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EVALUATION OF PRECIPITATION GAUGE DENSITY IN PUNPUN CATCHMENT OF GANGA RIVER SYSTEM

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PREFACE

Water is a precious gift of nature to humanity. Efficient planning of water resources management is, therefore, necessary for utilization of the limited resources available in the system. Keeping in view the vide variation in availability of water, planning and development of projects in such hydrological areas play an important role towards the development of water resources projects. For this purpose the proper network of data supply and data management is considered to be an essential feature.

The institution has taken up the task of designing raingauge network for few basins which can act as model study for state engineers to carry out similar studies for other basins. The Ganga Plains Regional Centre (Patna) after discussion with Govt. of Bihar has taken up this study for Punpun basin.

Statistical analysis of monthly rainfall data of raingauge stations has been carried out to study the network design of rainfall stations in the Punpun catchment which is one of the major right bank tributaries of river Ganga. Besides WMO Guidelines, Optimal raingauge network design, Key Station Network Method (Hall's method) and Spatial Correlation method (Kagan's method) have been effectively applied to identify the Optimum number of raingauge stations required for Punpun catchment. It is expected that utilising the methodology given in the study, the design of rainfall station network for other basins will be done by users so as to optimise the efforts of establishing raingauges for fruitful hydrological analysis.

This report entitled 'EVALUATION OF PRECIPITATION GAUGE DENSITY IN PUNPUN CATCHMENT OF GANGA RIVER SYSTEM' has been prepared by Ramakar Jha, Scientist'B', and Rahul Jaiswal, S.R.A., Regional Centre, Patna under the guidance of Dr. K.K.S. Bhatia, Scientist'F', Regional Centre Patna. The support of Scientific Staff members namely Sri Anup Kumar, R.A. and M.B. Santosh is appreciable.

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ABSTRACT

Design of data collection network to provide information for assessing, developing and managing the Water Resources is to evolve the total number of key stations for precipitation, river stage and discharge measurement, their efficient location based on certain scientific criteria for selection of each station;the time span and frequency of observation, and determination of priority of network establishment. It aims to provide density and distribution of stations in a region such that by interpolation between data sets at different stations, it should be possible to determine with sufficient accuracy, the characteristics of hydrometeorological elements anywhere in the region.

Precipitation is one of the basic data required for water resources studies. Estimation of the number and locations of the rain gauge stations which will provide sufficient information regarding rainfall falling over the catchment is referred as network design. A network of rain gauges are intended to serve general as well as specific purposes such as water supply, hydropower generation, flood forecasting, irrigation and flood control. During recent years, some network design studies have been carried out but inspite of its importance,studies for determining

optimum density of hydrometic network in particular are not extensive in India.

In the present report a study for design of raingauge network in Punpun catchment which is one of the important right bank tributaries of the river Ganga has been carried out. At present the Punpun river system ,comprising an area of 8530 Sq.km., is having 29 raingauge stations located inside or in the vicinity of the catchment. The river system receives about 85 to 87 percent of its annual rainfall during South -West monsoon period which occurs from June to september. For providing better estimates or aerial rainfall for operational purposes, during the flood and other hydrological factors, the network design of raingauges were estimated using three methods namely ;

(a) Optimal raingauge network,

(b) Hall's method involving key station network and

(c) Kagan's method involving the spatial inter station correlation.

The results indicated that the aerial rainfall in the catchment should be estimated with desired accuracy, and the variation in the aerial distribution as well as time distribution should be identified. All the three techniques for the network design have yielded comparable results.

1.0 INTRODUCTION

Throughout the world, hydrological data sets have evolved in response to the demands of data users, such as engineers, geologists, planners, or more recently hydrologists. Only in the last few decades has the concept of a well defined network of data collection activities begun to imapact types, the quantities and the qualities of the data that are available to aid in making water resources decisions. On the other hand, the costs associated with this effort have increased significantly in recent years and fiscal and man power constraints suggests that a reduction should be made. Thus it is essential that we optimize our network to get the maximum amount of hydrological information from the limited resources available for data collection activity.

The ideal network design would incorporate knowledge concerning the physical and stochastic nature of the hydrologic processes into a framework that accounts for the effects so that the data will have on future water resources decision. Network design is an iterative process, and design should be revaluated and updated periodically because :

(i) Since the data collected may change the designers perception of the hydrologic phenomena.

(ii) The data user may modify his procedures for the use of the data.

(iii) The information flow from an associated network may change because of changes in the network.

(iv) Better technique for network design may become available.

Hydrological and related meteorological data for a river basin are collected mainly to provide information for assessing, developing and managing water resources of the basin and its water related environment. The data recorded at the stations in network are usually fed, after processing, to a hydrological moodel to yield the necessary information for decision making. During recent years, the demand of users of hydrologic and meteorological data for modelling have resulted in introduction of precipitation (rain) gauge network design with automatic recording and transmission arrangements.

Rainfall is one of the most important factors for correct assessment of water resources. Even in case of long rivers where the forecasting methods are essentially based on gauge and discharge data, the rainfall data from various stations in the intermediate catchment(s) are very essentially used as a parameter resulting in marked improvement. So far forecasting in small and flashy rivers is concerned, the techniques of forecasting are primarily based on rainfall-runoff methods which requires rainfall data from sufficient number of stations in the catchment. The number of raingauge station in the basin should be such that :(i)the areal rainfall in the catchment can be estimated with desired accuracy and ;(ii) the variation in the areal distribution as well is time distribution can be identified.

The general purpose of a raingauge network is to provide data which can be used as a basis for a description of the rainfall process in time and space. While from the research viewpoint ,the collection of rainfall data is desirable in order to gain a better understanding of the spatial and temporal distribution of rainfall. The sampling ,collection and procesing of rainfall data must be justified primarily in terms of the economic benefitswhich can derive from their more immediate use. Thus,the design and operation of raingauge networks must be closely linked with various phases in the planning and operation of water resources systems.

In the present study ,three methods namely Optimal Network Design Method, Key Station Network Method (Hall's method) and Spatial Correlation Method (Kagan's method) has been applied for estimation of the number and locations of the raingauge stations which will provide sufficient information regarding rainfall falling over the Punpun river system (Fig.1), (an important right bank tributary of river Ganga). The

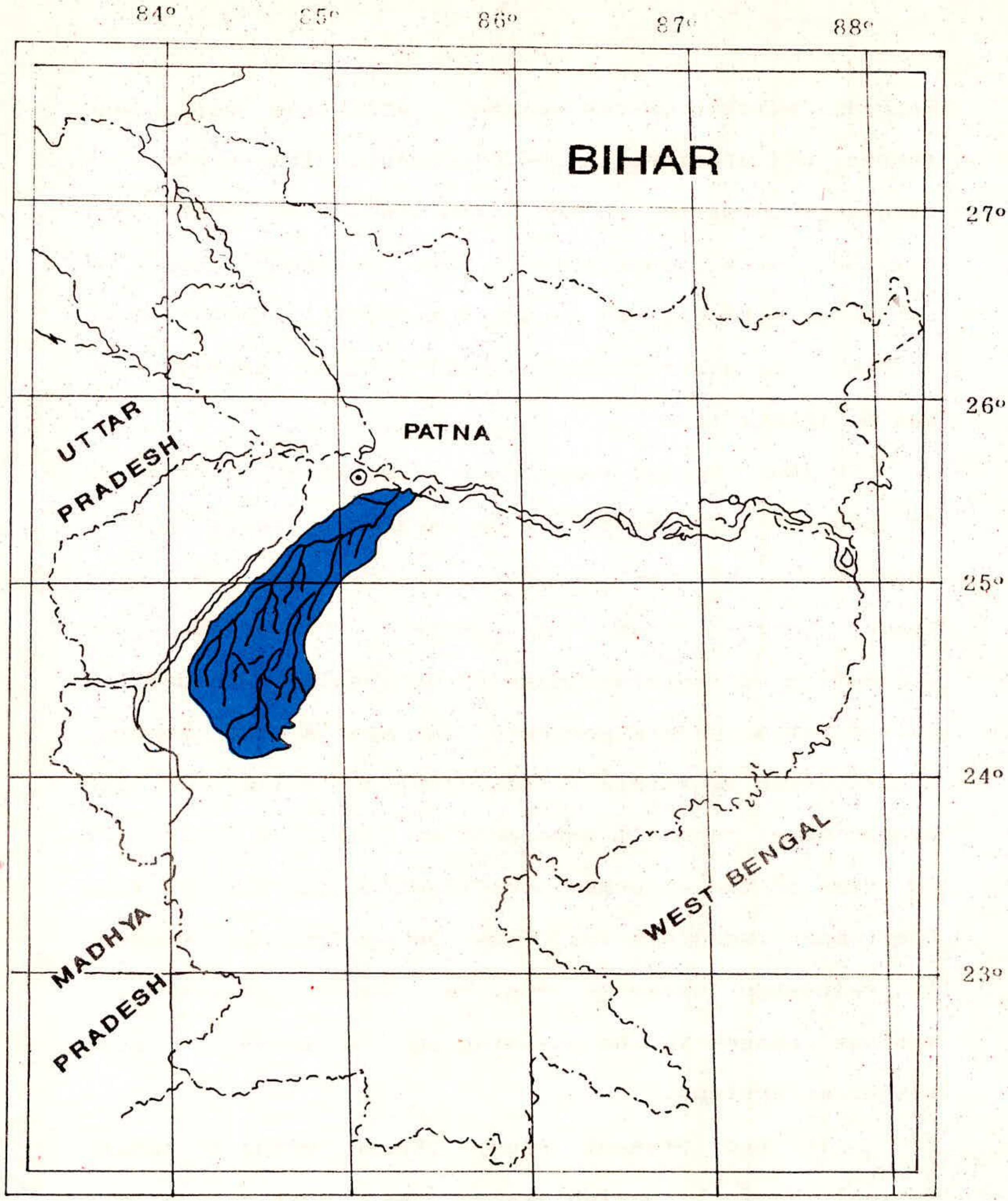

FIG.1: LOCATION MAP OF PUNPUN RIVER SYSTEM IN BIHAR

rainfall data for the periods 1974 to 1986 from the existing 29 raingauge stations inside or in the vicinity of the catchment comprising an area of 8530 sq.km. are utilised to develop the rainguge network design.

2.0 REVIEW

Interesting and valuable studies using very dense raingauge networks have been conducted to determine the standard error of average precipitation estimates over various size drainage areas with various raingauge network densities. Linsley et al (1947) had presented a U.S weather Bureau graph which suggested that the standard error of estimate of storm rainfall over Muskingum basin in Chicago, USA (CA=8000 sq. miles) was about 6 percent for a density of one rain gauge per 100 sq. miles (about 250. km^2) and about 14% for a density of one gauge per 500 sq. miles (about 1250 km^2).

Some of the earliest efforts in the area of data network design were reported by Langbein (1954, 1960, 1972) essentially consisting of guidelines to estimate the optimum number of base stations and operational time frames for secondary stations relative to precipitation data acquisition in a region. The criteria was to maximize the number of gauged stream years in a hydrologic basin. Langbein further detailed (1960) a number of correlation techniques and their utilization for extrapolation of streamflow data.

Huff and Neill (1957) carried out a study of aerial variability of rainfall in a region characterized by thunder storm activity in Illinois State, USA.

Rainhbird(1965) had discussed the problem of network design of precipitation stations and suggested an overview of the problem by assessing the accuracy of data required, the relative importance of precipitation data for the project and the time intervals for which such records need be maintained for a given region.

Hershfield (1965) analyzed rainfall data for 15 storms for each of 15 water sheds with a total of 400 raingauges and found that plots of correlation around key gauges showed evidence of anisotropy.

Caffey (1965) analysed the spatial correlation structure of annual rainfall from 1141 stations from the Western U.S and south-western Canada with an average length of record of 54 years.

The work of Kagan (1966) and Guscina _et al_ (1967) exemplifies some of earliest applications of spatial correlation analysis of rainfall; they presented plots of correlations as a function of distance from a central station for 12 hour ,24 hour, 10 day ,monthly and seasonal rainfall for locations in the valdai area of Russia ; the rate of decay was observed to increase with decreasing duration and was assumed to conform to

$$\rho(d) = \rho(o) \exp(-bd) \qquad ---(1)$$

where $b^{-1} = d_o$ is defined as the correlation radius or the distance at which the correlation decays by a factor of e, and $\rho(o)$ and is the value of the correlation function when extrapolated to zero distance.

The technique of harmonic analysis and the concepts of distributed linear systems had been applied by Eagleson (1967) to the problem of optimum density of rainfall networks for flood forecasting purposes. Specifications of network density for the study of long term catchment average rainfall was accomplished by considering the long term point rainfall as a homogeneous random variable to be sampled spatially. The author concluded that the incorporation of catchment dynamics into the design of flood forecasting networks reduces the number of gauges needed when compared with those obtained by mere consideration of precipitation variability. The Indian Standards Institute (ISI 4987-1968) suggested that one raingauge upto 500 km^2 might be sufficient in non orographic regions. In regions of moderate elevation (upto 1000 m above m.s.l.) the network density might be one raingauge for 250 km^2 to 400 km^2. In predominantly hilly areas and areas of heavy rainfall ,the density recommended was one for 130 km^2.

Huff and Shipp (1969) carried out an extensive spatial analysis of rainfall from three dense raingauge networks in Illinois ; data ranging from one minute rates to total storm , monthly and seasonal amounts were analysed. The effects of rain type ,synoptic storm type and other factors on spatial correlation were studied. Hutchinson (1969) analysed monthly and annual rainfall data from two areas in New Zealand, one relatively flat and the other with variable topography. Plots of correlation around key gauges showed distinct anisotropy for both areas as well as dependence of the rate of decay on topography.

Hendrick and Comer (1970) analysed the spatial structure of daily rainfall data from the Sleepers River Watershed in Northern Vermont. Data for days on which the rainfall at one or more gauges was ≥ 0.10, ≥ 0.50, ≥ 1.0 inches were selected for a winter season and a summer season.

The ISI standard and India Meteorological Dept.(1972) had recommended a simple formula based on Rycroft(1949)

$$N = (C_v/P)^2 \qquad \ldots.(2)$$

where N is the number of raingauges, C_v is the coefficient of variation of the rainfall of the existing raingauges and P is the percentage permissible or desired error of accuracy. Stol (1972) analysed daily rainfall data from 3 groups of stations aligned along different directions for an area in the Netherlands with no relief. Data for days with rainfall $>$ 0.5 mm. at all sites were analysed on a month by month basis; no evidence of anisotropy was found .The function

$$\rho(d) = \rho(o)\exp(-\beta d) \qquad ---(3)$$

was fitted for each month ,apparently by least squares regression.

Sharon (1974) discussed some of the limitations of correlation analysis as a basis for network design, particularly in relation to localized storm rainfall.

The world Meteorological Organization(1974) has recommended the following as minimum network densities for general hydrometeorological practices:

(i) For flat regions of temperate, mediterranean and tropical zones-one station for 600-900 km^2

(ii) For mountainous regions of temperate, mediterranean and tropical zones- one station for 100-250 km^2 .

(iii) For arid and polar regions -one station for 1500-10000 km^2 depending on feasibility.

O'Connell et al (1977) analysed an extensive volume of daily, monthly and annual rainfall data for two regions ,one in the east and one in the north of England. Data for a number of categories of daily rainfall were analysed; days on which daily rainfall at a selected number of gauges within each region exceeded 2 mm,5 mm and 10 mm represented three categories, while a fourth category consisted of data for every 20th day. Plots of the correlation fields around a number of key stations showed evidence of anisotropy ,and an increase in the rate of decay with decreasing threshold; the data for every 20th day showed the most rapid rate of decrease. Jones et al. (1979) used the optimal estimation procedure for preparation of maps of root mean square error of point interpolation for suggesting procedures for determining the accuracy of estimation of aerial rainfall for any shape of area and any configuration of gauges.

Based on optimal estimation procedures, O'Connell et al(1979) had assessed the accuracy requirements for point and aerial rainfall estimates using the data from existing network in the Wessex Water Authority of Southwest England. Root mean square errors of interpolation were calculated using the estimates of spatial auto correlation of daily and monthly rainfall. Mooley and Mohammed Ismail (1981) determined the network for estimation of aerial rainfall. They used the method of optimum estimation to determine the network density required for various limits of tolerable error in the aerial estimates of monthly, seasonal and annual rainfall for different size areas in Vidarbha.

Sreedharan and James (1983) used the spatial correlation technique proposed by Kagan for design of raingauge network in the Chaliyar basin in Kerala. Using monthly data of 31 raingauge stations for seven years, the number of raingauge stations required for estimating the aerial rainfall ith a given accuracy were derived by stipulating two criteria.

(i) the accuracy with which the average rainfall may be obtained over a given area and

(ii) the accuracy of spatial interpolation

Bastin et al. (1984) used a similar approach of optimal estimation for real time estimation of the aerial average rainfall . For this purpose, the rainfall has been modeled as a two dimensional random variable. The variance was minimized by using the Kriging technique. It was shown that the method could be used for the optimal selection of the raingauge locations in a basin.

Mehra(1986) had also used the Kagan's technique for determining the raingauge network using the accuracy criteria as above . A case study for 'Purna catchment' in Tapi basin has been presented by the author .

2.1 Approaches Based on Accuracy Criteria

Most of the approaches to network design reported in the literature have used some accuracy criteria as a basis for designing a network. Early contributions were based on the notion that the spatial correlation between gauges should be not less than some arbitrarily chosen level ; for example, Hershfield (1965) suggested that the level should be 0.9, and derived average gauge spacings on this basis. Hendrick and Comer (1970) followed a similar procedure ,but attempted to take account of anisotropy by centering gauges within ellipses corresponding to the 0.9

correlation contour.

Cislerova and Hutchinson (1972) used optimal point interpolation error for pairs of gauges (Gandin,1965) as a basis for the re-design of the raingauge network of Zambia aimed at bringing the density up to the WMO recommended standard of one gauge per 900 km². Maps of interpolation error for annual rainfall , expressed in absolute terms and as a percentage of mean rainfall, were used as a basis for identifying areas of deficient accuracy through reference to predetermined accuracy criteria, taken as 10 and 15 per cent of mean annual rainfall.

Delhomme and Delfiner (1973) used Universal Kriging to interpolate rainfall on a regular grid for a large storm over an arid region in Chad. In order to identify potential sites for new gauges to reinforce the network, they calculated the gain in accuracy in the estimation of mean rainfall during a storm resulting from siting a new fictitious gauge at point M within the basin ;this gain in accuracy was defined as

$$G_M = [\ \sigma_o^2 - \sigma_m^2]\ /\ \sigma_o^2 \qquad \text{---(4)}$$

where σ_m^2 and σ_o^2 are the estimation variances with and without the new gauge.. The quantity G_M was contoured over the basin and the maximum gain in accuracy from siting a new gauge was found to be 13% as opposed to 3% given by an empirical analysis.

Morin et al (1979) advocated the use of

principal component analysis in conjunction with optimal interpolation as an approach to raingauge network design .The former technique was applied to ten day rainfall totals from 30 stations sited within the Eaton River basin in Quebec (area 642 Km^2) and it was found that the stations could be divided into three groups, the composition and geographic distribution of which varied from season to season .

Crawford (1979) describes an experimental design model which has been developed to evaluate trade-offs involved in the optimal sampling of rainfall .

O'Connell et al (1978, 1979) employed optimal estimation procedure in the re-design of a raingauge network for an area of about 10,000 km^2 in the South of England. Their overall approach involved the following steps:

(i) evaluation of the accuracy requirements of users;

(ii) evaluation of the adequacy of individual gauges to provide reliable measurements;

(iii) calculation of the accuracy of point and aerial rainfall estimates for existing and proposed networks, and comparison with requirements of users.

2.2 Approaches Involving Both Cost and Accuracy

Bras and Rodriguez Iturbe (1976b) and Lenton and Rodriguez Iturbe (1977) present two different approaches to network design for the estimation of the aerial mean of rainfall events (spatial averaging) in which both cost and accuracy are explicitly considered. Both approaches use the same objective function as a starting point which may be written as

$$U(\underline{x}, \underline{b}, n) = E(\underline{x}, \underline{b}, n) + f\ C(\underline{x}, n) \qquad \text{---(5)}$$

where $\underline{x}$ denotes the locations of the gauges, $\underline{b}$ denotes the set of weights, n the number of gauges, $E(\underline{x}, \underline{b}, n)$ denotes the mean square error of the aerial average, f is a factor equivalencing cost and accuracy and $c(\underline{x}\ n)$ the annual operating and data processing costs of the set of gauges into which capital costs have been absorbed by distributing them among amortization items.

Bras and Rodriguez (1976b) define the term $E(\underline{x}, \underline{b}, n)$ as a sum of three terms .The first term represents model error and represents the error involved in approximating the continuous integral by a discrete summation of a set of weights applied to rainfall at points in space; the second term derives from estimating the discrete summation with noisy measurements ,and a third term accounts for dependence between these two types of error.

Lenton and Rodriguez-Iturbe (1977) formulated the minimization of (5) as a mathematical programming problem with the decision variables being the total number of raingauges, the coordinates of each of them and the estimator weights.

2.3 Approaches Based on Rainfall -Runoff Modelling

Bras (1978) has reviewed a number of selected papers. Early work by Eagleson (1967) in this area involved describing the rainfall field with a radial symmetric characteristic storm structure described in the case of a convective storm as

$$X_T(d) \,/\, X_T(o) = 1 - 0.72\ |d/d_o| \qquad ---(6)$$

where $X_T(o)$ denotes the depth of the storm of duration T at the origin, $X_T(d)$ is the depth at distance d, and d_o is defined as the distance corresponding to a correlation radius of 0.5. The temporal properties of rainfall storms were described using the autocorrelation functions; Eagleson then used deterministic linear systems theory in the frequency domain to derive the frequency spectrum of streamflow response. The effect of sampling rainfall in space at different finite densities was then determined by truncating the spectrum at different wave numbers and calculating the error in peak discharge prediction. Further applications of this approach are described by Eagleson and Goodspeed(1973).

Grayman and Eagleson (1971) used stochastic model based on the meso -scale and synoptic levels of storm structure to generate rainfall in time and space;the rainfall was then sampled using simulated radar and raingauge combinations and routed through a model based on a spatially distributed solution of the kinematic wave equations. Sampling requirements in space and time were studied in terms of the number of gauges required for calibrating the radar, averaging area for the radar signal and sampling interval for accurate peak flow prediction ;confidence limits for such predictions were also quoted for particular storm types.

Bras and Rodriguez-Iturbe (1976c) used a non stationary multidimensional stochastic model of rainfall to generate the input to a deterministic rainfall-runoff model;noisy 'measurements' of the rainfall were then sampled at a number of points ,and the Kalman filter was used to derive minimum mean square error estimates of rainfall intensity .This uncertainty was then propogated within a state space model of the rainfall-runoff process to derive the mean square error of estimated discharge.

Bras and Rodriguez- Iturbe (1976c) applied the approach to a hypothetical basin (Area 82 Sq. km),and concluded that raingauge location was important in determining the accuracy with which discharge could be simulated. It was observed that sampling in the upper catchment areas resulted in the deterioration of the simulation of the hydrograph rising limb compared to sampling the lower areas. Simulation accuracy was also found to be sensitive to the number of stations.

O'Connell _et_ _al_(1977,1978) carried out some experiments to assess the effect of network density and configuration on discharge simulation and forecasting. Two sets of experiments were conducted; the first involved calibrating the CLS model with thresholds (Todini and Wallis, 1977) on a daily basis for a number of catchments in the UK ranging in area from 75 Sq.km to about 500 Sq.km .The CLS model was first calibrated using all the available gauges to define the average daily rainfall input for each catchment;then by fixing the model parameters, and successively reducing the number of gauges used to define the average rainfall input ,the effect on the accuracy of discharge simulation was studied.

Jettmar _et_ _al_ (1979) carried out some experiments with a rainfall runoff model to determine the value to river flow forecasting of possible changes in existing rainfall and streamflow networks operated by the National Weather Service. A surrogate measure of benefits, called the "mean forecast lead time" (MFLT), was used as a basis for assessing the effects of network changes since the value of a river flow forecast depends on the lead time available for the flood plain dweller to respond to the forecast.

3.0 DESCRIPTION OF THE CATCHMENT

The Punpun catchment, one of the important right bank tributaries of river Ganga, was considered in the study. It originate from Chottanagapur hills of Palamu district in Bihar and lies approximately between longitude 84^0 10' to 85^0 20'E and latitude 24^0 11' to 25^0 25' N . It flows, for most of its portion, in a north east direction and join the Ganga at Fatwah, about 25 km downstream of Patna. The river is rainfed and carries little discharge during non- monsoon period.

The shape of the Punpun river system is roughly trapezoidal. The length of the catchment is about 180 km and the average width in upper and lower reaches of the river system is 60 km. and 25km. respectively. The total catchment area of the Punpun river system is about 8530 sq. km. which is one percent of total area of Ganga sub-basin in the country.

The length and the catchment area in respect of all the important tributaries have been worked out separately and shown in line diagram (Fig 2). The level of the land varies from 300 m near origin of the river to about 50 m near out fall into the river Ganga.

The general information about land use of Punpun basin indicate that the area under agriculture

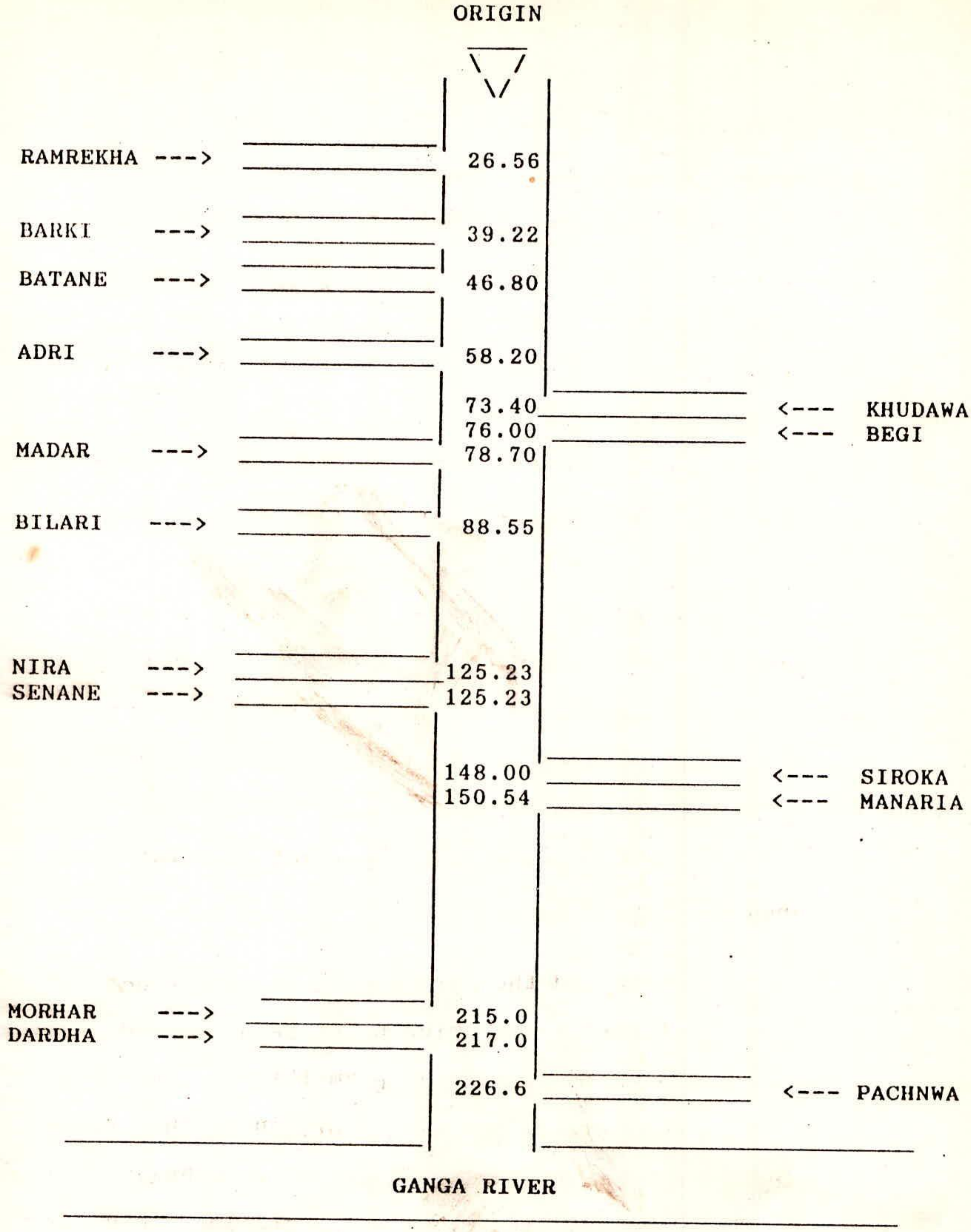

FIG. 2. LINE DIAGRAM OF PUNPUN RIVER SYSTEM

in the Punpun river system is about 5,000 sq.kms.

The gross cropped area and net area sown in river system are 5270 sq. kms. and 3990 sq. kms. respectively.

Broadly the geology of the areavaries from granite, gneiss, charnokites in the hills to the recent alluvium in the plains.

An approximate estimate of total groundwater potential has been made by applying Chaturvedi's formula. On this basis the total gross recharge in the Punpun river system comes to be 1.6 lakh ha.m.. However, only 70 % of the total gross recharge can be made available for utilization.

The river system receives about 85 to 87 percent of its annual rainfall during the South - West monsoon period which occurs from June to September. Average annual rainfall varies from 992 mm, near confluence with the Ganga (Patna District) to 1335 mm in the upper most reach (Palamu District). The average annual rainfall over the entire river system works out to 1181 mm. A list of precipitation gauge stations inside the Punpun river system with their locations (Fig.3), average annual rainfall, and the period on the basis of which computations were made is given in Table 1. The mean monthly rainfall pattern is also depicted in Fig.4.

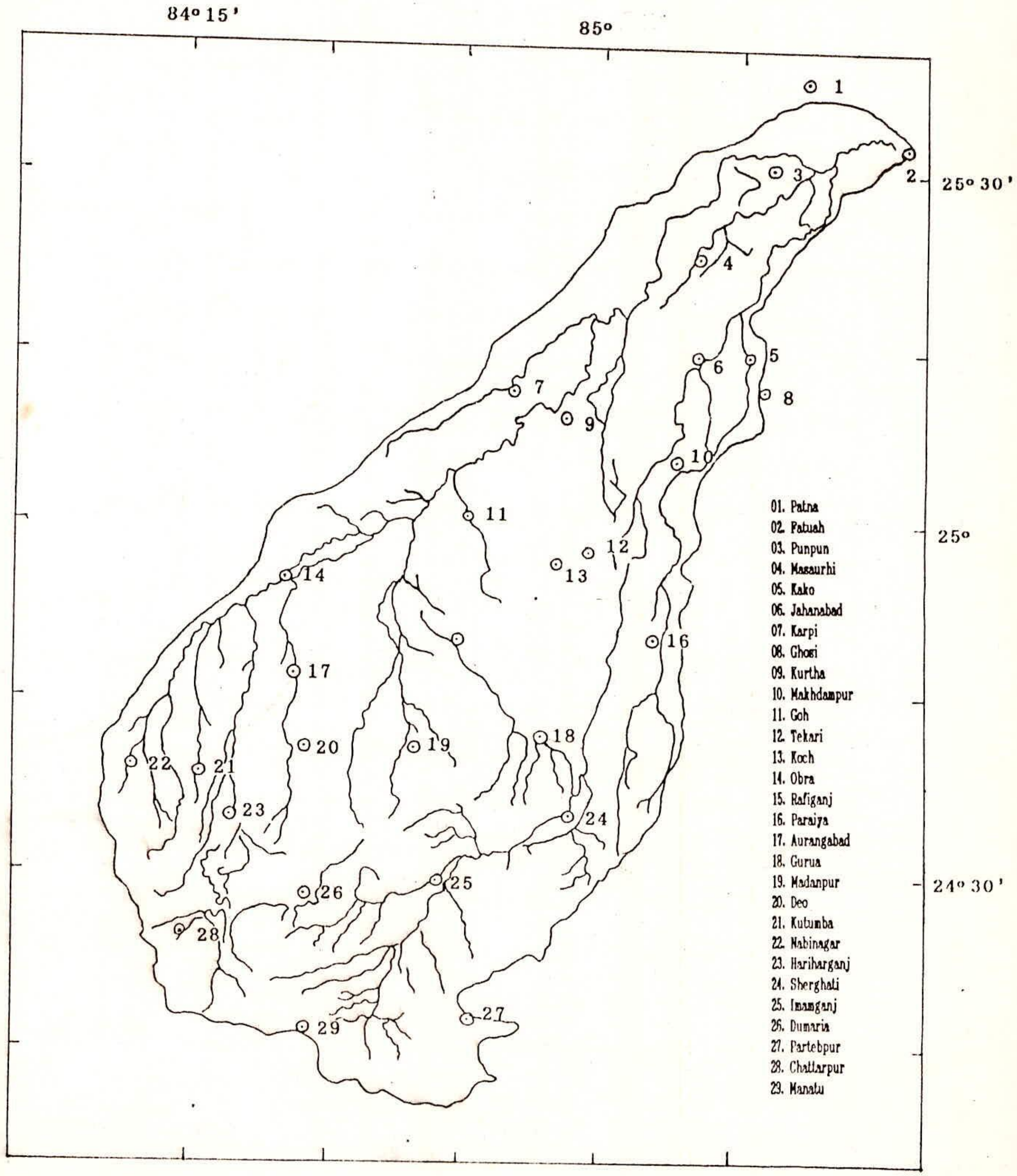

FIG.3: LOCATION OF RAINGAUGE STATIONS IN PUNPUN BASIN

TABLE 1 : LOCATION OF RAIN GAUGE STATIONS WITH AVERAGE ANNUAL RAINFALL

Sl.No.	Rain gauge Stations	Average Seasonal Rainfall	Latitude	Longitude
01.	Patna	952.12	25° 37'	85° 10'
02.	Fatuah	920.80	25° 30'	85° 19'
03.	Punpun	773.34	25° 29'	85° 07'
04.	Masaurhi	846.43	25° 21'	85° 02'
05.	Kako	754.36	25° 13'	85° 05'
06.	Jahanabad	899.74	25° 13'	85° 00'
07.	Karpi	809.01	25° 10'	84° 43'
08.	Ghosi	855.68	25° 10'	85° 06'
09.	Kurtha	1001.32	25° 08'	84° 48'
10.	Makhdampur	926.24	25° 04'	84° 58'
11.	Goh	881.05	24° 59'	84° 58'
12.	Tekari	757.22	24° 56'	84° 50'
13.	Koch	846.98	24° 55'	84° 47'
14.	Obra	831.66	24° 53'	84° 22'
15.	Rafiganj	819.55	24° 53'	84° 38'
16.	Paraiya	864.85	24° 49'	84° 56'
17.	Aurangabad	940.19	24° 45'	84° 23'
18.	Gurua	1006.54	24° 40'	84° 46'
19.	Madanpur	963.27	24° 39'	84° 35'
20.	Deo	806.56	24° 39'	84° 24'
21.	Kutumba	871.60	24° 37'	84° 14'
22.	Nabinagar	712.63	24° 37'	84° 08'
23.	Hariharganj	859.66	24° 33'	84° 17'
24.	Sherghati	927.01	24° 33'	84° 48'
25.	Imamganj	909.31	24° 27'	84° 36'
26.	Dumaria	681.30	24° 26'	84° 24'
27.	Partebpur	1167.12	24° 18'	84° 39'
28.	Chattarpur	872.48	24° 22'	84° 12'
29.	Manatu	980.12	24° 14'	84° 24'

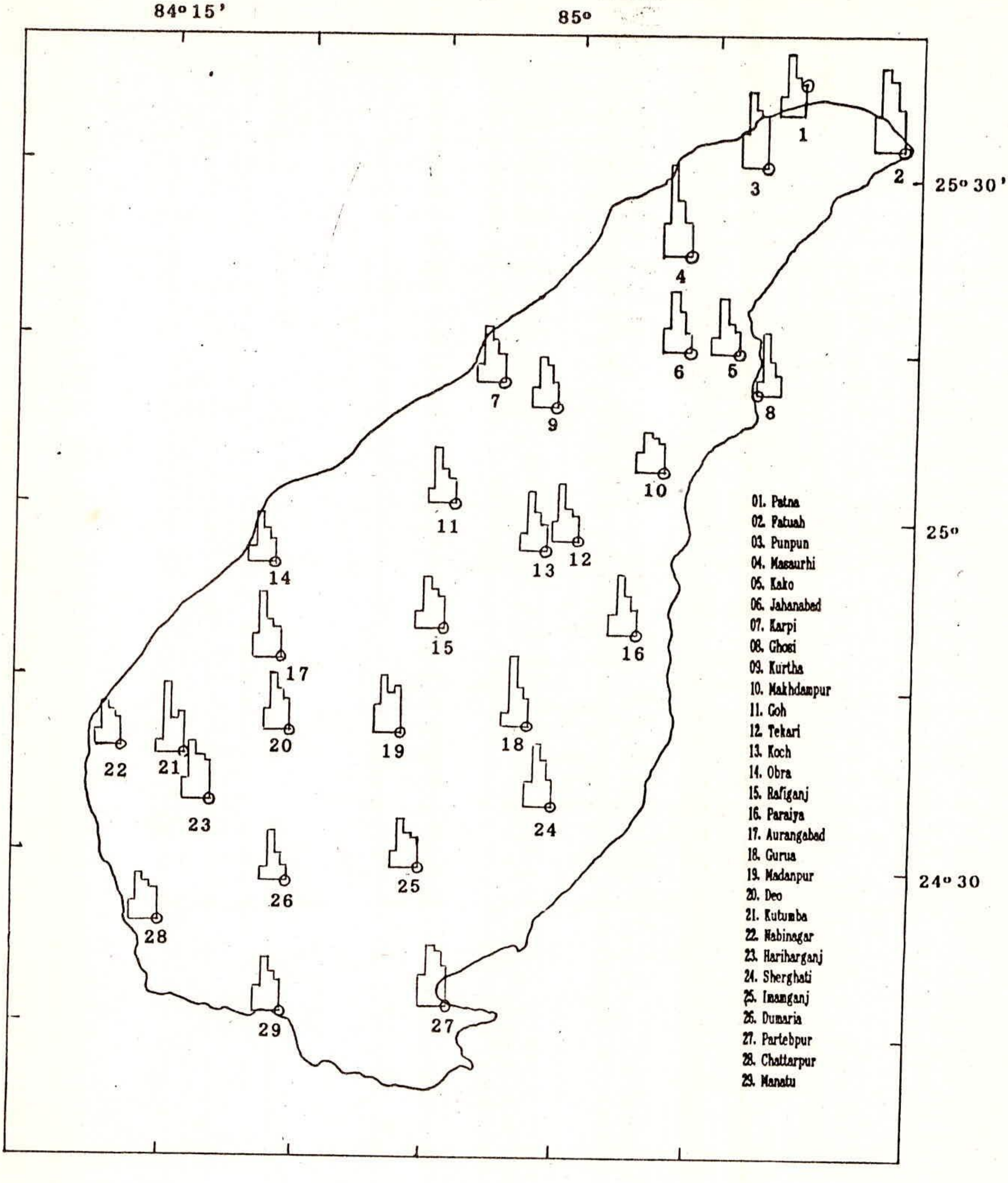

FIG.4: MEAN MONTHLY RAINFALL OF PUNPUN BASIN

4.0 STATEMENT OF THE PROBLEM

The concept of data networks has permitted streamlining of hydrological data , that is, a reduction of the resources consumed in data collection and pointed the way for expansion of substandard data collection activities to ensure that the right hydrological information is available at the right time.

For the managment of a water resources 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 hydrolocical parameter of water resources needs due attention. Earlier, observations were made for a single purpose,i.e. to determine the yield and design of a water supply impounding reservoir. Now, the tendency is to have multipurpose schemes on a much larger scale combining such uses as water supply, hydro-electric power generation, irrigation needs, flood a alleviation and general river management. The rain gauge networks studies are generally set for (a) Hydrological studies, (b) Climatological and water balance studies, (c) Floodforecasting and computation of runoff studies, and (d) Weather modification evaluation studies.

In the present study network design of precipitation gauges in the Punpun catchment of Ganga river (BIHAR) has been undertaken with the objective of estimation of the Optimum Network Density of precipitation gauging stations. The proper network design also provides guidelines for selection and demarcation of the rainfall gauging sites for the catchment.

Various stages of network design to be follwed are:

1. Location of area
2. Size of catchment
3. Physical features
    - (i) Drainage pattern
    - (ii) Surface relief
    - (iii) Geological structure
    - (iv) Vegetation
4. Climate of the area
5. Precipitation characteristics
6. Location of existing precipitation gauging stations and collection of data

   Determination of adequacy of existing network

8. Determination of number of new stations required
9. Planning of new sites in the network.

5.0 NETWORK DESIGN TECHNIQUES

5.1 WMO Guidelines

In designing rainfall station network it is required to determine; aerial rainfall in the catchment within a desired accuracy, intensity and duration of rainfall to develop suitable unit hydrograph with an eye on rainfall-runoff relations in the upper reaches of the catchment and, availability of rainfall data on real time basis.

The WMO (World Meteorological Organisation) has given the following guidelines for determining the minimum density of precipitation network.

MINIMUM DENSITY OF PRECIPITATION STATIONS

Region	Minimum density range (km^2/gauge)
Temperate, Mediterranean & Tropical zones	
1. Flat areas	600-900
2. Mountainous areas	100-250
3. Small mountainous islands	25
4. Arid & Polar zones	1500-10000

In India, the standard prescribed by High Level Committee on floods set up by Govt. of India has suggested to establish minimum one station per 518 sq. km. The minimum density network consists of three kinds of rain gauges:

Standard gauges: non recording to be read daily of other pre-determined intervals depending upon operational requirements.

Recording gauges: at least 10 % of the total gauges may be self recording type.

Storage gauges: In many locations though it is important to obtain rainfall data, due to lack of facility of reading and communication a standard gauge can not be installed. A gauge with large enough capacity which may be read monthly may be installed in such locations.

5.2 Optimal Network Design

The problem of ascertaining the optimum number of rain gauges 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 station is utilised for determinating the optimum number of raingauges. If there are already some rain gauges station in a catchment, the optimal number of stations that should exists to have an assigned percentage in the estimation of mean rainfall is obtained by statistical analysis as:

$$N = (C_v / P)^2 \qquad ---(7)$$

where

N = optimal number of stations

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

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

If there are m stations in the catchment each recording rainfall values P_1, P_2, ..., P_i, ..., P_m in a known time, the coefficient of variation C_v is known time, the coefficient of variation C_v is calculated as:

$$C_v = \frac{100 \times \sigma_{m-1}}{\overline{P}} \qquad ---(8)$$

where,

$$\sigma_{m-1} = \sqrt{[\Sigma(P_i)^2 - (\Sigma P_i)^2/m] / (m-1)} \qquad ---(9)$$

P_i = Precipitation magnitude in the ith station.

$$\overline{P} = 1/m(\Sigma P_i) \qquad ---(10)$$

In calculating N from above equ.(7) it is usual to take P = 10 %. It is seen that if the value of P is small, the number of rainfall gauge stations will be more.

5.3 Key Station Network Method

One of the moist rational method for determination of key station network is as suggested by Hall (1972). In this method, at first, correlation coefficients between the average of the storm rainfall and the individual station rainfall are found. The stations are then arranged in order of their decreasing co-relation coefficients and the station exhibiting highest correlation coefficient is called the first key station and its data is removed for the 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 station is called the second key station. Similarly, the third and further key stations are selected after removing the data of already selected key stations.

The next step is to provide a basis for determining the number of stations required for achieving an acceptable degree of error in the aerial estimate. For this, the sums of the squares of deviations of the estimated values of average rainfall from actual rainfall in respect of 1st, 2nd and 3rd station; etc. is determined and a graph is plotted between the sum of square of deviations and corresponding number of stations in combination. it will be seen that a stage comes when the improvement in the sum of squares of deviations is very little. The corresponding number of rain gauge stations at that stage is taken to be the representative or key network.

5.4 Spatial Correlation Analysis

Under the assumption that the spatial variability of rainfall can be quantified through a spatial correlation function a network of raingauges 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 conditions necessary for the existence of a spatial correlation function, such as hydrological homogeneity and isotropy are fulfilled. In mountainous regions these assumptions are unlikely to be fulfilled; flat areas with a relatively homogenous underlying surface are more appropriate.

A general theoretical review of spatial correlation methods for the planning of meteorological networks has been given by Gandin(1970). Some details of a specific approach and its application have been given by Kagan(WMO, 1972). The basis of the method advocated by Kagan is the correlation function $\rho(d)$ which is a function of 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 frequently be described by the following exponential form;

$$\rho(d) = \rho(o)\ e^{-d/d_o} \qquad \text{---(11)}$$

where,

$\rho(o)$ is the correlation corresponding to zero distance, and d_o is the correlation radius or distance at which the correlation is $\rho(o)/e$. Theoretically, $\rho(o)$ should equal unity but is rarely found to do so in practice due to random errors in precipitation measurement and microclimatic irregularities over an area. The variance of those random errors has been given by Kagan(1966) as

$$\sigma_1^2 = [1-\rho(o)]\sigma_h^2 \qquad ---(12)$$

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

The quantities $\rho(o)$ and d_o provide the basis for assessing the accuracy provided by a network. In this context, two accuracy criteria 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 centre station, and assuming $\rho(d)$ exists and is described by Equation 11, the variance of the error in the average precipitation over s is given by Kagan (1966) as:

$$V = [1-\rho(o)]\sigma_h^2 + 0.23\,\sigma_h^2 \sqrt{s}/d_o \qquad ---(13)$$

where the first term is attributed to random errors and is specified by eq.(12) and the second term is attributed to spatial variation in the precipitation field.

For an area S with n stations evenly distributed such that S = ns, the variance of the error in the average rainfall over S is given by

$$V = \sigma_h^2 / n\, [1-\rho(o) + 0.23 \sqrt{s}/d_o\sqrt{n}] \qquad ---(14)$$

The relative root mean square error is then defined as

$$Z_1 = \sqrt{V_n} / \overline{h} = C_v \sqrt{[1-\rho(o) + 0.23 \sqrt{s}/d_o\sqrt{n}] / n} \qquad ---(15)$$

where,

$C_v = \sigma_h / \bar{h}$ and $\bar{h}$ is the average precipitation over S. From eq.(15) the value of n required to meet a specified error criterion Z_1 can be obtained if the values of $\rho(o)$ and d_o are known, or conversely, given n, Z_1 can be evaluated.

The uniform spacing of station over the area S is such that S = ns can be achieved on the basis of a square grid for which the spacing between station is :

$$L = \sqrt{s/n} \qquad \text{---(16)}$$

However, a triangular grid is usually more convenient if the area S has a complex configuration; the spacing is then given by:

$$L = \sqrt{2s/n\sqrt{3}} = 1.07\sqrt{s/n} \qquad \text{---(17)}$$

<u>Criterion 2</u>: 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 centre of square and triangle, where the maximum errors of interpolation occur. For a triangular grid with spacing one, the relative error is given by Kagan as:

$$Z_3 = C_v \sqrt{[1/3 \{1-\rho(o)\} + 0.52 \{\rho(o)\sqrt{s}\}/\sqrt{n}\, d_o]} \qquad \text{---(18)}$$

assuming that $\rho(d)$ can be described by equation (11).

<u>Application</u>: The derivation of Z_1 and Z_3 in a particular case requires the estimation of $\rho(o)$ from which $\rho(d)$ and d_o can in turn be derived. The function $\rho(d)$ can be

evaluated by calculating the correlation $\rho_{(i,j)}$ between rainfall totals for a selected duration at stations i and j for all values of i and j, and classifying the values of $\rho_{(i,j)}$ as a function of distance between stations. The value of $\rho_{(i,j)}$ is calculated as :

$$\rho_{(i,j)} = \frac{\Sigma h_i h_j - [\Sigma h_i \ \Sigma h_j]/m}{\sqrt{[\Sigma h_i^2 - (\Sigma h_i)^2/m][\Sigma h_j^2 - (\Sigma h_j)^2/m]}} \qquad \text{---(19)}$$

where, the summations are taken from 1 to m and m is the number of pairs of observations. The determination of $\rho(o)$ and d_o then proceeds as follows:

(i) The correlation $\rho_{(i,j)}, (i,j=1,m)$ are classified into intervals on the basis of distance between stations,

(ii) The average distance and average correlation for the station falling within each interval are then calculated,

(iii) Average distance is then plotted against average correlation, and an exponential curve is drawn through the points, as no details of a more objective procedures are given in the literature (of Kagan, WMO, 1972). The value of $\rho(o)$ is found by extrapolating $\rho(d)$ to zero distance, and d_o is calculated as the distance corresponding to a correlation of $\rho(o)/e$. Alternatively, $\ln[\rho(d)]$ may be plotted against d which should result in a linear plot with slope $-1/d_o$ and intercept $\ln[\rho(o)]$ on the basis of eq. 11. Objective fitting of a straight to the plotted points by Least squares, for example might result in value of (o) 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 the raingauge station is very important in the design of precipitation gauge network. Isohytel method is commonly used to locate raingauges in the catchment. In this method Isohytes are overdrawn on the catchment. These isohytes divide whole catchment to number of zones. Number of stations should nearly be equal in every zone. The exact location should be decided keeping in view the following points.

i. The raingauge station should be located near village or town.

ii. The site should be accessible throughout the year.

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

iv. As far as possible each of the sub-catchment should be proportionate to the number of raingauge stations.

6.0 ANALYSIS OF RESULTS

Estimation of the number and locations of the precipitation (rain) gauge stations have been analyzed by W.M.O. guidelines, using optional raingauge network technique, Hall's method considering Key Station Network and Kagan's method considering spatial correlation Technique. The Punpun basin was selected for the study of precipitation (rain) gauge network design. The precipitation data used in the analysis were obtained from Hydrology Cell, Water Resources Department, Govt. of Bihar for the years 1974 to 1986.

6.1 WMO Guidelines.

As per the guidelines of World Meteorological Organigation, the distribution of precipitation gauges were obtained in Punpun catchment of Ganga river system (Table 2).

6.2 Optimal Raingauge Network Method.

In the analysis of Optimal Network Design, the coefficient of spatial variation of rainfall from the existing station is utilized for determining the optimum number of raingauges. The analysis in detail is given in Appendix I. The coefficient of variation was evaluated to be 11.1159 and the requirement of number of raingauges has been estimated for 5% and 10% error

TABLE 2: APPLICATION OF WMO GUIDELINES IN PUNPUN CATCHMENT

Description of Catchment area	Area in Sq.Km.	No. of Precipitation Gauge required
Area under Hills	2132.50	11
Area under Plains	6397.50	9
Total Area	8530.00	20

criteria. The number of raingauges required using this techniques were evaluated to be 5 and 2 for 5% and 10% error criteria.

The district wise distribution of precipitation gauges were also evaluated using Optimal Raingauge Network method for 5% and 10% error criteria(Table 3).

6.3 Key Station Network Method.

Utilizing the Hall's method, the key station network for Punpun catchment have been worked out on the basis of about 13 selected rainfall storms which occurred in the catchment in the past. The graph between maximum correlation coefficients and combination of station is shown in Fig. 5 and data are presented in Table 4. The sum of squares of deviation and corresponding number of stations in each combination of station of Ist , Ist and 2nd, & Ist, 2nd and 3rd stations etc. of representative stations has been presented in Fig. 6. As may be seen from the graph, there is no improvement in the reduction of sum of squares of deviation with the increase of station in the network after the 29th station. It is, therefore, suggested to have 29 raingauge station in the punpun catchment.

6.4 Spatial Inter Station Correlation Method.

Kagan (1966) and WMO (1972) proposed network of raingauges to meet a specified error criteria under the

TABLE 3: DISTRICT WISE DISTRIBUTION OF PRECIPITATION GAUGE STATIONS IN PUNPUN CATCHMENT

District	Existing Stations	Required Stations for	
		5 % error	10 % error
Patna	4	3	1
Gaya	13	5	2
Aurangabad	8	4	1
Palamau	3	2	1
Hazaribagh	1	1	1
Total	**29**	**15**	**6**

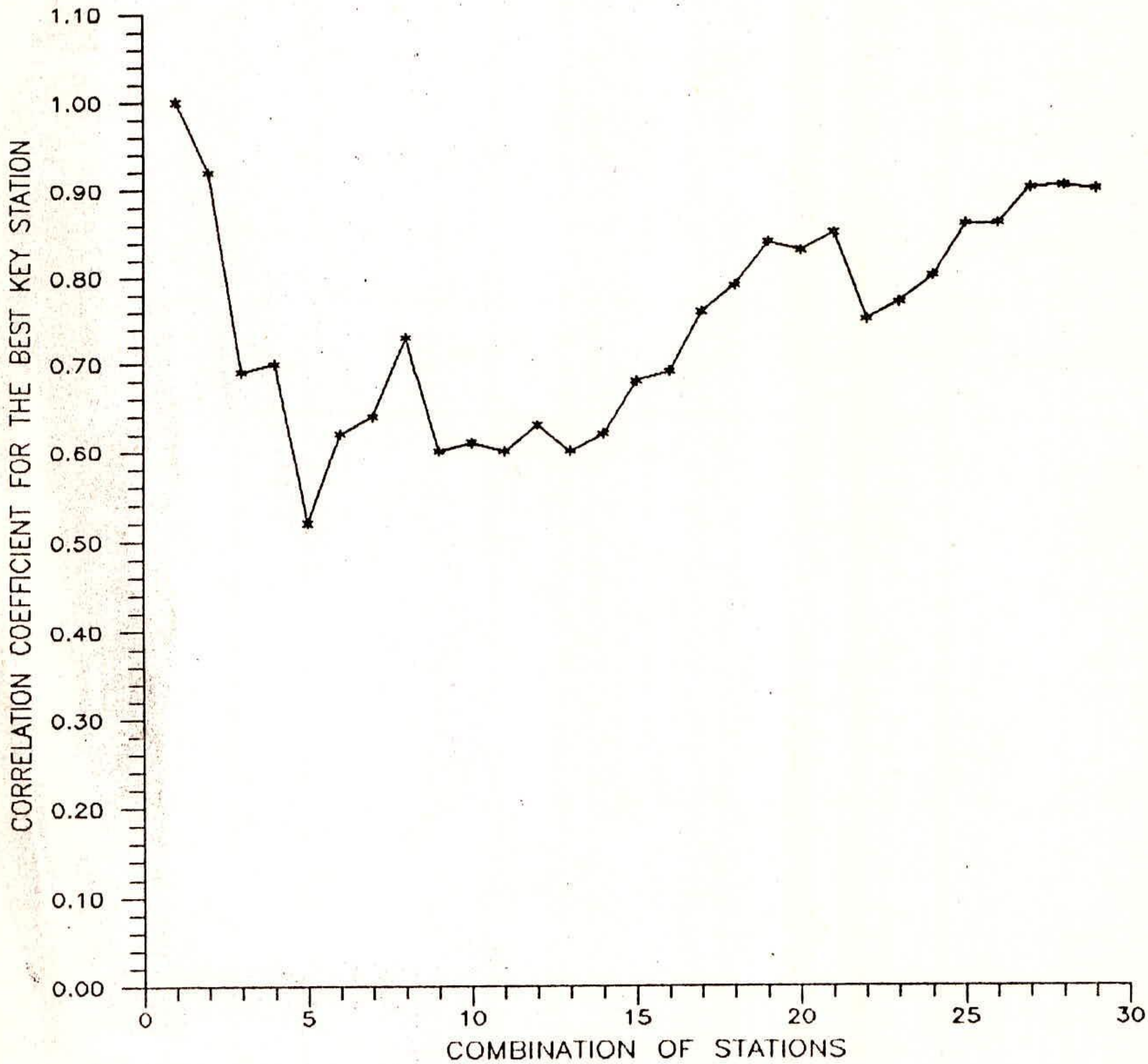

FIG.5: MAXIMUM CORRELATION COEFFICIENT FOR VARIOUS COMBINATION OF STATIONS

TABLE 4: STATIONS SHOWING MAXIMUM CORRELATION COEFFICIENT FOR ALL COMBINATION OF STATIONS.

Sl.No.	Raingauge Station	Value of corelation co-efficient	Combination of Stations
1.	Imamganj	0.898	29
2.	Sherghati	0.902	28
3.	Karpi	0.900	27
4.	Deo	0.864	26
5.	Makhdampur	0.865	25
6.	Chhattarpur	0.796	24
7.	Tekari	0.768	23
8.	Koch	0.751	22
9.	Aurangabad	0.849	21
10.	Gurua	0.834	20
11.	Madanpur	0.835	19
12.	Kutumba	0.790	18
13.	Fatuah	0.756	17
14.	Goh	0.693	16
15.	Ghosi	0.684	15
16.	Rafiganj	0.628	14
17.	Kurtha	0.601	13
18.	Partabpur	0.627	12
19.	Manatu	0.598	11
20.	Masaurhi	0.605	10
21.	Kako	0.603	09
22.	Obra	0.731	08
23.	Punpun	0.640	07
24.	Jahanabad	0.620	06
25.	Nabinagar	0.519	05
26.	Patna	0.700	04
27.	Hariharganj	0.685	03
28.	Paraiya	0.921	02
29.	Dumria	1.000	01

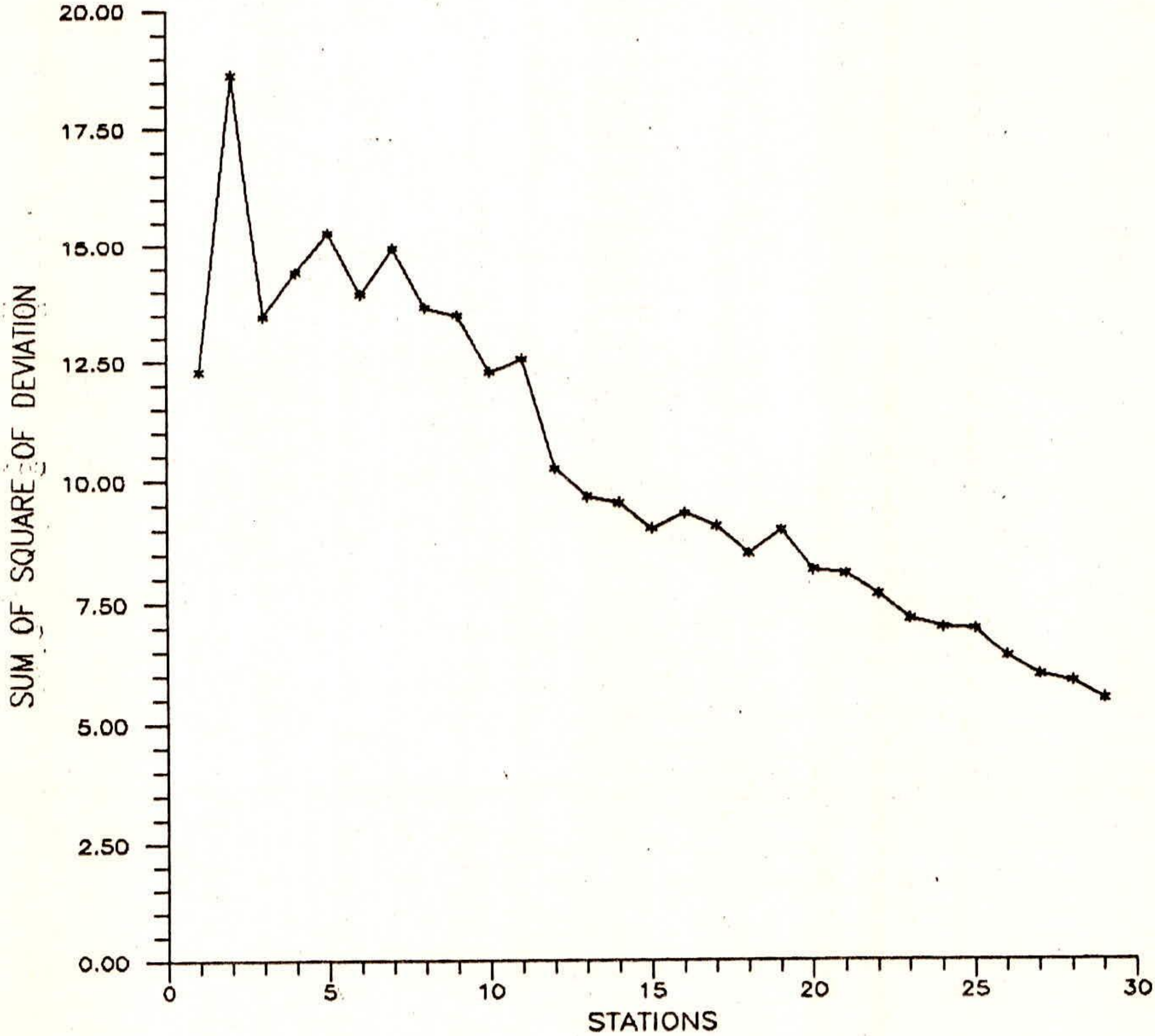

FIG.6: KEY STATION NETWORKS USING HALL'S METHOD

TABLE 5: MATRIX OF CORRELATION BETWEEN STATIONS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1 PATNA	1.0000																												
2 FATUAH	.3463	1.0000																											
3 PUNPUN	-.0388	.1553	1.0000																										
4 MASAURI	.0698	.2393	.2025	1.0000																									
5 KAKO	.2551	-.0595	.1177	.2445	1.0000																								
6 J'BAD	.6230	.3023	.0004	.3208	.1811	1.0000																							
7 KARPI	.4487	.4834	.1089	.3676	.6337	.4563	1.0000																						
8 GHOSI	.4016	.3276	.1610	.3843	.1155	.7363	.2658	1.0000																					
9 KURTHA	.0691	.0177	-.1292	.2343	.7616	.2513	.5021	.1705	1.0000																				
10 Mk'PUR	.4426	.2046	.4490	-.2621	.2143	.2601	.4924	.1337	-.1032	1.0000																			
11 GOH	.1389	.6466	.0924	-.1769	.2514	.1771	.5503	.1199	.2622	.4266	1.0000																		
12 TEKARI	.0351	.2235	.3785	.2918	.2179	.4079	.4858	.4056	-.0435	.5742	.3606	1.0000																	
13 KOCH	.1677	.1994	.2956	.1930	.2215	.5221	.3928	.5197	.3830	.5445	.2805	.5581	1.0000																
14 OBRA	.5729	.4519	.2072	.0759	.3118	.4182	.5425	.3217	.1099	.7154	.4692	.5018	.6448	1.0000															
15 R'GANJ	.2502	.5522	.1175	-.1941	.2806	.3044	.6360	.1212	.1384	.5255	.7531	.6270	.4434	.5928	1.000														
16 PARIYA	.0677	.4463	-.0236	.0355	-.6606	.0779	.0360	.0277	-.3683	.2035	.1839	.0549	.2717	.2476	.0988	1.0000													
17 A'BAD	.4976	.4334	.4782	-.0693	.2832	.3115	.3149	.3241	-.0136	.7136	.5254	.5389	.4610	.7180	.6286	-.0174	1.0000												
18 GURUA	-.2553	.1502	-.0020	.1507	-.5878	-.0092	-.1786	-.0363	-.2625	-.0665	-.3312	.0468	.2749	-.0943	.0064	.5795	-.2628	1.0000											
19 Md'PUR	.5924	.1393	.1651	-.2222	.3551	-.0471	.2000	-.0191	.0494	.5819	.1896	.0465	.1918	.5755	.3128	-.0977	.7238	-.3065	1.0000										
20 DBO	.5430	.2257	.0211	-.1403	.3223	.5233	.4324	.4345	.1949	.7288	.4628	.5517	.7221	.8483	.6299	.1062	.7436	-.1605	.5964	1.0000									
21 KUTUMBA	.0132	.3069	.0150	-.0736	.0000	.1096	.1977	.4660	.0062	.0032	.1702	-.0273	-.0002	-.0225	.0895	.0053	-.1483	-.0334	-.1783	-.0539	1.0000								
22 Nb'GAR	.7245	.5079	.1406	.2639	.4646	.6268	.6136	.5667	.3175	.5514	.3811	.4411	.6377	.8988	.5343	.0544	.7061	-.1308	.5774	.8173	.0781	1.0000							
23 H'GANJ	.7478	.2381	.3670	.3899	.4971	.2307	.3695	.2106	.1005	.5368	.1930	.1215	.1918	.6951	.2033	-.1687	.7132	-.4911	.8134	.5321	-.0850	.7297	1.0000						
24 S'GHATI	.7012	.6435	.0503	.2053	.2615	.7837	.5158	.5076	.3243	.3112	.4589	.2587	.4422	.5831	.5482	.0904	.5714	-.0334	.2637	.5549	-.0459	.7648	.4493	1.0000					
25 I'GANJ	.2507	.5318	-.0887	.4022	.5456	.2969	.6383	.2111	.4263	.1336	.4504	.3662	.3432	.7193	.5018	-.0569	.3993	-.1592	.2947	.4992	.0071	.7659	.4657	.5641	1.0000				
26 DUMARIA	-.0317	-.3159	-.2104	.2292	.3762	.2650	.2646	.3076	.1481	-.0978	-.2716	.3380	-.1173	-.1404	.1348	-.5347	-.2358	-.0279	-.3221	-.0668	-.0775	-.0185	-.1914	.0390	.1836	1.0000			
27 P'PUR	.3477	.3679	.3041	.1387	-.2084	.6812	.3221	.6575	-.0613	.5174	.2617	.4738	.6785	.7500	.2960	.4340	.6567	.0084	.4024	.7484	-.0123	.7462	.5596	.5848	.2730	-.3034	1.0000		
28 C'PUR	.5346	.2699	.0766	.1462	.5110	.2260	.6229	.0272	.4496	.5343	.3432	.2410	.4440	.5147	.5844	.0025	.5761	-.0513	.6680	.5924	-.3294	.6080	.5210	.5922	.3975	.0248	.3806	1.0000	
29 MANATU	.6632	.0230	-.0622	-.1597	.2491	.2211	.2795	.0951	-.0517	.5872	.3408	.2310	.2045	.5254	.3993	.0314	.5564	-.4623	.7876	.7549	-.1802	.5192	.6553	.2854	.1792	-.1789	.5609	.5820	1.0000

J'BAD = JAHANABAD, MK'PUR = MAKHDAMPUR, R'GANJ = RAFIGANJ, A'BAD = AURANGABAD
Md'PUR = MADANPUR, N'GAR = NABINAGAR, H'GANJ = HARIHARGANJ, S'GHATI = SHERGHATI,
I'GANJ = IMAMGANJ, P'PUR = PARTESPUR, C'PUR = CHATTARPUR

TABLE 6: AVERAGE DISTANCE AND AVERAGE CORRELATION COEFFICIENT FOR RAINGAUGE STATIONS IN PUNPUN BASIN

Sl. No.	Distance	No of Combinations	Mean Distance	Mean Correlation Coefficient
1.	0 - 05	01	4.90	0.5681
2.	05 - 10	3	8.57	0.0711
3.	10 - 15	10	12.79	0.4200
4.	15 - 20	24	18.13	0.2526
5.	20 - 25	20	21.51	0.2860
6.	25 - 30	22	27.87	0.3403
7.	30 - 35	24	33.02	0.2997
8.	35 - 40	21	38.12	0.3424
9.	40 - 45	27	42.73	0.3836
10.	45 - 50	24	47.45	0.2728
11.	50 - 55	24	52.11	0.2564
12.	55 - 60	17	57.64	0.2947
13.	60 - 65	19	62.70	0.2426
14.	65 - 70	18	67.55	0.2442
15.	70 - 75	14	72.22	0.2233
16.	75 - 80	12	78.20	0.2807
17	80 - 85	16	82.11	0.2672
18.	85 - 90	16	87.57	0.2607
19.	90 - 95	14	92.11	0.2196
20.	95 - 100	4	98.33	0.1634
21.	100 - 105	9	101.96	0.3408
22.	105 - 110	14	108.05	0.2668
23.	110 - 115	8	111.48	0.4102
24.	115 - 120	7	118.00	0.3401
25.	120 - 125	7	123.46	0.4124
26.	125 - 130	6	127.47	0.1304
27.	130 - 135	4	132.35	0.2855
28.	135 - 140	3	137.68	0.0622
29.	140 - 145	4	142.08	0.3014
30	145 - 150	5	148.28	0.2826
31.	150 - 155	4	150.85	0.0174
32.	155 - 160	3	157.50	0.1741
33.	160 - 165	0	000.00	0.0000
34.	165 - 170	2	168.00	0.3113
35.	170 - 175	1	170.40	0.2699
36.	175 - 180	1	178.50	0.6632

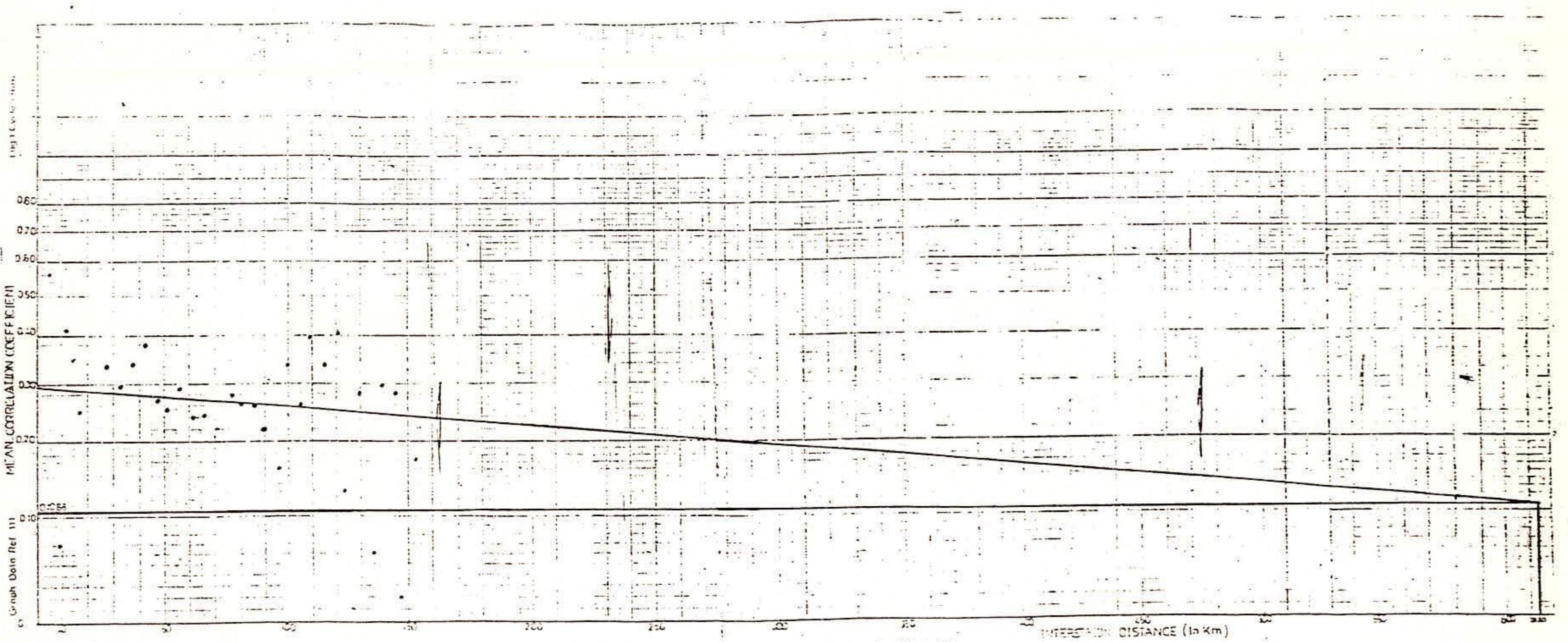

FIG. 7 RELATION BETWEEN MEAN CORRELATION COEFFICIENT AND INTERSTATION DISTANCE

TABLE 7 : THE VALUES OF RELATIVE ERROR(Z) AS A FUNCTION OF NUMBER OF RAINGAUGES(N)

Sl. No.	N	Z (%)
1	1	10.74
2	2	07.55
3	5	04.75
4	10	03.35
5	15	02.73
6	20	02.36
7	25	02.11
8	26	02.07
9	27	02.03
10	28	01.99
11	29	01.93
12	35	01.78
13	40	01.67
14	45	01.57
15	50	01.49
16	55	01.42
17	60	01.36

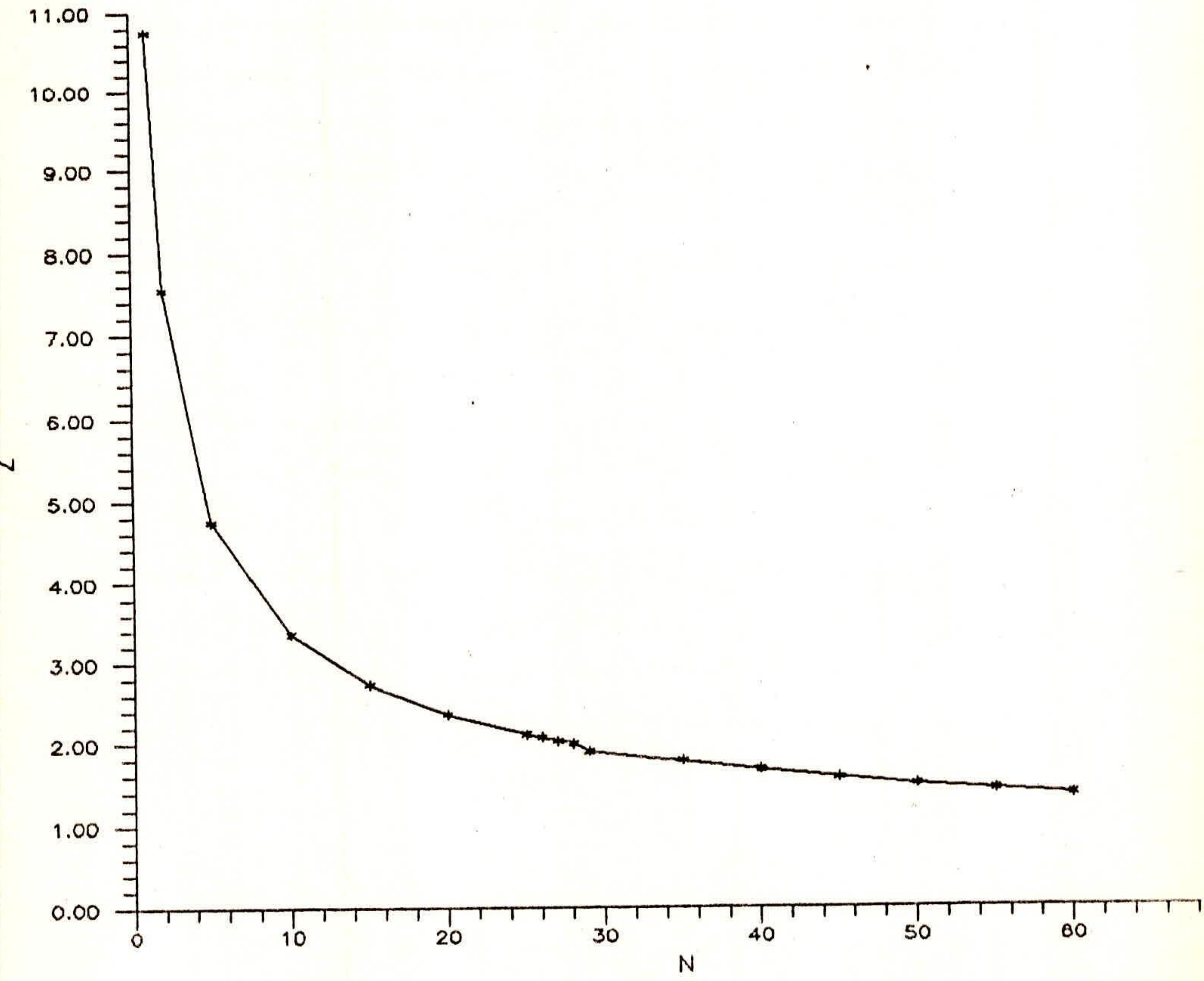

FIG.8 : VALUES OF Z IN RELATION TO N

assumption that the spatial variability of rainfall can be quantified through a spatial correlation function. Table 5 gives the cross-correlation of inter station in Punpun basin and the average distance and the average correlation for stations falling within each interval are given in Table 6..Fig. 7. shows the relationship between the distance and the correlation on semi log paper. The value of $\int(o)$ as read off the logarithmic ordinate which is intercepted by the extrapolated straight line fitted by eye to the plotted points. The value of $\int(o)/e$ is calculated as 0.1088 and the corresponding value of d_o is 613.80 km. (e=2.718).

Table 7 gives the variation of relative error (Z) with number of gauges (n) and the variation is shown in Fig.8. As may be seen from the graph that the relative error is decreasing as the number of raingauges station are increasing. But the changes in relative error is very less as we increase the number of raingauge stations after 25th station. Therefore, it is determined that the 25 station already installed in the Punpun catchment are sufficient for hydrological and hydrometeorological studies.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The precipitation gauge network design of a catchment incorporates knowledge concerning the physical and stochastic nature of the hydrologic processes into a framework that accounts for the effects on future water resources decisions. Estimation of number and location of the precipitation gauge stations have been analysed in Punpun catchment of Ganga river system using WMO guidelines, Optimal raingauge network techniques, Hall's method (key station method) and Kagan's method (Spatial Correlaltion techniques).

From the analysis of Precipitation gauge network design of Punpun catchment, the following points are concluded :

1. The daily rainfall data available only for the years 1974-86 from Hydrology Cell, Water Resources Department, State Government, Bihar were utilised for network design of precipitation gauge stations.
2. The data of Central Water Commission were not utilised because there are only few precipitation gauge stations in the Punpun catchment and available data are not sufficient to fulfil the requirement of network design for the basin.
3. WMO guidelines for the Punpun catchment suggests that according to the topography of Punpun basin the

required number of raingauges are 20 (Table 8).

4. The Optimal Raingauge Network Design technique results indicated that by considering the catchment as a whole the no. of raingauges required in the catchment, for 10 percent error, are 2 whereas for 5 percent error the no. of raingauges required for the catchment are only 5 (Table 8).

Considering the district wise distribution of precipitation gauge stations, the results obtained by using the above technique indicates that the required no. of precipitation gauge stations are 15 for 5% error and 6 for 10% error.

5. The key station network (Hall's) method indicates that 29 precipitation gauge stations are required for catchment (Table 8).

6. The Spatial Inter Station Correlation (Kagan's) method indicates that 25 precipitation gauge stations are required for catchment (Table 8).

7. The overall results have broadly indicated that the rainfall pattern is almost same in the catchment.

8. It is concluded that there should appropriate criteria for designing the network for hydrological purpose.

9. Due to lack of self recording raingauge in the catchment any modelling for forecasting seems to be difficult. Therefore, a better network of raingauge stations and self recording Raingauge stations is necessary.

TABLE 8: COMPARISON OF VARIOUS METHODS FOR RAINGAUGE REQUIREMENT

Name of Basin			PUNPUN
Existing no. of Precipitation Gauges			29
<u>No. of Precipitation Gauges required on the basis of</u>			
1. WMO Guidelines			20
2. Optimal Raingauge Network Design for			
(a) Entire catchment			
(i) 5 % error			5
(ii) 10 % error			2
(b) District wise			
(i)	Patna-	5 % error	3
		10 % error	1
(ii)	Gaya-	5 % error	5
		10 % error	2
(iii)	Aurangabad-	5 % error	4
		10 % error	1
(iv)	Palamu-	5 % error	2
		10 % error	1
(v)	Hazaribagh-	5 % error	1
		10 % error	1
3. Key Station Network Method			29
4. Spatial Correlation Analysis			25

7.2 Recommendations

If one carefully observes the various method of design of precipitation gauge network the following points emerges.

1. The guidelines which are given by W.M.O are on the basis of catchment area and topography. This method is normally suitable in those areas where no rainfall data are available.

2. Optimal raingauge network design shall consider coefficient of variation which will strengthen the design of existing network.

3. Key station network considers coefficient of correlation of storm data. This method can be used to locate the key stations in the basin and these key stations must be operational during flood period.

4. Spatial correlation analysis considers rainfall data and interstation distances. This method is more precise and accurate. Therefore this method can be used in other similar basins.

From the analysis of Punpun basin for ideal network of precipitation gauge stations and after using the four methods with the available data and comparison with the existing network it is recommended that under the situation it would be appropriate to use the analysis provided by Spatial correlation method. The advantage of this method is mainly the consideration of rainfall data and interstation distances.

There are 29 raingauge stations in the basin. The spatial correlation analysis concluded that 25 stations are sufficient. Hence the Isohytel overdrawn and preliminary analysis perform to conclude and identify stations which can be deleted. This analysis is presented in figure 9. Based on the analysis the station 1. **Kako** 2. **Kurtha** 3. **Koch** 4. **Kutumba** can be discontinued. However as no hydropower and irrigation project presently operational in the basin and number of proposed projects are under investigation it would be desirable that all stations are continued. This would provide necessary data, though more than required. However for a new project this would be welcome information.

Keeping in view the hydrologic similarities of other basins in the region it is recommended that spatial correlation analysis can be performed and ideal precipitation gauge network designed. This report will come as a handy tool for designing networks for other basin in the region.

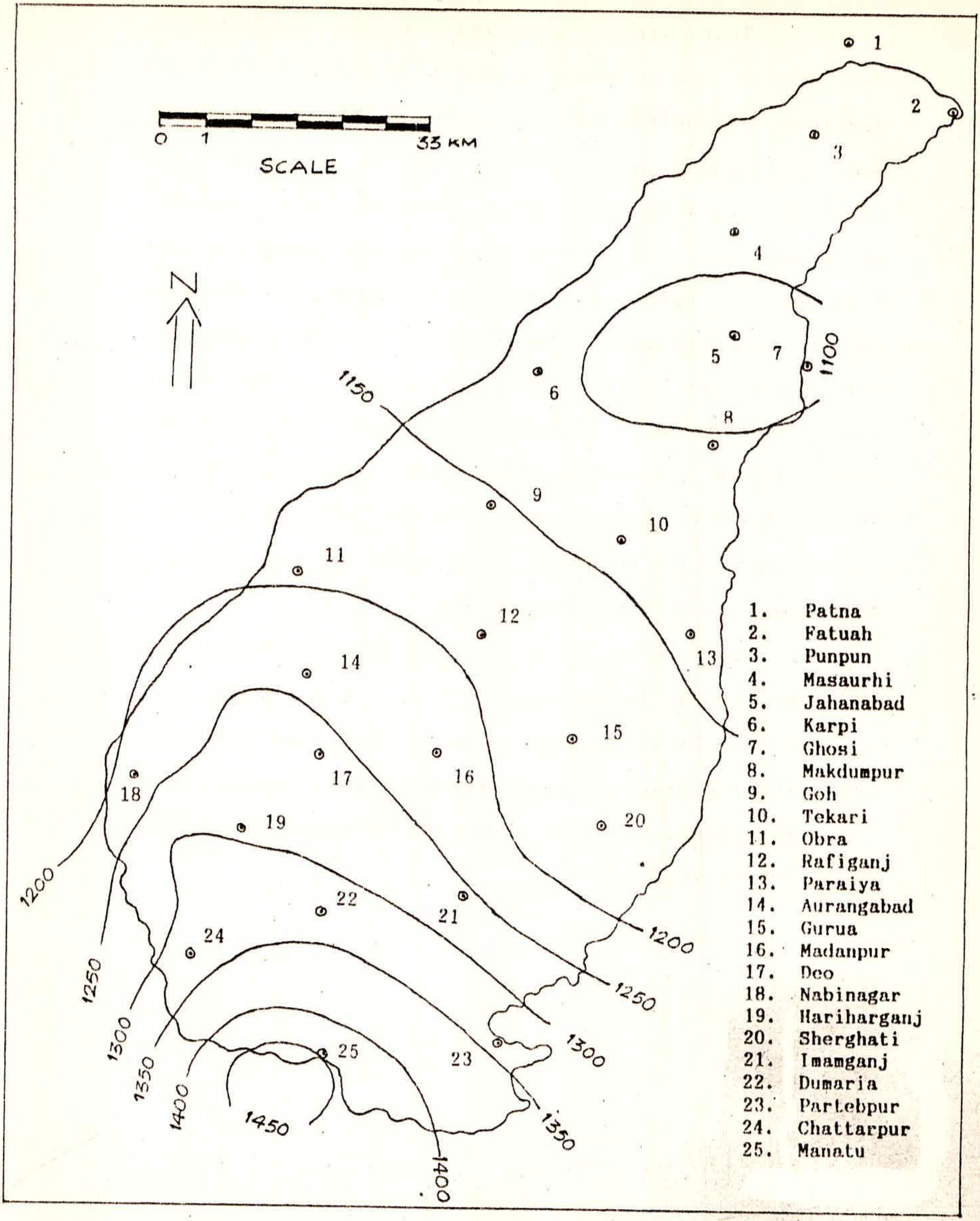

FIG 9. DISTRIBUTION OF PRECIPITATION GAUGES BY SPATIAL CORRELATION METHOD

APPENDIX I

Optimal Network Design

A stepwise procedure for the computation of the number of raingauges required (N) using coefficient of variation (C_v) of the rainfall in space and some required accuracy criteria (ϵ) is evaluated.

In the present study Punpun catchment having 29 raingauge stations is selected . The precipitation data for the years 1974- 86 are available for the analysis. The mean seasonal rainfall of these stations are listed in Table 1.

The coefficient of variation of rainfall is evaluated to be C_v = 11.1159. The number of raingauges required to estimate the average rainfall with a percentage error of 10 % or less is given by

$$N = (11.1159 / 10)^2 = 1.2 \qquad (1)$$
$$= \text{say } 2$$

The number of raingauges required to estimate the average rainfall with a percentage error of 05 % or less is given by

$$N = (11.1159 / 05)^2 = 4.94 \qquad (2)$$
$$= \text{say } 5$$

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