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PRECIPITATION NETWORK DESIGN FOR MYNTDU-LESKA BASIN

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ABSTRACT

Precipitation is the most basic data required for any water resources studies. 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 network design. A rain gauge network is intended to serve the general as well as specific purposes such as water supply, hydro power generation, flood forecasting, irrigation and flood control etc.

In the present study, the network design for the Myntdu basin has been carried out. The basin lies in the zone of highest rainfall in the world (Cherapunjee is about 50 km from Myntdu).The rains are of long duration and occur mostly between March and October. During March and April the rainfall is sporadic, but it is steady and heavy or very heavy during May to October. Annual rainfall in the basin is over 10,000 mm. There is wide spatial variation in this small but almost all hilly catchment. The rainfall data of seven existing raingauge station in and around the study area have been analysed using various methods which take into account the location and type of basin and its climate, precipitation characteristics from the existing rainguage stations etc. Apart from BIS recommendations, C_v method, Key station method and spatial correlation method have been tried. Based on the study, the accuracy of the existing network in estimating the average areal rainfall is not within the prescribed limits. To bring the accuracy within the reasonable limit, additional four raingauge stations have been proposed in the catchment with their possible locations.

1.0 INTRODUCTION:

A hydrological network is an organised system for the collection of information of specific kinds such as precipitation, run off, water quality, sedimentation and other climate parameters. The accuracy in the decision making in the water project design depends on how much information is available for the region concerned. Having enough relevant and accurate hydrologic information reduces the chances of underdesign or overdesign and thus minimizes the economic losses, which leads to the overall increase in the benefit/ cost ratio. The failure of many capital intensive projects throughout the world can be attributed in part to an inadequate record length, the sparseness of the network, and/ or inaccuracy of the hydrologic information. It has not, so far, been possible to define the optimum level of hydrologic information required for planning, design and development of a specific project in a region, due to difficulties in developing a benefit cost function of hydrologic information. It is, therefore, difficult to attain an optimum balance between, on one hand the economic risk arising from inadequate information and on the other hand, the cost of a hydrologic network capable of transmitting the required information. Unless techniques to evaluate such a balance are developed, the network design methods sited in the literature can not be universally applied.

There are several ways to define the objectives of the hydrological network design, but the fundamental theme, in most cases, is the selection of an optimum number of stations and their optimum locations. Other considerations that can arise in the network design are; achieving an adequate record length prior to utilizing the data, developing a mechanism to transfer information from gauged to ungauged locations when the need arises and estimating the probable magnitude of error or regional hydrologic uncertainty arising from the network density, distribution and record length. Another difficulty in developing a network design methodology is related to the complexity in dealing with the multi variate interaction of hydrologic events in the domains of space and time. The stochastic nature of the hydrologic variables complicates the problems further.

The objective of providing a network of rainguage is to adequately sample the rainfall and explain its variability within the area of concern. The rainfall variability depends on topography, wind, direction of storm movement and type of storm. The location and spacing of gauge depends not only on the above factors but also upon the use of that data for that region. For example in the tea garden areas of the North East region, the density of precipitation gauge is found to be much higher, even in the valleys, in comparison to the hills where jhoom cultivation are practiced, since the data are used for irrigation planning of the tea gardens. Network design covers following three main aspects (WMO, 1976):

a. Number of data acquisition points required.
b. Location of data acquisition points and
c. Duration of data acqusition from a network

Measurement stations are divided into three main categories by WMO, namely

1. Primary stations: These are long term reliable stations expected to give good and reliable records.
2. Secondary or Auxiliary stations: These are placed to define the variability over an area. The data observed at these stations are correlated with the primary stations, and if and when consistent correlations are obtained secondary stations can be discontinued or removed.
3 Special stations: These are established for particular studies and do not form a part of minimum network or standard network.

In the present study, the network design for the Myntdu basin has been carried out. The basin lies in the zone of highest rainfall in the world (Cherapunjee is about 50 km from Myntdu). The rains are of long duration and occur mostly between March and October. During March to April the rainfall is sporadic, but it is steady and heavy or very heavy during May to October. Annual rainfall in the basin is over 10,000 mm. There is wide spatial variation in this small but almost all hilly catchment. Various methods have been tried which takes into account the location and type of basin and its climate, precipitation characteristics from the existing rainguage stations etc. Apart from BIS recommendations, C_v method, Key station method and spatial correlation method have been tried for determining the number of raingauge stations. Based on the study certain conclusions have been made regarding the existing network accuracy, total number of additional stations to be installed in the catchment and their possible location.

2.0 LITERATURE REVIEW:

Various studies have been conducted to determine the standard error of estimates of precipitation with different size of drainage area with different rainguage densities since long. One of the earliest work is of Linsley et. al. (1947) determining the standard error of estimates of storm rainfall over Muskingum basin. Huff and Neil (1957) carried out a study of areal variability of rainfall in a region characterized by thunderstorm activities in Illinois state, USA.

Kagan (1966) has suggested a procedure for computing the error in estimation of mean areal rainfall which could be used as a criterion for determination of the optimum network density.

Eagleson (1967) used the technique of Harmonic Analysis and the concept of Distributed linear systems to study the sensitivity of peak catchment discharge to characterise spatial variability of convective and cyclonic storm rainfall. Sampling theorem was used to generalise the relations for optimum network density for flood forecasting.

The Indian Standard Institute (now Bureau of Indian Standards, IS 4987-1968) has recommended the design of a rainguage network based on type of area and rainfall type as follows:

1. For plain areas one rainguage upto 520 sq. km. shall be sufficient. However, if the catchment lies in the path of low pressure, the system which causes precipitation in the area during its movement which can be seen from the map published by India Meteorological Department, then the network should be denser particularly in the up stream.
2. In the region of moderate elevation (upto 1000m above msl), the network density shall be one rainguage in 260-390 sq. km.
3. In predominantly hilly areas and where heavy rainfall is experienced, the density recommended is one rainguage for every 130 sq. km.

Matheron (1971) considered the variables which show variations of relation to space and/or time as regionalised variables and developed the theory of regionalised variables. In this theory he proposed a method of estimation, which is termed as kriging technique, for spatial interpolation in random fields. Later, Delhomme and Delfiner (1973) used universal kriging to interpolate rainfall on a regular grid for a large storm over an arid region of Chad. They calculated the gain in the estimation of mean rainfall during a storm resulting by setting a new fictitious gauge at a point within the basin.

Hall (1972) suggested a method for determination of key station network for flood forecasting. First correlation coefficient between the average of the storm rainfall and individual rainfall are found. The stations are arranged in the descending order of the correlation coefficient and the station with the highest correlation coefficient, called key station, are considered for inclusion in the network. Then the first key data are removed and second key station from the remaining data is found similarly. As each stations gets added to the key station network, the total amount of the variance which is accounted for by the network at that stage is determined. From this the number of gauges required to achieve an acceptable degree of error can be found.

Osborn and Handley (1972) considered the climate of the watershed for determination of the optimum network density. On correlating the rainfall and runoff in a test basin of one square mile area, they observed that the optimum network density was varying directly with the accuracy and inversely with the area of the watershed.

The Bureau of Indian Standards and India Meteorological Department (1972) have recommended a simple formula:

$$N = \left(\frac{C_v}{P}\right)^2 \tag{2.1}$$

Where,

N = optimum number of Rainguages to be installed in the basin.

C_v = coefficient of variation of rainfall for the existing rainguage network

P = permissible degree of percentage error for estimation of the average areal rainfall.

Zamadzki (1973) derived analytical expression for the error in the area averaged rainfall as estimated by a network of rainguages, the fluctuations in the estimate and actual variance of the area averaged rainfall in terms of the mean, the mean square and the space auto-correlation function of the areal distribution of the rainfall. He evaluated the error equation for an exponential auto-correlation function and obtained a linear approximate expression.

Rodriguez-Iturbe and Mejia (1974) formulated a general methodology for design of rainguage network. They expressed the rainfall process in terms of its auto-correlation structure in time and space. They developed a general framework to estimate the variance of the sample long term mean areal rainfall of a storm event. Expressing the variance as a function of correlation in space, correlation in time, length of operation of the network and the geometry of the gauging array, they developed the trade-off of time verses space.

The World Meteorological Organisation (1976) has recommended the minimum network densities for general hydrometeorological practices.

1. For plain regions of temperate mediterranean and tropical zones one station for 600-900 sq. km.
2. for mountainous region of temperate mediterranean and tropical zones one station for 100-250 sq. km.
3. For arid and polar region one station for 1,500-10,000 sq. km.

Bras and Rodriguez-Iturbe (1976) considered rainfall as multidimensional stochastic process. By using such process and multivariate estimation theory they developed a procedure for designing an optimal network to obtain mean areal rainfall of an event over a fixed area. This methodology considered three aspects of network design, namely spatial uncertainty and correlation process, error in measurement techniques and their correlation and non-homogeneous sampling costs. They found out the optimal network (density and location of the rainguage) together with the resulting costs and mean square errors of rainfall estimations.

Bras and Colon (1978) developed a procedure for the estimation of mean areal rainfall through a state of augmentation procedure and the use of multivariate linear estimation concepts, in particular, the Kalman-Bucy filter. The resulted technique could be used to analyze the existing data network, design new networks and process data for new networks.

Crowford (1979) described an experimental design model using an array of multivariate sensors, which was developed to evaluate trade-offs involved in the optimal sampling of rainfall. The model was used to examine the effects of sensors density reduction on the ability of a sampling system to detect signal variations.

Jettmar et. al. (1979) presented a methodology for assessing the value of river flow forecasting by possible changes in the existing precipitation and stream flow networks.

Jones et. al. (1979) used the optimal estimation procedure for preparation of maps of root mean square error of point interpolation for suggesting the accuracy of estimation of mean areal rainfall for any shape of area and any configuration of raingauges.

Lane et. al. (1979) suggested the use of principal component analysis in conjunction with the optimal interpolation for design of rainguage network.

Moss (1979a) advocated the use of a third dimension, the model error for modeling the rainfall process and analysis of hydrologic networks. Later he (1979b) suggested that to achieve a complete network design, the efficiency of data collection and the effectiveness of the resulting information must be integrated.

O' connel et. al. (1979) employed optimal estimation procedure in the redesign of a rainguage network in South England. Root mean square errors were calculated using the estimates of spatial auto-correlation of daily and monthly rainfall. Later Mooley et. al.(1981) used this theory by imposing climatological constraints to minimise the root mean square error estimation. The areal value can be given by,

$$P_R = \frac{1}{A} \iint P(x,y)\,dx\,dy \qquad (2.2)$$

Where, P(x,y) is the rainfall at point (x,y).

This areal average can be estimated by a linear combination of point observational values as

$$\hat{P}_R = \sum_{j=1}^{n} W_j P_j \tag{2.3}$$

where n is the number of gauges. P_j is the rainfall at j th station.

The relative root mean square error is given by.

$$E = \left[\sum_{j=1}^{n} W_j P_j - \frac{1}{A} \iint_A P(x,y)\, dx\, dy \right]^2 \tag{2.4}$$

E should be minimum in an optimized network.

The optimum number of gauges required over an area for the estimation of areal rainfall can be directly determined from the relationship for a given error tolerance. The advantage of this method of optimum estimation is that it takes into account the local variation as well as inter station relationship of rainfall, spatial distribution of gauges over an area is also taken into account.

Thorpe et. al. (1979) suggested the use of double Fourier series for spatial interpolation of rainfall for a better estimation of mean areal rainfall.

Wood (1979) developed the sequential probability ratio test and applied to the network design problems. The decision whether to discontinue a station was considered to be dependent on the statistical considerations that to include the error probabilities of accepting a model when it is incorrect as well as rejecting it when it is correct.

Stole (1981) described an analytical method to determine the correlation function for a given storm, which has major uses in the spatial interpolation of rainfall and estimation of mean areal rainfall. Later he (1982) reviewed the phenomenon of occurrence of negative correlation functions between the gauge stations.

Dymond (1982) derived a simple expression for mean square error in basin rainfall as determined from a rainguage network. The expression involves the established correlation between the neighboring raingauges and the number of gauges in the network. A rational approach was proposed for network reduction. Later this method was reviewed by Bradsley and Manly (1985) and supported on the condition that, to apply this method the network should have negligibly small errors due to spatial variation of the rainfall process.

Husain (1989) applied the concept of maximum entropy for selection of optimum stations from a dense network and expansion of an existing network. He used the maximization of information transmission principle for above purposes.

Seed and Austin (1990) simulated the mean standard error using the sparse network to estimate the daily and monthly mean areal convective rainfall. They found out that a network with a regular configuration gives somewhat less variable errors than a random rainguage network.

3.1 General:

The study area of Myntdu river catchment is in the north-eastern frontier of the country comprising seven states including, Meghalaya to which it belongs. The physiography of the entire region is divided into three divisions, namely, Meghalaya Plateau, the North Eastern Hills and Basin, and the Brahmaputra Valley accounting for 13%, 65% and 22% of the total area respectively. The Myntdu river catchment lying between 25°10' to 25°17' north latitudes and 92°15' to 92°30' east longitudes is in Jayantia Hill district of Meghalaya, in the southern slope of the state adjoining Bangladesh. The geographical area of the catchment is about 350 sq. km. The area with elevation ranging from 595 to 1370 m above m.s.l. is narrow and steep, lying between the central upland region of Meghalaya and plains of Bangladesh. The fall of the hills at many places is sudden and sharp, forming deep gorges and river valleys. It is characterized by mountainous precipices, cliffs, waterfalls and scenic plateaus overlooking the plains.

The area is in the highest rainfall zone of the country. The rains are of long duration and occur mostly between March and October. During March and April the rainfall is sporadic, but it is steady and heavy or very heavy during May to October. Annual rainfall in Khasi Jayantia and Garo Hills is over 10,000 mm.

3.2 Myntdu River System:

The Myntdu river in the upper reaches originates at an elevation of approximately 1372 meters and flows south for a distance of about 10 km with a steep gradient upto an elevation of about 1220 meters. From this point the river takes a sharp bend towards East and flows in that direction for a distance of about 11 km through a wide valley full of cultivation and thickly populated villages. In the next 27 km the river gradually drops by about 595 meters and flows through narrow valleys towards Southwest for the first 16 km, while the next 11 km it flows towards South to an elevation of approximately 595 meters near Leska where two other tributaries namely Umshakaniang from the west & Lamu from the east meets the river. The river is named

3.3 Existing Observation Network :

Rainfall in the catchment occurs during June to October. There are also some pre-monsoon and post-monsoon showers. The average annual rainfall in the catchment is in the order of 7500 mm. Daily rainfall records have been maintained at four different raingauge stations namely Nukum (Pdengshkap), Bataw, Samsam and Jarain since 1975. Further, rainfall data of Jowai station are available with the India Meteorological Department for substantial period. The rainfall data at Sohmynthing and Jatah (in the near by catchment) have also been collected. Sohmynthing, Jarain and Nukum stations are just at the boundary of the basin while Samsam and Jowai stations are inside the catchment . Bataw and Jatah stations are in the adjoining catchment. As because no long term data is available at the stations inside the basin the two stations have been considered in the study to describe the spatial variability of the precipitation characteristics. The location of these stations are shown in **Fig. 1.** The detailed availability of rainfall data for the basin is given in **Table-1**. The main rainy season of this area is May to October with annual rainfall for the catchment varying from 3000mm to over 10,000mm. The approximate isohyetal maps of the basin in different season are given in **Fig. 2(a)** to **2(e)**.

Table-1. Data Availability

Station	Year
Jarain	1975,1977-94
Samsam	1975,1977-1990
Bataw	1975,1977-83,1985-1991
Nukum	1975,1977-96
Jowai	1981-83,1985-90
Jatha	1987,1992-1996
Sohmynthing	1992-1996

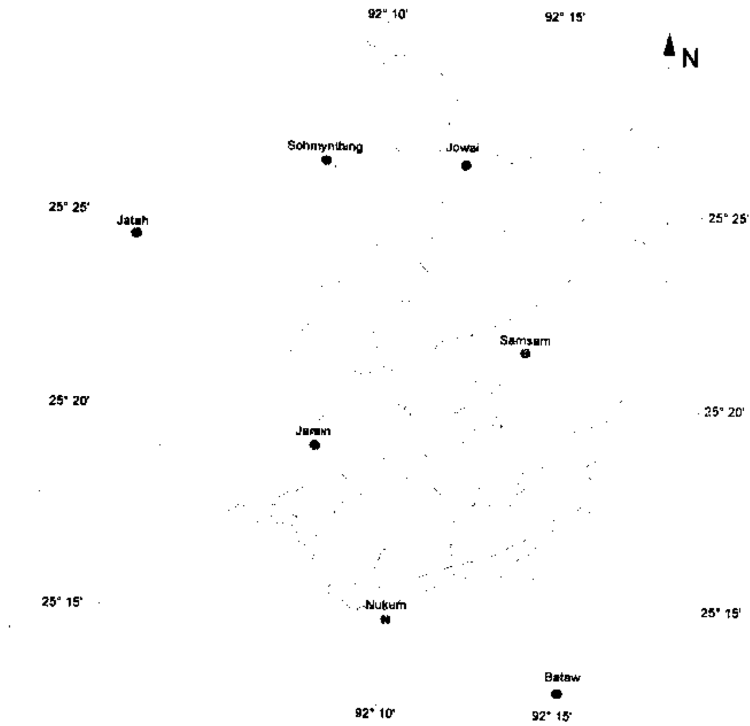

Fig. 1 Study area

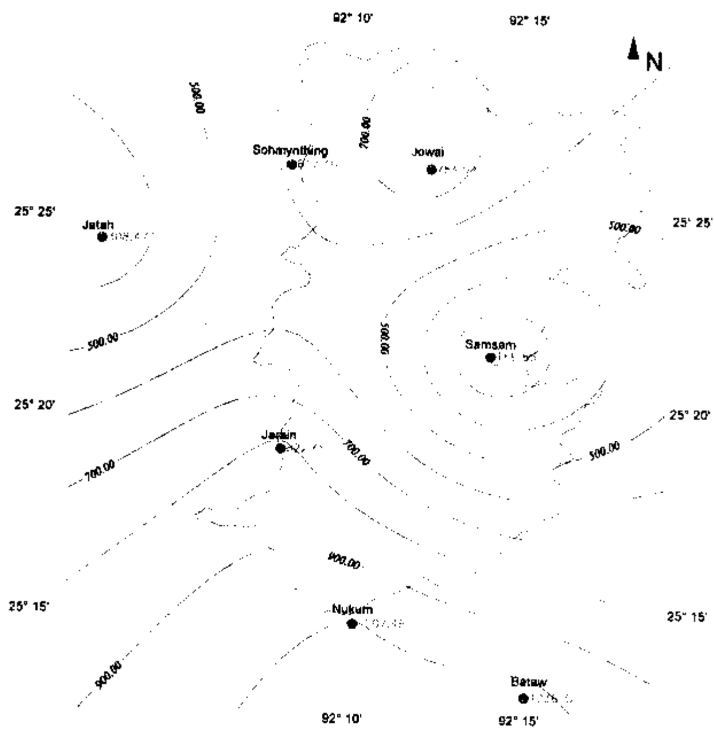

Fig. 2(a) Isohyetal map (pre-monsoon)

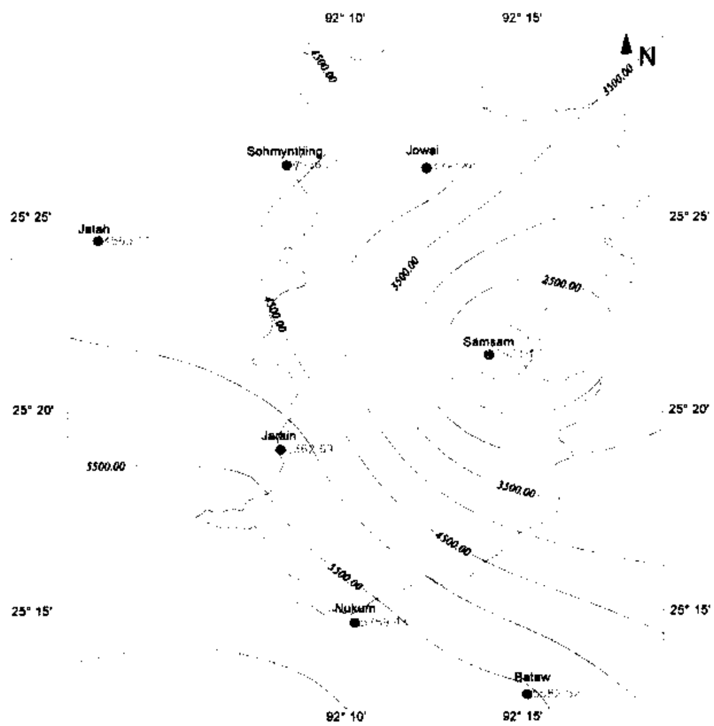

Fig. 2(b) Isohyetal map (monsoon)

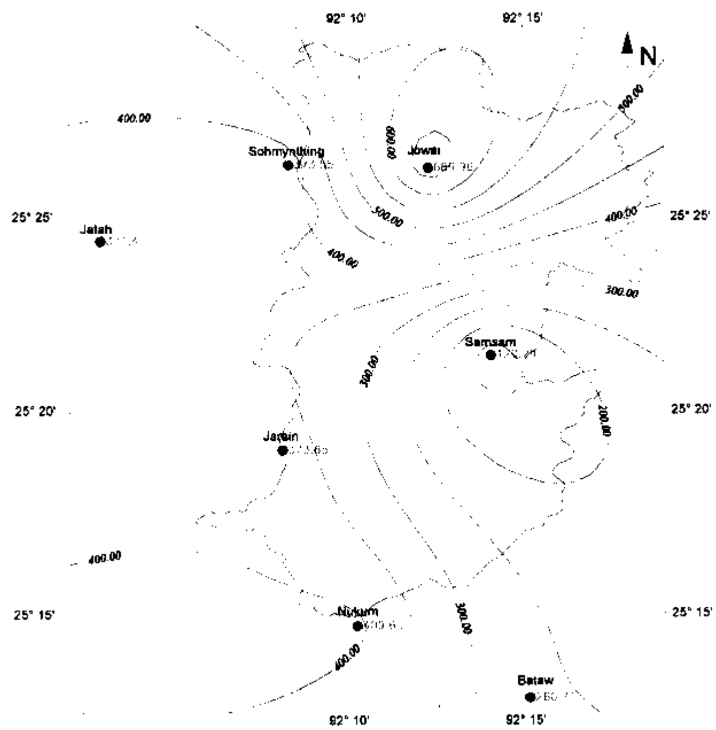

Fig. 2(c) Isohyetal map (post-monsoon)

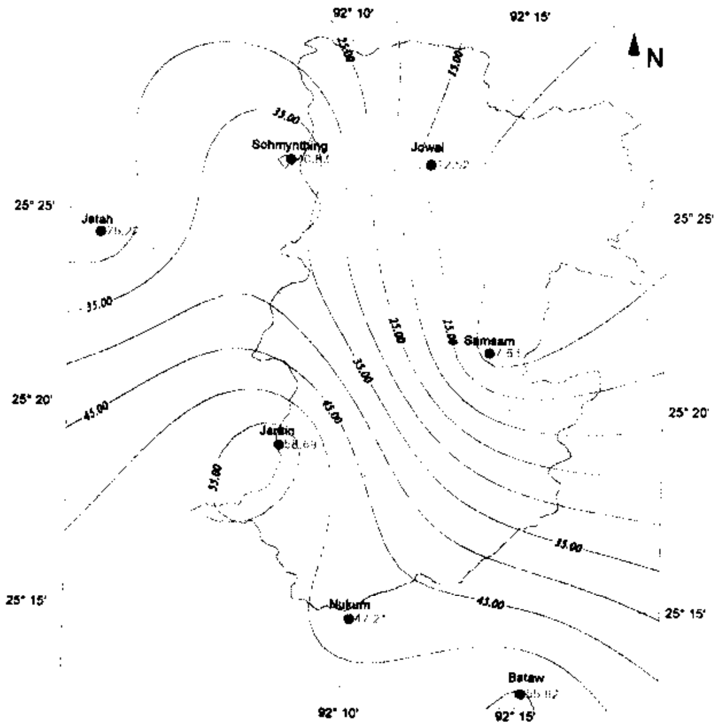

Fig. 2(d) Isohyetal map (winter)

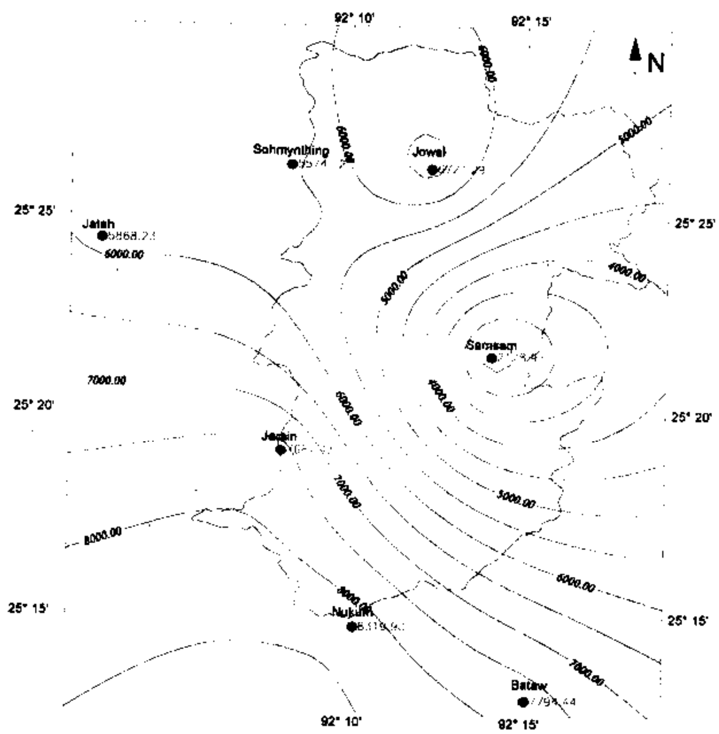

Fig 2(e) Isohyetal map (annual)

4.0 STATEMENT OF THE PROBLEM:

For the management of a water resource system different sets of data and criteria are necessary for different objectives for which the system has been planned. The task of rainfall station network which is one of the important hydrological parameter of any water resource project needs due attention. To cope with the requirements of always increasing population from the limited resource the general tendency is to propose multipurpose schemes in stead of single purpose. It means while designing the network in a basin proper attention must be given on the nature of project proposed in the catchment. The studies are generally set for :

a. Hydrological studies,
b. Climatological and water balance studies,
c. Flood forecasting and computation of runoff studies and
d. Weather modification evaluation studies.

The objective of the optimum network design, in this study, is the selection of an optimum number of stations and their judicious locations in the Myntdu basin where a hydro-electric power project has been proposed by Meghalaya State Electricity Board. Various stages of network design to be followed are:

1. Collection of information like:
    a. Location of area,
    b. Size of catchment,
    c. Climate of the area,
    d. Precipitation characteristics,
    e. Location of existing precipitation stations and collection of data,
2. Determination of accuracy of existing network,
3. Determination of number of new stations required and
4. Planning of new sites in the network.

3.0 STUDY AREA :

5.0 METHODOLOGY:

The following methodologies have been used in the present study

5.1 IS 4986-1968 guidelines:

The Bureau of Indian Standard suggests that one rainguage upto 500 sq. km. might be sufficient in non-orographic regions. In regions of moderate elevation (upto 1000 m above msl), the network density might be one rainguage for 260-390 sq. km. In predominantly hilly areas and areas of heavy rainfall, the density recommended is one for 130 sq. km.

5.2 C_v Method:

The problem of ascertaining the optimum number of raingauges in various basins is of statistical nature and depends on spatial variation of rainfall. Thus, the coefficient of spatial variation of rainfall from the existing stations is utilised for determining the optimum number of raingauges. If there are already some raingauges in the 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:

$$N = \left(\frac{C_v}{P}\right)^2 \qquad (5.1)$$

where,

N = optimal number of stations,

p = allowable degree of error in the estimate of mean rainfall and

C_v = coefficient of variation of rainfall values at the existing m stations.

If there are m stations in a catchment and P_1, P_2, ...P_m is the recorded rainfall at a known time at 1, 2, ...m station, then the coefficient of variation C_v is calculated as:

$$C_v = \frac{100 \times \sigma_{m-1}}{\overline{P}} \quad (5.2)$$

where

$$\sigma_{m-1} = \frac{\sqrt{\sum_{i=1}^{m} P_i^2 - m \times \overline{P}^2}}{(m-1)} \quad (5.3)$$

P_i = monthly average precipitation at i th station and

$\overline{P}$ = the average rainfall of 'm' number of stations, given by,

$$\overline{P} = \frac{\sum_{i=1}^{n} P_i}{m} \quad (5.4)$$

It is usual practice to take p =10%.

σ_{m-1} is used for calculation of C_v (Eq. 5.2) when number of stations, m, in the network is less than 30 otherwise σ_m can also be used.

5.3 Key Station Network Method:

One of the most rational method for determination of key station is as suggested by Hall (1972). In this method, at first, the correlation coefficient between the average of storm rainfall and the individual station rainfall are found. The stations are then arranged in the order of their decreasing correlation coefficients and the station exhibiting highest correlation coefficient is called the first key station and its data is removed for determination of next key station. The procedure is repeated by considering the average rainfall of the remaining stations. The station showing the highest correlation coefficient after removing the data of first key station is called the second key station. Similarly third and successive key stations are determined after removing the data of already selected key stations. Now the sum of the squares of deviations of the estimated values of average rainfall from the actual rainfall in respect of 1st, 2nd, 3rd key station etc. is determined and a graph is plotted between the sum of the square of deviation and corresponding number of stations in combinations. It will be seen that a stage comes when the improvement in the sum of squares of deviation is very little with the addition of more stations. The corresponding number of stations at that stage is taken to be representative and key stations for the network in the catchment/ basin.

5.4 Spatial correlation Method:

Under the assumption that spatial variability of rainfall can be quantified through a spatial correlation function, a network of rainguages can be designed to meet a specified error criterion (Kagan, 1966 and WMO, 1972). However in applying such an approach, care must be taken to ensure that condition necessary for the existence of spatial correlation function, such as hydrological homogeneity and isotropy are fulfilled; flat areas with a relatively homogeneous surface are more appropriate for the application of the technique. A general theoretical spatial correlation method for the planning of meteorological networks has been given by Gandin (1970). Some details of the specific approach and its application have been given by Kagan (WMO, 1972). The basis of this method is the correlation function ρ(d) which is a function of the distance between the stations, and the form of which depends on the characteristics of the area under consideration and on the type of precipitation. The function ρ(d) can frequently be described by the following exponential form:

$$\rho(d) = \rho(0)e^{-d/d_0} \qquad (5.5)$$

where ρ(0) is the correlation corresponding to zero distance and d_0 is the correlation radius or distance at which the correlation is ρ(0)/e.

Theoretically, ρ(0) should equal to unity but is rarely found so in the practice due to random errors in precipitation measurement and micro climatic irregularities over an area. The variance of those random errors has been given by Kagan (1966) as

$$\sigma_1^2 = \left[1 - \sigma(0)\right]\sigma_h^2 \qquad (5.6)$$

where σ_h^2 is the variance of the precipitation time series at a fixed point.

The quantities $\rho(0)$ and d_0 provide the basis for assessing the accuracy provided by a network. In this context two accuracy criterion may be of interest.

Criterion 1: The accuracy with which the average rainfall over a given area may be obtained is to be evaluated. For an area 's' with the center station, and assuming $\rho(d)$ exists and described as above, the variance of the error in the average precipitation over 's' is given by Kagan (1966) as:

$$v = \left[1 - \rho(0)\right]\sigma_h^2 + 0.23\sigma_h^2 \frac{\sqrt{s}}{d_0} \tag{5.7}$$

where, the first term is attributed to random error and second term with spatial variation in the precipitation field.

For an area 'S' with 'N' stations evenly distributed so that S = N × s, the variance of the error in the average rainfall in the area 'S' is given by

$$v_n = \frac{\sigma_h^2}{n}\left[1 - \rho(0) + 0.23\frac{\sqrt{s}}{d_0} \times \sqrt{n}\right] \tag{5.8}$$

The relative root mean square error is then defined as:

$$z_1 = \frac{\sqrt{v_n}}{\bar{h}} = \frac{C_v}{n}\sqrt{1 - \rho(0) + 0.23\frac{\sqrt{s}}{d_0} \times \sqrt{n}} \tag{5.9}$$

where $C_v = \sigma_h/h$ and h is the average precipitation over the area S. From the above equation the value of 'n' to meet a specified error criterion Z_1 can be obtained if the values of $\rho(0)$ and d_0 are known or vice versa. The uniform spacing of station over the area S is such that S = N ×s can be achieved on the basis of a square grid for which the spacing between the station is: L= √S/N. However a triangular grid is usually more convenient if the area S has a complex configuration and its spacing is given L=1.07 √S/N

Criterion 2: The accuracy of spatial interpolation is to be evaluated. Kagan (WMO, 1972) has given the relative errors associated with linear interpolation between two points and interpolation at the center of square and triangle, where the maximum error of interpolation occur. For a triangular grid with a spacing one, the relative error is given by as:

$$z_2 = C_v \sqrt{\frac{\left[1-\rho(0)\right]}{3} + \frac{0.52 \times \rho(0) \times \sqrt{s}}{\sqrt{n \times d_0}}} \quad (5.10)$$

Assuming that $\rho(d)$ can be described by equation (5.5)

Application: The derivation of z_1 and z_2 in a particular case requires the estimation of $\rho(0)$ from which $\rho(d)$ and d_0 can in turn be derived. The function $\rho(d)$ can be evaluated by calculating the correlation $\rho(i,j)$ as a function of distance between stations. The value of $\rho(i,j)$ is calculated as:

$$\rho(i,j) = \frac{\sum h_i h_j - \left[\sum h_i - \sum h_j\right]/m}{\sqrt{\left[\sum h_i^2 - \left(\sum h_i\right)^2/m\right]\left[\sum h_j^2 - \left(\sum h_j\right)^2/m\right]}} \quad (5.11)$$

where the summations are taken from 1 to m and m is the number of pairs of observations. For determination of $\rho(0)$ and d_0 distance is plotted against correlation and an exponential curve is drawn through the points. The value of $\rho(0)$ is found out by extrapolating $\rho(d)$ to zero distance, and d_0 is calculated as the distance corresponding to a correlation of $\rho(0)/e$. Alternatively, $\ln[\rho(d)]$ may be plotted against d which should result in a linear plot with slope $(-1/d_0)$ and intercept is $\ln[\rho(0)]$. The objective of fitting of a straight line to the plotted points by least square may result in values of $\rho(0)$ greater than unity which would be nonessential. Consequently, a subjective approach such as fitting by eye is apparently only the alternative.

5.5 Location of Precipitation Gauges:

Determination of location of rainguage station is very important in the design of precipitation guage network. Isohyetal method is commonly used to locate rainguages in the catchment. In this method the isohyetes are drawn over the catchment. This divides the whole catchment into a number of zones. Number of station should nearly be equal in every zone. The exact location should be decided keeping in view the following points:

a. The rainguage should be located near village or town.

b. The site should be accessible throughout the year.

c. The distribution should be uniform over the catchment area.

d. As far as possible number of rainguage should be proportionate to area of the sub-catchment in which it is placed.

6.0 ANALYSIS AND DISCUSSION:

Estimation of the number and location of the rainguage stations have been analysed by IS guidelines, C_v method, key stations method and correlation method. The Myntdu Leska basin selected for the study is having seven rainguage station in and around the basin in the catchment area of about 350 sq. km only. The catchment is basically hilly with a very small proportion of it is in plain. Therefore, it can be assumed that data of six stations should be sufficient to represent the rainfall in the basin but it is not the case. The rainfall in the catchment shows a wide variation in space and time. Also the location of these stations are not uniform over the catchment, therefore even if there is relatively large number of rainguage it does not give the adequate representation of the basin rainfall. Therefore, proper network design is required to sample the precipitation in the basin. The results and observations for each methods are herewith discussed in details as follows:

IS guidelines:

The catchment lies in the highest rainfall zone and almost all hilly (288.5 sq. km), it is recommended as per IS4987-1968 that there should be one rainguage for every 130 sq. km. As per this guidelines, the minimum number of rainguage in the hilly area should be equal to three and in plain one. Therefore, the method prescribed total number of four stations. Out of existing precipitation network four stations (Jowai, Samsam, Jarain and Nukum) are inside the catchment and other are outside the basin boundary. But the inside stations are not well distributed. The north east and south east parts of the catchment are totally unrepresented. Although there is a very small portion of the basin is in plain (49 sqkm), there is no raingauge station in the plain. Therefore this method suggest that one additional rainfall station should be installed in the plain area and the other suitable site for rainfall station is the north and north eastern part of the basin.

C_v Method:

The coefficient of variation evaluated for the average annual rainfall for the existing rainguage network is 0.33 and with N = 7, the probable error in the observation of the rainfall is 12.5%. The number of station and probable error are given in **Table-2** which shows that there should be at least 11 number of stations in the basin to give 10% probable error in its estimation.

Table-2 Variation of probable error with number of stations

Number of station	Probable error
1	0.33075
2	0.23388
3	0.19096
4	0.16538
5	0.14792
6	0.13503
7	0.12501
8	0.11694
9	0.11025
10	0.10459
11	0.09973

Key Station Network Method:

It has been tried to select the storms in such a way that the rainfall data at maximum number of stations are available. Because of the nature of unavailability of long term simultaneous data at every station only five stations are found (maximum possible) for which the data for 22 storms are available. Key stations then, have been determined as per the procedure given in methodology. **Table-3**. gives the details of combination of stations for determination of key stations and also their correlation. **Fig.3**. shows the maximum correlation coefficient for different combination of stations. Determination of key stations helps in the reduction of network. It helps in deciding that which stations is to be retained in the network to attain a certain accuracy level. The decrease in sum of the squares of deviation with the increase in the number of stations has been shown in **Table 4**. The **Fig 4**. shows the graphical representation of the **Table-4**. from which it can be seen that the combination of two consecutive keys stations namely Nukum and Jarain gives better estimation of rainfall in the basin in comparison with the three station combination namely Nukum, Jarain, and Bataw. As because the Bataw station is in the adjoining catchment and fulfilling the requirement of other basin also its continuation and discontinuation may not be decided based on the study of Myntdu basin only. But it can be very well apparent from the results that combination of data recorded at Bataw station may not be considered for the study of storm analysis of Myntdu basin. It may also be inferred that for key station determination the stations inside the catchment should only be considered. **Fig. 4.** also shows decrease in sum of the squares of deviation with increase in stations as expected.

Table-3. Correlation coefficient with different combination of stations

Sl No.	No. of station	Combination of stations	Key station	Correlation of key station
1	5	Jarain, Shamsam, Bataw, Nukum, Jowai	Nukum	0.9824
2	4	Jarain ,Shamsam, Bataw, Jowai	Jarain	0.95104
3	3	Shamsam, Bataw, Jowai	Bataw	0.95966
4	2	Shamsam, Jowai	Shamsam	0.87785

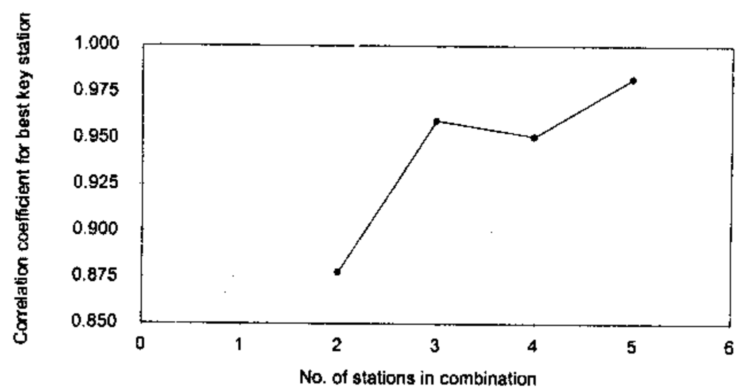

Fig. 3. Variation of correlation coefficient with number of stations.

Table-4. Change in the sum of the square of with increase in the number of station

No of stations	Sum of the square of error
1	156851
2	109229
3	143726
4	20774

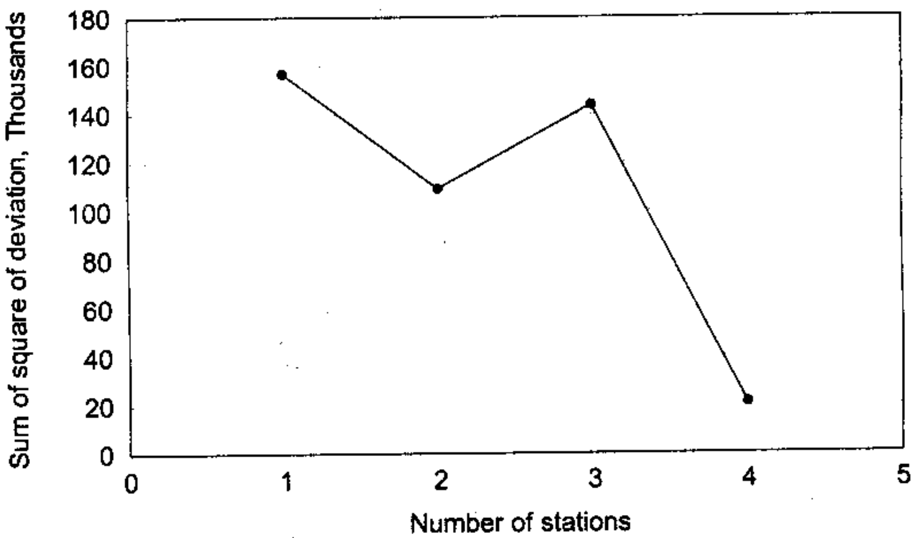

Fig. 4. Variation of sum of square of deviation with number of stations.

Spatial correlation Method

For spatial correlation method average monthly rainfall data has been used. As there are only seven stations under consideration in and around the basin total 21 number of combination is possible. The inter-station correlation and their distance is given in **Table-5**. **Fig. 5**. shows the best line fitting of the correlation and the distance (on semi log scale). The slope of this line is equal to -0.00359 which is equal $1/d_0$ and the Y intercept is 0.011205 which is $\log[\rho(0)]$. It means the value of d_0 is 278.55km. Then the relative error (root mean square error, RMSE) has been derived from the equation (5.9) and tabulated in **Table-6**. which shows the decrease in relative error with increase in number of rainguage stations. This is also shown in **Fig. 6**. The figure shows that the gain in the accuracy of rainfall estimation is very insignificant after introduction of fifth station. It means five stations can be recommended for this basin based on this study.

Table-5. Inter-station distance and their correlation

Station	Station	Distance (km)	Correlation
Jarain	Samsam	21.77	0.98275
Jarain	Bataw	32.00	0.94543
Jarain	Nukum	16.53	0.99583
Jarain	Jowai	30.26	0.94643
Jarain	Jatha	26.15	0.85554
Jarain	Sohmynthing	27.19	0.91714
Samsam	Bataw	31.76	0.92915
Samsam	Nukum	27.56	0.98940
Samsam	Jowai	18.80	0.93178
Samsam	Jatha	38.53	0.82839
Samsam	Sohmynthing	26.38	0.93439
Bataw	Nukum	17.75	0.93373
Bataw	Jowai	50.26	0.82684
Bataw	Jatha	58.16	0.78022
Bataw	Sohmynthing	54.44	0.83425
Nukum	Jowai	42.67	0.94680
Nukum	Jatha	42.20	0.85251
Nukum	Sohmynthing	42.75	0.92556
Jowai	Jatha	32.00	0.79332
Jowai	Sohmynthing	13.24	0.89358
Jatha	Sohmynthing	19.40	0.94167

Table-6. Variation of relative root mean square with number of stations

Number of station	RMSE	% RMSE
1	0.1386056	13.8606
2	0.0718527	7.18527
3	0.0461485	4.61485
4	0.0317898	3.17898
5	0.0220948	2.20948
6	0.0144843	1.44843
7	0.0026342	0.26342
8	Not defined	Not defined

Fig. 5. Relation between correlation coefficient and inter-station distance.

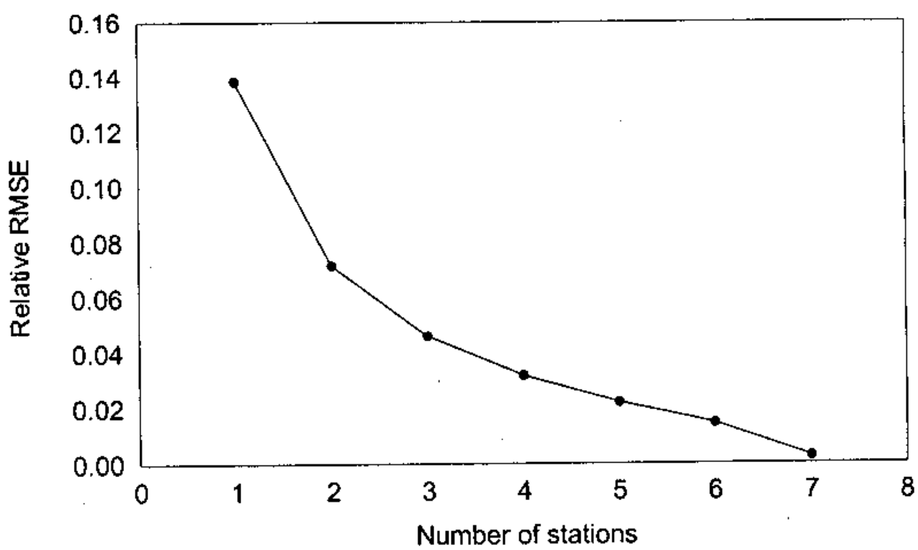

Fig. 6. Variation of relative root mean square error (RMSE) with number of stations

7.0 CONCLUSIONS:

The various methods suggested that the rainfall in the basin is not sampled well. As per the IS recommendations the number of station is of course sufficient but their distribution are not. The precipitation stations must be well distributed. Based on C_v method the accuracy of existing network work out to be 12.5%. It also prescribed additional four stations. Precipitation data at Samsam is always outlier and only because of this set of data the coefficient of variation is about 33%.

The key station method also suggests that addition of Samsam in rainguage network is in least priority after Jowai. Although spatial variability of the rainfall is observed throughout the basin, the rainfall suddenly drops at Samsam. In Spatial Correlation method the decrease in sum of the square of error is of course significant after the six station but still the slope of the curve remains steep. It suggest that more stations are needed to arrive at any conclusion to define the number of stations. But the steep slope certainly recommends additional rainguage stations in the basin.

Therefore, the maximum number of stations recommended by different method is 11. It means additional four stations are to be installed in and around the basin. To locate the site the spatial variability of the rainfall pattern must be taken into consideration. The isohyetal map of basin in the different period of time is shown in the **Fig. 2(a) to 2(e)**. As stated earlier that the rainfall pattern in and around Samsam has to be sampled well. There should be at least one station in the plain (valley) portion of the basin. Also, in the west, north east and south east part of the basin proper site should be selected for installing rainguage stations. But in these locations the population are very thin and also it is difficult to find a site having proper approach. There are very few number of villages/ built up areas and offices etc. in these parts of the basin. Taking these difficulties into consideration the feasible locations of additional four raingauge stations are as follows (Table 7).

Table-7. Feasible sites for additional raingauge stations

Location in the basin	Feasible site (village name)
West	Mowpyut
North east	Tongnah
South east	Lumputhu
Valley	Some site near the confluence of Um Rylein with main Myntdu river inside reserve forest

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