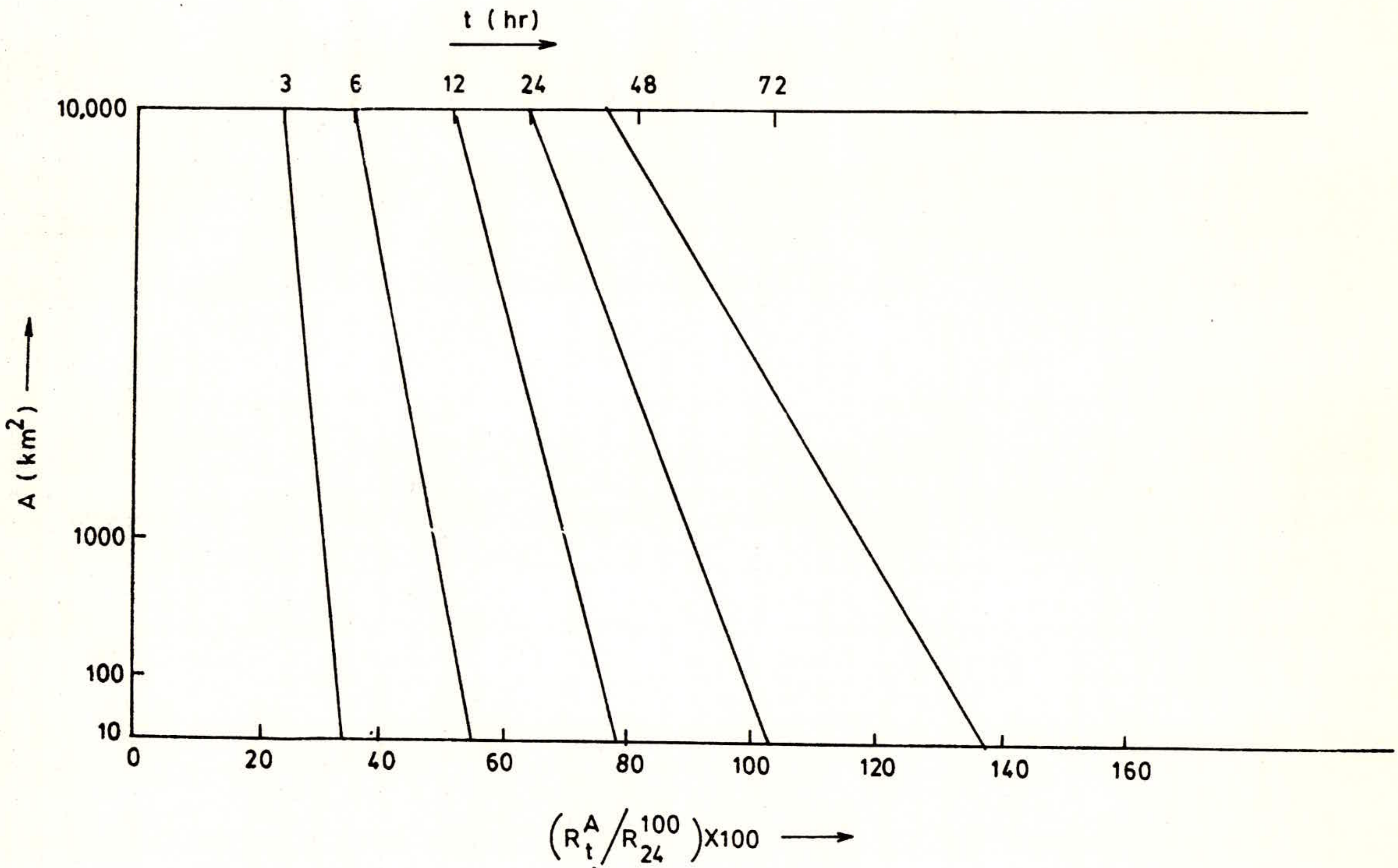
$$R_T^t = (a + b \ln T) (c t^n+d)$$

- **For a fixed T also find the relations.**

$$R_A^t = (\alpha + \beta \ln A) R_{1000}^{24}$$

which can be presented in nomogram as shown in Fig. 3

These factors may differ from one sub zone to the other. Hence different nomograms may be needed for different homogeneous subzones.



$$\frac{R_t^A}{R_t^{100}} = \alpha + \beta \log A$$

Fig. 3

(d) Snow cover monitoring

Network of observational sites ; Snow bound portion of a river basin usually comprises a number of sub-catchments belonging to various tributaries, nallahs or khuds, emerging out either from underground channels or from glaciers or mountainous lakes. In all cases the basic feed comes from snow melt; immediate or delayed. Hence a sub-catchment or a group of sub catchments should be taken as the unit for monitoring snow cover for hydrological purposes. In a unit there may be one or more observational sites depending on the following factors;

i) Area of the unit;

ii) Characteristic features of the basin like topography; vegetation cover, exposure to sun and wind. These features should be proportionately represented in network as far as possible;

iii) Purpose of observations;

iv) Availability of instrumentation and physical facilities.

Due to the constraints mentioned above, it is not possible to fix up any rigid criterion for the density of observational network. However, to account for the spatial variabilities and to estimate areal parameters from point observations reasonably accurate, the following suggestions for minimum network density, are made:

1. There should be one main observatory for each 1000-10,000 sqkm of area. It should be manned by a team of trained personnel and equipped with the instruments capable of observing most of the hydrological (discharge, snow depth, density, stratigraphic observations etc.). and meteorological (precipitation, temperatures, radiation, albedo, humidity, wind etc.) parameters. Sets of portable equipment and snow kits are also necessary for snow surveys and mass-balance observations.

2. Under the main observatory there should be a number of part-time or subsidiary observatories covering an area say 100-1000 sq km well distributed over the watershed.

3. It is still quite possible that difficult or uninhabited terrains remain uncovered by the manned stations mentioned above due to logistic problems. But to complete the network,

observations from these places are necessary. The sites of observations in these areas should be selected in advance, preferably during summer and observations can be taken by the following techniques:

a) Installing telemetering system connecting automatic recording instruments installed at the sites with the main or subsidiary manned stations. Calibrated poles may also be read by powerful binocular from distances of a few hundred meters.

b) Installing Data Collection platforms (DCPs) operating through satellites.

c) Periodical reconnaissance or survey with portable equipment. Calibrated poles or stakes must be installed in these areas during pre-snow period in order to assess the depth of accumulated snow. A fortnightly or monthly reading may be adequate.

4. It is also important to map the area of permanent ice cover and firm and also to monitor snow line variations periodically (say weekly or fortnightly). Monitoring of variations in snow line altitude can be made:

a) actual point observation of snow line and its mapping using area-elevation relationship of the catchment;

b) mapping of satellite imageries on cloud free days;

c) surveys by air.

A practical evaluation of water equivalent (w) of snow cover in observational site 50 m x 50 m.

Steps

(1) Form a grid as shown in Fig. 4 and take snow pit observations at each of 9 gird point (x). Suppose at these points snow depths are h_1, h_2, ...h_9 and bulk snow pack densities P_1 , P_2 ...P_9.

ii) Form a circle of radius 5m around each grid point and take only snow depths observations at 10 points on the circumference of each circle. Let mean depths of standing snow along these circles be H_1 , H_2 .....H_9 and standard deviation s_1, s_2, s_9,. See calculation table 2 for mean depth of standing snow.

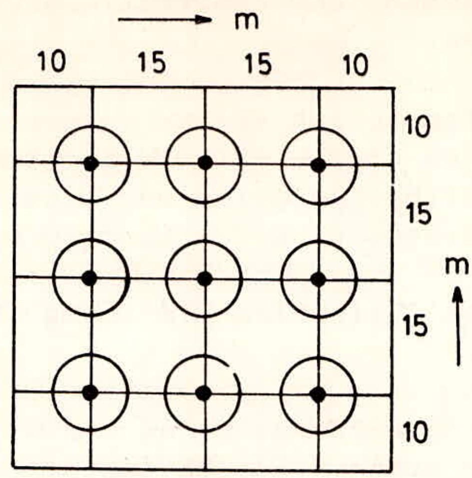


Fig. 4

Grid pt	h	l	s	H	Water equivalent (w) at grid pt	W around circle
1	h_1	l_1	s_1	H_1	$w_1 = h_1 l_1$	$W_1 = H_1 l_1$
2	h_2	l_2	s_2	H_2	$w_2 = h_2 l_2$	$W_2 = H_2 l_2$
⋮	⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮	⋮
9	h_9	l_9	s_9	H_9	$w_9 = h_9 l_9$	$W_9 = H_9 l_9$

Mean depth of standing snow $= \dfrac{h_1 + 10 \cdot 11_1}{11}$

(e) Trend in rainfall

Whenever some abnormal weather activities like heavy rains or prolonged dry spells are experienced. It is a common tendency to question whether the climate is changing or change in trend is being set up. For example, an unprecedented amount of 73.6 cm was recorded at Manavaden and 71.1 cm at Junagarh in Gujarat on 22 June, 1983.

Such unusual occurrences are the part of weather fluctuations and may not contribute to any trend in long term rainfall series. it is to be understood that the climate of place is the composite weather condition which is determined by averaging the atmospheric elements like temperature and rainfall over a long period of time, say 30 to 50 years. The abnormal events of weather area too rare to change these averages. In general from the above analysis it is apparent that the abnormal fluctuations of the recent years are of random nature and no trend is being set up in the rainfall pattern in any part of the country. Climate is not undergoing any drastic change.

5.0 ERRORS IN MEASUREMENT OF PRECIPITATION

Annual global precipitation is 113 cm (India 117 cm). Annual normal varies from 1 mm to 26,000 mm. Also, in one day over 1000 mm has been observed (Cherrapunji 1440 mm on 14 June 1876; Dharampur 990 mm on 2 July 1941). Thus the precipitation has large variation in time and space. We cannot measure the exact amount of precipitation over an area. The conventional as well as the remote sensing techniques have several draw backs. Thus all the methods for obtaining areal precipitation are the 'estimation' and are subject to many errors. This is serious limitations to the hydrological forecast.

In conventional method the point rainfalls are averaged. The spatial variability is larger in short duration rainfall like hourly and daily as compared to seasonal and annual. This lead to sampling error which can be reduced by increasing network density. There is error in point measurement also. Due to wetting evaporation, splashing of raindrops and deficiency in catch due to wind cause an underestimation of rainfall measurement up to 30% .The losses may be even more in the mountainous areas. Radar and satellite techniques help to locate areas of heavy rainfall and the position, direction of movement of important rainstorms. However, a quantitative measurement of areal rainfall are not yet suitable for operational use.

The radar observes the intensity of rainfall continuously over an area of 200 km radius but the accuracy is higher for the area closer to radar. Back scattered power received from cloud nuclei/raindrops varies with the radar reflectivity and radar constant. It varies inversely with square of distance and beam attenuation. Its reflectivity is the total reflecting of area of all the precipitation nuclei. Each particle contributes as input proportional to its back scattering cross section. This cross section depends on radar wavelength and size, and dielectrical properties of the particles. Hence to establish a relation between rainfall rate R and radar reflectivity z, it is required to know the drop size distribution. The relation $D^6 = Z = AR^b$ is commonly used (Z in mm^6/m^3 & R = mm/hr Unit). According to Marshal and Palmar the constants are A = 200 and b = 1.6.

The quantitative estimation of radar echoes is not very accurate. The radar echoes provide very valuable information about the center of the storm i.e. the center of maximum rainfall when it lies in between the two gauge stations otherwise this valuable information is missed in the isohyetal analysis.

At present, satellite data are useful only for estimating convective precipitation. Chorographic and cyclonic types of precipitation are not covered under satellite technique. The rainfall intensity is related to brightness and temperature of cloud top. The areal estimate has a number of error sources in transformation procedures, processing and analysis.

A rainfall event varies in space from a few km in a thunder cloud to several thousand km under well defined pressure system. Also short duration rainfall for convective clouds varies in time and space, intensity decreasing with a distance from the center. The satellite data provide useful information about formation and movement of clouds, but the quantitative estimate of precipitation is not yet realistic. They have limited utility especially over large areas where rain gauge network is scanty.

6.0 CONCLUSION

Funding constraints have prevented satisfactory development of operational network in hydrometeorology. Similar restraints are obvious in matters of purchasing technology. Still worse is to attract and retain technical staff to maintain the network. The overall assessment, thus, reveals that we have very much inadequate network in many areas especially in the mountainous catchments where even the logistics are poor. Recent WMO/UNESCO Water Resources Assessment (1991) indicated that observing networks are declining in some countries particularly developing ones.

Secondly, the new technologies are not available to developing countries. Even if these are made available at high initial cost, the lack of high level skills to maintain the equipment makes it more difficult to sustain.

Thirdly, the indifferent management and unknown resources lead to inefficiencies which ruin the infrastructure.

And now entire system turning towards commercialisation would demand careful costing of products and services and charging on information which has so far been provided free. All this needs hard work and more research.

More demands on water resources exert equal pressure on hydrometeorology to bring more avenues to meet the situation through research and development.A lot of work has been done in the country for managing the structures as well as catchments to meet challenges brought about by water demands and floods. Hydrometeorology is equipped to meet the challenges.

REFERENCES

Fruhling, 1961, 'Area depth rainfall formulates', Journal of Geophysical Research, 66,6.

Kaur, S. and Upadhyay, D.S., 1987, 'Precipitation network design for mountainous catchment', Mausam, 38,1,73-78.

Ramanathanm, A.S. et al., 1981, 'Precipitation network design for hydrological purposes', Part-I, IMD.

Rodriquez-Itrube, I. and Mejia, J.M., 1974, 'The design of rainfall networks in the time and space', Water Resources Res., 10, 713-729.

Upadhyay, D.S. and Kaur, S., 1990, 'Finite mixture of extreme value distribution for rainfall frequency analysis', Mausam, 41, 4, 627-630.