CASE STUDY

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NETWORK DESIGN OF RAINGAUGE STATIONS FOR NAGALAND

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PREFACE

Rapid economic development and population growth exert great pressure on water resource development requiring an active control. The necessity of creating a strong data base for Water Resource Planning especially for developing countries is well known. Rainfall being primary input to water budgeting, a systematic study of this data is essentially required. Although systematic measurement of rainfall has a long history, the design procedures involving areal variability are recent.

A point rainfall is collected at a given station. But water resource engineers are interested in the knowledge of total rainfall over an area. For extracting the areal information, one cannot increase the raingauge stations uncritically as they involve considerable cost. An ideal design procedure could be based an economic considerations. However there is no method now available for such considerations. An engineering approach is the only resort to the data collection problem now. In this statistical structure of rainfall over the area under consideration is studied from the existing data. Therefrom the number of stations required to represent the rainfall over the area for a prescribed accuracy is arrived at.

In this report, a network desig of raingauge stations for the state of Nagaland has been made. The Directorate of Irrigation and Flood Control provided the data used in the study.

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ABSTRACT

A sound hydrological data base is very essential for Water Resources Planning. The main aim of hydrological network is to provide a distribution of stations for an area so as to measure adequately the required parameters. With the increase in gauging stations, hydrological information available also increases. But as one increases the number of gauging stations the cost associated with these measurements also increases considerably. Infact, the network design is an economic issue. Hence one should not attempt to increase the number of gauging stations uncritically and increase the data. Certain statistical techniques allow us to determine the number of gauges required for certain objectives. These techniques require a prior knowledge of variation of the hydrological parameter to be observed which is obtained from available data. Brief discussion of different methods of Raingauge network generally used for network design and the underlying principles are given in this report. Applying four different methods the raingauge network design for the state of Nagaland has been made in the study, reported. The ISI Code, C_v method , Spatial Correlation method, Dymond and Zawadzki methods have been choosen for the above design inview of the data availability. The requirement of raingauge stations with the relative error on mean areal rainfall and spatial interpolation error are computed. It is found that the requirement of stations computed using various methods are nearly the same for a desired accuracy on mean areal precipitation. District wise requirement of raingauge stations has been given in this report. It is found that sixty three raingauge stations including seven self recording stations would be sufficient at present for the state of Nagaland. However on receipt of more rainfall observation the design may be revised.

1.0 INTRODUCTION

The need for systematic observation of hydrological parameters are well known. Establishment of such observation stations are generally made based on project necessities. In many cases on completion of the project the continued measurements are not taken up. For making integrated planning of water resources development, the variation of different hydrological parameters could not be described sufficiently in many basins with available observation which hampers the planning. Hence it is necessary to increase the observation on different hydrological parameters in these basins. The network density requirement vary greatly from one physio-geographical region to another and they should be based on the statistical structure of the observed hydrological parameter. As one increases the network of observation of any parameter, the cost associated with it also increases as depicted shown conceptually in Fig.1. It should be noted that the problem faced by hydrological community in this regard cannot be solved by collecting data uncritically. Strictly speaking the number of gauging stations required for a given area, is an economic problem. As the precipitation is the primary input to all hydrological analysis, network design of precipitation station has been an area of great interest to hydrologists. Planning a network of raingauges should always be done in conjunction with plans of measurements of other hydrological variables (WMO,1976). Since precipitation is the main input to most of the hydrological analysis, it is essential to know the amount of precipitation received during a specified period of time. It is important to bear in mind that we are interested basically not in the point precipitation, but in the average figures for a particular area. The density requirement of the network should therefore be based on the required accuracy for determining the precipitation averaged over an area. Some times they may be based on other criteria like flood forecasting/warning etc. The present report aims at the analysis of the spatial variation of rainfall observed in Nagaland and the application of statistical techniques for the network design. Design of primary raingauge stations are considered with an objective of

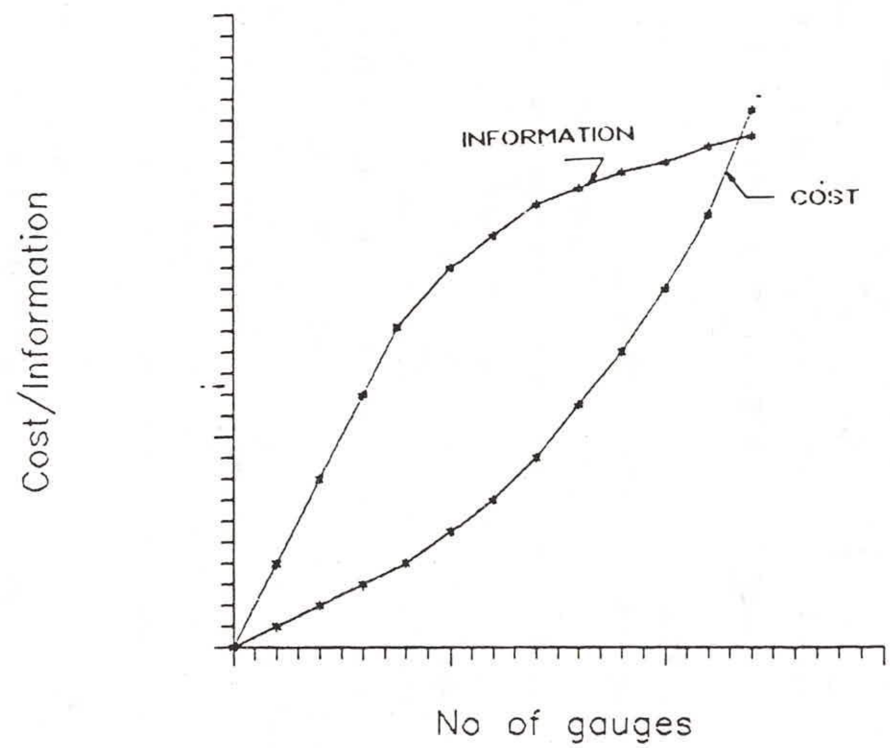

FIG.1. EFFECT OF INCREASE IN NUMBER OF GAUGES

accessing the rainfall receipt in Nagaland.

A brief review of different methods viz, ISI Code, WMO specification, C_v method, Spatial Correlation method, Optimisation methods, Principal Component Analysis, Dymond and Zawadzki methods have been given in section 2.0. After breif description of the study area application of four different methods are provided in section 4.0 along with recommendation. Appendix I provides basic statisticsused for the design.

2.0. REVIEW

2.1. ISI AND WMO SPECIFICATIONS

ISI codes & WMO specification provides certain recommendations on the density of precipitation network. Further IMD, WMO manuals also recommend certain statistical procedure. The latter procedure requires prior knowledge of the variation of the rainfall over the area under consideration, but when the existing raingauges are large, a true variation of the rainfall can be determined from which minimal/optimal need can be easily found. However this variation is obtained through the available rainfall data pertaining to that area. Hence a note of caution is necessary when using data from sparse observation for design.

The object of providing a network of raingauges 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 as well as type of storm. The location and spacing of gauge depend not only on the above factors but also upon the use of precipitation data for that region for the people. Network design covers following three main aspects(WMO, 1976):

i. number of data acquisition points required;
ii. location of data acquisition points and
iii. duration of data collection from a network.

Measurement station are divided into three main categories by WMO, viz.

i. Primary stations:- These are long term reliable stations expected to give good and representative records.

ii. Secondary stations or Auxilary Stations :- These are placed to define the variability over an area. The readings observed at these stations are correlated with the primary stations, if and when consistent correlation are obtained, secondary station may be discontinued or removed.

iii. Special Stations:- These are established for particular studies and do not form part of a minimum network.

If economy permits it is desirable to establish primary stations along with large number of secondary stations so that useful statistical relationship can be developed between the primary and secondary stations.

The WMO (1976) has recommended the following as minimum network densities for general hydrometerological 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 depending upon the feasibility.

The ISI 4987 - 1968 standard also lays down recommendations for distribution density.

1. For Plain areas one raingauge up to 520 Sq. Km. shall be sufficient to plain areas. However if the catchment lies in the path of low pressure, system which cause precipitation in the area during its movement which can be seen from maps published by IMD, then the network should be denser particularly in the up stream.
2. In region of moderate elevation (up to 1 Km above mean sea level), the network density shall be one raingauge in 260 Sq. Km. to 390 Sq.Km.
3. In predominantly hilly areas and where heavy rainfall is experienced the density recommended was one raingauge in not more than 130 Sq. Km.

2.2 RAINFALL ANALYSIS FOR DESIGN

The quantitative study of statistical structure of meteorological network design was first attempted by Dr. O.A.Drozdov in 1936. He has introduced the use of standard error of linear interpolation at the mid point between a pair of stations for determining permissible distance. Pioneering studies by him and Dr.A.A. Špelevskij in 1946 formed the basis of many of the development that took place in network design.

The rainfall data recorded at individual sites are combined in a suitable way to obtain a representative estimate of the areal rainfall and this value may depart from the true areal mean for the following reasons:

(a) inadequate coverage of the area by the gauges,
(b) systematic errors of instrumental measurements ie, poor siting of the raingauge, incorrect exposure of the instrument etc.
(c) random errors ie, observational error, errors due to the type of precipitation, micro climatic irregularities of the site etc.

Gandin suggests that a reliable data set of about sixty stations with a minimum of sixty observations at different times is required for deriving the statistical structure of the observation. The frequency of the data set used should not be too short for network design - in practice hydrologists have used daily, ten daily monthly or annual intervals for design purposes.

The common practice is to evaluate the error associated with a particular sampling density. Quite often an error criterion is applied. Some of the methods which are being used are simple random sampling, correlation function, regression techniques, structural functions, and the spatial application of time series analysis. These methods assume that the values recorded by each station is independent of the values recorded by other gauges in the area considered.

2.3. C_v METHOD

The ISI Code and IMD (1972) have recommended a simple formula.

$$n = (C_v/e)^2 \qquad \ldots\ldots (1)$$

where n is the number of raingauges
C_v is the coefficient of variation of the rainfall of the existing raingauges, given by σ_n/P
σ_n is the overall monthly variance
P_{av} is the arithmetic mean of monthly rainfall

over the area.
e is the error permissible or the desired error of accuracy

2.4 OPTIMUM ESTIMATION METHOD

The theory of optimum estimation by imposing climatological constraints minimises the root mean square error estimation Mooley et al. (1981).

The areal value $P_R = (1/A) \iint P_j \, dx \, dy$ ......(2)

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

$$P_R = \sum_{j=1}^{n} W_j P_j \qquad \text{......(3)}$$

where n is the number of gauges.
P_A is the rainfall at different stations (ie j = 1,2,...n)

The weight value W_j can be found out by substituting R obtained from eqn.(2).

The relative mean square error E is given by

$$E = \left\{ \sum_{j=1}^{n} W_j P_j - (1/A) \iint_A P_j \, dx \, dy \right\}^2 \qquad \text{......(4)}$$

which should be minimum.

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 di tribution of gauges over an area is also taken into account Mooley et al. (1981).

2.4.1. POLYNOMIAL SURFACE FITTING:-

A polynomial surface is fitted by the method of least squares over the data. Given a set of observed point (x,y) where (x,y) are the geometric coordinates of the raingauge and P are the observed rainfall values. The rainfall P_c are calculated using

$$P_c = b_1 + b_2x + b_3y + b_4x^2 + b_5xy + b_6y^2 \quad ......(5)$$

The second degree polynomial coefficients $(b_1, ..., b_6)$ are evaluated using least square techniques. This method of describing the rainfall surface can be used to find the areal rainfall. By varying the number of existing raingauges steadily the method can be applied repeatedly to determine the optimum raingauge network for the estimation of areal rainfall for a desired level of accuracy.

2.4.2. KIRGING METHOD

An optimum interpolation between gauge values can be implemented by Kirging. This is essentially a method of estimation of areal rainfall. Kirging was originated by Matheron (1971). Hughes and Lettenmaier (1981) suggested the potential use of Kirging in network design.

Consider an area A, over which a number of raingauge are sited with some additional observation points. The unknown mean precipitation for the area is defined as

$$P = (1/A) \int_A P_R(x)\, dx \quad .....(6)$$

x is the location of a point of observation.
$P_R(x)$ is a function describing depth of storm over region A.

Taking account of the time interval, k used in the discretization of the observed rainfall an estimate of P(k) from a storm can be given for the set of rainfall observations in area A and expressed as

$$P(k) = \sum_{i=1}^{n} W_i(k)\; q\;(K, x_i) \qquad \ldots\ldots(7)$$

where W_i is the solution of the Kirging system by a set of weight i = 1 to n.
n is the number of gauges.
k is a discreted time interval.
$q(k, x_i)$ is the rainfall depth at location x_i over time duration k.

Spatial relationship between rainfall depths at location x_i and x_j is given by

$$\rho(d) = \alpha d^{\beta} \qquad \ldots\ldots(8)$$

where $\rho(d)$ is the value at a separation distance, 'd', between location x_i and x_j

The other forms of Kirging methods are Linear, non linear and disjunctive Kirging more details can be seen in Kassim (1991).

2.5 HALLS METHOD

Hall (1972) suggested a method for determination of key station network for flood forecasting purpose. First correlation coefficient between the average of the storm rainfall and individual station rainfall are found. The stations are arranged in descending order of correlation coefficient and the station with highest correlation coefficient are considered for inclusion in the network. The station with highest correlation coefficient is called the key station. The first key station data are removed, the second key station among the remaining raingauge stations is found similarly. 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. From this the number of gauges required for achieving an acceptable degree of error can be found.

2.6 OPTIMUM POINT INTERPOLATION METHOD

The interpolation method can be separated into three groups polynomial, weighted mean and optimum interpolation. In the interpolation method, weighing factors W_j can be calculated depending on the distance between interpolation points (o) and adjacent point (i), and then be used in estimating the value of the given variable at the point of interest.

In optimum interpolation problems can be formulated in the form of linear weighing coefficients W_i of the known values of rainfall f_i' at n observation points $u_i, \ldots u_n$ for determining the values f at point u .

$$f_o = \sum_{j=1}^{n} W_j f_j \quad \text{and also} \qquad \ldots\ldots(9)$$

$$f'_o = \sum_{j=1}^{n} W_j f'_j$$

where $f'_o = f_o - \bar{f}_o$, $f'_i = f_i - \bar{f}_i$ and W_j are weighing factors.

Mean Square Interpolation error is given by

$$E = m^{-1} \sum_{j=1}^{m} \left(f'_o - \sum_{i=1}^{n} W_i f'_i\right)^2 \qquad \ldots\ldots(10)$$

where m represents individual events More details of this method can be seen in Unal etal (1983)

2.7. SPATIAL CORRELATION METHOD

Two statistical methods of areal rainfall analysis applicable to rain gauge network design generally used by hydrologists are

i. The Kagon method based on cross co-relation techniques.
ii. Trend surface representation of rainfall by least squares fitting of polynomials.

The spatial variability can be quantified through a spatial correlation function and network of raingauges can be designed to meet a specified error criterion. However in applying such an approach, care must be taken to ensure that conditions necessary for the existence of a spatial correlation function, such as horizontal homogeneity and isotropy, are fulfilled. Experience suggest that homogenity and isotrophy can be assumed without causing significant error for the covariance function and structure function (see Appendix I) for flat areas with a relatively homogenous underlying surface. In mountainous region these assumptions are not generally fulfilled. The objective of these assumptions is to make sure that the above functions depend mainly on the distance.

Validity of these assumptions over the available data can be clearly seen by plotting correlation and covariance function against distance. An erratic plot with no trend invalidates the above assumption. It is also possible that the correlation aspect shows a dependence where as the covariance lacks homogenity. If data of any particular station is suspected they may be excluded from the analysis as they may either be inaccurate or unrepresentative. In this way the above assumptions can be fulfilled with reasonable accuracy.

The basis of the method advocated by Kagan (1966) is the correlation function $\rho(d)$ where 'd' is the distance between stations, and the form of which depends on characteristics of the area under consideration and on the type of precipitation. The function $\rho(d)$ can be described by the following exponential form.

$$\rho(d) = \rho(0)e^{-d/do} \quad \ldots\ldots (11)$$

where $\rho(0)$ is the correlation corresponding to zero distance.

d_0 is the correlation radius or distance at which the correlation is $\rho(0)e^{-1}$, (e = 2.71828)

Theoretically $\rho(0)$ should be equal to unity as it is the correlation corresponding to zero distance but it is rarely found in practice as in the present case also, due to random errors in precipitation measurement and micro climatic irregularities over an area which make $\rho(0)$ less than unity. The two parameters $\rho(0)$ and d_0 are necessary for assessing the accuracy of a given raingauge network.

The correlation function largely depends on the interval of precipitation total. Analysis on different interval like daily, ten daily, monthly, reveals that longer the interval over which the precipitation is totaled, the slower the decrease of the correlation function with the increasing distance. The error in determining total precipitation also increases as the length of interval decreases. Therefore the network density requirement are more rigid for short interval of time for which it is necessary to know the total precipitation.

The relative root mean Square error E is defined by Kagen (1966) as

$$E = (\sigma(h)^{0.5} / F_{av}) = C_v \ ((1-\rho(0)) + 0.23 \ ((A/n)^{0.5}/d_0))/n) \quad \ldots\ldots(12)$$

where $\sigma(h)$ is the variance of the error in average rainfall; A is the area. He used an arithmetic (equal weight 1/n) mean while deriving the above equation and assumed maximum error to occur at the centre of the triangular element considered.

From equation (12) the value of 'n' required to meet a specified error criterion 'E 'can be obtained if the values of $\rho(0)$ and d_o are known.

A dense network of rainfall stations over a certain area gives results of the neighbouring stations, that are highly correlated and do not furnish further information.

The uniform spacing of stations (d) over the area 'A' can be given assuming triangular grid by:

$$d = 1.07 \ (A/n)^{0.5} \qquad \ldots\ldots(13)$$

2.7.1. Spatial Interpolation

Most of the proposed spatial interpolation techniques are of the type weighted average of surrounding stations using the formula (Kruizinga et al. 1978)

$$P_{av} = \sum_{k=1}^{n} W_k \ h_k \ldots\ldots(14)$$

where P_{av} is the estimated rainfall
h_k is the measured rainfall amount at the surrounding stations.
W_k is the applied weights.
n is the surrounding stations.

In most cases one requires that $\sum_{k=1}^{n} W_k = 1$

The methods differ in the choice of weights only, in some cases the weights are independent of the distance (Saltes 1972) in other cases the weights are optimized on the basis of correlation function.

The accuracy of spatial interpolation is to be evaluated. Kagen (1966) has given the relative errors associated with linear interpolation between two points and interpolation at the centre of a square and a triangle, where a maximum error of interpolation occur. For a triangular grid with spacing d, the relative error is given by

$$E_I = C_v \ ((0.33(1- \rho(0)) + 0.52 \ \rho(0)(A/n)^{0.5}/d_0))^{0.5} \ldots\ldots(15)$$

$\rho(d)$ can be described by eq.(11)

The resulting error for different number of raingauges can be found from the above equation.

2.8. Principal Component Analysis method (PCA)

In this method, the maximum number of climatologically homogenous sub-divisions was delineated. The delineation also involves the use of interlocation correlation analysis and vector clusters of the locations onto pairs of the significant PCA modes, together with several other statistical or physical analysis in order to determine the physical reality of the derived homogenous climatological subdivisions. In the development of the minimum raingauge network, the maximum number of climatologically homogenous sub divisions are used. This method ensures that each climatologically homogenous subdivisions is represented by at least one rainfall station.

Recognising a general weakness of network design methods on the basis of a specified error criteria in the areal rainfall estimates that they provide large number of raingauges even for dry area where rainfall dependent activities are the least Basalirwa et al. (1993) have used PCA method for network design of raingauge stations for Uganda. They expected that large spatial rainfall variations can occur in dry area during dry seasons causing a dense network. Considering the economic they suggested minimum raingauge network where representation of each of the homogenous rainfall subdivions can be made.

The basic PCA model has been expressed by Harman (1976) among many others as

$$Z_j = \sum_{k=1}^{m} a_{jk} \; F_k (j = 1, 2, \ldots\ldots n) \qquad \ldots\ldots(16)$$

where Z_j is the standardized variable j; F_k is the hypothetical factor k (principal component); a_{jk} is the standardized multi regression co-efficient of variable j or factor k; m is the number of common factor and n is the number variables.

To ensure that the stations which represented the individual homogenous subdivisions are realistic and represent most of the required informations, the principle of commonality are used. The commonality of each variable Z_j given by (h_j) is obtained by

$$(h_j)^2 = \sum_{k=1}^{m} (a_{jk})^2 (j = 1,2,.........n) \qquad ......(17)$$

The commonality of a station, represents the degree of association that the station has with all other stations in the data set. The best representative station will be the station with highest commonality among the stations of a homogenous group.

The ability of the generated minimum raingauge network in representing the areal rainfall characteristics within the individual homogenous regions can be examined by computing the correlation coefficient between the rainfall totals at the representative station (j) over time (t) and the areal rainfall estimates from the individual homogenous groups.

To determine the representativeness of each chosen station. An equation that expresses areal rainfall values as a function of the representative station is given by

$$P_R\ (t) = a + b\ P_j(t) \qquad ......(18)$$

where

$P_R(t)$ is the areal rainfall estimate for the homogenous group over time t;
$P_j(t)$ is the rainfall total at station j over time t;
a and b are regression coefficients.

The variance accounted by the representative station is based on this linear model. A case study using this method upon Uganda can be seen in Basalirwa (1993.)

2.9. DYMOND AND ZAWADZKI METHODS

It is usual to go in for large number of raingauge stations to gain complete knowledge of precipitation phenomena occuring in a project area. After an initial period of close monitoring of rainfall in a given area it is desirable to reduce the number of raingauge stations in order to reduce the man power and other efforts required for observations. While reducing/minimising the number of raingauge stations the random error is kept in view. A systematic sampling of an areal rainfall is the prime object. Statistical methods with special application to rainfall data have been developed with specific reference to such situations. Hendrick and Comer(1970) have derived correlation function which has been used by many approximating it by a linear variation.

Zawadzki (1973) considered a rectangular area of dimension $L_1 \times L_2$ over which N, number of raingauges (n x m) are situated spaced at Δx and Δy. He derived an expression for the mean square error E^2 of areal rainfall (arithmetic average)

$$E^2 = (1/(nm)^2) \sum_{i=1-n}^{n-1} \sum_{j=1-m}^{m-1} (n-|i|)(m-|j|)A(i\Delta x, j\Delta y)$$

$$+(1/(L_1L_2)^2) \int_{-L_1}^{L_1} \int_{-L_2}^{L_2} (L_1-|x|)(L_2-|y|)A(x,y)dxdy$$

$$-(2/nmL_1 L_2) \sum_{i=1-n}^{n-1} \sum_{j=1-m}^{m-1} (n-|i|)(m-|j|)$$

$$\times \int_{x=(i-\frac{1}{2})\Delta x}^{(i+\frac{1}{2})\Delta x} \int_{y=(j-\frac{1}{2})\Delta y}^{(j+\frac{1}{2})\Delta y} C_v^2 \; A(x,y)dxdy \qquad \ldots\ldots(19)$$

Here, the error E is the difference between the average rainfall of N gauges and the average that would have been had N been increased to sufficiently large that any further increase would not change the average and A(x,y) is the expected value of the product of rainfall observed in two gauge stations defined by x,y co-ordinates. The rainfall used in the above equation is for a prescribed period.

The coefficient of variation of rainfall is defined by

$$C_v = \{[(P)^2]_{av} - [P_{av}]^2\}^{1/2} / [P_{av}] \qquad \ldots\ldots(20)$$

where $[P_{av}]$ is the expected rainfall over any point within the given area which is assumed to be constant over that area.

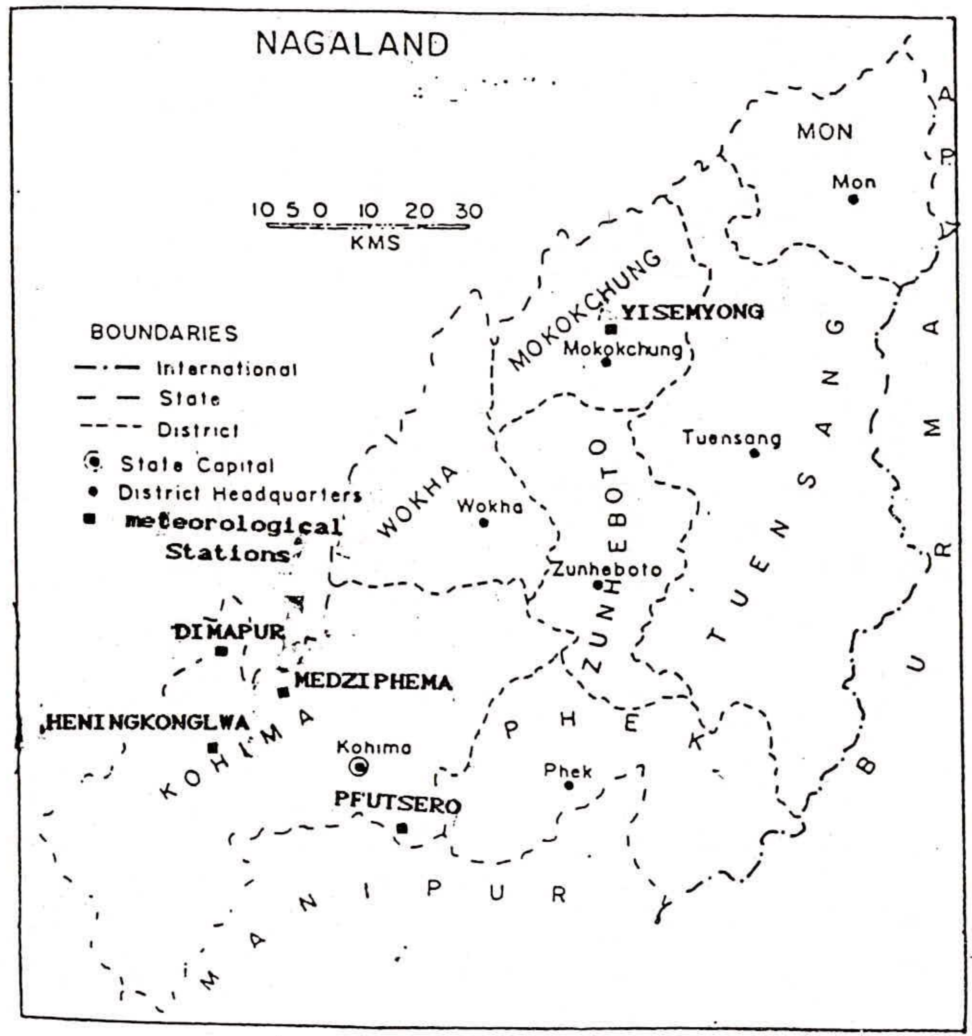

FIG.2. STUDY AREA AND EXISTING METEROLOGICAL STATIONS

The correlation function is defined by

$$(x,y) = \{A(x,y)-[P_{av}]^2\}/\{[(P)^2]_{av} - [P_{av}]^2\} \ldots\ldots (21)$$

These expressions have been reduced by Dymond(1982) to the following for the case of a square area with uniform spacing of gauging stations.

$$(E/P_{av}) = \{[(1-\rho_n)C_v^2 \; n^{-1/2}]/3\}^{1/2} \ldots\ldots (22)$$

where ρ_n is the correlation between neighbouring gauges (average of correlation coefficients) and N is the total number of gauges. Zawadzki assumed an exponential decay of correlation function which is given below

$$(E/P_{av}) = C_v^{0.88}(1-\rho_n)^{0.44}(C_v^2 + 1)^{0.66}/(2.23 \; N^{0.46}) \ldots\ldots (23)$$

The above equations can be used for finding out the r.m.s. error of an areal rainfall which is observed by many gauges providing information of the spatial variation of the rainfall. However one has to be cautious of the variation caused by strong winds which might be occuring. The observational deficiency caused by strong winds have been studied by Aldridge(1976) and Neff(1977).

Dymond studied the monthly rainfall data from raingauge network of Rangitawa basin in New Zealand and illustrated the use of the above analysis.

3.0. DESCRIPTION OF THE STUDY AREA

Nagaland is a mountainous state with highly elevated ridges spurs and peaks. Baring a few hundred Sq.Km of plains around Dimapur foot hills and along river beds, the entire state is hilly. Nagaland is the 3rd smallest state of the country after Sikkim and Goa. Nagaland stretches between 26° 6'N and 29° 4'N latitudes between 92° 20'E to 95° E longitude and is shown in Fig.2. The state is bounded by Assam in the west, Arunachal Pradesh in the North, Burma is the east and

Manipur in the South.

It has an area of 16,579 Sq.Km. Nagaland as per the 1981 censes had a population of 7,74,930 with an average density of 47 persons per sq.km. The state comprises of seven administrative districts. The districts are Kohima, Phek, Wokha, Zunheboto, Tuensang and Mon, 17 subdivisions, 21 development blocks, 963 inhabited villages and 7 towns. The table I shows the area of each district.

TABLE I

AREA OF EACH DISTRICT OF NAGALAND

S.No.	District	Area (Sq.Km)
1.	Kohima	4,041
2.	Phek	2,026
3.	Wokha	1,628
4.	Zunheboto	1,255
5.	Mokokchang	1,615
6.	Tuensang	4,228
7.	Mon	1,786

The elevation of Nagaland ranges from 914m to 3840m above msl. The Barial range locally known as Radhuma enters the state from north Kachar and after passing through Kohima runs in the direction of Wokha. Japava which lies to the south of Kohima is the highest peak of Barail (Radhuma) range and attains a height of 3804m above msl. At this place the range is met by the meridinal axis of axis prolonged from the Arakanyoma (the major mountain system of Burma) and from this point the main range runs in a north and north easterly direction. Owing to a sudden rise of the Barail Range on its northern face, about 12Km rise miniature type of valley is formed in between the Barail range and Samaguling Hills. Kohima and Naga hills are located further east. The Patkai range forms a watershed which constitutes the international boundary between India and Burma. Saramati situated in Tuensang district is the highest peak of Nagaland which is 3877m above msl. The other peaks include Japfu (3,014m), Ezupu (2,841m), Paona (2,486m), Angola (2,062m), Laishing (2,059m). Parts of Japfu mountain summit owing to its high altitude are snow bound during the cold weather (Dec and Jan). The elevational features can be seen in Fig.3.

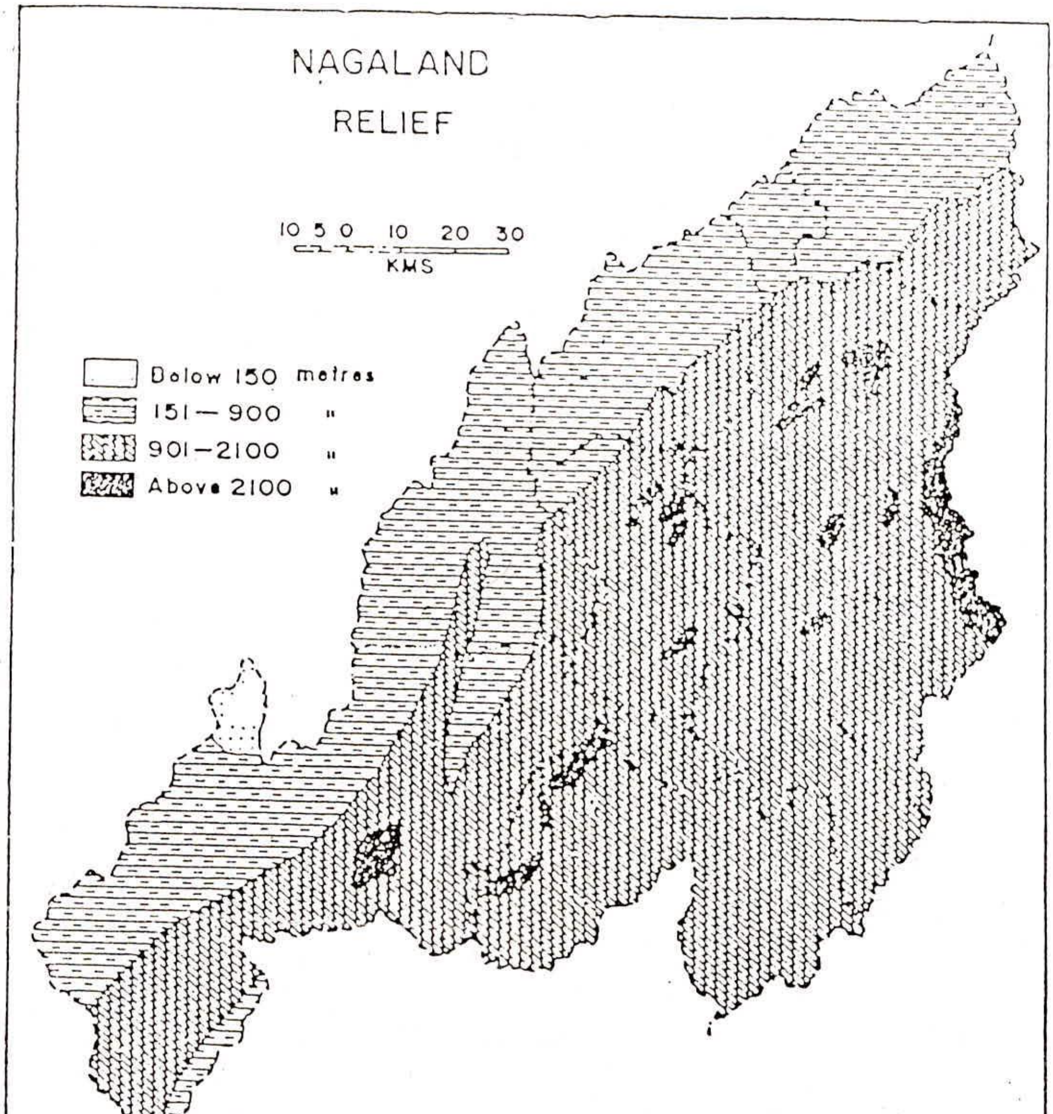

Fig. 3. Elevational features of Nagaland

Nagaland is predominantly a tribal state. The entire tribal population is divisible into twenty major tribal groups. The dominant tribes which have their defined cultural jurisdiction are the Ao's, Angamis, Changs, Chàkhesang, Kabius, Khein - Mangas, Konyaks, Kukis, Lothas (Lhotas), Maos, Mikris (Mikhirs), Phoms, Rengmas, Sangtams, Semas, Thankuls, Yimchungars and Zelliang.

English is the official language of the state for administration and education. However, the common language used by the tribal people is Nagamese and English. About 49% of the total population is literate and only 15.5% live in urban areas (Hussain, 1994).

3.i. GEOLOGY

The entire Nagaland has almost identical geological formation, Naga Hills is a continuation of the Himalayan folded mountains. The formations belong to the Tertiary period. The tertiary succession of Nagaland is given below (Hussain, 1994).

Recent Pleistocene	Unconfirmity	Alluvium and high level terraces.
Pliocene	Dihing Series Unconfirmity	Loose sandstones, clay and pebbles beds.
Mio-Pliocene	Namsang beds Unconfirmity	Soft coarse sandstorms, clay and occasional coal conglo-mates.
Miocene	Tijsans Series	Girujan, Mottled clays and clay fine grained stages sand stones.
Tipam Stage		Coarse grained Sandstone ferrogenous micancom sand, storms and minor clay.
Surma Series	Tikat Parbat Carbonaceous stage	Sandstones shales and coal seams.
Oligocene Brail	Baragolai Satge Naogaon Sandstone stage.	Sandstone, shales
Eocence Disang Series		Grey Sp. intery shales and salt haversed by their quartz veins and experienced intrusion.

The southern Nagaland has the Barail and Disang formations. The Disang confirming to the oldest rocks are dominant towards the east between Japfu and Saramati at an altitude of 914m to 1,220m, but the Barail series are more conspicuous towards the west. Slate of superior quality is found abundantly in Tizu valley which is used by the Nagas for their building and for commercial purpose. Disang beds are generally deep at steep angles. The structure is soft, thin splinting character has helped to cause frequent landslides around Kohima. Deposits of chrysotile asbestos are found towards the south bordering Burma between Puchimi and Kerrosin in Tizu valley.

3.2. DRAINAGE

The state of Nagaland is drained by numerous streams and rivers. Some of the important rivers are Dzulu, Dhansiri, Dikhu, Milak, Zungki, Tizu. Most of these rivers originate from the central mountain ranges. From the centre the rivers move north and southwards. The Doyang river which originates from the vicinity of Mao village of the Angami territory of the Kohima District is the largest stream of the Nagaland state. It flows northward and is navigable for a short distance before it enter the valley of Brahmaputra.

All the rivers of Nagaland discharge little quantities of water during winter seasons but in the rainy season they suddenly assume threatening posture. The inundated streams and rivers cause heavy soil erosion and become difficult to feed during the summer monsoon seasons. Most of the rivers are not navigable owing to mountainous topography.

There is a famous Lacham, a natural lake in eastern Chakhesang, east of Masluri. There is also a another small lake called Achie in Pfutsero. At Dimapur tanks surviving as historical relics of the old Kachari kings are still to be seen in Purnabazaar but many have become mere pits and hallows as they are all dried up. The most important tanks are Bongola, Padum, Jor, Bamon, Dipo,Thana, Podo, and Garani Pukhari.

3.3. CLIMATE AND WEATHER

In general the climate of Nagaland is modified tropical monsoon type and comes under 4 sub-divisions as classified by IMD for their studies of rainfall departure. In this climate temperature at low altitudes remain high throughout the year excepting the month of December and January. The summer monsoon is strong which generally lasts from mid June to mid October in Nagaland. The monsoon climate is characterized by different seasons which is caused by the southwest and northeast monsoon.

At the time of North East monsoon winds are of continental origin and blows generally in the state from west to east and during south west monsoon they are oceanic in nature and blow mostly in Nagaland from southwest to northeast. Almost all the rainfall recording stations of Nagaland record over 75% of their total rainfall during the rainy season (mid June to mid October).

January is the coldest month of the year, occurrence of fog and mist are the common phenomenon in this month. The relative humidity in December and January varies between 40 to 60%. Areas situated above 2000m record very low temperature during winter. March to mid June is the period of warm summer and at low altitudes the temperature varies between 15 C to 38 C. The relative humidity in summer varies between 60 to 78%.

The summer monsoon is strong which generally lasts from mid June to mid October in Nagaland. The summer monsoon usually begins in the state by the middle of June and most of the rainfall recording stations receive over 75% of the total rainfall during the rainy season. July is the wettest month and December is the dry month of the year. On certain occasions slight to light snowfall has been observed on Saramati (3877m) and other loftier peaks. Frost is the quite common feature in winter which hampers the agricultural operation in Jhum land. The premonsoon showers in Nagaland occur in the latter part of

April and continues with intermittent gaps, till the onset of summer monsoon. These premonsoons are highly beneficial for the Jhum operations. In the rainy season the rainfall alternates with short spell of a day or two..

3.4. NATURAL VEGETATION

The state of Nagaland is well endowed with forests. The natural vegetation of Nagaland has great diversity ranging from the alpine and bamboo forests to scrub forests of the foot hills to the deciduous forests at the lower altitudes and gentle slopes. The natural vegetation of Nagaland is mainly classified into (i) Wet evergreen (ii) Sub tropical wet hill (iii) Wet temperate and (iv) Pine forests.

The plain area around Dimapur and the tracts adjacent to the Assam valley are bound with evergreen vegetation. The main species of this region comprises Nahor, Sam, Poma, Khokan, Jhan, Makan, Gonseroi, Amain, Hingari, Hollong, Lali, Rata, Titasopa and Nagaser.

The sub tropical wet hill vegetation thrives at an altitude ranging from 300m to 1200m above msl. The main species are Chestnut, Michelia, Champaca, Schima Wallichii, Gmelina Arborea, Albizzia and members of Meliaceae.

In between 1000m to 1300m is the home of pine trees, oak is also found in this zone. Above 1300m to 2000m elevation are the wet temperate forests. The main species are Betula, Rhododen-dron, Magnolia, Juglansrégia and Runus. According to 1986 census Nagaland has a forest cover for an area of about 2,87,556 hectares out of which 28,560 (9.33%) hectares are clothed with reserved forests, 51,799 (18%) by protected forests and 2,07,198 hectares (72%) by private forests.

3.5. SOILS

In general the soil cover in Nagaland excepting the valleys and along the foothills is quite thin on the steeper slopes, torrential rains result in soil erosion.

The soil material washed is deposited in the valleys and along the foothills. The levelled flood plains which covers less than 5% of the total area of the state are covered by clayey loams. These soils are rich in lumus content and therefore well known for their fertility.

The hilly and mountainous slopes of Nagaland are covered by laterates and ferroginous red soil. Jhumming is normally practiced in the ferroginous red soils. In southern parts of Nagaland, especially the territory occupied by Angamis, Chakhesang and Zelliangs, the rock strata being weak, landslides are frequent and occur almost annually during the monsoon and post monsoon periods.

3.6 AGRICULTURE

Nagaland is essentially an agrarian state, about 80% of its total population is directly dependent on agriculture. jhumming (more about jhumming can be seen in Palaniappan ,1993) also known as slash and burn is widely practiced in the hills of Nagaland. It covers over 73% of the total area of the state. Banana, pine-apple and ginger are planted on the fertile soils, pumpkin, beans and sweet potatoes in areas with ash content potatoes in well drained fertile patches, yams in moist depression, climbers along the fences and grains on the drier areas of Jhum field.

TABLE - II

Area under different land use in Nagaland (in hectares)

	Year 1982-83	1983-84	1984-85	1985-86	1986-87
1. Forest	2,86,138	2,88,252	2,88,252	8,62,532	8,62,532
2. Area not available for Cultivation.					
a) Land put to non-agricultural use.	28,089	27,840	27,840	27,844	27,844

3. Other uncultivated land excluding.					
a) Land under Misc. tree crops and grooves.	2,00,194	2,00,090	2,02,192	1,89,511	1,86,175
b) Cultivable waste land.	62,784	95,120	62,050	62,050	96,360
4. Fallow land					
a) Current fallow	95,145	95,120	95,130	95,213	1,18,428
b) Fallow land other than current fallow	2,61,839	2,63,650	2,63,740	2,57,203	2,35,707
5. Net area sown	1,64,650	1,85,002	1,82,800	1,66,730	1,70,990
6. Area sown more than once	13,390	9,788	8,480	19,340	19,960
7. Total cropped area: Gross	1,78,040	1,94,790	1,91,280	1,85,970	1,90,955

TABLE - III
ROTATION OF CROPS IN NAGALAND

First Year		Second Year	
Kharif Summer Season	Rabi Winter Season	Kharif Summer Season	Rabi Winter Season
a. Paddy, Kachu, Sesamum, vegetables, Ginger, Mejade, Jute hemp, tapioca.	-	Short duration paddy or maize or small millets.	-
b. Maize mixed with Nagdal, Cotton.	Rap seeds	Kiri (small millets)	-
c. Paddy, lentil, Nagdal	-	Kiri mixed with Nagdal	-
d. Jobster, maize, pulses	-	Potatoes, millets	-
e. Potatoes	-	Potatoes	-
f. Sweet potatoes, tobacc vegetables, maize	- -	Early paddy or millets or vegetables.	-

3.7. MINERALS

Nagaland is not rich in minerals. The Nagzira coal field and its south westerly extension is the major coal providing centre of Nagaland. The coal of these mines contains moisture (4.35%), volatile matter (48%), fixed carbon (47.7%) and ash (1.95%). Coal is also found at Janji and the Disai valley south west of Nagzira fields. In Disang

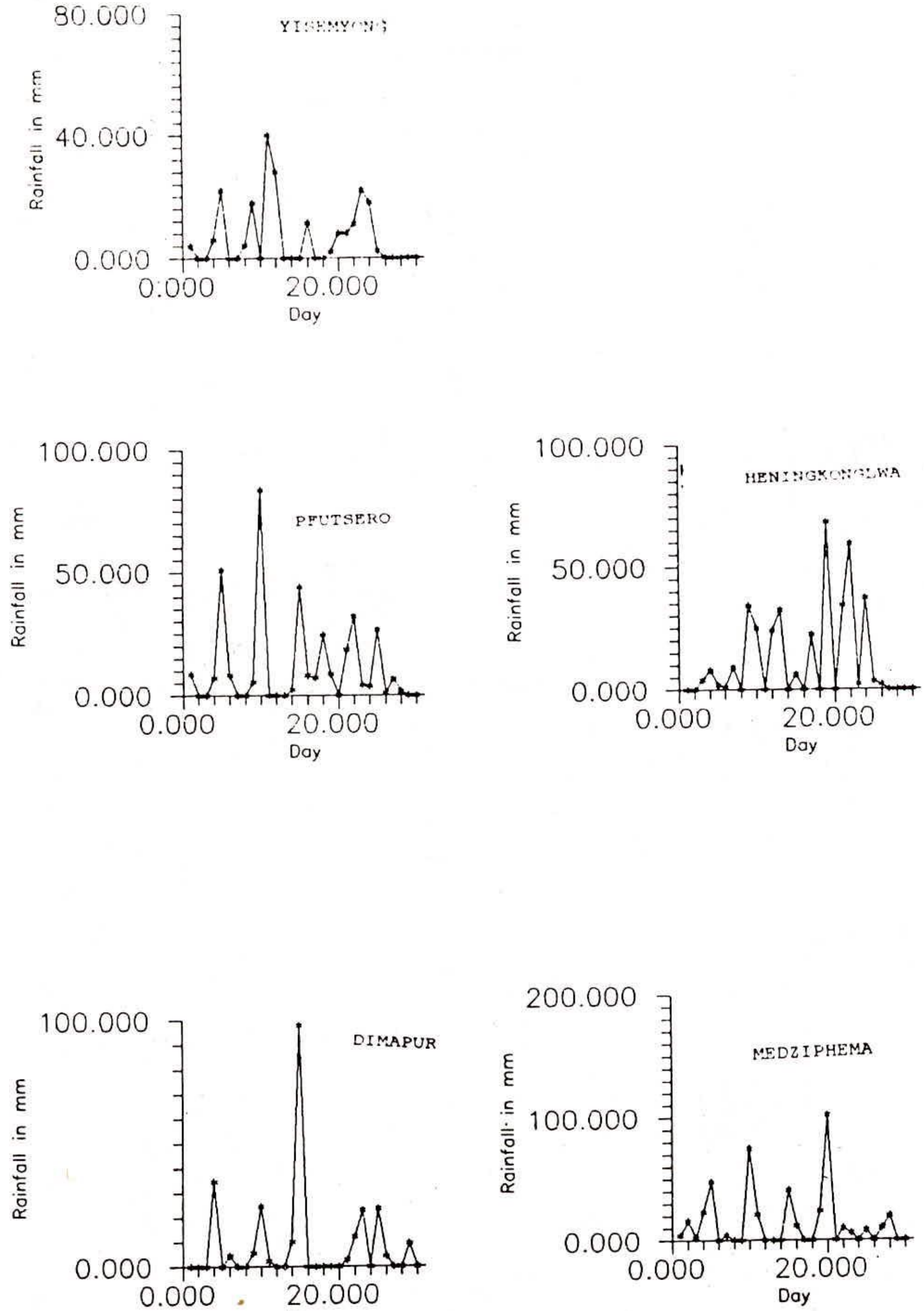

FIG.4-A. VARIATION OF DAILY RAINFALL OBSERVED IN NAGALAND

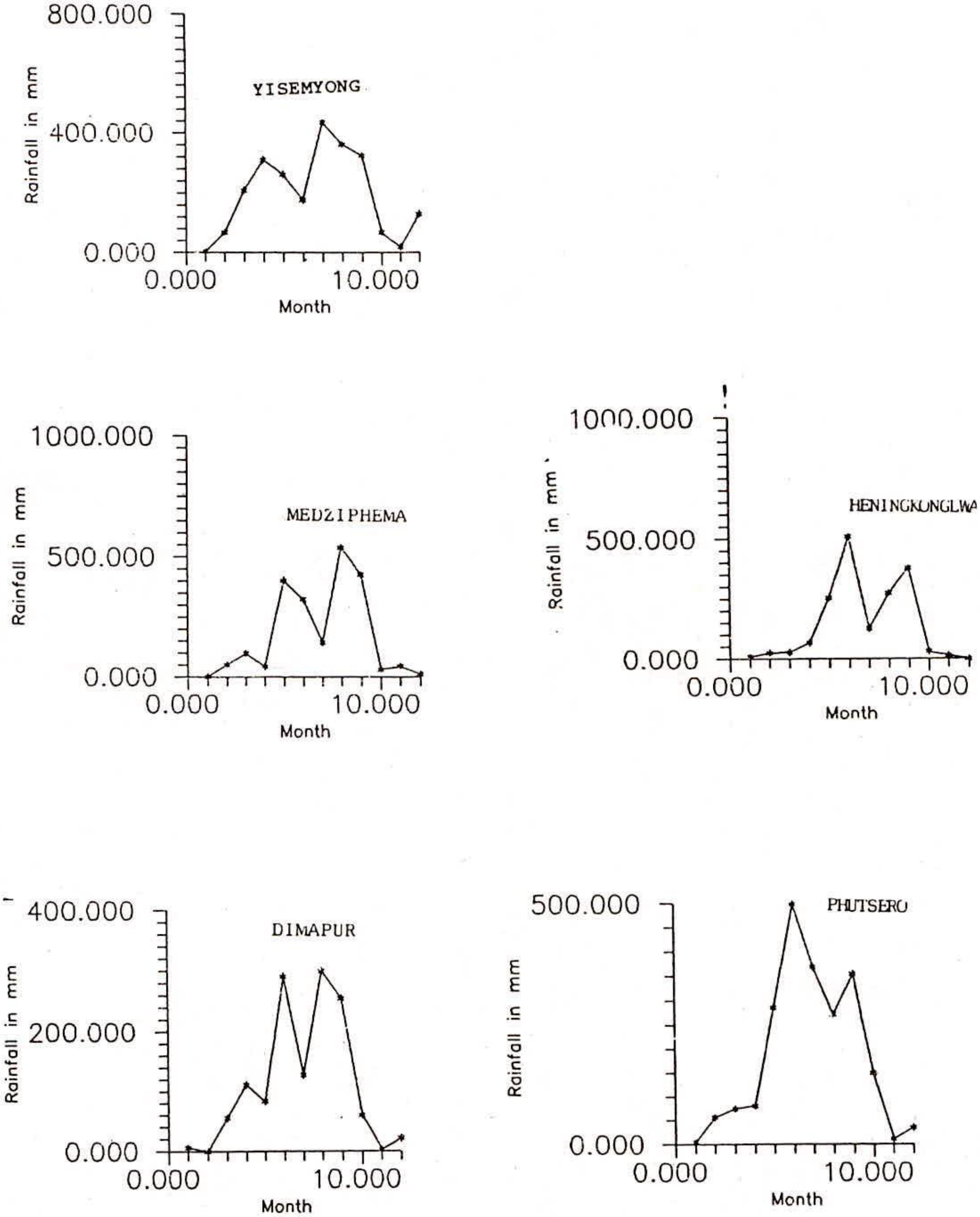

FIG.4-B: VARIATION OF MONTHLY RAINFALL OBSERVED FOR THE YEAR 1985 IN NAGALAND

valley coal seems are located around the settlements of Lismen, Aonokpu, Merinokpu and Lakhuni coal seams have also been located in Tiru valley area of Mon district. Oil seepage are also found in Dikhu valley. The people of adjacent settlements collect the crude oil for local use. Marble has been found near Burma border in Tuensang district. Limestone deposits around Nimi (Tuensang District) and Wazeho (Phek District) have been located. Magnetite have been reported in Teusang and Phek district. Sandstone is found and mined near Kohima, Mokokchung and Wokha. Good quality slate is mined in Tensang district and is used for rooging purpose.

3.8. EXISTING NETWORK

Nagaland State Department of Agriculture established five raingauge stations in different parts of the State and observed rainfall since 1978. The existing network stations marked on the map is shown in Fig.2. Continous rainfall records are available for 5 stations mentioned in Table - III as per the publication, (Investigation Cell (M.I.), Department of Agriculture), Govt. of Nagaland (11). Rainfall varies greatly both in time and space. Considering the continuity of the records the rainfall data pertaining to 1980 to 1985 have been included in this study. The variability can be visualized by analysing rainfall records of different gauging stations. Fig.4a-b shows the daily (Aug. 1985), monthly (1985) variation of rainfall between different gauging stations in Nagaland for the same period.

TABLE-IV

NAME OF THE STATION	AVERAGE ANNUAL RAINFALL (MM)	AVERAGE NO. OF RAINY DAYS
Dimapur	1407.07	112
Pfutsero	1720.66	125
Medziphema	2092.54	113
Heningkunglwa	1772.59	113
Mokokchung	2405.78	133

4.0. NETWORK DESIGN

The following methods have been used in the present analysis which are described in the early sections:

1. ISI Code;
2. C_v Method;
3. Spatial Correlation Method (Kagen,1966);
4. Dymond and Zawadzki Methods.

In view of the non-availability of rainfall data representing different homogenous regions of the study area the Principal Component Analysis proposed by Basalirwa (1993) has not been carried out.

4.1. ISI CODE

Although Nagaland is a hilly area the water resource development being at its nascent stage the lower limit specified for category 2 (elevation upto 1Km above sea level) by ISI code 4987 - 1968 is adopted which requires one station per (station unit area) 260 Sq.Km.

Number of stations n = (Area / station unit area)

= (16,579/260)

= 63 stations.

Table below shows the District wise distribution of raingauge for Nagaland:

TABLE - V
DISTRICT WISE RAINGAUGE DISTRIBUTION - ISI

District	Area	No. of raingauge
Kohima	4041	15
Phek	2026	08
Wokha	1628	06
Zunheboto	1255	05
Mokokchung	1615	06
Teunsang	4228	16
Mon	1786	07

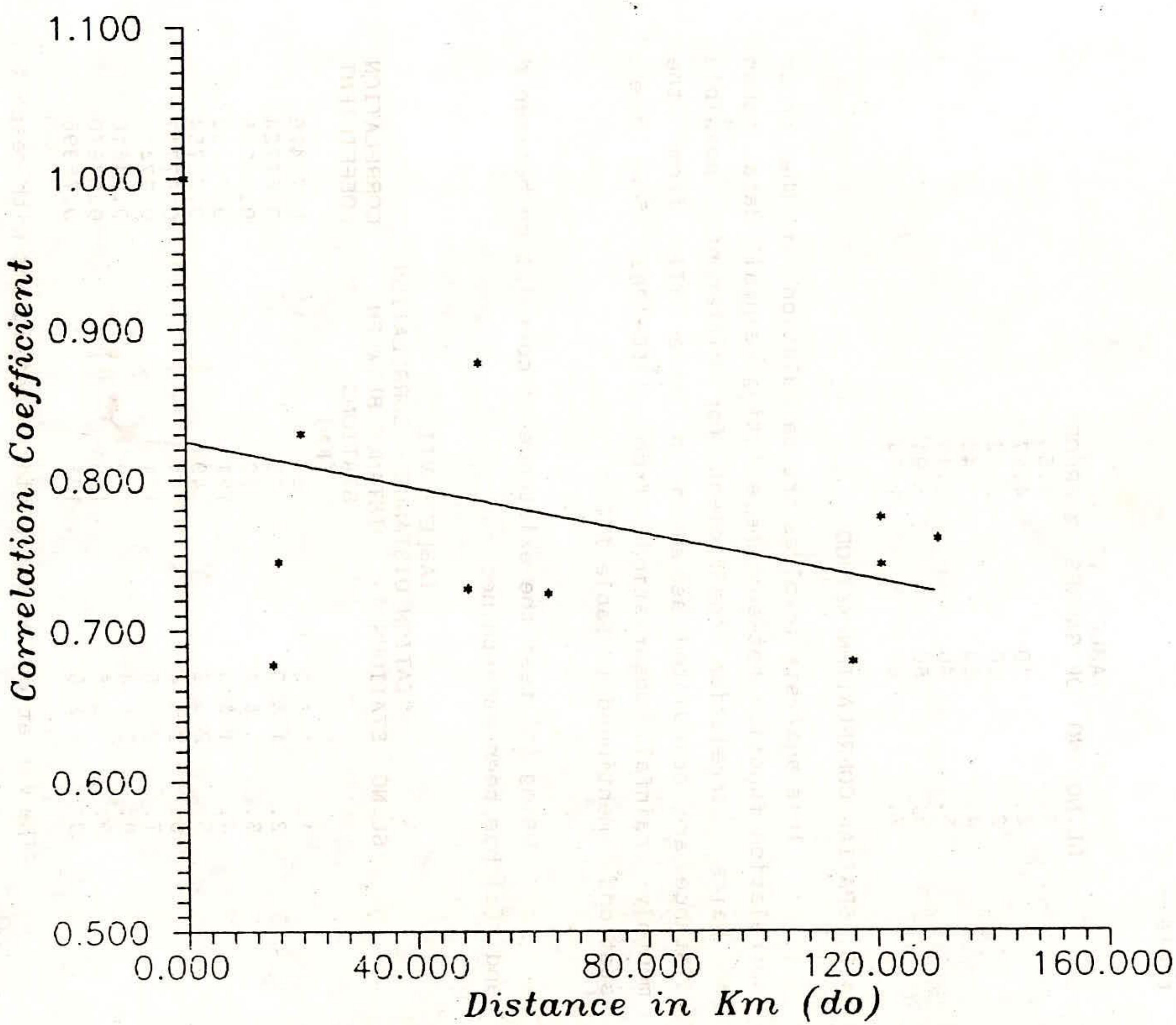

FIG. 5: RELATION BETWEEN DISTANCE (d) AND CORRELATION COEFFICIENT (d)

4.2. C_V METHOD

Using the method described in the section the coefficient of variance of monthly rainfall (observed at all the existing five stations) is found to be 0.135. The number of gauges required to estimate the average rainfall with different percentage of error as per eqn.(1) as been given in table - VI.

TABLE - VI

SL.NO.	NO OF GAUGES	% ERROR
1.	2	9.55
2.	10	4.27
3.	20	3.02
4.	30	2.46
5.	40	2.13
6.	50	1.91
7.	60	1.74

4.3. SPATIAL CORRELATION METHOD

This analysis involves the calculation of the cross correlation function between the existing rainfall data taken in pairs. Correlation coefficient for different possible distance are calculated as shown in Table- VII from the monthly rainfall observation from 1980-1985 for the stations mentioned in Table-III.

Using 't' test the existence of correlation between d and r(d) has been ascertained

TABLE - VII

STATION DISTANCE - CORRELATION

SL.NO	STATIONS	DISTANCE BETWEEN STATIONS (Km)	CORRELATION COEFFICIENT
1.	1 & 2	63	0.72426
2.	1 & 3	15	0.67724
3.	1 & 4	20	0.83025
4.	1 & 5	121	0.74280
5.	2 & 3	49	0.72754
6.	2 & 4	51	0.87717
7.	2 & 5	121	0.77429
8.	3 & 4	16	0.74518
9.	3 & 5	116	0.67870
10.	4 & 5	131	0.75996

The variation of correlation coefficient with respect to distance is shown in Fig.5. A straight line is fit (using least square method) to the plotted points.

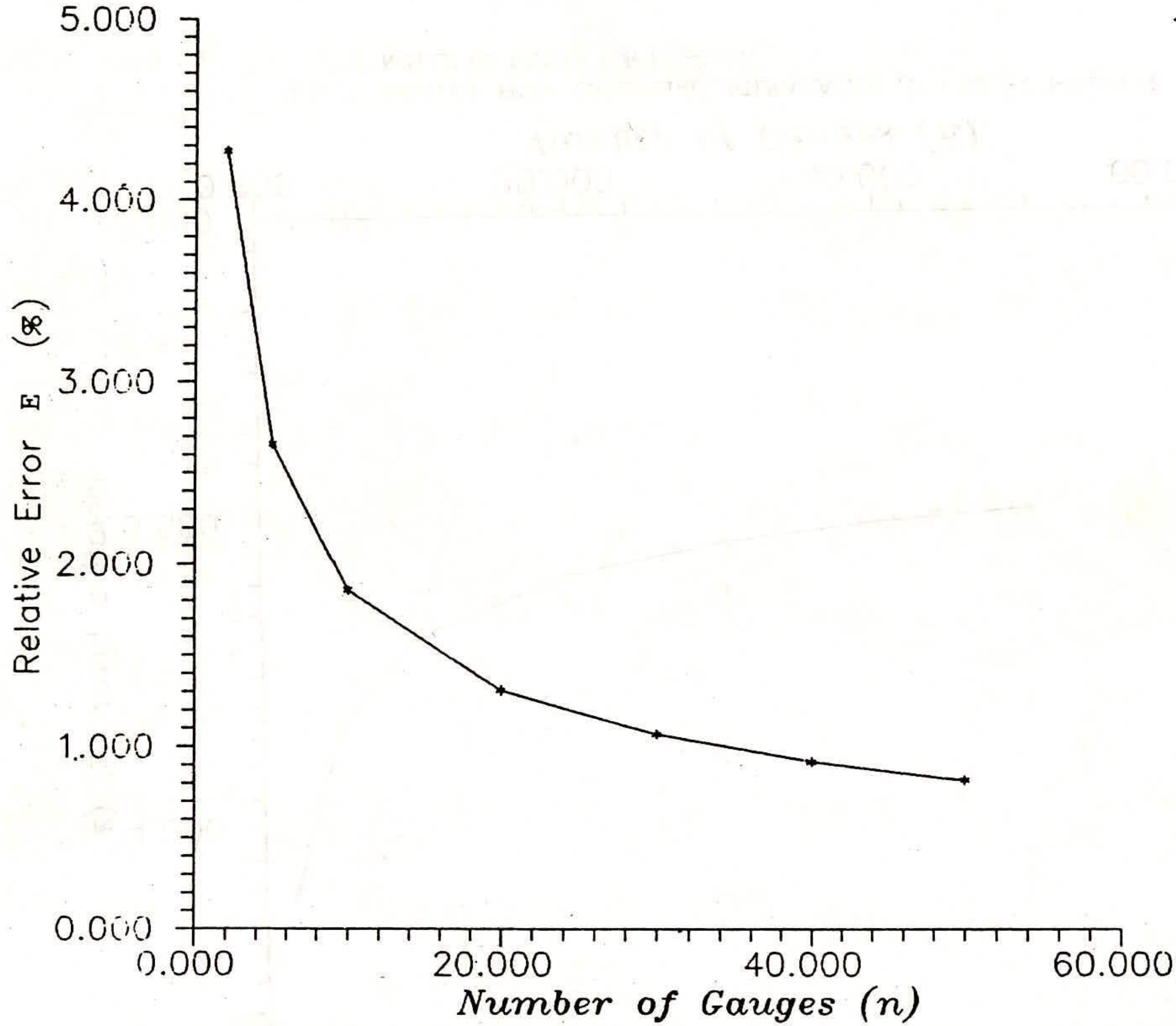

FIG.6: RELATIVE ERROR OF MEAN AREAL RAINFALL (E) AS A FUNCTION OF NUMBER OF GAUGES FOR NAGALAND

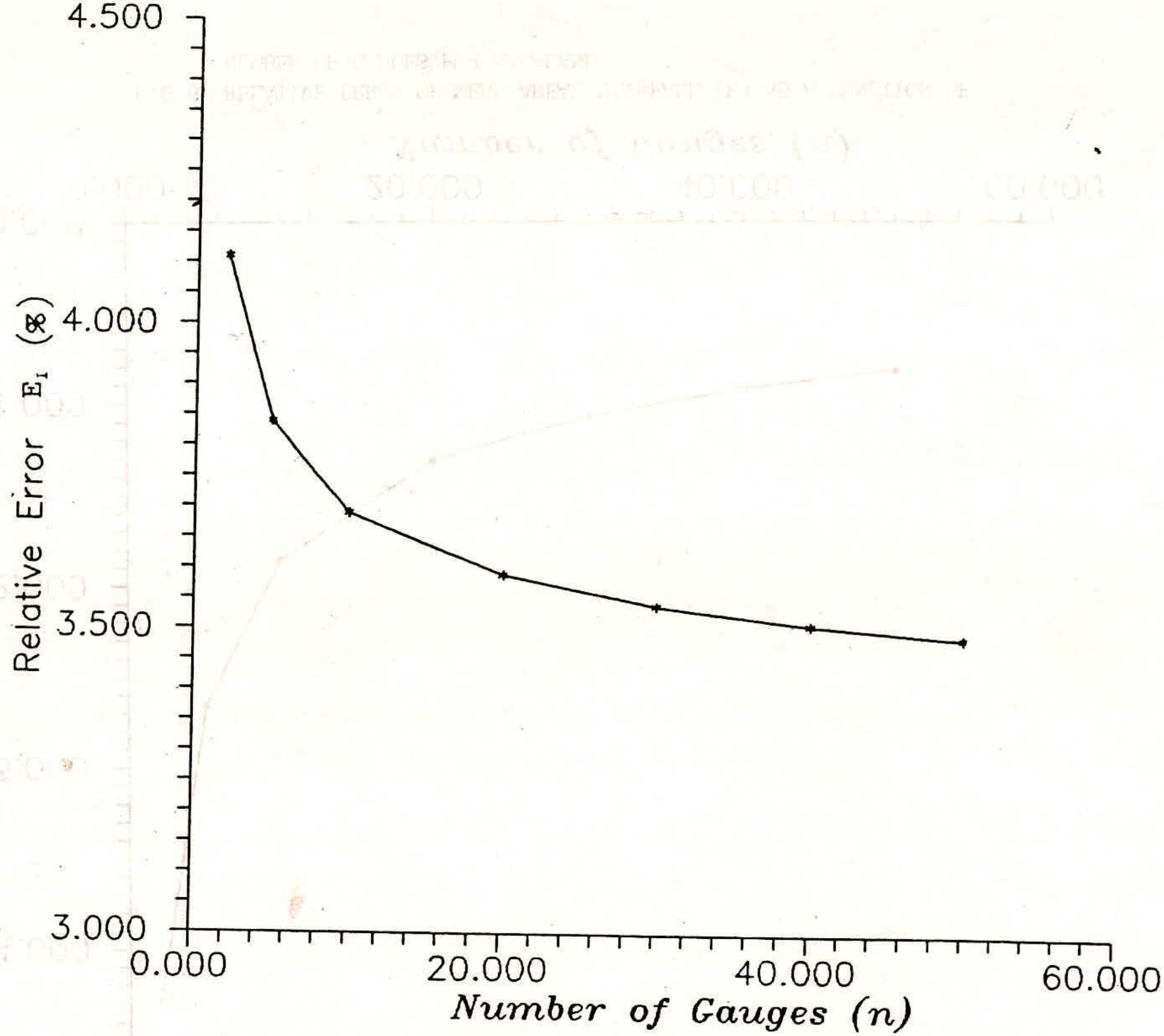

FIG.7: RELATIVE ERROR OF SPATIAL INTERPOLATION (E_1) AS A FUNCTION OF NUMBER OF GAUGES FOR NAGALAND

From this figure it is seen that the straight line intercepts the 'Y' axis at 0.825 which is the value of $\rho(0)$ and corresponding d_0 is found to be 1302 km.

Substituting the above values in eqn.(12) and in eqn.(15) the value of E and E_I for the area 16579 Sq.Km.and for the given n, E , E_I is calculated to be as shown in Table - VIII. It may be seen that with an increase of number of gauges accuracy also increases. However, there is no appreciable increase in accuracy results with increase in number of gauges beyond 60.

TABLE - VIII

ERROR FOR DIFFERENT NUMBER OF GAUGES - SPATIAL CORRELATION METHOD

SL.NO.	NO. OF GAUGES	E(%)	E_I(%)	L(Km)
1.	2	4.27	4.11	97
2.	5	2.66	3.84	61
3.	10	1.86	3.69	43
4.	20	1.31	3.59	30
5.	30	1.07	3.54	25
6.	40	0.92	3.51	21
7.	50	0.82	3.49	19
8.	60	0.75	3.48	17

Hence the required number of gauges is 60.

Fig.6 & 7 shows the variation of the relative error in the estimation of mean areal rainfall (E) and spatial interpolation error (E_I) as a function of number of gauges.

District wise relative error of mean areal rainfall (E) and spatial interpolation (E_I) are shown in table IX.

TABLE - IX

District:- Kohima (Area =4041 Sq.Km)

SL.NO.	NO. OF GAUGES	E(%)	E_I(%)	L(Km)
1.	2	4.03	3.60	48
2.	4	2.83	3.48	34
3.	6	2.30	3.43	27
4.	8	1.99	3.40	24
5.	10	1.78	3.38	21
6.	11	1.69	3.37	20
7.	12	1.62	3.37	19
8.	13	1.56	3.36	18
9.	14	1.50	3.35	18
10.	15	1.45	3.35	17
11.	16	1.40	3.34	17
12.	18	1.32	3.34	16

District Phek (Area = 2,026 Sq.Km)

SL.NO.	NO. OF GAUGES	E(%)	E_I(%)	L(Km)
1.	2	4.00	3.49	34
2.	4	2.82	3.40	24
3.	6	2.29	3.37	19
4.	8	1.98	3.34	17
5.	9	1.87	3.34	16
6.	10	1.77	3.33	15
7.	12	1.62	3.32	13
8.	14	1.50	3.31	12
9.	16	1.40	3.30	12
10.	18	1.32	3.30	11

District Wokha (Area = 1,628 Sq.Km)

SL.NO.	NO. OF GAUGES	E(%)	E_I(%)	L(Km)
1.	2	3.99	3.46	30
2.	4	2.81	3.38	21
3.	6	2.29	3.35	17
4.	7	2.12	3.34	16
5.	8	1.98	3.33	15
6.	10	1.77	3.32	13
7.	12	1.62	3.31	12
8.	14	1.50	3.30	11
9.	16	1.40	3.29	10
10.	18	1.32	3.29	10

District Zunheboto (Area = 1,255 Sq.Km)

SL.NO.	NO. OF GAUGES	E(%)	E_I(%)	L(Km)
1.	2	3.99	3.43	26
2.	4	2.81	3.36	18
3.	5	2.51	3.34	16
4.	6	2.29	3.33	15
5.	7	2.12	3.32	14
6.	8	1.98	3.31	13
7.	9	1.87	3.31	12
8.	10	1.77	3.30	11
9.	12	1.62	3.29	10
10.	14	1.49	3.29	10
11.	16	1.40	3.28	9
12.	18	1.32	3.28	8

District Mokokchung (Area = 1,615 Sq. Km)

SL.NO.	NO. OF GAUGES	E(%)	E_I(%)	L(Km)
1.	2	3.99	3.46	30
2.	4	2.81	3.38	21
3.	6	2.29	3.35	17
4.	7	2.12	3.34	16
5.	8	1.98	3.33	15
6.	10	1.77	3.32	13
7.	12	1.62	3.31	12
8.	14	1.50	3.30	11
9.	16	1.40	3.29	10
10.	18	1.32	3.29	10

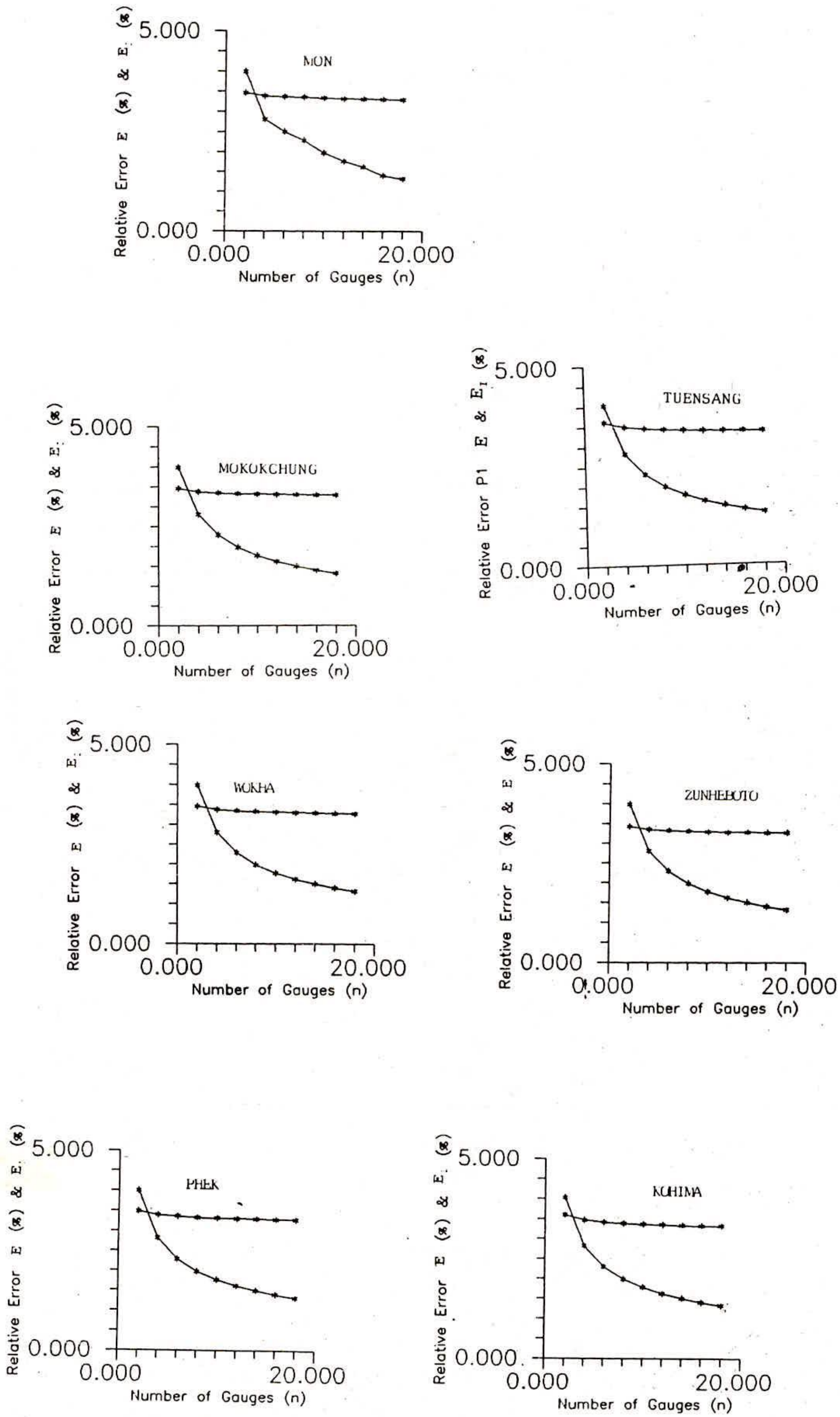

FIG. 8: DISTRICT_WISE RELATIVE ERROR OF MEAN AREAL RAINFALL (E) AND SPATIAL INTERPOLATION ERROR (E) AS A FUNCTION OF NUMBER OF GAUGES

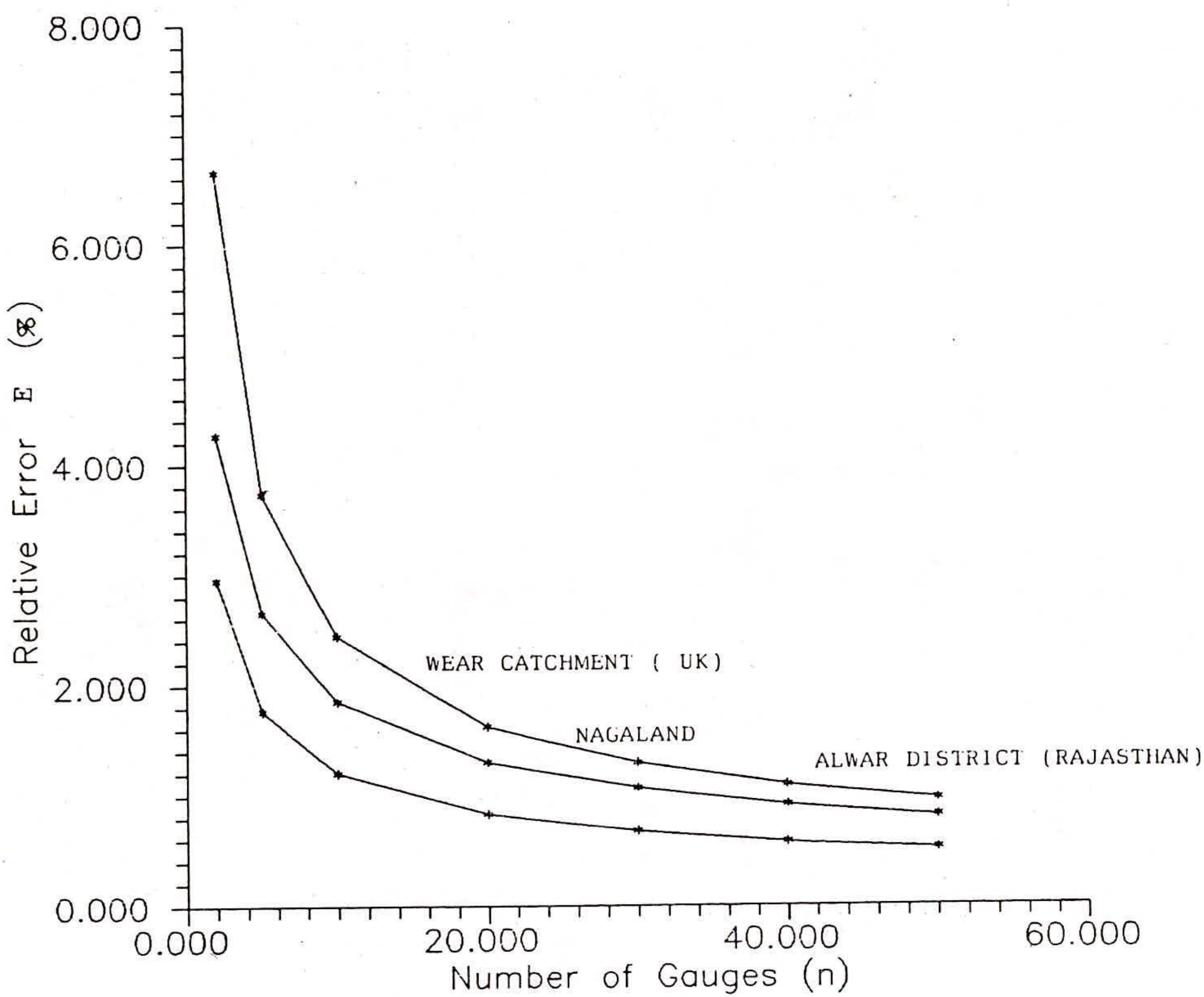

FIG. 9: COMPARISON OF VARIATION OF MEAN AREAL RAINFALL ERROR (E) AS A FUNCTION OF NUMBER OF GAUGES WITH TWO OTHER AREAS

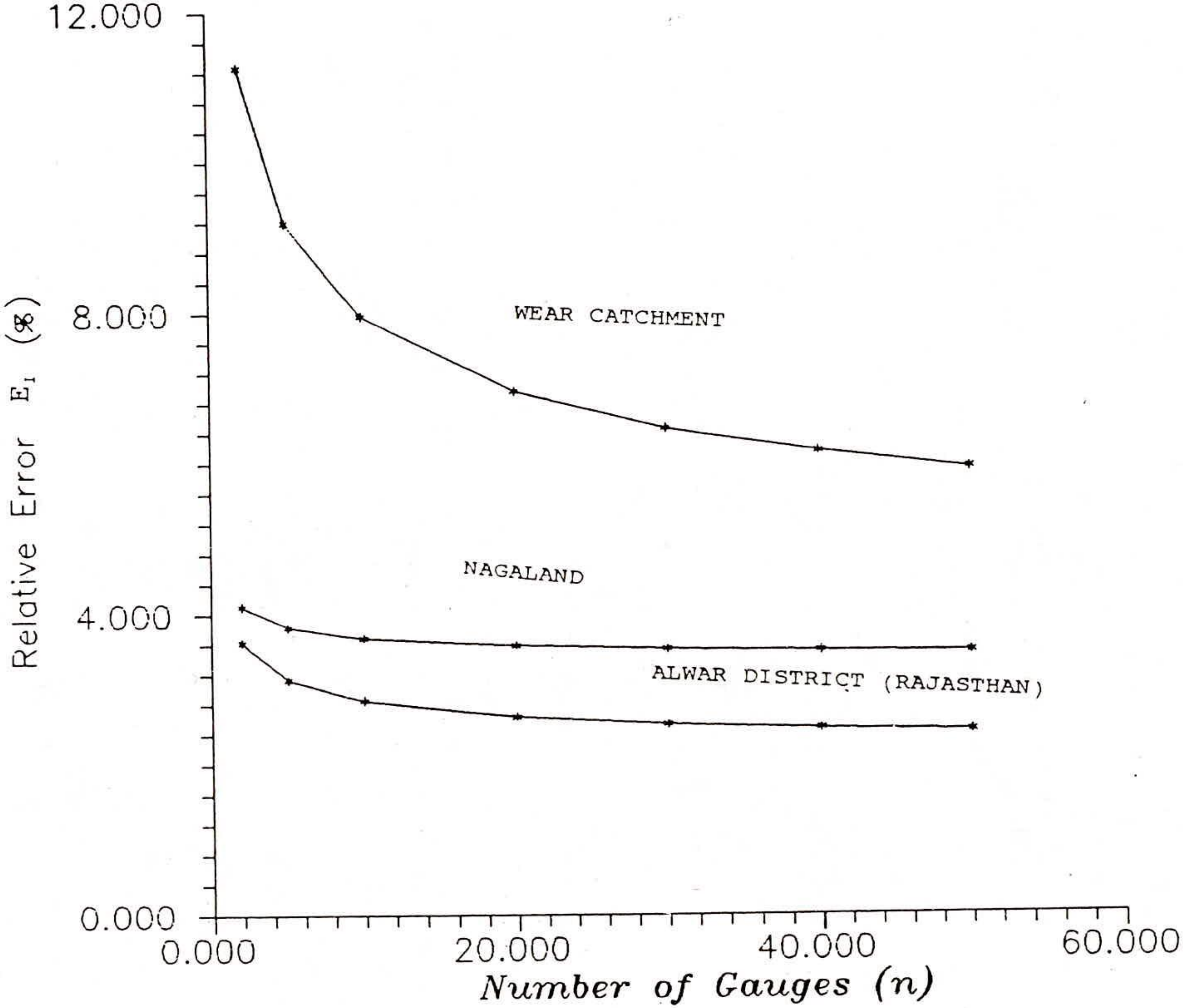

FIG.10. COMPARISON OF VARIATION OF SPATIAL INTERPOLATION ERROR (E_I) AS A FUNCTION OF NUMBER OF GAUGES WITH TWO OTHER AREAS

District Tuensang (Area = 4,228 Sq.Km)

SL.NO.	NO. OF GAUGES	E(%)	E_I(%)	L(Km)
1.	2	4.03	3.61	49
2.	4	2.83	3.49	34
3.	6	2.30	3.44	28
4.	8	1.99	3.41	24
5.	10	1.78	3.39	22
6.	11	1.70	3.38	20
7.	12	1.62	3.37	20
8.	13	1.56	3.36	19
9.	14	1.50	3.36	18
10.	15	1.45	3.35	17
11.	16	1.40	3.35	17
12.	17	1.36	3.34	16
13.	18	1.32	3.34	16

District Mon (Area = 1,786 Sq.Km)

SL.NO.	NO. OF GAUGES	E(%)	E_I(%)	L(Km)
1.	2	4.00	3.47	31
2.	4	2.81	3.39	22
3.	5	2.51	3.37	20
4.	6	2.29	3.36	18
5.	7	2.12	3.35	17
6.	8	1.98	3.34	15
7.	9	1.87	3.33	15
8.	10	1.77	3.32	14
9.	11	1.69	3.32	13
10.	12	1.62	3.31	13
11.	14	1.50	3.30	12
12.	16	1.40	3.30	11
13.	18	1.32	3.29	10

Fig.8 shows the district wise variation of relative of error on mean areal rainfall (E) and spatial interpolation error (E_I) as a function of number of gauges.

Fig.9. & Fig.10. shows the relative error of mean areal rainfall (E), spatial interpolation (E_I) as a function of number of raingauges. Similar analysis done by Mr.E.M.Shaw and Mr.P.E.O'Connel (4) for Wear catchment (U.K) and by Seth et al (1986) for Alwar district in Rajasthan (India) are shown in these figures for the sake of comparison. The general variation appears to be the same.

4.4. DYMOND AND ZAWADZKI METHODS

Using the eqn (22) & (23) proposed by Dymond (1983) and by Zawadzki (1973) respectively for finding out the Root Mean Square Error of basin rainfall as described in section (2.9), the following table of error vs gauges are computed.

TABLE - X

STATION ERROR - DYMOND AND ZAWADZKI

Sl.No.	No. of stations	Dymond's rms	Zawadzki's error
1.	2	3.24	3.02
2.	5	2.57	1.98
3.	10	2.16	1.44
4.	20	1.82	1.05
5.	30	1.64	0.87
6.	40	1.53	0.76
7.	50	1.45	0.69
8.	60	1.38	0.63

4.5. RECOMMENDATIONS

The requirement of number of gauges is found to be 63, 60 and 60 for ISI Code, C Method and Spatial Correlation Methods respectively. The largest requirement of stations amongst these calculated number of gauges stations is chosen.

The required number of stations for Nagaland is 63, out of which 7 number are to be self recording raingauges (SRRG).

The distribution of gauges both ordinary and self recording for different districts in Nagaland is shown below in Table XI.

TABLE - XI

DISTRICT WISE DISTRIBUTION OF RAINGAUGES

L.NO.	DISTRICT	NO. OF GAUGES	SRRG
1.	Kohima	15	01
2.	Phek	08	01
3.	Wokha	06	01
4.	Zunheboto	05	01
5.	Mokokchung	06	01
6.	Tuensang	16	01
7.	Mon	07	01

It should be remembered that the analysis was carried using 5 stations, mostly covering the lower elevational area as can be seen in fig.3. As more data are collected a revision is necessary. While applying the statistical formulations one should not be over confidence of the accuracy provided by them, but also minimum requirement should be considered.

5.0. CONCLUSION

The rainfall data observed at five different station since 1980 are analysed for network design using four different methods. It is seen that the requirement by both ISI and spatial methods at spatial interpolation error of 3.35% is the same. The computations using methods by Dymond(1982) and Zawadzki (1973) supports the above requirement. It should be remembered that the statictical estimation made here in are based on comparatively unreliable data with respect to their spatial variations (Nagaland being predominantly hilly). For this reason the above study can be regarded merely as a first approximation and provide only an idea for planning a network. In such hilly terrain, one would normally tend to recommend a large number of raingauge for accurate representations of orographic variations, but it is irrational to include such large number of stations without definite studies on the rainfall variation structure and without a definite program on water related activity. On the other hand one would hesitate to increase the network from five gauges to sixty three - a twelve fold increase. Having arrived at sixty three stations from a systematic and scientifically based study, a network of sixty three stations as per table is recommended. The data from these sixty three stations could be further utilised for revising the network.

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STATISTICS USED FOR NETWORK DESIGN

Example given below illustrates different statistics used in the method for network design for Nagaland.

Mean, $P_{av} = (P_1 + P_2 + ... + P_M)/M$

where P_1, P_2, etc are M different rainfall values observed at n different stations.

Coefficient of Variation :

$$S = \{[(P_1 - P_{av})^2 + (P_2 - P_{av})^2 + ... + (P_m - P_{av})^2] / M\}^{0.5}$$

$$C_v = (S / P_{av})$$

Correlation Coefficient :

$$S_1 = \{[(P_1 - P_{av1})_1 + (P_1 - P_{av1})_2 + .. .+ (P_1 - P_{av})_m] / (m-1)\}^{0.5}$$

$$S_2 = \{[(P_2 - P_{av2})_1 + (P_2 - P_{av2})_2 + ... + (P_2 - P_{av})_m] / (m-1)\}^{0.5}$$

$$r_{12} = [(P_1P_2)_1 + (P_1P_2)_2 + ... + (P_1P_2)_m - M_{av1}P_{av2}]^{0.5} / S_1S_2(m-1)$$

Here m is the number of observations at each of the stations. This coefficient varies from +1 to -1 and it will be equal to 1 if all points (P_1 vs P_2) exactly fall on to a straight line.

Example given below provides the above calculations using data of three stations for ten observations.

Sl.No	P (mm)	$(P-P_{av})$	$(P-P_{av})^2$
1	1.40	-235.20	55317.47
2	23.00	-213.60	45623.54
3	54.60	-182.00	33122.79
4	80.20	-156.40	24459.92
5	184.40	-52.20	2724.49
6	491.80	255.20	65128.73
7	243.00	6.40	41.00
8	275.80	39.20	1536.90
9	397.00	160.40	25729.23
10	178.80	-57.80	3340.45
1	7.80	-228.80	52347.91
2	36.40	-200.20	40078.70
3	98.00	-138.60	19209.04
4	56.00	-180.60	32615.15
5	205.20	-31.40	985.75
6	577.60	341.00	116283.30
7	247.60	11.00	121.07
8	208.80	-27.80	772.65
9	189.20	-47.40	2246.44
10	336.20	99.60	9920.83
1	9.60	-227.00	51527.48
2	66.00	-170.60	29103.22
3	144.20	-92.40	8537.14
4	110.80	-125.80	15824.80
5	458.40	221.80	49196.72
6	574.20	337.60	113976.00
7	568.00	331.40	109828.20
8	490.70	254.10	64568.51
9	467.20	230.60	53177.90
10	316.00	79.40	6304.89

MEAN P_{av} = 236.60 mm
S_1 = 162.62360
S_2 = 169.41940
Correlation coefficient
taking stations (1) and (2) = 0.8337933

CHARACTERISTIC OF STATISTICAL STRUCTURE OF A HYDROLOGICAL PARAMETER.

Extracting statistical characteristic of a random field is to obtain the structure of covariance and correlation function. The deviation of a hydrological P :

$$P'(x,y) = P(x,y) - P_{av}(x,y)$$

where x,y are coordinates defining the point of observation. The average of the deviations is zero. The average of the square of this quantity is known as variance, v.

$$v(x,y) = [(P'(x,y)]^2_{av}$$

Structure function of P - mean square of the difference in value of P' taking a pair of points.

$$D\ (x_1,y_1,x_2,y_2) = [P'(x_1,y_1) - P'(x_2,y_2)]^2_{av}$$

Covariance function of P - mean product of P' at two points

$$M\ (x_1,y_1,x_2,y_2) = [P'(x_1,y_1) \times P'(x_2,y_2)]_{av}$$

A particular case

$$M\ (x_1,y_1,x_1,y_1) = [P'(x_1,y_1)]^2_{av}$$

$$= v(x_1,y_1)$$

For a set of n observational points the values of above function form a set of symmetrical matrices of order n.

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