ANALYSIS OF RAINFALL DATA FOR ESTIMATING THE INTENSITY DURATION-FREQUENCY RELATIONSHIP FOR THE NORTH-EASTERN REGION OF BANGLADESH

A Thesis

by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED BY <u>MD. ABDUL MATIN</u> ENTITLED <u>ANALYSIS OF RAINFALL DATA FOR ESTIMATING THE INTENSITY - DURATION-FREQUENCY RELATIONSHIP FOR THE NORTH-EASTERN REGION OF BANGLADESH</u> BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING (WATER RESOURCES).

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ABSTRACT

This thesis deals with the analysis of extreme value rainfall data for the north-eastern region of Bangladesh. Daily maximum rainfall data for the districts of Sylhet, Dhaka, Mymensingh, Jamalpur, Tangail and Comilla have been analysed and discussed in this thesis. Probable maximum rainfall has been estimated for all the 68 stations within the region using Harshfield's revised approach of PMP. Rainfall data corresponding to different return periods have been calculated by using the double exponential distribution function. Generalized maps for one-day probable maximum rainfall and daily rainfall having 2 years return period have been prepared for the region under study. An empirical equation has been proposed to calculate the daily rainfall data for different return periods from the daily 2-year value. Short duration rainfall data i.e. 5 min, 10 min, 15 min, 30 min, 1 hour and 2 hour data having 2 years return period have been calculated on the basis of U.S. depth-duration ratios and Hershfield & Wilson's diagram. Calculated short duration data has been presented in the form of isohyetal maps. An intensity-duration-frequency curve has also been developed and presented for the region under study.

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M.A.M.

TABLE OF CONTENTS

CHAPTER

Page

LIST OF TABLES

LIST OF FIGURES

FIGURE | Page

FIGURE | | Page

NOTATIONS

I	-	Rainfall intensity, inch/hour
K	-	Frequency factor
M	-	Rank of item in the series
N	-	Sample size
P_T^t	-	Maximum t-minutes rainfall depth in inch for T-year return period
P_T^{24h}	-	Maximum 24-hour rainfall depth in inch for T-year return period
S_N	-	Standard deviation of sample
S_{N-1}	-	Standard deviation of series omitting highest value in the series
T	-	Return period in years
t	-	Duration of rainfall event in minutes
U	-	Mode or location parameter
x	-	Initial variate
$\bar{X}_N$	-	Sample mean
$\bar{X}_{N-1}$	-	Mean of the series omitting highest value in the series
X_T	-	Annual maximum daily/hourly rainfall in inch
X_{max}	-	Highest value in the data series
y	-	Reduced variate
$\bar{Y}_N$	-	Theoretical quantity
σ_N	-	Theoretical quantity
β	-	Scale parameter which is analogous to standard deviation σ.

CHAPTER I

INTRODUCTION

1.1 General

Rainfall is an input to the hydrologic system. Any type of input-output analysis requires the interpretation of the input data. Information on rainfall data is important in various types of hydrologic studies such as (1) Storm analysis over a catchment (2) Depth-area-duration studies (3) Intensity-duration-frequency analysis (4) Estimation of design flood (5) Stream flow forecasting and reservoir regulation (6) Probability analysis to determine the supplimentary irrigation potentialities etc.

Storm analysis over a catchment can be classified into three types of studies: viz. (a) Point (or station) analysis (b) Time distribution analysis and (c) Areal distribution analysis. In case of point analysis, the rainfall data are usually obtained from the measurements in non-recording gauges. The time distribution analysis is usually made by data obtained from recording raingauges. The data are copied from the graphic chart and the rainfall is accumulated for the storm period. A mass curve is drawn for the accumulated rainfall data. This curve permits the interpretation of short period intensity data of the storm. Comparison of several mass curves allows the interpretation of storm movement over the region. The mass curve may be used to determine a generalized summery of the performance of a particular storm for comparison with other stations or with other storms.

The depth-area-duration analysis was devised to determine the greatest rainfall amounts for various durations and various size areas over different regions for a certain season. A depth-area-duration curve expresses graphically the relationship between a progressively decreasing average depth of rainfall over a progressively increasing area from the centre of the storm outwards to its edge. It can be constructed from any isohyetal map by planimetering the area associated with each isohyete of rainfall depth and by plotting the progressively decreasing average depth as ordinates and the corresponding areas as abscissa. These curves are used in determining the size of the design rainfall and design flood for a project by the storm transposition method.

In case of rainfall intensity-duration-frequency analysis, first the magnitudes of rainfall intensities of various frequencies are derived for a number of selected durations such as 5 min, 10 min, 15 min, 60 min and so on. Then the average intensity is plotted against duration for a particular frequency. Such curves are called intensity-duration-frequency curves.

Generally the information on rainfall may be presented in many ways. For quick reference most countries have equal rainfall contour maps (isohyetal maps) for different durations. For given locations prediction formulae or graphs are also available. The local historical information, when analysed and plotted gives yield versus return period data for various durations, either in graphical form or as a prediction formula.

A knowledge of extreme value point rainfall of an area is essential for the proper planning and design of small hydraulic structures. Storm sewers in urban development, culvert on highways and railways, drainage system on air-field etc., may all be designed more economically when the frequencies of rainfall intensities are known.

1.2 Objectives of the Study

The greatest need for information relating to rainfall frequencies is apparent in various economic studies and in efficient design of hydrological projects. In this regard, the designer are often required to know (a) What is the largest rainfall of a particular duration that a basin is likely to experience, (b) how often does a rainfall of a particular magnitude occur, (c) what is the probable maximum rainfall for a given location to be expected etc.

A review of partinent literature shows that all the rainfall analysis in our country have been directed toward the agricultural potentialities and are related to long-duration rainfall data. No attempt has so far been made to study the short duration intensities in Bangladesh. Therefore, the followings were chosen as the principal objectives of this study over the North-Eastern region of Bangladesh comprising the districts (old) of Sylhet, Dhaka, Mymensingh, Jamalpur, Tangail and Comilla.

(1) Preparation of a generalized intensity-duration-frequency curve for the whole region under study.

(2) Preparation of a generalized isohyetal map for one-day 2-year rainfall using the double exponential distribution function.

(3) Development of an empirical relationship so that one-day maximum rainfall for different return periods may be obtained directly with the help of 2-year generalized map.

(4) Preparation of a generalized isohyetal map of one-day probable maximum rainfall using the Hershfield Technique.

1.3 Statement of the Problem

Estimation of PMP: In situations where no risk can be undertaken due to failure of structures, the design is normally based upon the extreme rainfall that a basin is likely to experience. The estimate of extreme rainfall has in the recent years come to be known as probable maximum precipitation (hereafter referred as PMP). It is defined as the magnitude of storm rainfall which represents the upperlimit of precipitation over a place or an area within a given time.

In this study PMP has been worked out for 68 raingage stations in the north-eastern zone of Bangladesh using the technique of Hershfield [14] .

Rainfall depth for different return period: In case of small hydraulic structures such as culverts, bridges, etc. where cent percent safety in not required, the design is usually based upon maximum rainfall corresponding to a certain return period. An attempt has, therefore been made here to study the maximum one-day point rainfall over the region for different return periods from 2 to 100 years. The double exponential distribution function has been used to analyze the daily maximum rainfall data for all the 68 stations over the region.

Development of short duration rainfall data: Maximum rainfall intensities for short durations such as 5, 10, 15, 30 minutes, 1 and 2 hours are needed by civil engineers because the frequencies of short duration, high-intensity rainfalls form an important part of the information required for many projects. But records for short-duration rainfall are generally scarce because their collection requires continuously recording raingauges. Short-duration rainfall data are extremely scarce in developing countries like Bangladesh. It is therefore necessary to use rainfall relationships to develop short-duration rainfall data useful in Bangladesh.

Bell [3] , Reich [22] Hershfields, Weiss, and Wilson [9] have demonsrated that United States rainfall relationships can be applied to other parts of the world e.g. South Africa, Alaska, Hawaii, Pueto Rico and Australia. Depth-Duration ratios of the other countries as reported by Bell [3] tend to confirm the United States values and Riech [22] suggested that U.S. depth-duration ratios are applicable throughout the world. Therefore, in this study, short-duration rainfall depth-duration-frequency data for the north-eastern zone of Bangladesh has been developed on the basis of rainfall relationships as recommended by U.S. Weather Bureau [12] and Hershfield & Wilson nomogram [9] .

All data analysed in this study were obtained from Bangladesh Water Development Board. It is expected that this study will be of great help for the engineers working with different water resources projects.

CHAPTER II

REVIEW OF LITERATURE

2.1 Determination of Probable Maximum Precipitation

2.1.1 Traditional Approach

A large number of studies of probable maximum precipitation have been conducted over the past 25 years in United States. These studies generally used the "traditional approach" which are composed of a combination of theoretical and empirical method [24,25]. Hydro-meteorological technical report no. 33 [24] , prepared on the basis of traditional approach, presents generalized charts and diagram giving PMP estimates for several combinations of areas and durations east of 105°W. In a paper [1] Ackermann questioned the degree of acceptance of the estimates derived from the traditional approach. Hershfield [14] reported that several studies using this approach have terminated with very divergent results for the same area. World Meteorological Organization Guide to Hydro-meteorological practices [26] has recommended Hershfield Technique which is applicable to point rainfall values for arriving at tentative estimates of PMP for which long-term daily rainfall data for individual stations are available but where the adequate data for applying the traditional approach are lacking.

2.1.2.1 Hershfield's Earlier Technique

Hershfield [11] proposed a method for systematic analysis of precipitation data based upon statistical consideration for the estimation of extreme rainfall. Most of the relationships presented in Hershfield's study were based on 24-hour rainfall data collected from about 2600 stations (95000 station-year data). In 1961, Hershfield established that there are two things which should be considered when estimating PMP; more data and statistical technique. Long records of rainfall data are now available and the annual maximum 24-hour amounts have been extracted from climatic tabulation. Hersfield compared the results based on his method of PMP analysis with those obtained from traditional approach and revealed that the estimates by latter approach depended heavily on meteorological parameters such as precipitable water in atmosphere, inflow winds etc. Hershfield then concluded that his method would provide a basis for the judicious use of rainfall design criteria by estimating PMP.

Hershfield used chow's [5] general equation for frequency analysis in developing his earlier technique for the computation of PMP.

In 1951 Chow V.T. expressed the general equation for a random hydrologic variable as

$$X_T = \bar{X} + KS \qquad \ldots \qquad \ldots \qquad (2.1)$$

where X_T is the rainfall having a return period T in years. $\bar{X}$ and S are the mean and standard deviation respectively of the series of annual maximum. K is the frequency factor which depends on the type of distribution used.

Hershfield used equation (2.1) in the form of

$$X_M = \bar{X}_N + K_M S_N \quad \ldots \quad \ldots \quad (2.2)$$

where X_M is the magnitude of PMP for a given station of a particular duration $\bar{X}_N$ and S_N are the adjusted mean and standard deviation of the annual series respectively. Here both mean and standard deviation should be adjusted for (a) Maximum observed rainfall (b) Sample size and (c) Data defficiency (observational day series versus 1440-minute series).

2.1.2.2 Defination of Independent K_M

The value of K_M in equation (2.2) is obtained from the following equation

$$K_M = \frac{X_{max} - \bar{X}_{N-1}}{S_{N-1}} \quad \ldots \quad .. \quad (2.3)$$

where the mean ($\bar{X}_{N-1}$) and standard deviation (S_{N-1}) of annual series for each station are found out by omitting the highest value in the series, X_{max} is the highest value of data in the series. The term "K_M" as used by Hershfield, is known as independent K_M.

2.1.2.3 Empirical Equation for Estimating PMP

Using the above procedure Hershfield [11] calculated the values of K_M for 2648 stations in United States. He observed that there were four values of K_M between 13 and 15. The value 15 was considered as the highest because it enveloped all the maximum 24-hour rainfall and was referred as the world envelope value. Therefore equation (2.2) may be expressed as an empirical form for estimating PMP as

$$X_M = \bar{X}_N + 15\ S_N \qquad \ldots \qquad \ldots \qquad (2.4)$$

2.1.3 Use of Regional Envelope Value of K_M

Wilson [27] , Mazumder & Rangarazan [19] reviewed the idea of Hershfield and found that PMP values using equation (2.4) overestimated the precipitation data for some region. They therefore, pointed out that the one single value of K_M is not transposable universally throughout the world. In a study of rainfall over Uttar Pradesh in India, Dhar & Kamte [7] found that the highest value of K_M for 24-hour duration was 12. In 1978 Changrancy and Hem Raj [4] used Hershfield's technique for estimating PMP for Madhya Pradesh region in India and reported that the values of K_M were generally higher for areas of relatively higher monsoon rainfall or of higher magnitude of one-day maximum rainfall. They, therefore, modified the Hershfield's equation (eqn.2.4), using the enveloping value of K_M applicable to Madhya Pradesh, in the form of $X_M = \bar{X}_N + 7\ S_N$. It is, therefore advisable to use regional envelope value of K_M instead of using world envelope value.

2.1.4 Harshfield's Revised Approach

In 1965 Hershfield [14] made an extension and revision of paper [11] in which a large number of 24-hour rainfall data were utilized for arriving at an enveloping rainfall curve. In his study, he considered the series of annual maximum rainfall for different durations ranging from 5-min to 24-hour. Plotting of the values of K_M against the mean for different duration, he obtained a family of curves as shown in Fig. 1. These curves show that K_M is a function of storm duration and mean of annual series and has a tendency to decrease with increase of rainfall magnitude of different duration.

2.2. Probability Distributions Used in Rainfall Frequency Analysis

2.2.1 A Review on Comparison of Some Methods of Distribution

In 1959 Huff and Neill [16] compared five distributions for their ability to estimate the largest rainfall value in Illinois. The distributions included Gumbel (extreme-value distribution-I), Lognormal, Frechet, Log-skew and Jekinson method. Analysis were performed on both seasonal and annual maximum for storm period of one to ten days. Results of this study indicated that no marked superiority was obtained from any of these methods. In a paper, Hershfield and Kholar [10] appraising the predictive value of the Gumbel procedure from 60-minute rainfall data observed that this procedure was acceptable for practical purposes. Again Hershfield [15] made an extension to two other methods and additional duration to compare the three extreme-value procedures of rainfall distribution. The extreme-value procedures were Fisher-Tippet type-I distribution fitted by both Gumbel and Lieblin method and lognormal distribution fitted by method of moments. He then concluded that type-I distribution fitted by Gumbel procedure was the best of three procedures for estimating the probability of extreme value rainfall data (Fig. 2). Chow [6] also applied this procedure to study the rainfall intensity-frequency in Chicago, Illinois and the same method has therefore been selected for this present analysis of rainfall data in Bangladesh.

2.3. Double Exponential Distribution Function

The double exponential distribution function of the largest value in its cumulative form is defined as

$$P = F(X) = \exp\left(-e^{-y}\right) \quad \dots \quad \dots \quad (2.5)$$

and $$y = \frac{x - U}{\beta} \quad \dots \quad \dots \quad (2.6)$$

where y is the dimensionless reduced variate, x is the initial variate, the quantity U is the mode or location parameter of the distribution, β is a scale parameter which is analogous to the standard deviation, σ, of normal distribution. The parameters U and β completely define the distribution.

Combining above two equations, the distribution function may be written as $F(x) = \exp\{-\exp(\frac{1}{\beta}(x-u))\}$. It was introduced for extreme values by R.A. Fisher & I.H. Tippet [28] . This function is sometimes known in Hydrology as Gumbel distribution because of Gumbel's various studies using this distribution in the flood frequency analysis.

2.3.1 Prediction Equation for the Double Exponential Distribution Function

This involves the computation of the sample mean $\bar{X}_N$ and the standard deviation S_N of annual series of sample of size N. The estimators of two parameter U & β are given by

$$U = \bar{X}_N - \frac{\bar{y}_N}{\sigma_N} S_N \qquad \dots \qquad \dots \qquad (2.7)$$

$$\beta = \frac{S_N}{\sigma_N} \qquad \dots \qquad \dots \qquad (2.8)$$

where $\bar{y}_N$ and σ_N are the theoretical quantities which are function of sample size only. Gumbel provides a table of values (Table-6) for $\bar{y}_N$ and σ_N as function of sample size N. Therefore the prediction equation for rainfall magnitude

(x_T) may be expressed by the following function

$$x_T = U - \beta \ln \ \{\ln(\frac{T}{T-1})\} \quad \ldots \quad (2.9)$$

where T = Return periods in year.

2.4 Short Duration Rainfall Depth-duration-Frequency Relationship

2.4.1 Harshfield's and Reich's Study

The relationship described by Hershfield [13] and Reich [22] , provide a useful methods for estimating short duration rainfalls from long duration rainfalls and other readily available information. These methods seem indispensible in areas where the only useful data are of long durations and in such cases they probably provide the best available estimates of short duration rainfalls with return periods less than 10-years.

2.4.2 Maximum Rainfall Intensity-Duration Formulas

Several formulas have been proposed [6] for expressing rainfall frequency relations. Most of early ones were simple in form; they considered only one or two of the causal factors and were derived from localized data. Some formulas as found in present day literature are discussed below.

2.4.2.1 Jenkinson Formula

The relationships between rainfall intensity of different duration for considerable time period follow very closely a general function which approximates to a rectangular hyperbolic form. These equations applied over wide geographic areas permit the extrapolation of short-duration maximum intensity probabilities from available long-duration maximum intensity probabilities for local sites. The Jenkinson formula: $I = I_0\ (1 + BD)^{-n}$, for example relates maximum intensity (mm/h) for duration D(h) to an "instantaneous" maximum rainfall intensity (I_0) and a negative power function comprising duration (D) in hours and a coefficient (B), which increase in value with increase in annual rainfall magnitude.

2.4.2.2 Mecallum's Formula

An expression similar in form to the Jenkinson formula, but much simplified has been used with success in East Africa [20] and U.K. [23] for maximum rainfall intensities between 15 minute and 24-hour duration. ($I_t = \kappa\ t^{-n}$, where I_t is the rainfall intensity for duration t and κ and n are constants.

2.4.3 Depth-Duration and Depth Frequency Ratios

2.4.3.1 U.S. Weather Bureau and Hathways' Study:

The United Stated weather Bureau recommends one empirical relationship derived entirely from short-duration data [12] and shows that the t minute rainfall has a consistant ratio to the 1-hour rainfall of the same return period. These ratios are 0.29, 0.45, 0.57 and 0.79 for 5,10, 15 and 30 minute rainfalls respectively. The estimated errors associated with the ratios ranges from 5% to 8% for the whole United States, which is of the same order as the errors due to sampling deficiencies. A similar relationship was implied in an earlier study of short duration data in the United States by Hathway [8] who presented his findings in a graphical form.

2.4.3.2 Bell's Study

Bell F.C. [3] extended the depth-duration ratios of United States Weather Bureau upto 2-hr rainfall. Using 157 stations with more than 40-years data published in U.S. Weather Bureau Tech. paper no. 25. Bell computed mean 2-hour ratio as 1.25 with standard deviation of 0.08. This computation corresponds to an average error of approximately 6% and is shown in Fig. 3. Lines with slopes representing the 5 min, 15 min, and 30 min ratios given by U.S. Weather Bureau are also shown in Fig. 3. Depth-duration ratios of other countries as reported by Bell are summerized below:

Country		5 min	10 min	15 min	30 min	2-hour
U.S.A.		0.29	0.45	0.57	0.79	1.25
Australia		0.30	-	0.57	0.78	1.24
USSR	Max	0.37	-	0.61	0.87	1.40
	Min	0.26	-	0.49	0.71	1.20
Average		0.32	-	0.55	0.71	1.30

The above table shows that the variations among Depth-duration ratios found in USA, Australia and USSR are very small. Hence these ratios tend to support Reich's [22] suggestion that United States ratios may be applicable through-out the world.

Bell also proposed some empirical relationships for the high-intensity, short-duration rainfall depth.

$$\frac{P_T^t}{P_{10}^t} = 0.21 \ln T + 0.52, \quad 2 \leqslant T \leqslant 100 \quad \ldots \quad (2.10)$$

where P_T^t is the depth of t-minute, T-year return period rainfall and P_{10}^t is the depth of a t-minute, 10-year return period rainfall.

The depth frequency relationship was combined with depth-duration data by first expressing the ratios of P_T^t to 60-minute depth, P_T^{60}, as

$$\frac{P_T^t}{P_T^{60}} \text{ min} = 0.54\, t^{0.25} - 0.50, \text{ for } 5 \leqslant t < 120 \text{ min} \ldots (2.11)$$

and then combining equations (2.10) and (2.11) to give

$$P_T^t = (0.21 \ln T + 0.52)(0.54\, t^{0.25} - 0.5)\, P_{10}^{60} \quad \ldots \quad (2.12)$$

for $2 \leqslant T \leqslant 100$ years

and $5 \leqslant t < 120$ min

For locations where the records are inadequate, the following empirical relationships were proposed.

$$P_2^{60} = 0.17\, MN^{0.33} \quad \text{if} \quad 0 \leqslant M \leqslant 2.0 \quad \ldots \quad (2.13)$$

$$1 \leqslant N \leqslant 80$$

$$= 0.21\, M^{0.67}\, N^{0.33} \quad \text{if } 2.0 < M \leqslant 4.5$$

$$1 < N < 80$$

in which P_2^{60} = 2 year, 1-hour rainfall in inch

M = mean of annual maximum daily rainfall in inch

N = Mean annual number of thunderstorm days.

Bell also reported that 2-year, 1-hour rainfall may be used to estimate values for other durations and frequencies by using

$$P_T^t = (0.35 \ln T + 0.76)(0.54\, t^{0.25} - 0.50)\, P_2^{60} \quad \ldots \quad (2.14)$$

and claimed that this equation fit the curves by Hershfield and Wilson [9] diagram (Fig. 26), and Reich [22] with deviation less than 10%. He used data for Australia, south Africa, Hawaii and puteoricho, Alaska (Fig. 4) for evaluation of the above relationships and found the U.S. ratios of depth frequency would give reasonable estimate in most places of the would.

2.5. Rainfall Studies in Bangladesh

The rainfall distribution in Bangladesh reflect topography. For example, the Sylhet and the Chittagong districts are the two distinctly wet belts seperated by a wide dry zone. The two wet belts are the hilliest portion of the country. The highest rainfalls do not, however, coincide with the highest lands. The most intelligent guess on the basic reason for climate of Bangladesh is the differential heating of vast areas covered by land and water, which causes the monsoons, and the variations in the rainfall [18].

A detail rainfall study in Bangladesh was carried out by Manalo [18] and presented in his report "Agro-climatic survey of Bangladesh". In this report the author described the characteristic features of the climatic regimes of the country for evaluating the potentialities of cropping system. The appendix of the report contain 11 tables dealing with monthly data from 120 raingauge stations in 19 hydrological districts of Bangladesh. The results of the analysis was presented in the form of isohyetal maps representing mean annual rainfall, mean monthly rainfall, mean seasonal rainfall, number of months with rainfall 100 mm and 200 mm, months of start and end with rainfall 100 mm and 200 mm etc. To portray the succession of weather sequences during the year, Manalo prepared histograms of the monthly rainfall (Fig.5) over the stations. These graphs have little prognostic values for short period of one or two days but they tell us about the rainfall we should normally expect.

Fig. (6) shows Bangladesh' mean annual rainfall, which ranges from 1400 mm in dry Rajshahi area to over 5,000 mm in the Sylhet region. The Rajshahi is the driest part of Bangladesh. The Chittagong and the Chittagong Hill Tracts have rainfall not exceeding 3000 mm. In the extreme north-west, the Rangpur-Dinajpur area has an annual rainfall of from 2000 to 2400 mm. The monsoon bursts with its full fury over Bangladesh by July or August. It is active from June to October. The rainfall distribution during the monsoon period is indicated by the isohyets in Fig. (7). The pattern of this rainfall distribution is very similar to that of the mean annual rainfall.

Khan [17] estimated rainfall probabilities for 2-week running period using daily rainfall data for 36 years of record (1934-69) from 13 different locations. His analysis, is helpful for designing a proper cropping pattern and for determining the capacity of the supplimentary irrigation system.

A joint study by BWDB and UNDP [2] was made to determine the probabilities of heavy rainfall in Bangladesh. This study included rainfall duration from 1 to 6-day. In this study, 6-day duration was selected as an upper limit, because this period is consistant with critical period of inundation of the rice crop. The data sources used was the daily rainfall data from Bangladesh Meteorological Department as listed below:

Station	Length of record used
Comilla	1947-79
Dhaka airport	1954-80
Mymensingh	1947-80
Srimangal	1947-70
Sylhet	1947-80
Bogra	1947-80
Dinajpur	1947-80
Rajshahi	1951-80
Rangpur	1947-80

For each year of the record the annual maximum daily rainfall and the totals for the maximum consecutive 2-6 day periods were extracted. These data were then ranked in a probability plotting position according to Blom formula:

$$P = 1 - \frac{m - 0.375}{n + 0.25}$$

where m = position of item in the rank

n = total number of data item

and P = Probability of rainfall greater than a certain value

The data were than plotted on logrithum probability paper and estimates abstracted for return periods of 5, 10, and 20 years. The results of the analysis are shown in Fig.(8) and Fig. (9).

CHAPTER III

DATA COLLECTION

3.1 Source of Rainfall Data

The main source of daily rainfall data is the Bangladesh Water Development Board. Rainfall records of 24 hour duration are available in BWDB for a considerable time periods for a large number of stations. In order to have a longer record of rainfall for analysis, BWDB always preserve the 24-hour amounts in the form of data index card which were collected from more than 200 raingauge stations in different hydrological districts. For a particular water-year, annual rainfall data, number of rainy days in a year, monthly rainfall data, maximum depth-duration data etc., are also available in the data index card.

3.2 Study Region

One the basis of hydrological unit, Bangladesh may be devided into 4 regions (a) North-west (b) South-west region (c) South-east region and (d) North-east region. North-east region of Bangladesh comprises the hydrological districts of Sylhet, Mymensingh, Dhaka, Jamalpur, Tangail and Comilla.

According to climatic classification (Fig. 10) as shown in the appendix-B, the type 2.2 (2 to 4 month dry 7 to 9 month wet), covers the foothills of northern Sylhet. Likewise, type 3.2 (5 to 6 month dry, 7 to 9 month wet) covers the Sylhet in a meandering pattern. Type 3.3 (5 to 6 month wet, 5 to 6 month dry) covers the biggest part of the of the country including Dhaka, Mymensingh, Tangail and Comilla. The Sylhet-Mymensingh have at least one month with greater than 500 mm rainfall. The Charapunji (not in Bangladesh) which is the rainiest place in the world is located near the north-east of Sylhet. Hence it is imperative that the N-E zone of Bangladesh is comparatively wet over which the rainfall lasts for about seven months of the year in average. The present study of rainfall analysis covers the most rainy North-Eastern region of Bangladesh.

3.3 Data Collection and Presentation

All the stations within the study area were first verified for the entire gauge records. Stations to be used in this study were then selected. The principal criteria being that the record from 1961/62 to 1981/82 should be complete or nearly so. This exercise provided a network of 68 raingauge stations out of 76 stations in the region. The annual maximum daily data from all the 68 stations and 16 other stations from other parts of the country were extracted from BWDB data index cards (Table-2). The mean annual data, number of rainy of days greater than 0.01" were also collected from the same cards. To facilitate the use of the collected data in various analysis, all the data were presented in a tabular form.

An important aspect of the data processing was the checking of station location throughout the region, because this information is essential for the preparation of isohyetes of analysed rainfall data. The corrected station location was taken from water balance studies report (North-east data). In this report [2] , the gauge location published in Hydrological year-Book (Vol.1 Rainfall and evap. 1965/66), was checked against 1:50,000 topographic survey map. The corrected latitudes and longitudes of all the stations are given in the station index (Table-1).

Annual thunderstorm days data for various year from 1961 to 1970 over 23 different location in Bangladesh (Fig.11) were collected from climatological section, Bangladesh Meteorological Department (Table-3). To perform a particular comperative study, hourly rainfall data for the Sylhet and Dhaka station were also extracted from the BWDB water supply paper no. 19. These data are presented in Table-4.

CHAPTER IV

ANALYSIS OF DATA

4.1 Introduction

Experience has shown that many original data have partically no significance in the analysis because the hydrologic design of a project is usually governed by a few critical condition. The cases where the design is governed by the most critical conditions, the annual maximum data should be used for a particular analysis. The maximum values of annual observations are also ameanable to probability analysis because its items are casually independent and occur in a random fashion.

4.2 PMP Analysis

The mean ($\bar{X}_N$) and standard deviation (S_N) of the rainfall sample for each of the station were computed by the conventional procedures as given by

$$\bar{X}_N = \frac{\Sigma\ x}{N} \qquad \cdot\cdot \qquad \cdot\cdot \qquad (4.21)$$

$$S_N = \sqrt{\frac{\Sigma(x-\bar{X}_N)^2}{N-1}} \qquad \cdot\cdot \qquad \cdot\cdot \qquad (4.22)$$

The values of K_M were calculated by the equation

$$K_M = \frac{X_{max} - \bar{X}_{N-1}}{S_{N-1}} \qquad \cdots \qquad \cdot\cdot \qquad (2.3)$$

where K_M is the frequency factor defined by Hershfield.

On the basis of K_M and $\overline{X}_N$, an enveloping curve was prepared as shown Fig. 15. Using the K_M values from Fig. 15, PMP values were found out by using the equation as follows

$$X_M = \overline{X}_N + K_M S_N \quad \ldots \quad (2.2)$$

To obtain the final values of PMP, the computed PMP values were multiplied by the factor 1.13 (slope of the line of observational-day series verses 1440-minute series, shown in Fig. 14) to adjust for the deficiencies in observational day data [11] . Before calculating PMP values, all the $\bar{X}_N$ and S_N data were also adjusted by the empirical adjustment factors given by Hershfield [11].Fig. (12) and Fig. (13) shows the diagrams for various adjustment. The results of the PMP estimation are shown in Table-5.

4.3 Frequency Analysis

Daily maximum rainfall magnitudes for different return periods of each of the 68 stations were found out by using the equation:

$$X_T = U - \beta \ln \left(\ln \left(\frac{T}{T-1}\right)\right) \quad \ldots \quad (2.9)$$

where $U = \bar{X}_N - \frac{\bar{y}_n}{\sigma_N} S_N \quad \ldots \quad (2.7)$

and $\beta = \frac{S_N}{\sigma_N} \quad \ldots \quad (2.8)$

The predication equations for maximum daily rainfall and the computed rainfall data for return periods of 2, 5, 10, 20, 50 and 100-year for all the stations are shown in Table-7 and Table-8 respectively.

Average ratios of 5-year, 10-year, 20-year, 50-year and 100-year maximum rainfall data to 2-year rainfall for each of the station were determined and the results are presented in Table-9. An empirical equation of 24-hour rainfall for different return periods as a ratio of 24-hour, 2-year value was then established by fitting the mean ratios as a function of the return period in a semilog paper (Fig. 22) and is given by

$$\frac{P_T^{24h}}{P_2^{24h}} = 0.36 \ln T + 0.75 \qquad \ldots \qquad (4.30)$$

where P_T^{24h} = maximum 24-hour rainfall value for T year return period

P_2^{24h} = maximum 24-hour rainfall value for 2 year return period

Typical plotting of data in probability paper for some of the stations are shown in Fig. 16,17,18,19,20 & 21. The ordinate of the plotting represents the maximum daily/hourly rainfall (X_T) and the abscissa represents the return period (T). The probability paper was so designed that the ordinate scale is linear and abscissa scale is of double exponential type. Plotting positions were determined by the formula

$$T = \frac{N + 1}{M}$$

where M is the rank of the item of series. M being 1 for the largest value.

4.4 Development of Short-duration Rainfall Data

In developing countries like Bangladesh, short-duration rainfall data are scarce. However, the rainfall records for 24-hour duration are available for a number of stations. Estimation of 1-hour, 2-year rainfall data has been made by using Hershfield and Wilson's diagram [9] on the basis of available climatic parameters. The parameters used are: (i) mean annual precipitation (ii) mean annual number of days with rainfall greater than 0.01" (iii) mean annual maximum daily rainfall and (iv) mean annual number of thunderstormdays.

Using these available climatic records, 1-hour 2 year rainfall values for 23 different locations in Bangladesh have been calculated. Ratios of 2-year 1-hour to 2-year 24-hour values were then computed. These ratios lie in the range of 0.36 to 0.49 for Bangladesh. All these results are shown in Table-10. The mean of the above 23 ratios (Fig. 25) is 0.428 with a standard deviation of 0.037. Using the mean value of the ratio (0.428) and the 2-year 24-hour rainfall data, the 2-year 1 hour rainfall data for all the 68 stations over the north-eastern region have been developed.

Rainfall data for other durations such as 5 min, 10 min, 15 min 30 min and 2-hour have been developed by using the depth-duration ratios given by U.S. Weather Bureau and Bell [12,3]. The results are shown in Table-11.

Isohyetal maps: Results of all the above analysis have been presented in the form of generalized isohyetal maps for (i) One-day PMP (Fig.23) (ii) One-day rainfall having 2-year return period (Fig.24) (iii) 5 min, 10 min, 15 min, 30 min, 1 hour and 2 hour maximum rainfall having 2-year return period. (Fig. 27 to Fig. 32).

4.5 Generalized Intensity-Duration-Frequency Curve

To establish a intensity-duration-frequency curve for the whole north-eastern region, the 24-hour 2 year rainfall data for all the 68 stations were plotted as shown in Fig. 33. The average value of 24-hour 2 year data was obtained as 5.85. This value therefore represents the 24-hour 2-year rainfall for the region under study. 2-year 1 hour rainfall data was calculated by multiplying the 24-hour 2 year value with the ratio 0.428. One hour data for frequencies 5,10,20,50 and 100 year return periods have been calculated by using the equation presented by Bell [3] as $P_T^{60min} = (0.35 \ln T + 0.76)\ P_2^{60min}$. Where P_2^{60min} is the rainfall magnitude for 2-year 1 hour. Again, the data for other durations e.g. 5 min, 10 min, 15 min, 30 min, and 2-hour have been computed by the depth duration ratios viz. 0.29, 0.45, 0.57, 0.79 and 1.25 respectively for the same return period, 24-hour rainfall data for different return periods were determined by equation $P_T^{24h} = (0.36 \ln T + 0.75)\ P_2^{24h}$ (eqn. 4.30).

All the data resulted from the above analyses were divided by the corresponding duration for obtaining the rainfall intensity shown in Table-14 and were therefore used to draw a intensity-duration-frequency curve (Fig.34).

CHAPTER V

DISCUSSIONS

(i) By way of comparison, Hershfield's enveloping curve and the curve based on North-Indian data are shown in Fig. 15. These curves show that the values of K_M as obtained from Hershfield's curve are more than twice the values of those obtained for north-eastern region of Bangladesh. However, the curves obtained for north-eastern zone of Bangladesh is almost parallel to that obtained from the North-Indian data and these two curves follow each other very closely (Fig. 15 II & Fig. 15 III respectively).

(ii) The distribution of K_M as shown in Table-12 gives the highest value of 7.23. This value, therefore, may be considered as the enveloping value of K_M. Thus the empirical equation for PMP values for the region under study may be written as:

$$X_M = \bar{X}_N + 7.23\ S_N \qquad \ldots \qquad (5.0)$$

(iii) Return periods of PMP for some stations are given in Table-13. From this table it is clear that the probable maximum rainfall have longer return period i.e. the probability of occurance is extremely small.

(iv) The PMP isohyetal map (Fig. 23) shows that the higher values of extreme rainfall (isoline 25 inch to 30 inch) occur over the northern part (Sylhet, part of Mymensingh and Jamalpur districts) of the region under study. Almost the rest whole of the area of the region is covered by the isolines between 25 inch and 19 inches.

(v) The 2-year isohyetal map (Fig. 27 to Fig. 32) for different durations show the similar rainfall distribution pattern and reflects more or less similar distribution as that of mean annual rainfall (Fig. 6).

(vi) The ratio of daily rainfall values for different return period to 2-year 24 hour value as found to be

$$\frac{P_T^{24h}}{P_2^{24h}} = 0.36 \ln T + 0.75,$$ which fits the data very well as indicated in the Fig. 22.

(vii) In this study, the mean ratio of 2-year 1-hour to 2-year 24-hour rainfall was found to be 0.428 with s.d of 0.036. Murry [21] reported that this ratio lies between 0.35 to 0.45 for India. He also mentioned that the mean ratio for 75 stations of the continental United states is 0.435 with s.d of 0.105 and south African stations is 0.50. Therefore, the ratio 0.428 for Bangladesh appears to be quite consistant with that of other countries.

(viii) Fig. 34 shows the generalized intensity-duration frequency curve for the region under study. Based on hourly rainfall data, two typical point intensity-duration frequency curves for Sylhet and Dhaka (Fig. 35 and Fig. 36

respectively) were prepared. Superimposition of these two point curves on the generalized curves (Fig. 37-a, -b, -c, -d, -e and -f) reveals that these curves are almost parallel and follow each other quite closely. The average deviation of the point curve data are approximately 14% and 20% for Sylhet and Dhaka respectively from that of generalized curve values. Results from the point analysis as shown in Fig. 35 and Fig. 36 were based on hourly data for about 10-years only, whereas the generalized cuves (Fig. 34) were derived from sufficiently long series of 24-hour data and on the basis Hershfield & Wilson diagram (Fig. 26). This might have resulted in the above discrepencis. However it can be concluded that the curves in Fig. 34 reveal the realistic and reasonable estimate of rainfall intensity data for relatively heavily rainfall areas of Bangladesh, particularly in Sylhets, Dhaka and Northern hilly parts of Mymensingh and Jamalpur districts.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions can be drawn from the various analyses of rainfall data presented in this study.

(a) The generalized intensity-duration-frequency curve as shown in Fig. 34, may be used with reasonable accuracy to estimate the short-duration rainfall intensity data for the north-eastern region of Bangladesh.

(b) For any location within the region, maximum rainfall depths for the given duration of 5 min, 10 min, 15 min, 30 min, 1-hour, and 2-hour having two-year return period can be obtained from Fig. 27,28,29,30,31 and 32 respectively by interpolation of data between the nearby iso-hyetes.

(c) One-day rainfall data having 2-year return period as given in Fig. 24, may be converted to rainfall data having different return per-od e.g. 5,10,20, 50 and 100 year etc. by using the equation

$$P_T^{24h} = (0.36 \ln T + 0.75)\, P_2^{24h}.$$

(d) The depth-frequency relationships for individual rainfall stations as given in Table-7 can be used to compute the daily maximum rainfall depth for any desired return period.

(e) For greater safety, probable maximum rainfall data for one-day duration as given in Fig. 23, can be used for estimating the daily rainfall-runoff volume.

6.2 Recommendation for Future Study

Similar analysis of rainfall data should be made for other regions of Bangladesh such as:

(i) North-western region,

(ii) South-eastern region,

(iii) South-western region, etc.

During such studies special attention should be paid in evaluating the effects of orography and other similar meteorological factors that might cause zonal variation of curve parameters.

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— X —

APPENDIX A

TABLES

TABLE -1

INDEX OF RAINFALL STATIONS

Sl.No.	Station names	BWDB Nr	Location N deg	Location N min	Location E deg	Location E min
1.	Atia (Tangail)	R2	24	22	89	55
2.	Bancharampur	R351	23	44.5	90	49
3.	Bajitpur	R61	24	13.5	90	57.5
4.	Bhairab Bazar	R101	24	02.7	90	59.3
5.	Bhaluka	R5	24	25	90	24
6.	Bholaganj	R102	25	06.7	91	45.1
7.	Brahmanbaria	R103	23	58.7	91	07
8.	Chandbagh (Sylhet)	R104	24	34.8	91	55.2
9.	Chanpurbagan(")	R105	24	09.3	91	29
10.	Chhatak	R107	25	01.4	91	38
11.	Comilla	R356	23	27.5	91	11
12.	Dhaka	R9	23	45.2	90	22.5
13.	Dakshinbagh	R108	24	38	92	22.5
14.	Daulatpur	R10	23	56	89	50.4
15.	Durgapur(Mymensingh)	R63	25	07.5	90	41
16.	Fatullah	R408	23	40	90	31.6
17.	Gaffargaon	R64	24	24	90	35
18.	Gobindaganj	R109	24	55.7	91	41.7
19.	Gopalpur	R13	24	32	89	58
20.	Gouripur	R65	24	45	90	35
21.	Habiganj	R110	24	22	91	25.5
22.	Islampur	R66	25	03.8	89	49
23.	Itakhola	R111	24	09	91	22
24.	Itna	R112	24	30	91	07
25.	Jamalpur	R67	24	54	89	57

Table-1(Contd.)

Sl. No.	Station names	BWDB Nr	Location N deg	Location N min	Location E deg	Location E min
26.	Jaria-Jhanjail	R68	25	00	90	39.3
27.	Joydebpur	R17	24	00	90	25
28.	Kaliajuri	R113	24	41.5	91	09
29.	Kamalganj(Sylhet)	R114	24	21	91	51.5
30.	Kapasia	R70	24	07	90	36
31.	Kasbah	R362	23	43	91	08.5
32.	Kishoreganj	R71	24	26	90	47.5
33.	Lallakhal (Sylhet)	R116	25	05.7	92	11.7
34.	Langla	R117	24	29.5	91	98
35.	Latu	R118	24	49	92	15.5
36.	Manikganj	R20	23	51	90	03
37.	Manumukh	R119	24	35	91	43
38.	Markuli	R120	24	41	91	43
39.	Mirzapur	R21	24	05	90	10
40.	Moulvi Bazar	R122	24	28.5	91	46.8
41.	Muktagacha	R72	24	45	90	16
42.	Munshiganj	R365	23	33.1	90	32.2
43.	Muradnagar	R366	23	38.3	90	57
44.	Mymensingh	R73	24	46	90	24
45.	Nabinagar	R367	23	53.5	90	58.5
46.	Nalitabari (Taraganj)	R74	25	04.8	90	10.7
47.	Nandail	R75	24	33.8	99	40.3
48.	Narsinghdi	R76	23	57.3	90	42
49.	Nasirnagar	R132	24	11.8	91	12
50.	Nawabganj (Dhaka)	R412	23	38	90	09
51.	Netrokona	R123	24	53	90	43
52.	Pagla	R124	24	54.5	91	27.1
53.	Phulbaria	R27	24	37.5	90	16

Table-1(Contd.)

Sl. no.	Station names	BWDB Nr	Location N deg	N min	E deg	E min
54.	Phulpur	R77	24	57.3	90	22
55.	Pingna	R28	24	35	89	50
56.	Raipur	R371	23	31	90	53
57.	Ramchandrapur	R373	23	43	90	53.3
58.	Sarail	R131	24	02	91	07
59.	Savar	R31	23	49	90	18
60.	Sharishabari	R32	23	44	89	49
61.	Sherpur (Mymensingh)	R78	25	00	90	00.8
62.	Shibpur	R79	24	01.5	90	46
63.	Shreepur	R37	24	11.7	90	29
64.	Srimangal	R126	24	18.2	91	44
65.	Sunamganj	R127	25	04.5	91	25
66.	Sylhet	R128	24	53.4	91	52
67.	Tajpur	R129	24	42.5	91	44
68.	Zakiganj	R130	24	56	92	19

TABLE-2.

ANNUAL MAXIMUM DAILY RAINFALL DATA IN INCHES

For Sylhet District

Water year	BWDB Raingauge station number							
	R-102	R-104	R-105	R-107	R-108	R-109	R-110	R-111
1961/62	-	3.90	6.70	-	-	-	6.22	6.42
1962/63	8.02	6.40	6.05	8.93	4.77	4.61	4.52	4.90
1963/64	15.60	4.62	4.75	8.62	4.12	9.96	6.19	4.46
1964/65	11.36	8.47	5.72	8.44	5.43	9.99	6.00	4.45
1965/66	9.37	5.34	2.87	6.40	6.00	6.59	6.67	4.10
1966/67	11.23	5.95	4.16	8.46	10.00	7.82	5.30	5.50
1967/68	12.42	4.06	3.75	8.00	4.80	6.70	6.02	4.35
1968/69	5.25	5.02	5.06	8.10	7.62	5.02	5.04	4.85
1969/70	7.20	5.90	8.23	8.02	6.50	8.30	5.60	11.30
1970/71	5.90	6.00	3.75	6.98	8.60	10.51	4.75	6.80
1971/72	-	4.86	9.15	7.50	4.18	6.75	6.35	8.10
1972/73	9.57	9.10	4.70	12.00	9.26	10.50	5.10	-
1973/74	9.24	5.35	7.15	9.10	8.20	9.95	5.55	5.20
1974/75	11.15	6.80	5.40	13.70	6.05	10.598	5.80	7.20
1975/76	-	8.22	4.15	8.40	3.88	8.58	3.50	6.72
1976/77	6.27	5.62	7.92	22.00	6.18	10.95	5.60	6.60
1977/78	9.43	5.12	4.27	9.60	5.77	12.13	8.83	3.95
1978/79	6.88	4.16	3.65	4.90	8.12	5.13	4.50	3.80
1979/80	9.49	6.38	-	8.98	6.39	6.83	-	-
1980/81	6.41	7.30	-	5.30	7.31	7.00	-	-
1981/82	8.77	4.28	-	7.64	3.52	4.60	-	-
1982/83	8.50	-	-	8.00	-	-	-	-

Table-2(Contd.)

For Sylhet District

Water year	BWDB Raingauge station number							
	R-114	R-116	R-118	R-117	R-120	R-119	R-122	R-124
1961/62	5.29	9.58	-	4.29	-	4.30	3.85	-
1962/63	5.70	15.11	7.11	5.51	4.01	4.02	5.27	6.25
1963/64	5.03	11.68	4.50	4.13	7.11	5.43	3.70	9.75
1964/65	4.29	12.29	-	4.90	6.45	5.60	5.10	7.95
1965/66	5.95	7.35	8.00	3.68	4.53	4.78	5.60	7.00
1966/67	4.45	7.54	7.80	6.04	5.18	4.30	4.50	8.65
1967/68	3.92	7.58	4.90	3.64	5.53	9.13	4.58	4.36
1968/69	6.38	8.42	7.00	7.19	6.47	5.04	5.75	10.05
1969/70	6.45	10.45	5.00	4.40	4.35	3.90	4.90	5.85
1970/71	4.22	10.90	11.04	6.10	4.24	6.92	5.70	8.22
1971/72	-	11.58	-	4.46	-	8.07	3.71	-
1972/73	5.00	-	6.50	5.48	5.12	7.99	4.10	8.60
1973/74	4.85	9.25	5.50	4.32	4.79	5.75	5.68	10.00
1974/75	4.52	9.79	5.80	4.30	5.47	8.59	4.09	9.45
1975/76	5.95	11.55	3.50	6.60	4.28	-	4.00	5.05
1976/77	7.30	13.00	8.60	7.63	9.10	8.60	8.30	8.85
1977/78	6.80	7.90	3.47	6.20	4.05	6.94	8.53	11.78
1978/79	3.48	8.27	5.11	5.27	4.28	7.03	7.70	9.40
1979/80	4.76	9.80	6.44	4.14	-	7.44	5.33	9.55
1980/81	6.20	5.09	7.50	5.35	-	5.50	4.72	5.00
1981/82	5.12	5.67	5.20	4.80	-	6.84	5.50	7.00
1982/83	4.64	7,50	8.60	4.43	-	10.50	5.70	-

Table-2(contd.)

For Sylhet District

Water year	BWDB Raingauge station number				
	R-126	R-127	R-128	R-129	R-130
1961/62	3.75	10.16	6.14	-	-
1962/63	4.60	7.00	7.82	6.82	7.42
1963/64	6.22	8.19	7.43	-	5.50
1964/65	3.88	12.13	8.73	7.43	8.40
1965/66	7.96	11.48	7.08	5.92	7.10
1966/67	4.37	15.11	6.14	4.57	6.70
1967/68	4.95	9.64	5.81	12.24	5.00
1968/69	6.39	10.93	6.80	7.09	5.80
1969/70	7.90	12.51	8.04	11.55	6.52
1970/71	5.30	7.20	8.63	8.53	7.25
1971/72	4.89	6.72	7.00	8.62	4.65
1972/73	3.20	13.22	11.62	9.75	7.80
1973/74	4.27	11.30	8.10	5.53	7.30
1974/75	5.17	11.00	13.59	9.00	9.50
1975/76	7.45	9.00	6.71	7.08	9.00
1976/77	7.80	8.50	14.32	11.04	14.00
1977/78	6.78	8.25	6.51	9.50	6.05
1978/79	4.89	7.95	9.15	9.50	7.35
1979/80	5.00	12.82	7.58	9.00	7.21
1980/81	3.39	8.25	7.55	8.22	6.45
1981/82	6.00	8.94	8.00	7.35	5.28
1982/83	5.00	8.20	6.40	11.75	5.42

Table-2(Contd.)

For Dhaka District

Water year	BWDB raingauge station number				
	R-076	R-412	R-031	R-079	R-037
1961/62	6.62	-	-	-	-
1962/63	4.32	10.33	9.70	10.30	4.20
1963/64	5.73	4.49	3.42	8.30	6.30
1964/65	6.73	5.62	6.50	5.14	7.20
1965/66	4.79	5.00	7.05	7.50	5.20
1966/67	7.34	7.03	4.79	6.26	6.70
1967/68	4.97	3.79	5.60	3.71	9.20
1968/69	3.99	7.10	6.40	7.18	8.20
1969/70	6.18	2.84	3.65	7.10	5.10
1970/71	7.57	4.25	3.22	6.12	5.40
1971/72	7.90	5.03	3.45	6.12	4.70
1972/73	4.30	8.81	4.50	5.10	5.10
1973/74	5.66	5.08	5.25	12.87	7.20
1974/75	7.12	4.27	5.35	6.32	3.50
1975/76	4.11	4.15	9.26	5.22	6.70
1976/77	7.32	5.92	6.37	7.00	5.50
1977/78	4.85	2.10	3.90	3.94	5.20
1978/79	8.88	3.90	6.50	4.90	6.00
1979/80	6.18	2.40	7.35	6.92	5.30
1980/81	6.44	3.10	3.61	4.20	-
1981/82	5.75	-	-	5.54	-
1982/83	-	-	-	-	-

Table-2(Contd.)

For Mymensingh District

Water year	BWDB Raingauge Station Number							
	R-005	R-101	R-061	R-063	R-064	R-065	R-112	R-068
1961/62	-	-	-	4.49	-	-	-	-
1962/63	-	4.52	5.75	5.20	9.30	3.72	5.09	3.55
1963/64	4.40	6.80	4.35	5.28	6.85	2.22	8.38	-
1964/65	5.55	10.38	5.49	10.00	4.30	4.58	8.05	4.60
1965/66	4.75	6.00	4.76	8.10	7.26	5.10	7.68	7.20
1966/67	5.22	4.05	4.94	4.25	4.33	3.50	-	6.80
1967/68	7.55	7.20	5.23	6.31	4.41	4.75	4.49	6.25
1968/69	5.10	5.78	5.11	5.18	5.26	5.50	8.99	5.75
1969/70	7.40	9.13	9.10	6.65	8.61	4.50	4.55	4.62
1970/71	2.42	4.00	5.02	8.91	8.35	6.01	3.50	5.30
1971/72	-	-	5.38	6.30	3.50	8.40	4.30	5.25
1972/73	6.72	2.90	-	12.27	3.50	5.60	4.50	13.41
1973/74	10.42	5.70	9.10	6.00	14.50	-	7.05	11.05
1974/75	3.56	-	-	8.15	5.50	5.20	7.38	7.17
1975/76	4.50	2.85	4.86	7.99	6.20	9.00	3.94	8.33
1976/77	6.50	5.80	8.67	6.75	3.90	6.33	5.09	7.73
1977/78	6.30	5.30	6.73	6.09	4.00	4.62	6.20	10.00
1978/79	6.20	4.80	4.45	6.25	7.00	10.48	6.07	12.25
1979/80	4.32	7.90	10.00	-	4.70	8.20	-	11.00
1980/81	-	4.79	4.20	-	-	-	-	-
1981/82	-	-	-	-	-	-	-	-
1982/83	-	-	-	-	-	-	-	-

Table-2(Contd.)

For Mymensingh District

Water year	BWDB Raingauge Station Number					
	R-113	R-071	R-072	R-73	R-075	R-123
1961/62	-	6.20	-	3.98	-	4.81
1962/63	3.75	3.70	7.40	5.26	-	5.12
1963/64	7.23	7.85	6.22	-	6.60	7.92
1964/65	6.56	6.52	6.05	6.22	4.30	5.72
1965/66	6.47	7.22	3.70	5.00	6.85	6.05
1966/67	10.95	5.85	4.10	3.50	5.45	5.62
1967/68	7.28	7.45	4.10	4.85	5.96	4.27
1968/69	8.15	4.16	9.62	8.36	7.32	5.53
1969/70	8.00	7.60	11.00	5.89	6.70	6.20
1970/71	5.92	6.80	8.92	4.87	6.15	6.20
1971/72	10.70	4.50	10.86	4.88	6.82	3.30
1972/73	23.03	3.20	8.05	4.53	12.05	9.40
1973/74	10.07	11.79	9.75	5.11	10.12	11.05
1974/75	8.64	3.50	4.75	6.00	6.52	5.20
1975/76	7.00	4.00	7.55	6.14	4.72	6.59
1976/77	6.00	4.50	7.52	7.30	6.80	7.90
1977/78	4.70	3.85	6.57	5.65	4.17	8.10
1978/79	11.00	4.82	5.30	4.90	4.38	5.50
1979/80	-	9.80	4.80	8.05	8.79	9.70
1980/81	-	-	-	-	-	4.20
1981/82	-	3.80	-	-	-	-
1982/83	-	-	-	-	-	-

Table-2(Contd.)

For Jamalpur District

Water year	BWDB Raingauge Stations Number						
	R-066	R-067	R-074	R-027	R-077	R-032	R-078
1961/62	-	3.32	3.38	-	-	3.42	3.07
1962/63	3.30	5.56	3.27	-	6.05	5.76	4.77
1963/64	-	6.00	7.64	5.00	6.60	5.05	6.60
1964/65	10.00	10.50	10.64	4.65	5.50	6.00	14.91
1965/66	6.80	7.30	6.89	5.63	3.73	6.81	7.20
1966/67	4.25	5.09	3.30	3.40	4.00	4.43	5.42
1967/68	5.10	6.83	6.00	5.00	4.05	4.81	6.23
1968/69	4.00	4.91	6.35	4.82	4.80	5.69	5.95
1969/70	4.50	6.80	7.60	7.75	3.18	5.33	4.59
1970/71	4.50	2.50	6.50	5.51	8.85	4.02	4.42
1971/72	7.00	[illegible]	5.20	3.42	[illegible]	3.64	10.12
1972/73	5.70	4.60	6.50	5.75	2.85	4.72	10.12
1973/74	9.50	8.00	7.00	10.48	3.50	6.61	8.44
1974/75	5.80	8.45	5.00	3.05	4.09	4.56	8.13
1975/76	4.50	2.95	3.38	3.78	3.15	3.05	3.17
1976/77	8.00	5.75	4.65	3.90	7.36	5.92	4.61
1977/78	11.50	4.75	4.00	4.70	5.50	5.45	4.29
1978/79	3.70	3.35	3.20	6.54	-	4.70	4.35
1979/80	-	4.30	6.50	5.51	-	3.70	4.50
1980/81	-	-	-	-	-	-	-
1981/82	-	-	-	-	-	-	-
1982/83	-	-	-	-	-	-	--

Table-2(Contd.)

For Comilla District

Water year	BWDB Raingauge Stations Number								
	R-351	R-103	R-356	R-367	R-362	R-366	R-132	R-371	R-131
1961/62	5.40	11.00	5.07	7.84	3.87	-	-	-	5.90
1962/63	4.90	5.50	3.90	3.84	3.75	2.85	6.85	3.32	8.85
1963/64	6.75	-	6.15	5.62	6.75	0.90	4.16	8.36	5.17
1964/65	-	-	-	-	-	-	5.25	-	6.35
1965/66	4.65	6.10	6.50	4.62	6.15	1.25	3.94	4.50	6.50
1966/67	6.45	4.75	5.26	5.17	8.62	0.97	5.15	8.00	8.00
1967/68	5.75	6,00	8.50	6.50	4.85	0.95	3.46	3.90	11.90
1968/69	3.80	5.25	4.83	5.80	4.95	1.77	5.28	4.65	3.75
1969/70	9.62	6.50	5.42	5.75	4.15	4.95	6.72	4.10	7.75
1970/71	3.55	4.20	4.93	6.20	4.12	5.70	4.97	5.00	4.50
1971/72	5.32	6.95	4.63	5.87	-	6.50	7.45	7.40	-
1972/73	2.52	3.30	3.89	4.50	2.65	3.82	4.62	3.05	10.23
1973/74	7.16	6.25	3.98	6.50	3.56	4.40	4.70	4.45	4.35
1974/75	4.26	6.00	5.15	5.45	4.92	6.00	5.05	9.85	3.80
1975/76	7.05	7.88	4.07	4.18	5.17	3.60	4.19	7.70	7.00
1976/77	4.76	6.75	6.29	5.80	5.27	2.60	2.60	3.90	7.75
1977/78	3.53	9.00	3.79	3.50	4.94	5.58	5.09	4.45	4.25
1978/79	7.13	6.45	4.85	4.30	5.78	6.35	-	5.50	5.15
1979/80	7.25	-	4.25	8.00	6.92	5.60	-	-	-
1980/81	5.37	-	3.15	9.95	3.32	5.50	-	-	-
1981/82	-	-	7.40	-	3.54	6.00	-	-	-
1982/83	-	-	-	-	-	-	-	-	-

Table-2(Contd.)

For Tangail District

Water year	BWDB Raingauge Stations Number			
	R-002	R-013	R-021	R-028
1961/62	1.95	-	-	2.15
1962/63	1.36	3.90	-	5.48
1963/64	4.00	5.90	3.97	5.95
1964/65	5.35	4.08	-	5.65
1965/66	2.95	4.20	4.88	6.95
1966/67	3.57	3.21	5.07	4.98
1967/68	3.55	3.60	2.42	6.60
1968/69	3.24	4.70	6.61	6.95
1969/70	-	5.80	4.48	4.72
1970/71	3.35	7.00	6.19	6.04
1971/72	5.02	3.00	9.02	5.17
1972/73	2.63	5.30	4.25	3.85
1973/74	3.38	4.10	7.85	7.11
1974/75	4.20	2.85	4.75	4.48
1975/76	3.90	4.50	4.50	3.75
1976/77	6.99	7.55	4.30	7.02
1977/78	4.19	4.06	6.72	5.55
1978/79	7.18	10.05	4.60	7.80
1979/80	5.58	4.95	3.70	-
1980/81	8.31	3.25	2.68	-
1981/82	-	5.80	3.00	-
1982/83	-	-	-	-

\- Indicate No Data Available

TABLE -3

ANNUAL THUNDER STORM DAYS FOR VARIOUS YEARS

Name of the Centres	Years					
	1961	1962	1963	1964	1965	1966
Bogra	45	40	51	72	43	41
Sylhet	67	X	69	150	110	95
Pabna	104	72	95	X	X	X
Rangamati	82	89	X	83	68	82
Jessore	X	59	70	X	70	59
Dhaka	74	68	79	95	51	61
Ishurdi	X	9	82	58	56	55
Brahmanbaria	32	59	55	72	49	22
Chittagong	50	45	48	67	61	46
Cox's Bazar	29	29	28	34	46	36
Srimongal	X	14	62	26	X	24
Barisal	16	10	6	40	42	31
Comilla	X	30	X	15	19	X
Faridpur	28	39	33	X	25	21
Rangpur	38	12	21	22	24	20
Dinajpur	27	22	42	30	18	X
Mymensingh	42	55	33	34	28	23
Serajganj	6	21	10	X	17	X
Narayanganj	43	42	25	21	16	X
Rajshahi	X	X	X	X&	X	X
Lalmanirhat	X	X	X	X	X	X
Sandip	X	X	X	X	X	X

X Indicate no record available

Table-3(Contd.)

Name of the Centres	Years					
	1967	1968	1969	1970	Total	Average
Bogra	58	48	54	33	485	49
Sylhet	132	116	115	128	982	109
Pabna	X	62	80	76	489	82
Rangamati	83	94	82	83	726	81
Jessore	82	94	88	77	599	75
Dhaka	67	67	64	81	715	72
Ishurdi	62	81	88	77	564	63
Brahmanbaria	52	55	50	47	493	49
Chittagong	52	55	69	68	361	56
Cox's Bazar	50	54	37	31	374	37
Srimongal	X	79	40	X	245	41
Barisal	47	59	63	61	435	44
Comilla	X	X	X	X	64	21
Faridpur	22	X	24	31	223	28
Rangpur	32	28	46	39	282	28
Dinajpur	18	31	23	22	233	26
Mymensingh	27	20	9	21	282	28
Serajgonj	37	X	X	36	207	26
Satkhira	X	X	X	5	59	12
Narayanganj	11	X	12	X	170	24
Rajshahi	X	48	59	32	139	46
Lalmanirhat	X	X	X	31	31	31
Sandip	X	X	X	20	20	20

X Indicate no record available

TABLE- 4

HOURLY RAINFALL DATA IN INCHES FOR SYLHET & DHAKA.

Rank	Hourly rainfall for Sylhet station (inch)	Hourly rainfall for Dhaka Station (inch)
1	1.43	1.46
2	1.52	1.48
3	1.60	1.53
4	1.61	1.60
5	1.72	1.68
6	1.81	1.84
7	1.90	1.85
8	2.50	1.92
9	2.56	1.94
10	2.86	2.13
11	3.09	2.18
12	3.56	2.18
13	-	2.24
14	-	2.40
15	-	2.63
16	-	3.34
17	-	-

TABLE -5

RESULTS OF PMP ESTIMATION

BWDB Station no.	Mean (adjusted)	Standard deviation (adjusted)	K_M value from curve	PMP (inch)	Final PMP (inch)
SYLHET DISTRICT					
R - 102	9.33	2.51	4.60	20.89	23.60
R - 104	6.03	1.58	6.90	16.93	19.13
R - 105	5.62	1.97	7.00	19.41	21.93
R - 107	5.57	3.31	7.05	28.90	32.66
R - 108	6.53	2.04	6.50	19.79	22.36
R - 109	8.42	2.64	5.20	22.15	25.03
R - 110	5.83	1.01	6.95	12.85	14.52
R - 111	5.85	1.68	6.95	14.65	16.55
R - 114	5.46	1.10	7.20	13.38	15.12
R - 116	9.86	2.84	4.30	22.07	24.95
R - 117	5.30	1.18	7.22	13.82	15.62
R - 118	6.58	1.99	6.45	19.41	21.94
R - 119	6.69	2.00	5.80	18.29	20.67
R - 120	5.40	1.25	7.20	14.40	16.27
R - 122	5.43	1.42	7.20	15.65	17.69
R - 124	8.36	2.37	4.95	20.11	22.20
R - 126	5.77	1.73	7.00	17.88	20.20
R - 127	10.43	3.36	4.10	24.20	27.35
R - 128	8.30	2.45	5.10	20.64	23.22
R - 129	8.89	2.43	4.80	20.55	23.22
R - 130	7.12	1.69	5.75	16.84	19.02

Table-5(Contd.)

BWDB Station no.	Mean (adjusted	Standard deviation (adjusted)	K_M value from curve	PMP (inch)	Final PMP (inch)
		DHAKA DISTRICT			
R-009	6.44	1.88	6.60	18.85	21.30
R-010	4.09	1.62	7.23	15.80	17.86
R-408	5.79	1.58	7.00	16.85	19.00
R-017	5.71	1.87	7.10	18.10	21.45
R-069	5.13	1.69	7.23	17.35	19.60
R-070	6.77	2.73	6.60	24.72	27.93
R-020	4.51	1.82	7.23	17.69	19.96
R-365	5.60	1.34	7.00	14.98	16.93
R-076	6.21	1.49	6.65	16.12	18.21
R-412	4.96	2.07	7.20	19.86	22.45
R-031	5.64	2.01	7.00	19.71	22.27
R-079	6.61	2.30	6.40	21.33	24.10
R-037	6.15	1.48	7.10	16.65	18.82
		MYMENSINGH & JAMALPUR DISTRICTS			
R-101	5.90	2.18	7.10	21.37	24.16
R-061	6.24	2.11	6.60	20.16	22.78
R-063	7.05	1.97	6.00	18.85	21.29
R-064	6.12	2.36	6.80	15.27	17.25
R-065	5.86	2.29	6.90	21.66	24.48
R-066	6.17	2.55	6.80	23.48	26.54

Table-5 (Contd.)

BWDB Station no.	Mean (adjusted)	Standard deviation (adjusted)	K_M value from curve	PMP (inch)	Final PMP (inch)
R-112	6.12	1.80	7.00	18.72	21.50
R-067	5.41	2.13	7.20	21.78	23.82
R-068	7.86	3.25	5.50	25.73	29.07
R-071	5.91	2.26	6.90	21.52	24.32
R-072	7.25	2.69	5.90	23.10	26.10
R-073	5.80	1.43	7.10	15.95	18.00
R-074	5.64	2.07	7.20	20.54	23.14
R-123	6.58	2.10	6.40	20.04	22.62
R-032	5.14	1.23	7.23	14.03	15.86
R-078	6.28	2.33	6.95	22.47	25.39
R-113	8.25	2.84	4.95	22.31	25.20
R-005	5.71	1.77	6.95	18.01	20.35
R-027	5.25	1.55	7.20	16.39	18.52
R-077	4.88	1.69	7.20	17.03	19.24
R-075	6.75	1.986	6.20	19.00	21.47
COMILLA DISTRICT					
R-351	5.69	1.82	7.10	18.62	21.04
R-103	6.54	1.78	6.80	18.69	21.12
R-356	5.24	1.30	7.20	14.60	16.50
R-367	5.93	1.59	7.00	14.05	19.27
R-362	5.03	1.50	7.20	15.83	17.89

Table-5 (Contd.)

BWDB Station no.	Mean (adjusted)	Standard deviation (adjusted)	K_M value from curve	PMP (inch)	Final PMP (inch)
R-366	4.10	2.51	7.20	22.17	25.05
R-132	5.11	1.35	7.20	14.80	16.72
R-371	5.56	2.16	7.10	20.92	23.64
R-131	6.62	2.39	6.40	21.95	24.80
TANGAIL DISTRICT					
R-002	4.29	1.86	7.20	17.70	20.00
R-013	4.96	1.70	7.20	17.20	19.41
R-021	5.03	1.83	7.20	18.20	20.57
R-028	5.82	1.68	7.10	17.75	20.05

TABLE-6

VALUES OF $\bar{y}_N$ AND σ_N AS A FUNCTION OF SAMPLE SIZE N.

N	$\bar{y}_N$	σ_N	N	$\bar{y}_N$	σ_N
8	0.48430	0.90430	46	0.54680	1.15380
9	0.49020	0.92880	47	0.54730	1.15570
10	0.49520	0.94970	48	0.54770	1.15740
11	0.49960	0.96760	49	0.54810	1.15900
12	0.50350	0.98330	50	0.54854	1.16066
13	0.50700	0.99720	51	0.54890	1.16230
14	0.51000	1.00950	52	0.54930	1.16380
15	0.51280	1.02050	53	0.54970	1.16530
16	0.51570	1.03160	54	0.55010	1.16670
17	0.51810	1.04110	55	0.55040	1.16810
18	0.52020	1.04930	56	0.55080	1.16960
19	0.52200	1.05660	57	0.55110	1.17080
20	0.52355	1.06283	58	0.55150	1.17210
21	0.52520	1.06960	59	0.55180	1.17340
22	0.52680	1.07540	60	0.55208	1.17467
23	0.52830	1.08110	62	0.55270	1.17700
24	0.52960	1.08640	64	0.55330	1.17930
25	0.53086	1.09145	66	0.55380	1.18140
26	0.53200	1.09610	68	0.55430	1.18340
27	0.53320	1.10040	70	0.55477	1.18536
28	0.53430	1.10470	72	0.55520	1.18730
29	0.53530	1.10860	74	0.55570	1.18900
30	0.53622	1.11238	76	0.55610	1.19060
31	0.53710	1.11590	78	0.55650	1.19230
32	0.53800	1.11930	80	0.55688	1.19382
33	0.53880	1.12260	82	0.55720	1.19530
34	0.53960	1.12550	84	0.55760	1.19670
35	0.54034	1.12847	86	0.55800	1.19800
36	0.54100	1.13130	88	0.55830	1.19940
37	0.54180	1.13390	90	0.55860	1.20073
38	0.54240	1.13630	92	0.55890	1.20200
39	0.54300	1.13880	94	0.55920	1.20320
40	0.54362	1.14132	96	0.55952	1.20440
41	0.54420	1.14360	98	0.55980	1.20550
42	0.54480	1.14580	100	0.56002	1.20649
43	0.54530	1.14800	150	0.56461	1.22534
44	0.54580	1.14990	200	0.56715	1.23598
45	0.54630	1.15185	250	0.56878	1.23292

Source: RAUDKIVI, A.J,1976, Hydrology; Pergamon Press.

TABLE 7

DEPTH-FREQUENCY RELATIONSHIP FOR INDIVIDUAL STATIONS

BWDB Station no.	Equation by Double Exponential Distribution Function
	SYLHET DISTRICT
R-102	$X_T = 7.825 - 2.356 \ln(\ln(\frac{T}{T-1}))$
R-104	$X_T = 5.141 - 1.350 \ln(\ln(\frac{T}{T-1}))$
R-105	$X_T = 4.553 - 1.650 \ln(\ln(\frac{T}{T-1}))$
R-107	$X_T = 7.580 - 1.802 \ln(\ln(\frac{T}{T-1}))$
R-108	$X_T = 5.439 - 1.709 \ln(\ln(\frac{T}{T-1}))$
R-109	$X_T = 6.996 - 2.145 \ln(\ln(\frac{T}{T-1}))$
R-110	$X_T = 5.10 - 1.038 \ln(\ln(\frac{T}{T-1}))$
R-111	$X_T = 4.88 - 1.776 \ln(\ln(\frac{T}{T-1}))$
R-114	$X_T = 4.766 - 0.926 \ln(\ln(\frac{T}{T-1}))$
R-116	$X_T = 8.333 - 2.280 \ln(\ln(\frac{T}{T-1}))$
R-117	$X_T = 4.603 - 1.004 \ln(\ln(\frac{T}{T-1}))$
R-118	$X_T = 5.468 - 1.773 \ln(\ln(\frac{T}{T-1}))$
R-119	$X_T = 5.606 - 1.703 \ln(\ln(\frac{T}{T-1}))$
R-120	$X_T = 4.641 - 1.298 \ln(\ln(\frac{T}{T-1}))$
R-122	$X_T = 4.624 - 1.245 \ln(\ln(\frac{T}{T-1}))$

Table-7(Contd.)

BWDB Station no.	Equation by Double Exponential Distribution Function
R-124	$X_T = 7.064 - 1.870 \ln (\ln (\frac{T}{T-1}))$
R-126	$X_T = 4.757 - 1.296 \ln (\ln (\frac{T}{T-1}))$
R-127	$X_T = 8.838 - 2.077 \ln (\ln (\frac{T}{T-1}))$
R-128	$X_T = 7.067 - 2.055 \ln (\ln (\frac{T}{T-1}))$
R-129	$X_T = 7.452 - 1.945 \ln (\ln (\frac{T}{T-1}))$
R-130	$X_T = 6.151 - 1.861 \ln (\ln (\frac{T}{T-1}))$
DHAKA DISTRICT	
R-009	$X_T = 5.116 - 1.826 \ln (\ln (\frac{T}{T-1}))$
R-010	$X_T = 3.226 - 1.251 \ln (\ln (\frac{T}{T-1}))$
R-408	$X_T = 5.130 - 1.347 \ln (\ln (\frac{T}{T-1}))$
R-017	$X_T = 4.733 - 1.488 \ln (\ln (\frac{T}{T-1}))$
R-069	$X_T = 4.219 - 1.457 \ln (\ln (\frac{T}{T-1}))$
R-070	$X_T = 5.378 - 2.351 \ln (\ln (\frac{T}{T-1}))$
R-020	$X_T = 3.683 - 1.504 \ln (\ln (\frac{T}{T-1}))$
R-365	$X_T = 4.881 - 1.210 \ln (\ln (\frac{T}{T-1}))$

Table-7(Contd.)

BWDB Station no.	Equation by Double Exponential Distribution Function
R-076	$X_T = 5.363 - 1.281 \ln(\ln(\frac{T}{T-1}))$
R-412	$X_T = 3.991 - 1.952 \ln(\ln(\frac{T}{T-1}))$
R-031	$X_T = 4.820 - 1.713 \ln(\ln(\frac{T}{T-1}))$
R-079	$X_T = 5.446 - 1.989 \ln(\ln(\frac{T}{T-1}))$
R-037	$X_T = 5.246 - 1.311 \ln(\ln(\frac{T}{T-1}))$
MYMENSINGH & JAMALPUR DISTRICTS	
R-101	$X_T = 4.767 - 1.920 \ln(\ln(\frac{T}{T-1}))$
R-061	$X_T = 5.122 - 1.788 \ln(\ln(\frac{T}{T-1}))$
R-063	$X_T = 5.916 - 1.887 \ln(\ln(\frac{T}{T-1}))$
R-064	$X_T = 4.860 - 2.557 \ln(\ln(\frac{T}{T-1}))$
R-065	$X_T = 4.709 - 2.003 \ln(\ln(\frac{T}{T-1}))$
R-066	$X_T = 4.940 - 2.313 \ln(\ln(\frac{T}{T-1}))$
R-112	$X_T = 5.103 - 1.648 \ln(\ln(\frac{T}{T-1}))$
R-067	$X_T = 4.898 - 1.944 \ln(\ln(\frac{T}{T-1}))$
R-068	$X_T = 6.262 - 2.698 \ln(\ln(\frac{T}{T-1}))$

Table-7(Contd.)

BWDB Station no.	Equation by Double Exponential Distribution Function
R-071	$X_T = 4.753 - 2.904 \ln(\ln(\frac{T}{T-1}))$
R-072	$X_T = 5.883 - 2.166 \ln(\ln(\frac{T}{T-1}))$
R-036	$X_T = 4.959 - 1.196 \ln(\ln(\frac{T}{T-1}))$
R-074	$X_T = 4.684 - 1.825 \ln(\ln(\frac{T}{T-1}))$
R-123	$X_T = 5.456 - 1.838 \ln(\ln(\frac{T}{T-1}))$
R-032	$X_T = 4.312 - 0.982 \ln(\ln(\frac{T}{T-1}))$
R-078	$X_T = 5.263 - 1.710 \ln(\ln(\frac{T}{T-1}))$
R-005	$X_T = 4.773 - 1.759 \ln(\ln(\frac{T}{T-1}))$
R-027	$X_T = 4.357 - 1.684 \ln(\ln(\frac{T}{T-1}))$
R-077	$X_T = 4.030 - 1.640 \ln(\ln(\frac{T}{T-1}))$
R-075	$X_T = 5.687 - 1.934 \ln(\ln(\frac{T}{T-1}))$
R-113	$X_T = 6.59 - 2.031 \ln(\ln(\frac{T}{T-1}))$

Table-7 (Contd.)

BWDB Station no.	Equation by Double Exponential Distribution Function
R	COMILLA DISTRICT
R-351	$X_T = 4.712 - 1.580 \ln (\ln (\frac{T}{T-1}))$
R-103	$X_T = 5.370 - 1.310 \ln (\ln (\frac{T}{T-1}))$
R-356	$X_T = 4.464 - 1.210 \ln (\ln (\frac{T}{T-1}))$
R-367	$X_T = 4.990 - 1.455 \ln (\ln (\frac{T}{T-1}))$
R-362	$X_T = 4.200 - 1.343 \ln (\ln (\frac{T}{T-1}))$
R-366	$X_T = 2.982 - 1.873 \ln (\ln (\frac{T}{T-1}))$
R-132	$X_T = 4.362 - 1.172 \ln (\ln (\frac{T}{T-1}))$
R-131	$X_T = 5.417 - 2.170 \ln (\ln (\frac{T}{T-1}))$
	TANGAIL DISTRICT
R-002	$X_T = 3.354 - 1.406 \ln (\ln (\frac{T}{T-1}))$
R-013	$X_T = 4.040 - 1.623 \ln (\ln (\frac{T}{T-1}))$
R-021	$X_T = 4.100 - 1.616 \ln (\ln (\frac{T}{T-1}))$
R-028	$X_T = 4.880 - 1.330 \ln (\ln (\frac{T}{T-1}))$

TABLE -8

DAILY MAXIMUM RAINFALL FOR DIFFERENT RETURN PERIOD

BWDB Station no.	Daily maximum rainfall (inch) for different retern period					
	2-year	5-year	10-year	20-year	50-year	100-year
			SYLHET DISTRICT			
R-102	8.689	11.210	12.903	14.528	16.630	18.665
R-104	5.635	7.165	8.178	9.156	10.406	13.350
R-105	5.158	7 .029	8.268	9.456	10.994	12.123
R-107	8.24	10.28	11.635	12.932	14.610	15.860
R-108	6.067	8.005	9.288	10.519	12.111	13.304
R-109	7.783	10.214	11.823	13.368	15.365	16.864
R-110	5.481	6.659	7.459	8.187	9.154	9.879
R-114	5.105	6.155	6.850	7.516	8.519	9.024
R-116	9.168	11.753	13.463	15.105	17.227	18.819
R-117	4.971	6.109	6.862	7.585	8.520	9.226
R-118	6.117	8.127	9.457	10.734	12.384	13.622
R-120	5.116	6.588	7.562	8.496	9.704	10.611
R-119	6.230	8.160	9.438	10.664	12.249	13.439
R-122	5.080	6.491	7.425	8.322	9.481	10.351
R-124	7.773	9.869	11.272	12.618	14.359	15.667
R-126	5.532	6.701	7.672	8.606	9.707	10.720
R-127	9.600	11.943	13.511	15.007	16.940	18.393
R-128	7.821	11.149	11.691	13.170	15.084	18.797
R-129	8.165	10.369	11.828	13.229	15.039	16.397
R-130	6.833	8.942	10.338	11.678	13.411	14.712
R-111	5.530	7.450	8.796	10.154	11.800	13.040

Table-8(Contd.)

BWDB Station no.	Daily maximum rainfall(inch) for different return period					
	2-year	5-year	10-year	20-year	50-year	100-year
			MYMENSINGH & JAMALPUR DISTRICTS			
R-101	5.470	7.647	9.088	10.470	12.258	13.600
R-061	5.777	7.804	9.145	10.432	12.096	13.346
R-063	6.607	8.746	10.162	11.520	13.277	14.596
R-065	5.443	7.713	9.216	10.658	12.526	13.922
R-112	5.707	7.575	8.811	9.998	11.532	12.683
R-067	5.310	7.514	8.972	10.372	12.181	13.540
R-068	7.250	10.309	12.333	14.275	16.787	18.672
R-071	5.520	7.894	9.465	10.972	12.922	14.385
R-072	6.677	9.132	10.532	12.316	14.333	15.846
R-073	5.377	6.754	7.652	10.807	9.628	10.467
R-074	5.352	7.421	8.790	10.104	11.803	13.079
R-123	6.129	8.213	9.592	10.915	12.626	13.910
R-032	4.672	5.785	6.522	7.229	8.143	8.831
R-078	5.889	7.828	9.111	10.342	11.934	13.755
R-005	5.471	7.411	8.730	9.997	11.630	12.860
R-027	4.974	6.883	8.146	9.358	10.930	12.100
R-077	4.630	6.490	7.720	8.900	10.420	11.574
R-066	5.787	8.400	10.140	11.800	13.960	15.580
R-075	6.396	8.590	10.030	11.430	13.230	14.580
R-113	7.334	9.64	11.160	12.620	14.510	15.430
R-						

Table-8(Contd.)

BWDB Station no.	Daily maximum rainfall in inch for Different Return Period					
	2-year	5-year	10-year	20-year	50-year	100-year
			DHAKA DISTRICT			
R-009	5.79	7.85	9.23	10.54	12.24	13.52
R-010	3.68	5.10	6.04	6.94	8.11	8.98
R-408	5.62	7.15	8.16	9.13	10.39	11.33
R-017	5.28	6.97	8.08	9.15	10.54	11.58
R-069	4.75	6.40	7.50	8.55	9.90	10.92
R-070	6.24	8.90	10.67	12.36	14.55	16.19
R-020	4.23	5.94	7.07	8.15	9.55	10.60
R-065	5.32	6.70	7.60	8.48	9.60	10.45
R-076	5.83	7.28	8.25	9.17	10.36	11.26
R-412	4.71	6.92	8.38	9.79	11.61	12.97
R-031	5.45	7.39	8.47	9.91	11.62	12.68
R-079	6.18	8.43	9.92	11.35	13.20	14.60
R-037	5.72	7.21	8.20	9.14	10.36	11.28

Table-8(Contd.)

BWDB Station no.	Daily rainfall in (inch) for Different Return Period					
	2-year	5-year	10-year	20-year	50-year	100-year
			COMILLA DISTRICT			
R-351	5.29	7.08	8.27	9.40	10.88	11.98
R-103	5.85	7.33	8.32	9.26	10.48	11.40
R-357	4.90	6.28	7.19	8.05	9.18	10.03
R-067	5.52	7.17	8.26	9.31	10.66	11.68
R-362	4.69	6.21	7.22	8.19	9.44	10.38
R-366	3.668	5.79	7.20	8.54	10.29	11.59
R-132	4.79	6.12	7.00	7.84	8.93	9.75
R-371	5.21	7.41	8.86	10.25	12.00	13.42
R-131	6.21	8.67	10.30	11.86	13.88	15.39
			TANGAIL DISTRICT			
R-002	3.87	5.46	6.52	7.53	8.84	9.82
R-013	4.63	6.47	7.69	8.86	10.37	11.50
R-021	4.69	6.52	7.74	8.90	10.40	11.53
R-028	5.37	6.88	7.87	8.83	10.06	10.99

TABLE-9

RATIO OF 5-year, 10-year, 20-year, 50-year & 100-year, 24-hour rainfall to 2-year 24-hour rainfall over N-E ZONE OF BANGLADESH

Return Periods	Name of the Districts	No. of Stations	Mean ratio to 2-year, 24-hour rainfall	Standard deviation	Average of Mean ratio to 2-year 24-hour rainfall over whole north-east zone
5-year	Sylhet	21	1.285	0.052	Mean = 1.347 with S.d. = 0.029
	Dhaka	13	1.343	0.066	
	Mymensingh	14	1.364	0.062	
	Jamalpur	7	1.372	0.0623	
	Tangail	4	1.369	0.059	
	Comilla	9	1.351	0.095	
10-year	Sylhet	21	1.458	0.101	Mean = 1.575 with S.d. = 0.055
	Dhaka	13	1.568	0.110	
	Mymensingh	14	1.608	0.099	
	Jamalpur	7	1.618	0.107	
	Tangail	4	1.614	0.087	
	Comilla	9	1.585	0.158	
20-year	Sylhet	21	1.649	0.096	Mean = 1.803 with S.d. = 0.075
	Dhaka	13	1.789	0.150	
	Mymensingh	14	1.874	0.119	
	Jamalpur	7	1.855	0.147	
	Tangail	4	1.849	0.120	
	Comilla	9	1.807	0.217	
50-year	Sylhet	21	1.890	0.140	Mean = 2.086 with S.d. = 0.093
	Dhaka	13	2.073	0.200	
	Mymensingh	14	2.146	0.184	
	Jamalpur	7	2.160	0.200	
	Tangail	4	2.153	0.163	
	Comilla	9	2.096	0.296	
100-year	Sylhet	21	2.096	0.133	Mean = 2.305 with S.D. = 0.101
	Dhaka	13	2.281	0.248	
	Mymensingh	14	2.37	0.220	
	Jamalpur	7	2.40	0.230	
	Tangail	4	2.380	0.194	
	Comilla	9	2.315	0.356	

TABLE 10

RATIOS OF 2-year, 1-hour to 2-year 24-hour

Sl. No.	Name of the centers	Mean Annual rainfall (inch)	Mean of Annual series of max. daily rainfall (inch)	Mean Annual number of days with rainfall ≥0.01"	Mean Annual number of thunder-storm days	2-year 1-hour rain-fall (inch)	2-year 24-hr. rain-fall (inch)	Ratio of 2-year 1-hour to 2-year 24-hr.
1.	Chittagong	114.74	9.32	109	56	3.5	8.88	0.394
2.	Jessore	65.04	14.93	102	75	2.30	4.60	0.460
3.	Cox's bazar	151.25	10.16	122	37	3.50	9.60	0.364
4.	Bogra	69.13	5.23	88	49	2.23	5.04	0.442
5.	Barisal	85.90	5.90	114	44	2.50	5.56	0.449
6.	Pabna	60.43	4.41	92	82	2.00	4.02	0.497
7.	Ishardi	62.39	5.04	73	63	2.40	5.02	0.417
8.	Faridpur	71.41	4.64	102	28	2.00	4.48	0.446
9.	SerajGanj	67.70	5.07	97	26	2.25	4.91	0.458
10.	Lalmonirhat	91.60	6.61	8 1	31	2.40	6.35	0.378
11.	Dinajpur	70.00	5.24	89	26	2.00	5.09	0.391
12.	Rajshahi	5 6.60	5.58	94	46	2.50	5.33	0.470
13.	Sandip	147.86	7.32	104	20	2.75	6.34	0.433
14.	Satkhira	66.80	5.70	94	12	2.25	5.51	0.411
15.	Rangpur	85.40	6.52	100	28	2.60	5.96	0.436
16.	Sylhet	154.45	8.15	150	109	2.90	7.82	0.371
17.	Dhaka	75.90	6.06	110	72	2.50	5.79	0.433
18.	Srimangal	93.3	5.44	124	41	2.40	5.53	0.434
19.	Comilla	90.50	5.50	122	21	2.20	4.91	0.448
20.	Mymensingh	87.85	5.58	118	28	2.60	5.397	0.481
21.	Brahmanbaria	80.2	6.05	93	49	2.50	5.85	0.427
22.	Narayanganj	73.65	5.67	102	24	2.30	5.43	0.423
23.	Rangamati	101.00	8.17	117	81	2.80	7.81	0.360

TABLE-11

SHORT DURATION RAINFALL DATA HAVING 2-YEAR RETURN PERIOD

BWDB Station no.	For 5 min duration (inch)	For 10 min duration (inch)	For 15 min duration (inch)	For 30 min duration (inch)	For 1-hour duration (inch)	For 2-hour duration (inch)
SYLHET DISTRICT						
R-102	1.08	1.67	2.12	2.94	3.72	4.65
R-104	0.69	1.08	1.37	1.90	2.41	3.01
R-105	0.64	0.99	1.25	1.74	2.20	2.75
R-107	1.02	1.58	2.00	2.78	3.52	4.40
R-108	0.75	1.16	1.47	2.05	2.59	3.24
R-109	0.96	1.49	1.89	2.62	3.32	4.15
R-110	0.68	1.053	1.33	1.85	2.34	2.93
R-111	0.68	1.06	1.34	1.86	2.36	2.95
R-114	0.63	0.98	1.24	1.72	2.18	2.72
R-116	1.13	1.76	2.23	3.09	3.92	4.90
R-117	0.61	0.95	1.21	1.67	2.12	2.65
R-118	0.76	1.18	1.49	2.07	2.62	3.27
R-120	0.63	0.985	1.25	1.73	2.19	2.74
R-119	0.77	1.20	1.52	2.11	2.67	3.34
R-122	0.63	0.97	1.24	1.71	2.17	2.71
R-124	0.96	1.49	1.89	2.62	3.32	4.15
R-126	0.68	1.06	1.34	1.86	2.36	2.95
R-127	1.19	1.84	2.34	3.24	4.10	4.21
R-128	0.97	1.50	1.90	2.64	3.34	4.17
R-129	1.01	1.57	1.99	2.76	3.49	4.36
R-136	0.84	1.31	1.66	2.31	2.92	3.65

Table-11(Contd.)

BWDB Station no.	For 5 min duration (inch)	For 10 min duration (inch)	For 15 min duration (inch)	For 30 min duration (inch)	For 1-hour duration (inch)	For 2-hour duration (inch)
			DHAKA DISTRICT			
R-009	0.72	1.11	1.41	1.95	2.47	3.08
R-010	0.45	0.71	0.89	1.24	1.57	1.96
R-408	0.69	1.08	1.37	1.90	2.40	3.00
R-017	0.65	1.02	1.29	1.78	2.26	2.82
R-069	0.57	0.91	1.16	1.60	2.03	2.54
R-070	0.77	1.20	1.52	2.11	2.67	3.34
R-020	0.52	0.81	1.03	1.43	1.81	2.26
R-365	0.66	1.02	1.29	1.79	2.27	2.84
R-076	0.72	1.12	1.41	1.97	2.49	3.11
R-412	0.58	0.90	1.14	1.59	2.01	2.51
R-031	0.67	1.05	1.33	1.84	2.33	2.91
R-079	0.76	1.19	1.50	2.08	2.64	3.30
R-037	0.93	1.44	1.83	2.53	3.21	4.01
			MYMENSINGH & JAMALPUR DISTRICT			
R-101	0.68	1.05	1.33	1.85	2.34	2.93
R-061	0.72	1.11	1.41	1.95	2.47	3.08
R-063	0.82	1.27	1.60	2.23	2.82	3.53
R-064	0.71	1.12	1.41	1.96	2.48	3.10
R-065	0.67	1.05	1.32	1.83	2.32	2.90
R-066	0.71	1.12	1.41	1.96	2.48	3.10
R-067	0.65	1.02	1.29	1.93	2.27	3.05

Table-11(Contd.)

BWDB Station no.	For 5 min duration (inch)	For 10 min duration (inch)	For 15 min duration (inch)	For 30 min duration (inch)	For 1-hour duration (inch)	For 2-hour duration (inch)
R-112	0.70	1.00	1.39	1.93	2.44	3.05
R-068	0.90	1.40	1.77	2.45	3.10	3.87
R-071	0.68	1.06	1.35	1.86	2.36	3.87
R-072	0.83	1.28	1.62	2.25	2.85	3.56
R-036	0.67	1.04	1.32	1.82	2.31	2.89
R-074	0.66	1.03	1.31	1.81	2.29	2.86
R-123	0.76	1.18	1.49	2.07	2.62	3.27
R-032	0.58	0.89	1.13	1.57	1.99	2.49
R-078	0.73	1.13	1.44	1.99	2.52	3.15
R-005	0.67	1.04	1.32	1.82	2.31	2.89
R-113	0.91	1.41	1.78	2.47	3.13	3.91
R-075	0.79	1.23	1.56	2.16	2.74	3.42
R-027	0.61	0.95	1.21	1.67	2.12	2.65
R-077	0.57	0.89	1.13	1.56	1.98	2.47
			COMILLA DISTRICT			
R-351	0.65	1.01	1.29	1.78	2.26	2.82
R-103	0.72	1.12	1.42	1.97	2.50	3.12
R-356	0.61	0.94	1.19	1.65	2.09	2.61
R-367	0.68	1.06	1.35	1.86	2.36	2.95
R-362	0.58	0;90	1.14	1.58	2.00	2.50
R-366	0.45	0.71	0.89	1.24	1.57	1.96

Table-11(Contd.)

BWDB Station no.	For 5 min duration (inch)	For 10 min duration (inch)	For 15 min duration (inch)	For 30 min duration (inch)	For 1-hour duration (inch)	For 2-hour duration (inch)
R-132	0.59	0.91	1.17	1.59	2.05	2.56
R-373	0.59	0.91	1.17	1.59	2.05	2.56
R-131	0.77	1.19	1.51	2.09	2.65	3.31
TANGAIL DISTRICT						
R-002	0.48	0.74	0.94	1.30	1.65	2.06
R-013	0.57	0.89	1.13	1½56	1.98	2.47
R-021	0.58	0.90	1.14	1.58	2.00	2.50
R-028	0.67	1.04	1.31	1.82	2.30	2.87

TABLE-12

DISTRIBUTION OF INDEPENDENT K_M

Range of K_M	No. of Stations	Remark
1.00 - 2.00	4	
2.01 - 2.50	12	
2.51 - 3.00	20	
3.01 - 3.50	15	Highest value
3.51 - 4.00	8	of K_M is 7.23
4.01 - 4.50	4	
4.51 - 5.00	1	
5.01 - 6.00	2	
6.01 - 7.00	1	
7.01 - 7.50	1	

TABLE-13

RETURN PERIODS FOR PROBABLE MAXIMUM RAINFALL FOR SOME STATIONS

BWDB Station no.	Name of the Station	Probable maximum Rainfall (PMP) (inch)	Return Period (Years)
R-128	Sylhet	23.20	3,591
R-073	Mymensingh	18.00	53,940
R-009	Dhaka	20.21	38,833
R-067	Jamalpur	23.82	19,976
R-002	Atia(Tangail)	20.00	18,652
R-365	Comilla	16.50	20,385

TABLE-14

GENERALIZED INTENSITY-DURATION-FREQUENCY DATA FOR NORTH-EAST REGION

Return Periods in year	Rainfall intensities (inch/hour) for different durations						
	5 min	10 min	15 min	30 min	1-hour	2-hour	24-hour
2	9.00	6.75	5.70	3.95	2.50	1.56	0.24
5	11.97	8.96	7.57	5.24	3.32	2.07	0.32
10	13.65	10.70	8.24	6.19	3.92	2.45	0.37
20	15.75	12.33	10.30	7.14	4.52	2.82	0.43
50	18.44	14.46	12.08	8.37	5.30	3.31	0.50
100	20.63	16.16	13.49	9.35	5.92	3.70	0.55

TABLE -15

DATA FOR POINT RAINFALL INTENSITY-DURATION-FREQUENCY CURVE FOR SYLHET

Return Period Years	Rainfall intensities (inch/hour) for different duration						
	5 min	10 min	15 min	30 min	1-hour	2-hour	[illegible]
2	7.25	5.63	4.75	3.29	2.09	1.30	[illegible]
5	9.97	7.74	6.53	4.53	2.87	1.79	[illegible]
10	11.76	9.13	7.71	5.34	3.38	2.11	[illegible]
20	13.50	10.48	8.85	6.13	3.88	2.42	[illegible]
50	15.72	12.20	10.30	7.14	4.52	2.83	[illegible]
100	17.40	13.50	11.40	7.90	5.00	3.13	[illegible]

TABLE-16

DATA FOR POINT RAINFALL INTENSITY-DURATION-FREQUENCY CURVE FOR DHAKA

Return Period Years	Rainfall intensities (inch/hour) for different duration					
	5 min	10 min	15 min	30 min	1-hour	2-hour
2	6.74	5.88	4.28	3.08	1.96	1.27
5	9.48	6.66	5.62	3.90	2.47	1.60
10	10.75	7.56	6.16	4.43	2.80	1.82
20	12.00	8.46	6.88	4.94	3.13	2.03
50	13.61	9.60	7.80	5.60	3.55	2.30
100	14.82	10.44	8.48	6.10	3.86	2.50

APPENDIX B

FIGURES

APPENDIX B

FIGURES

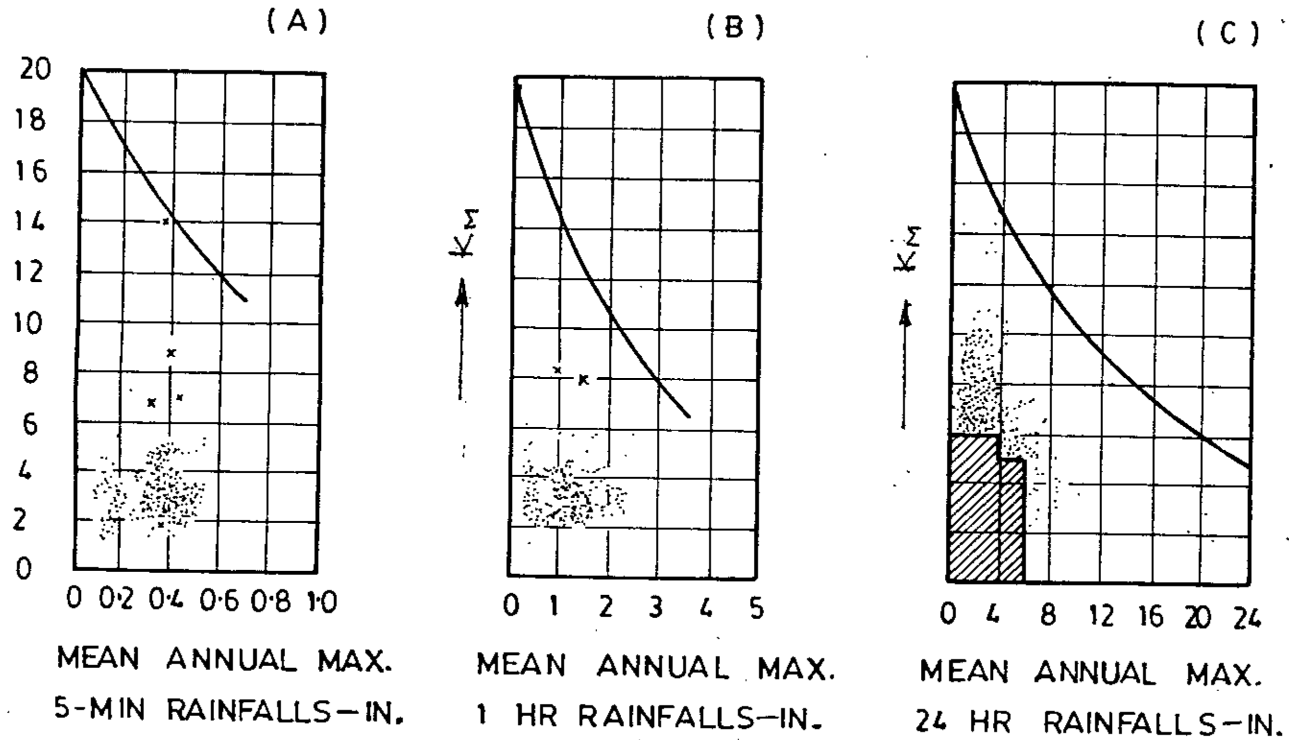


FIG. 1. K_M AGAINST MEAN ANNUAL MAXIMUM RAINFALLS

(After Hershfied, 1965)

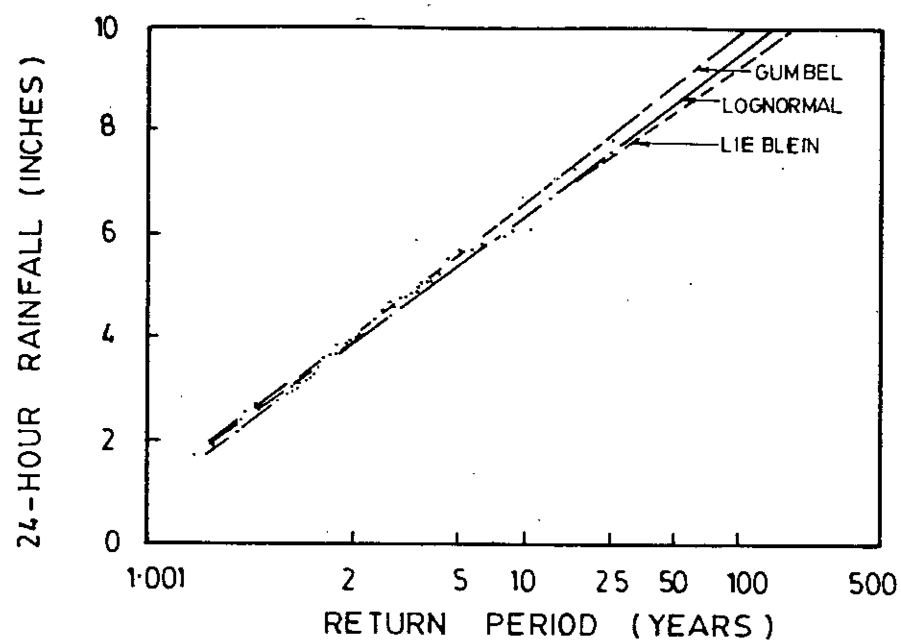


FIG. 2. A COMPARISON OF THE GUMBEL, LOGNORMAL, AND LIEBLEIN PROCEDURES FOR MONTGOMERY, Ala (After Hershfield, 1962)

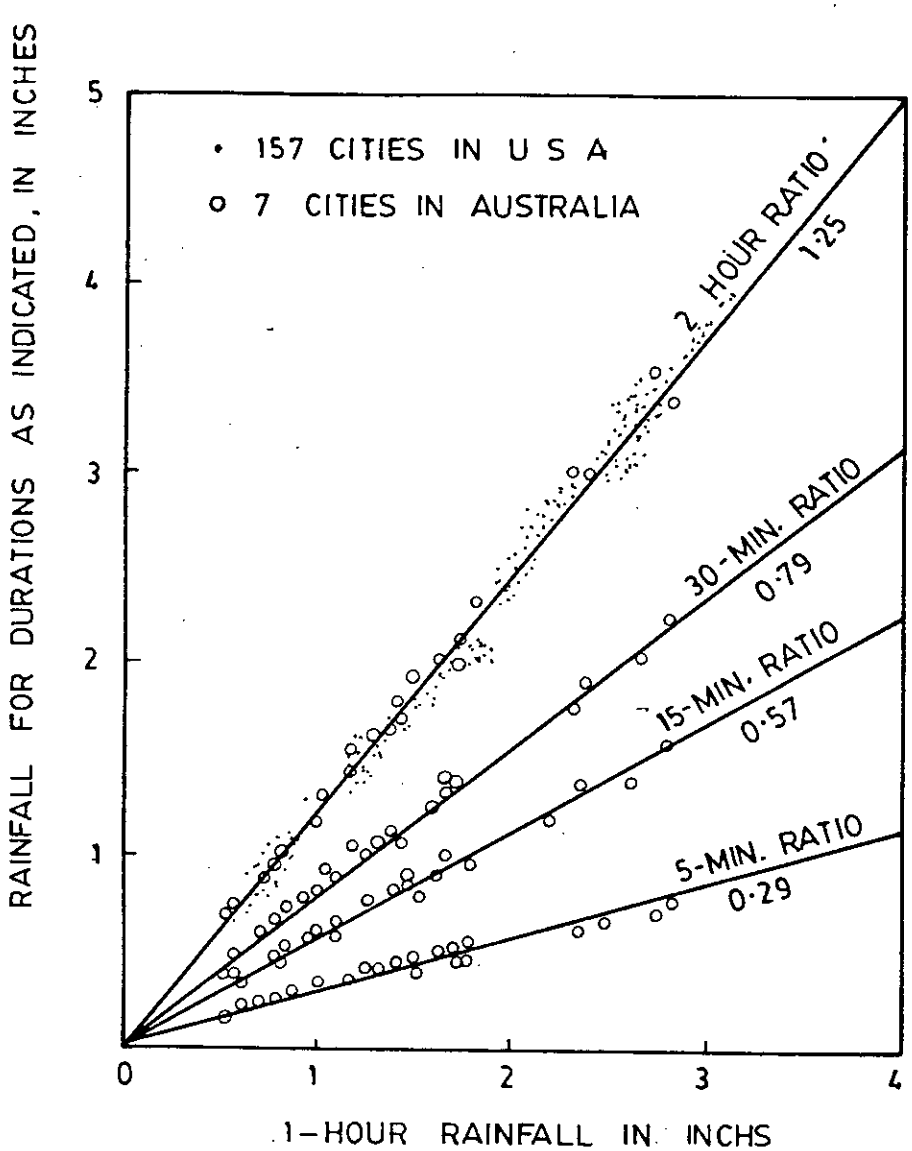


FIG. 3. DEPTH - DURATION RELATIONSHIP FOR U. S. A. & AUSTRALIA (After Bell, 1969)

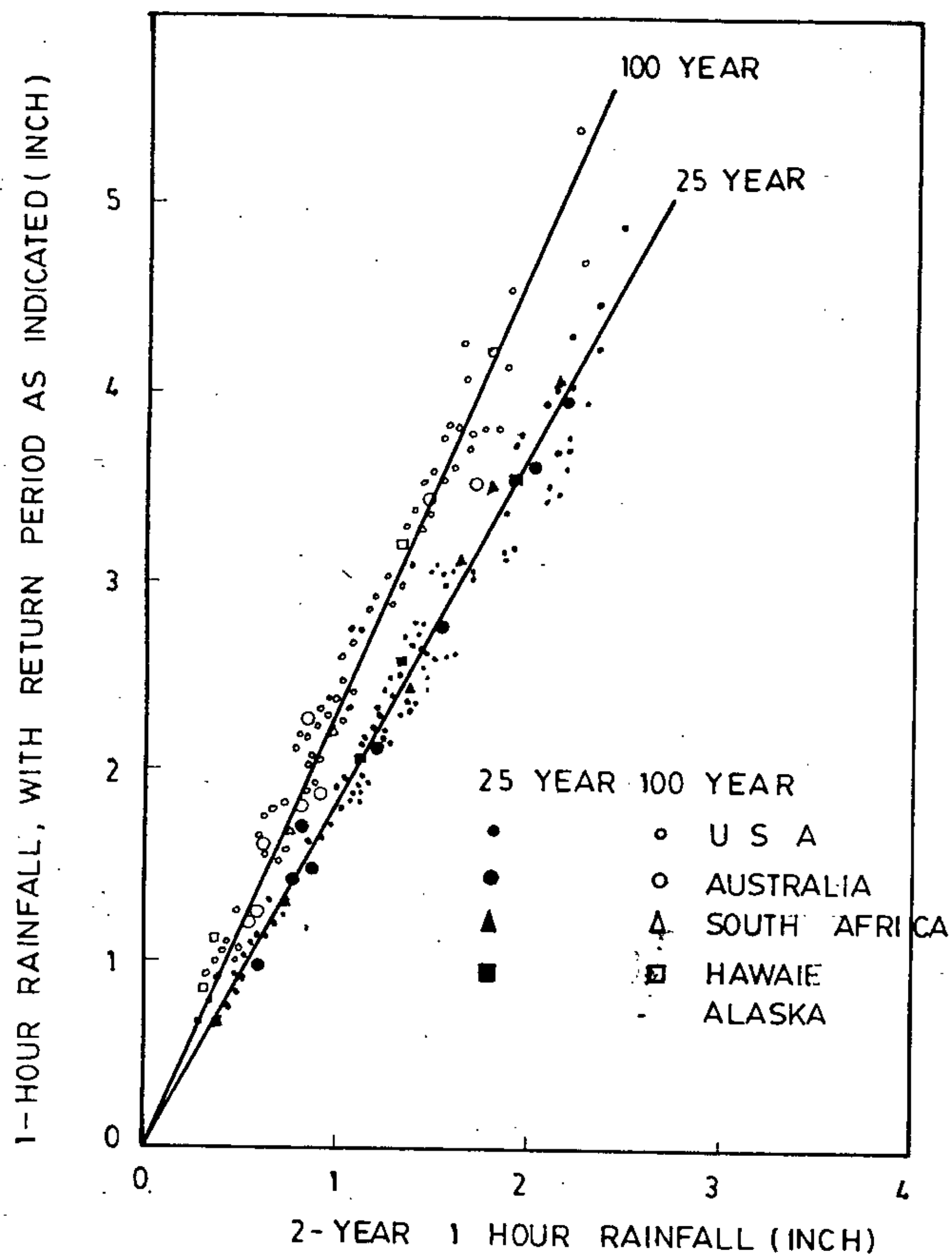


FIG. 4. DEPTH FREQUENCY RELATIONSHIP WITH 2-YEAR 1 HOUR VALUE AS DENOMINATOR (After Bell-1969)

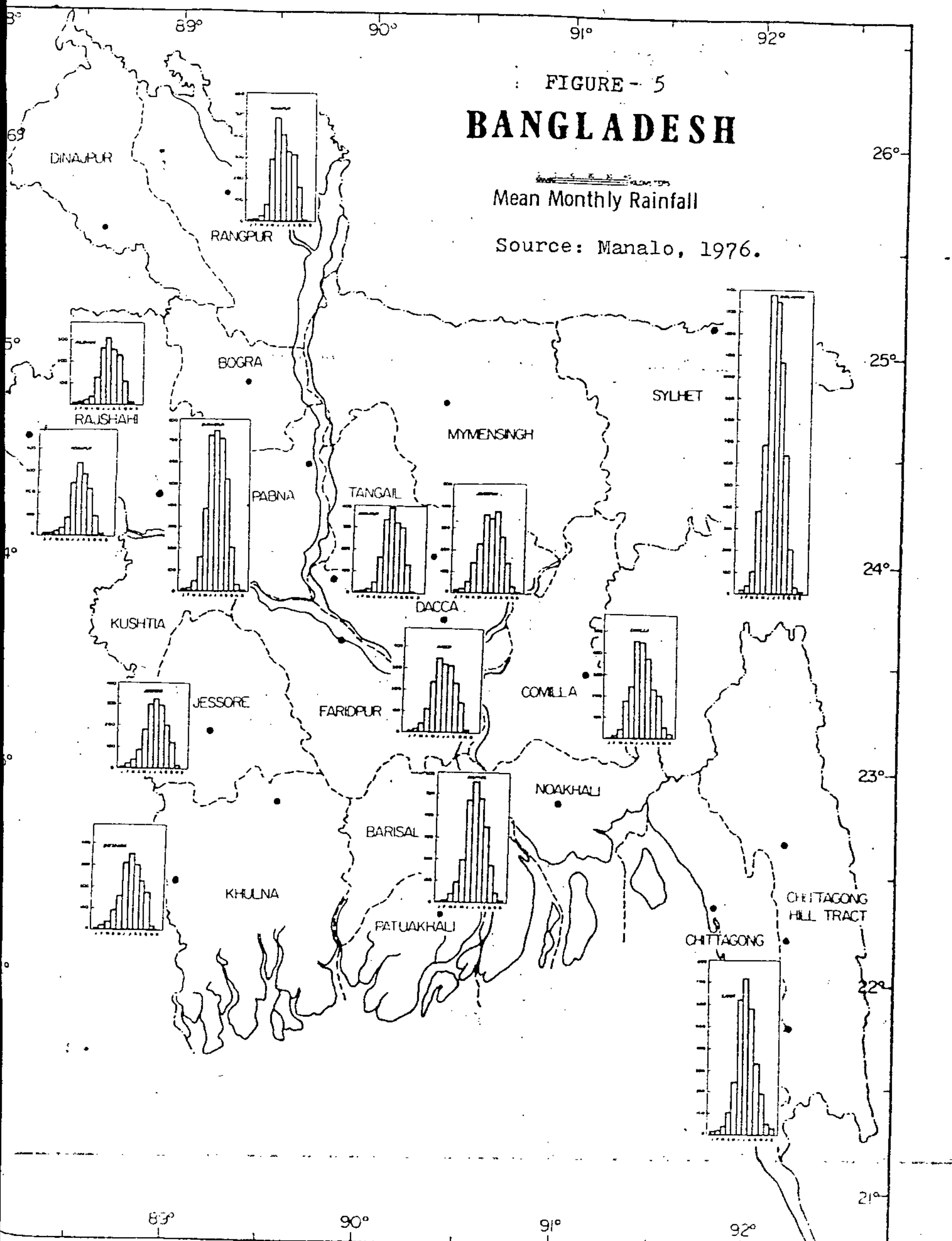


FIGURE - 5
BANGLADESH
Mean Monthly Rainfall
Source: Manalo, 1976.
89°
90°
91°
92°
26°
25°
24°
23°
22°
21°
DINAJPUR
RANGPUR
BOGRA
RAJSHAHI
PABNA
TANGAIL
MYMENSINGH
SYLHET
DACCA
KUSHTIA
JESSORE
FARIDPUR
COMILLA
NOAKHALI
BARISAL
KHULNA
PATUAKHALI
CHITTAGONG
CHITTAGONG HILL TRACT

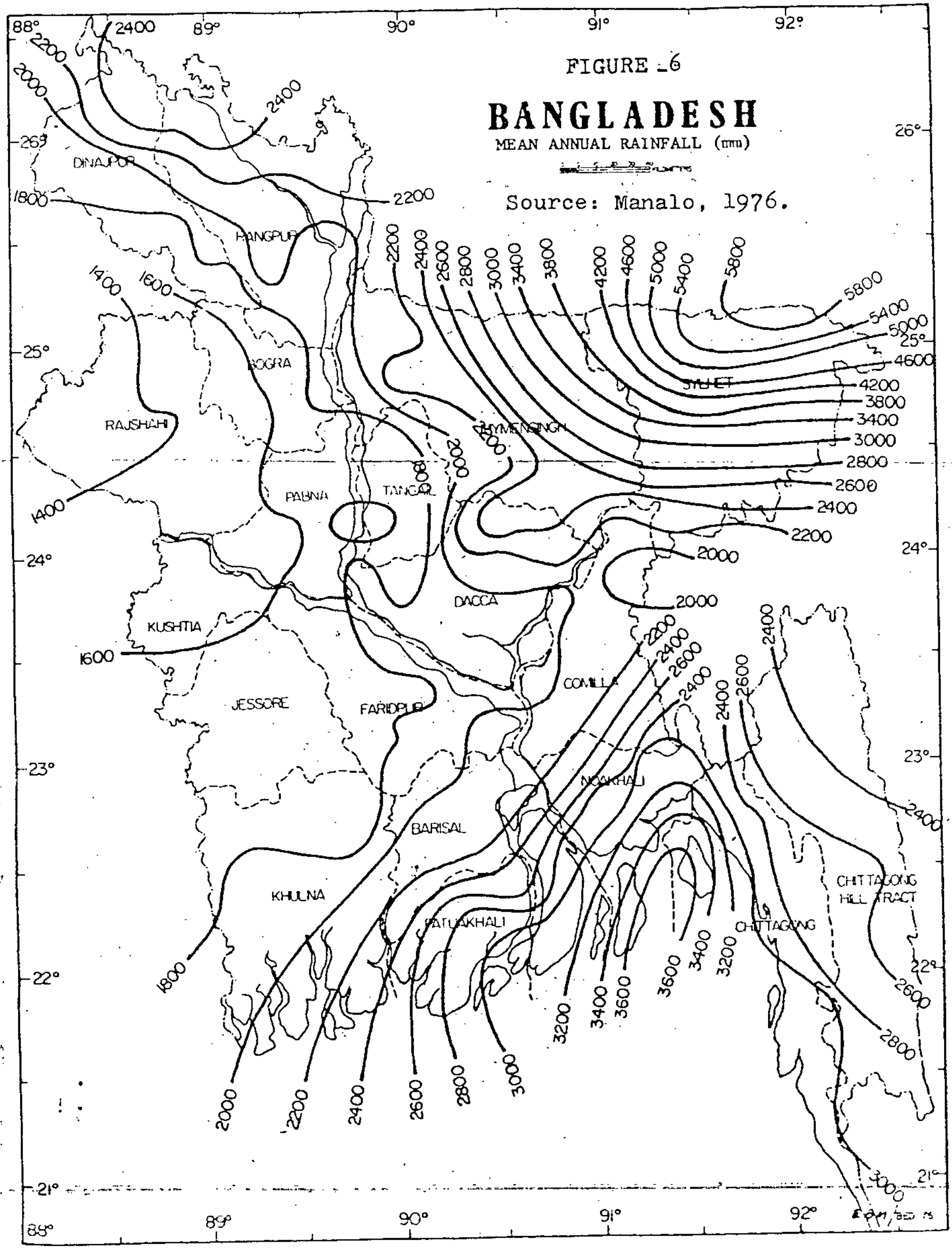


FIGURE 6
BANGLADESH
MEAN ANNUAL RAINFALL (mm)
Source: Manalo, 1976.
DINAJPUR
RANGPUR
BOGRA
RAJSHAHI
MYMENSINGH
SYLHET
PABNA
TANGAIL
DACCA
KUSHTIA
JESSORE
FARIDPUR
COMILLA
NOAKHALI
BARISAL
KHULNA
PATUAKHALI
CHITTAGONG
CHITTAGONG HILL TRACT
88°
89°
90°
91°
92°
26°
25°
24°
23°
22°
21°

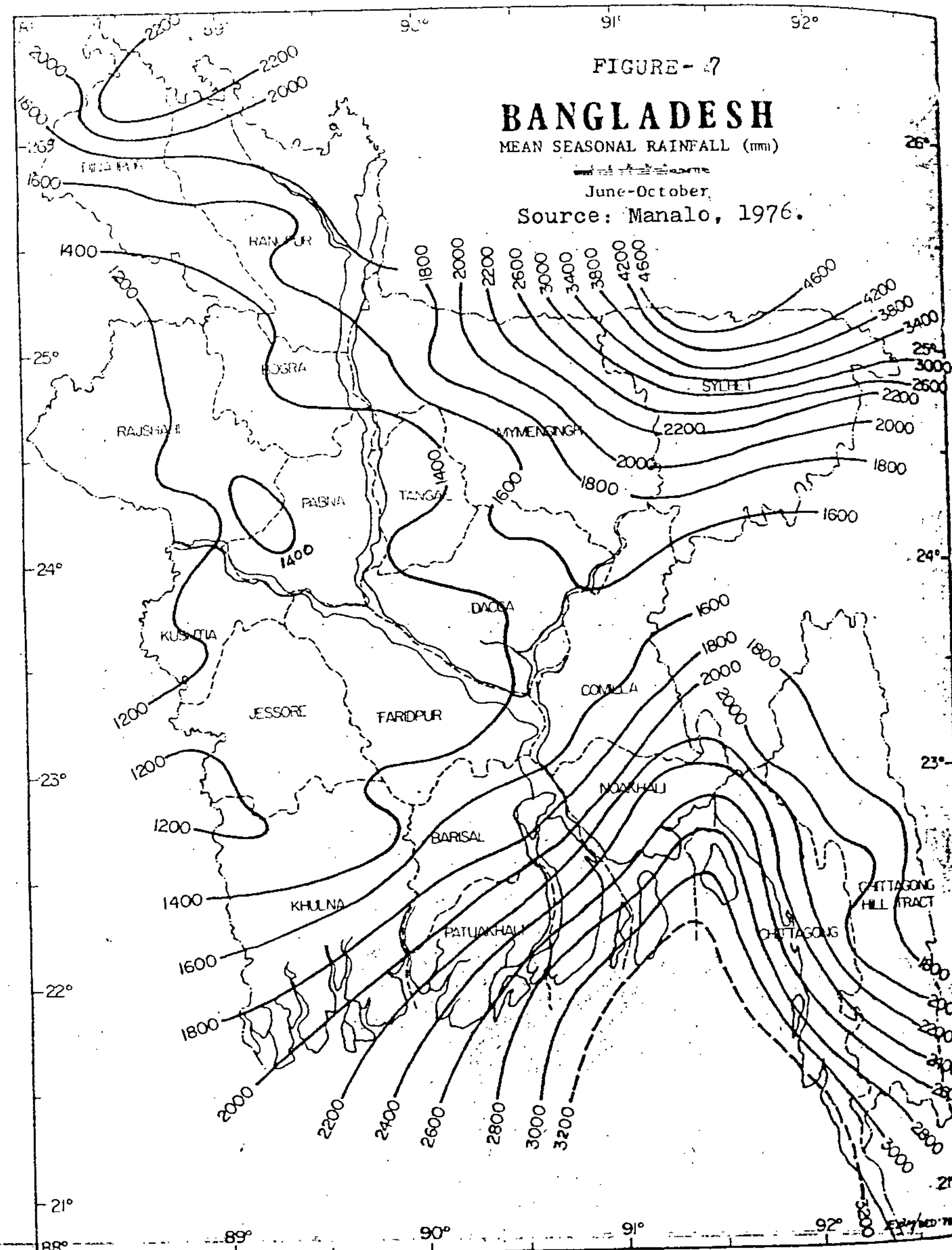


FIGURE- 7
BANGLADESH
MEAN SEASONAL RAINFALL (mm)
June-October
Source: Manalo, 1976.
RANGPUR
BOGRA
RAJSHAHI
PABNA
TANGAIL
MYMENSINGH
SYLHET
DACCA
KUSHTIA
JESSORE
FARIDPUR
COMILLA
NOAKHALI
BARISAL
KHULNA
PATUAKHALI
CHITTAGONG
CHITTAGONG HILL TRACT

ESTIMATES OF 2-DAY RAINFALL:

1 IN 20 YEARS—345 mm
1 IN 10 YEARS—310 mm
1 IN 5 YEARS—271 mm

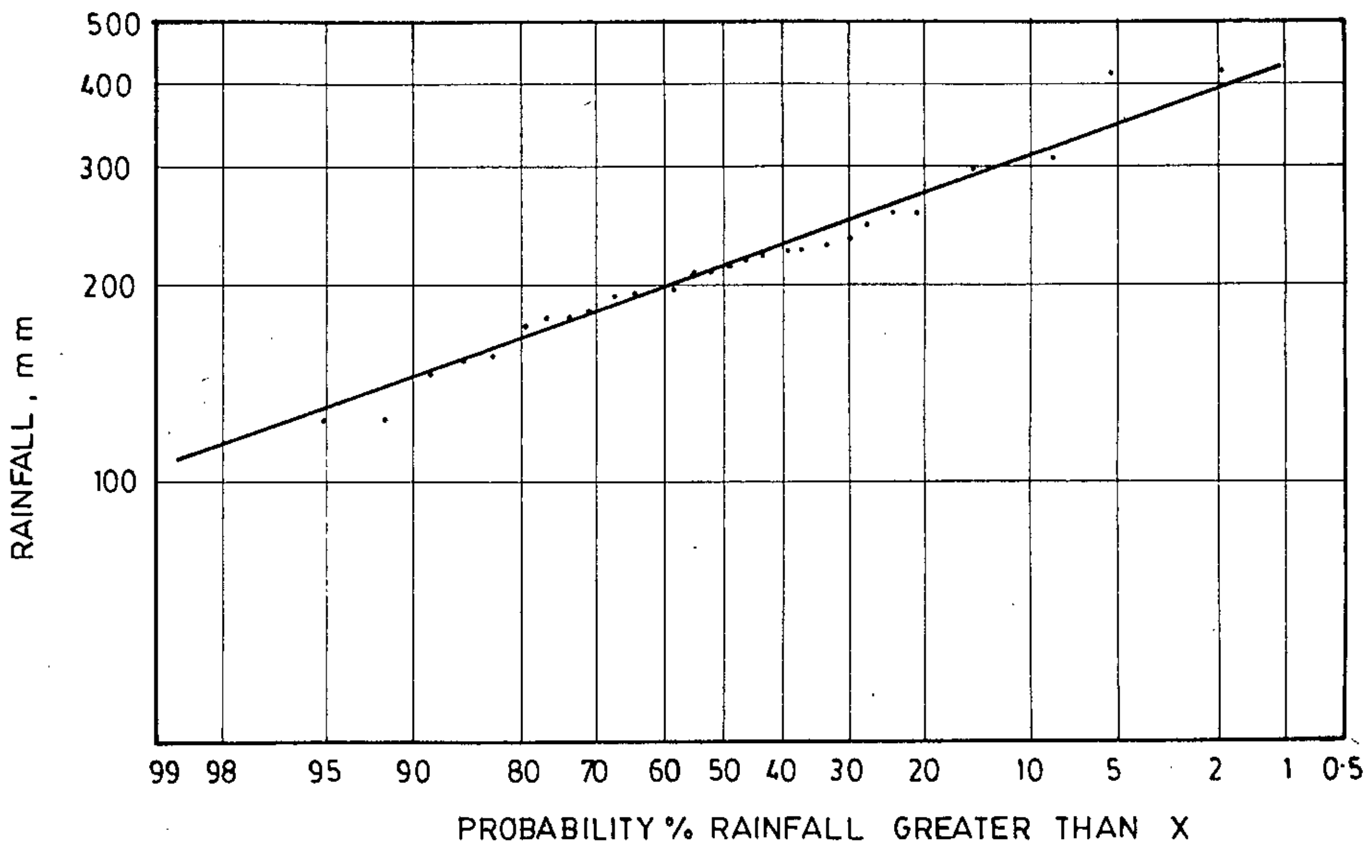


FIG. 8 PROBABILITY OF 2-DAY ANNUAL MAXIMUM RAINFALL FOR RANGPUR, (Source: Water Balance Studies report, 1982)

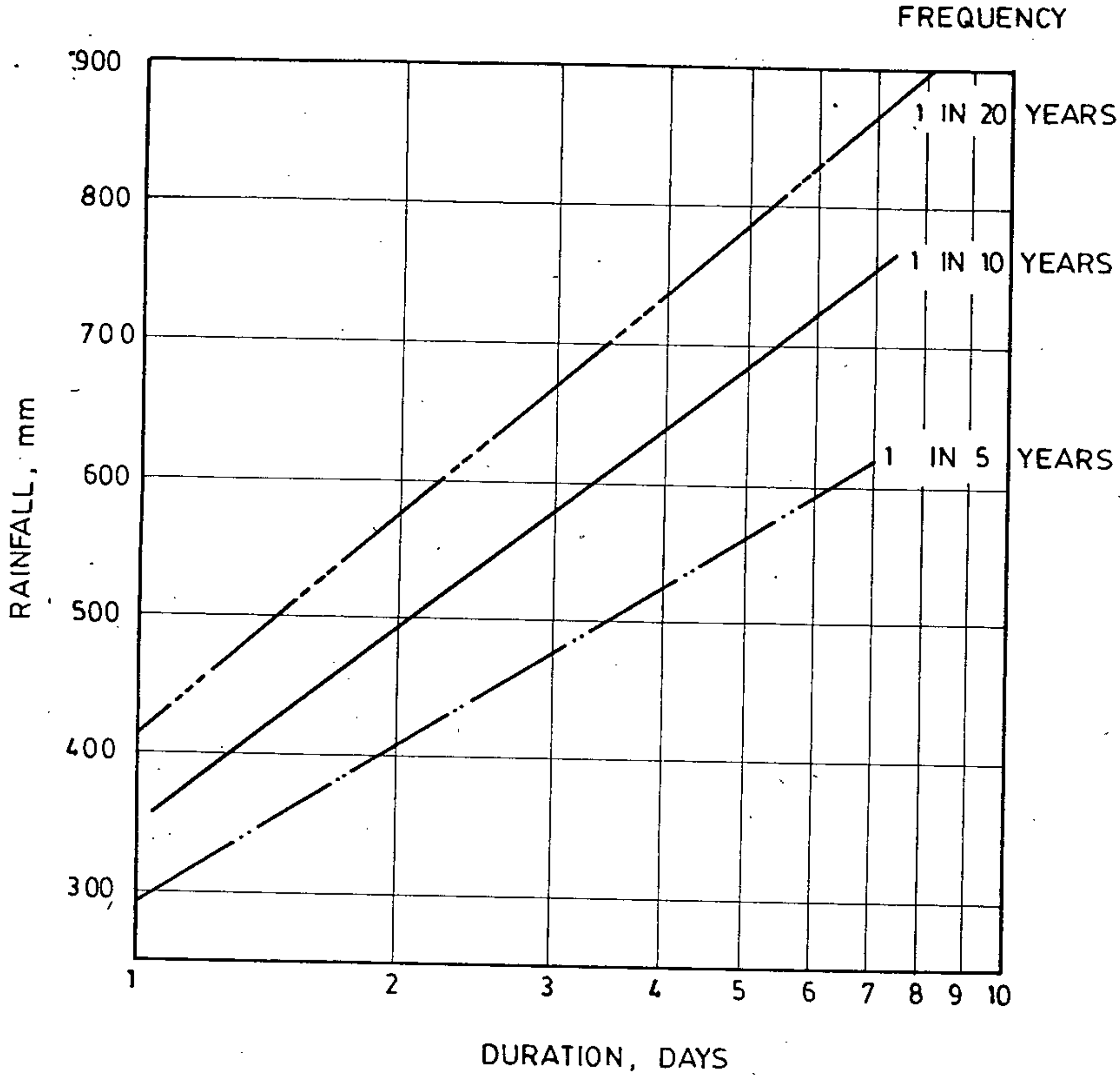


FIG. 9 DEPTH - DURATION - FREQUENCY CURVE FOR SYLHET
(Source: Water Balance Studies report; 1982)

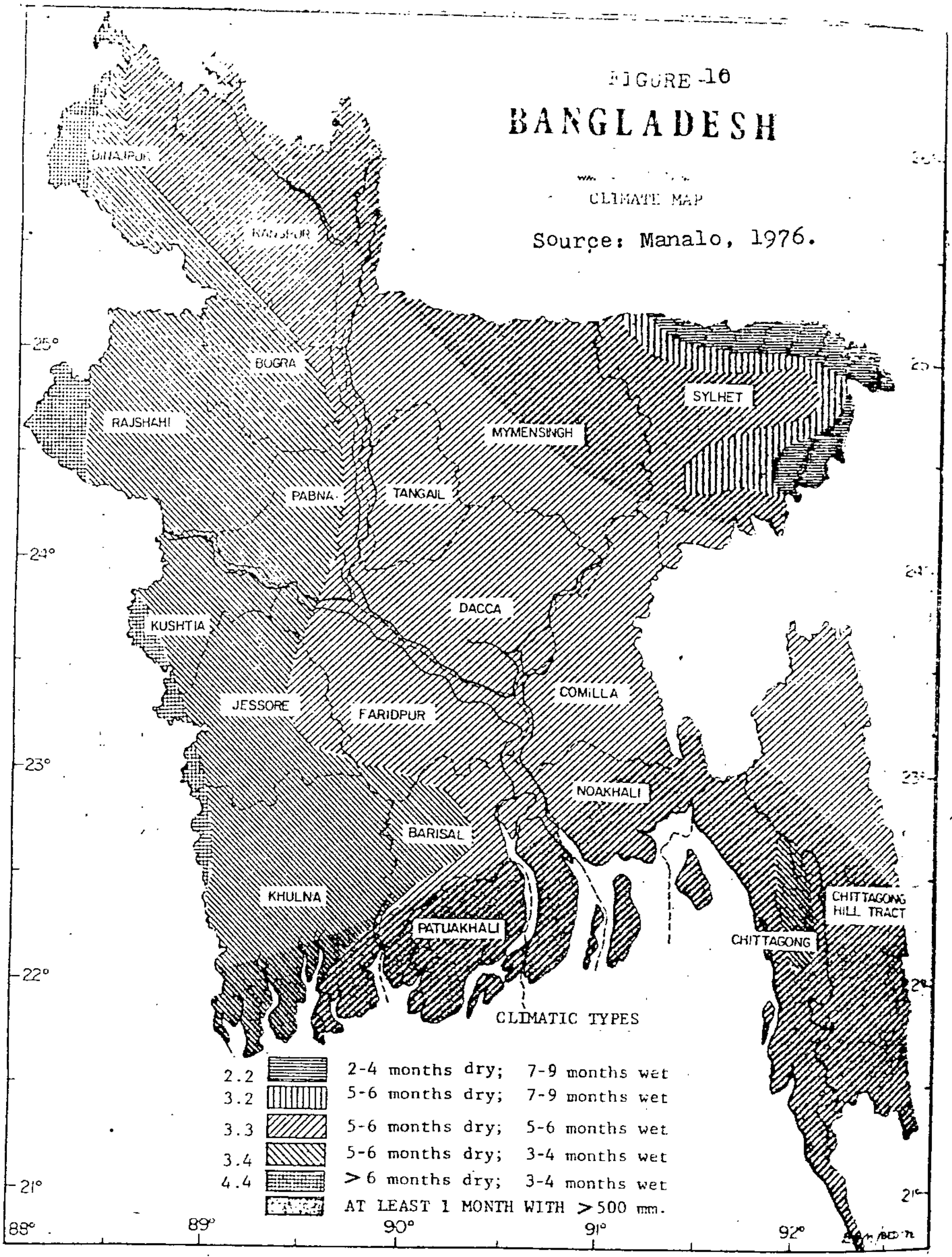


FIGURE 16
BANGLADESH
CLIMATE MAP
Source: Manalo, 1976.
DINAJPUR
RANGPUR
BOGRA
RAJSHAHI
PABNA
TANGAIL
MYMENSINGH
SYLHET
KUSHTIA
DACCA
COMILLA
JESSORE
FARIDPUR
NOAKHALI
BARISAL
KHULNA
PATUAKHALI
CHITTAGONG
CHITTAGONG HILL TRACT
25°
24°
23°
22°
21°
88°
89°
90°
91°
92°
CLIMATIC TYPES
2.2 2-4 months dry; 7-9 months wet
3.2 5-6 months dry; 7-9 months wet
3.3 5-6 months dry; 5-6 months wet
3.4 5-6 months dry; 3-4 months wet
4.4 > 6 months dry; 3-4 months wet
AT LEAST 1 MONTH WITH > 500 mm.

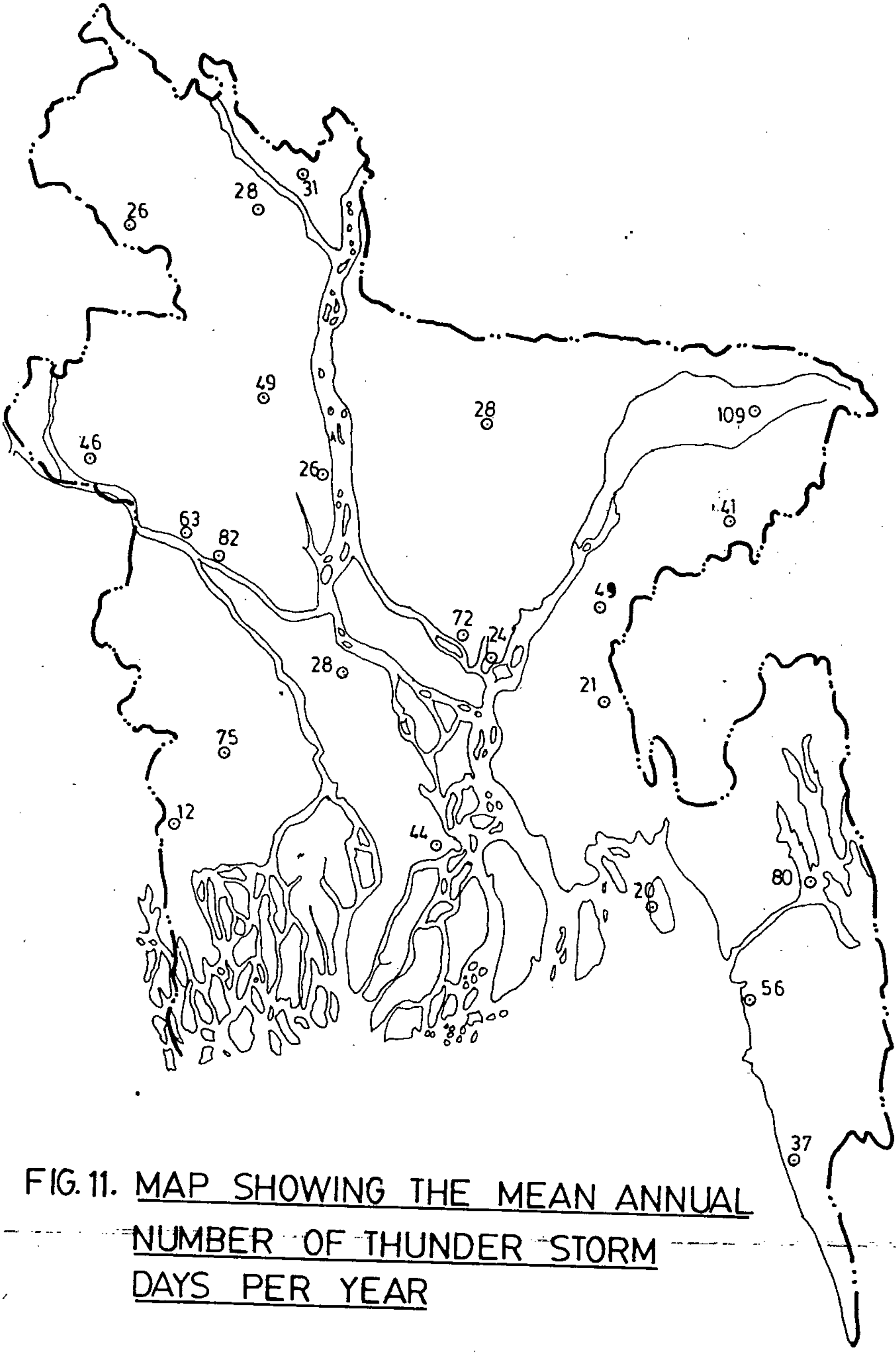


FIG. 11. MAP SHOWING THE MEAN ANNUAL NUMBER OF THUNDER STORM DAYS PER YEAR

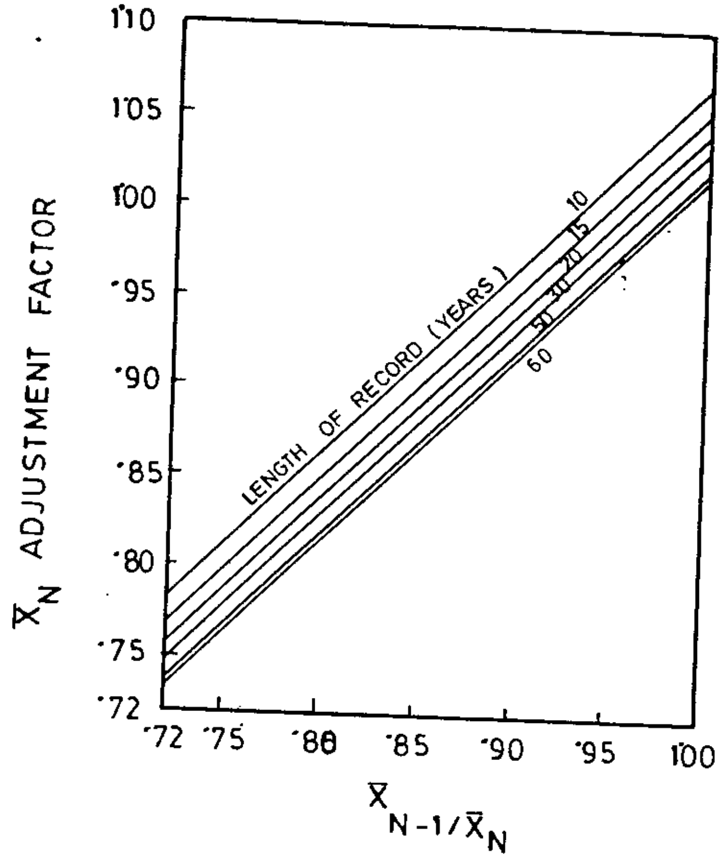


FIG.12(a) ADJUSTMENT OF MEAN FOR MAXIMUM OBSERVED RAINFALL (After Hershfield, 1961)

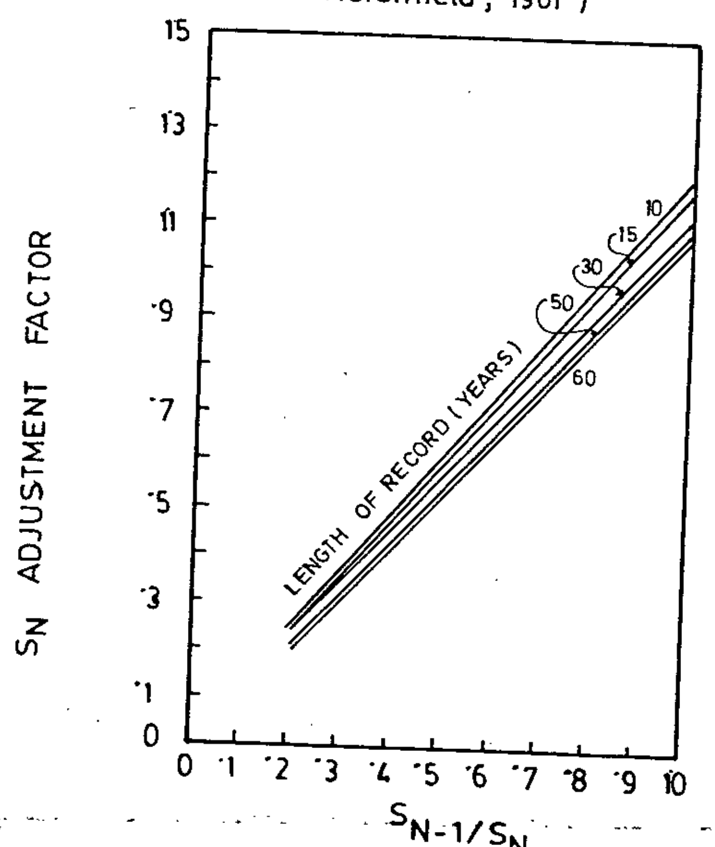


FIG.12(b) DIAGRAM FOR ADJUSTING THE STANDARD DEVIATION FOR THE MAXIMUM OBSERVED RAINFALL (After Hershfield, 1961)

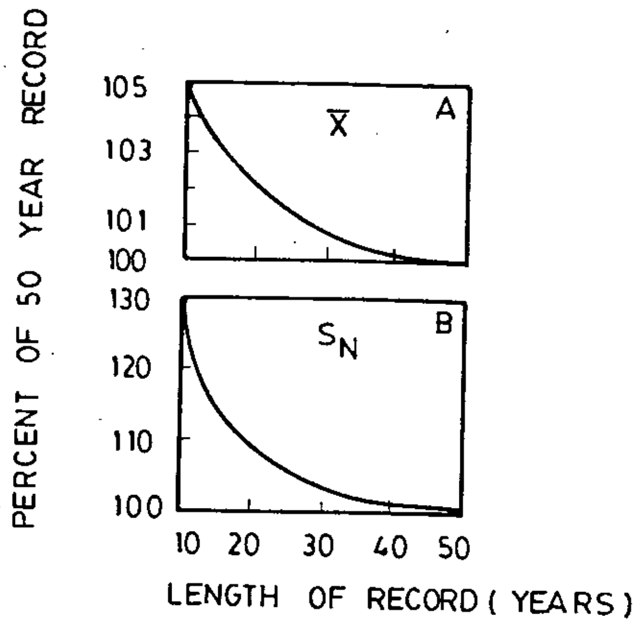


FIG. 13. SAMPLE–SIZE ADJUSTMENT DIAGRAMS FOR MEAN & STANDARD DEVIATION (After Hershfield, 1961)

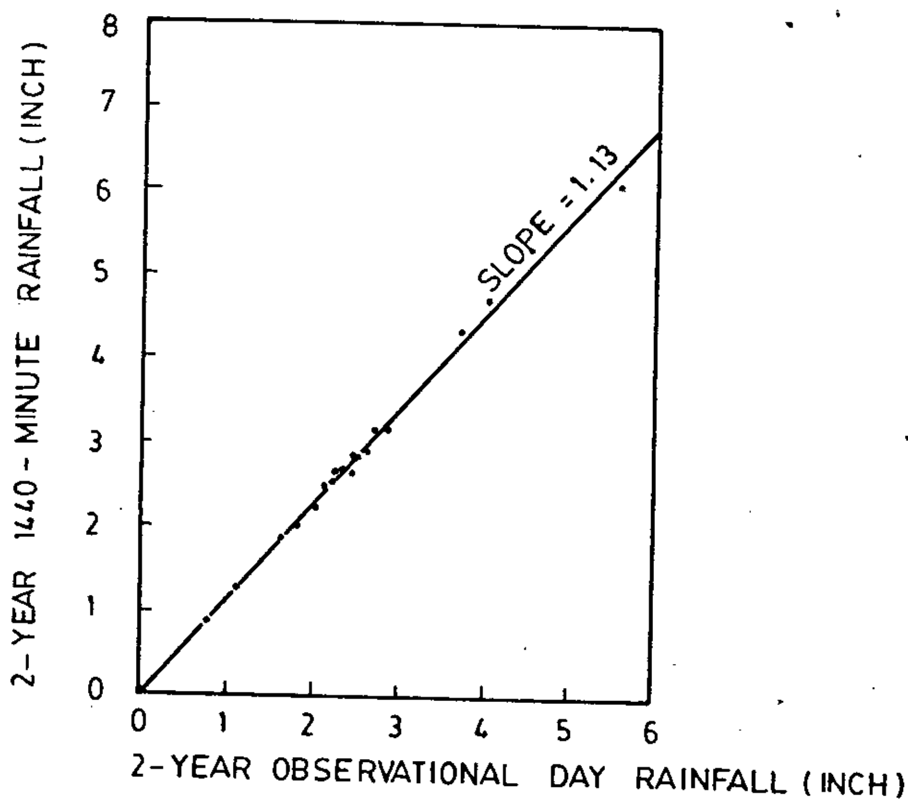


FIG. 14. RELATIONSHIP BETWEEN 2-YR 1440-MIN AND 2-YR OBSERVATIONAL DAY RAINFALL (After Hershfield, 1961)

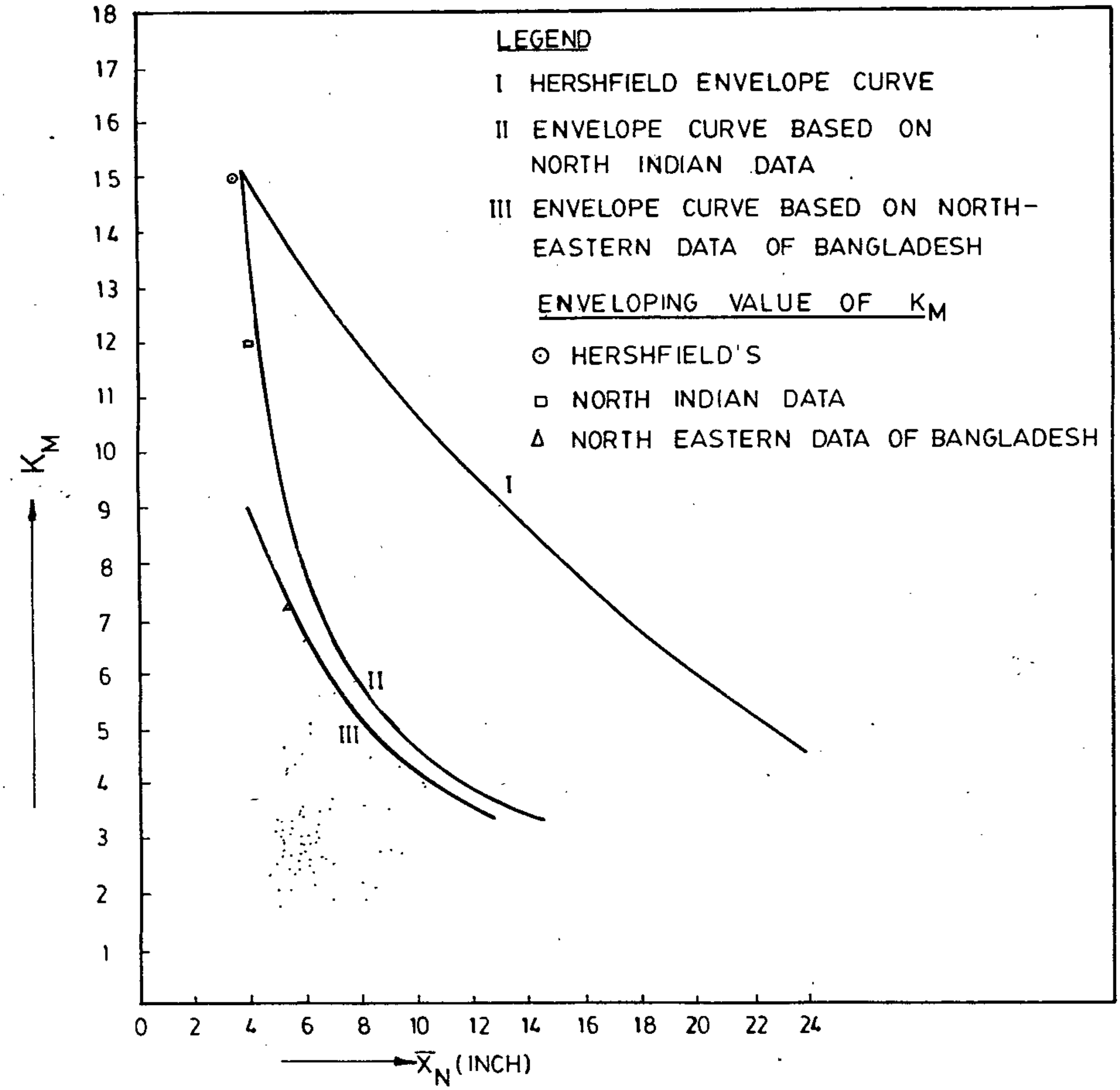


FIG. 15. K_M AS A FUNCTION OF MEAN ANNUAL MAXIMUM ONE-DAY RAINFALL

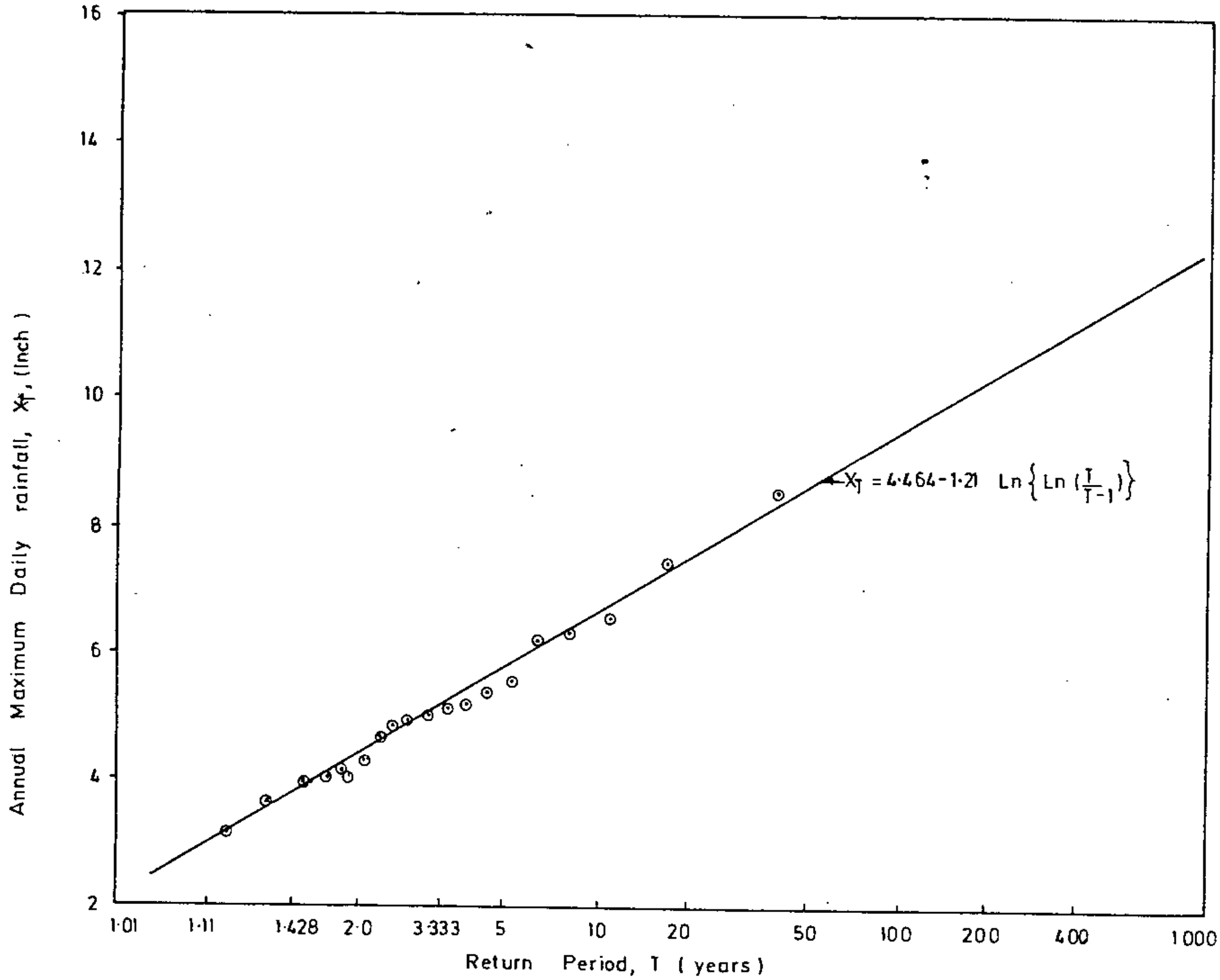


Fig. 16 Distribution of annual daily maximum rainfall for COMILLA Station

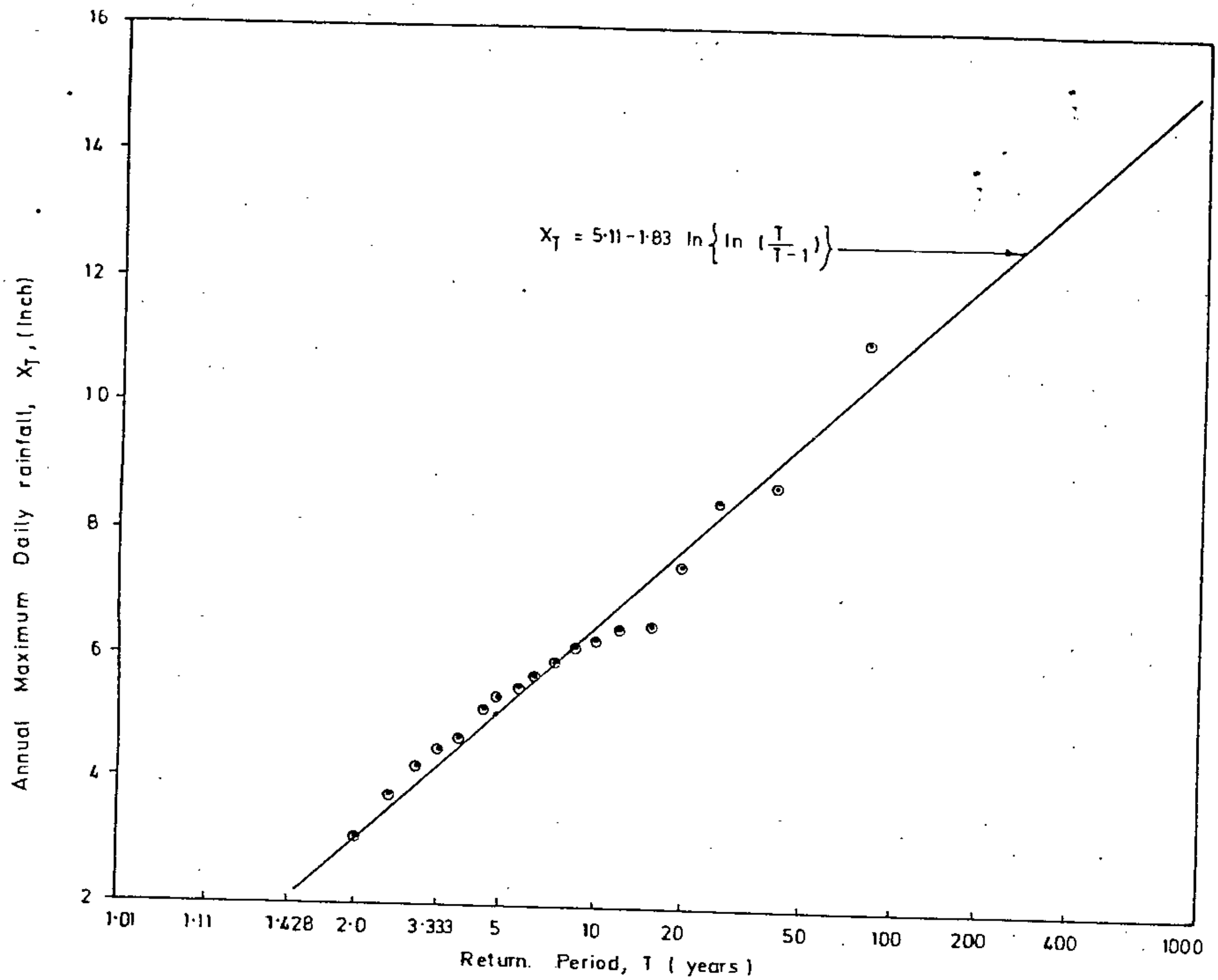


Fig. 17. Distribution of annual daily maximum rainfall for DHAKA Station

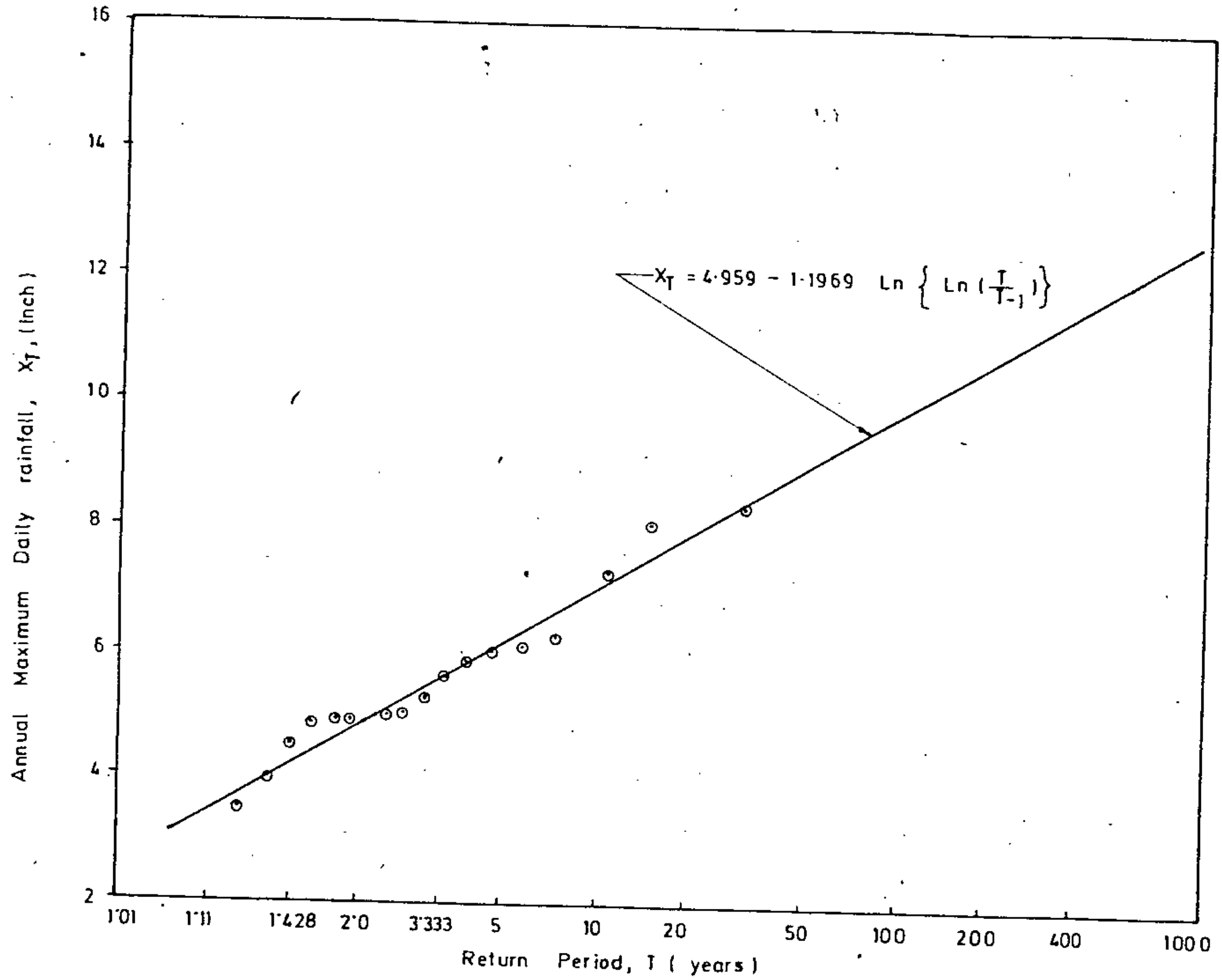


Fig. 18. Distribution of annual daily maximum rainfall for MYMENSINGH Station

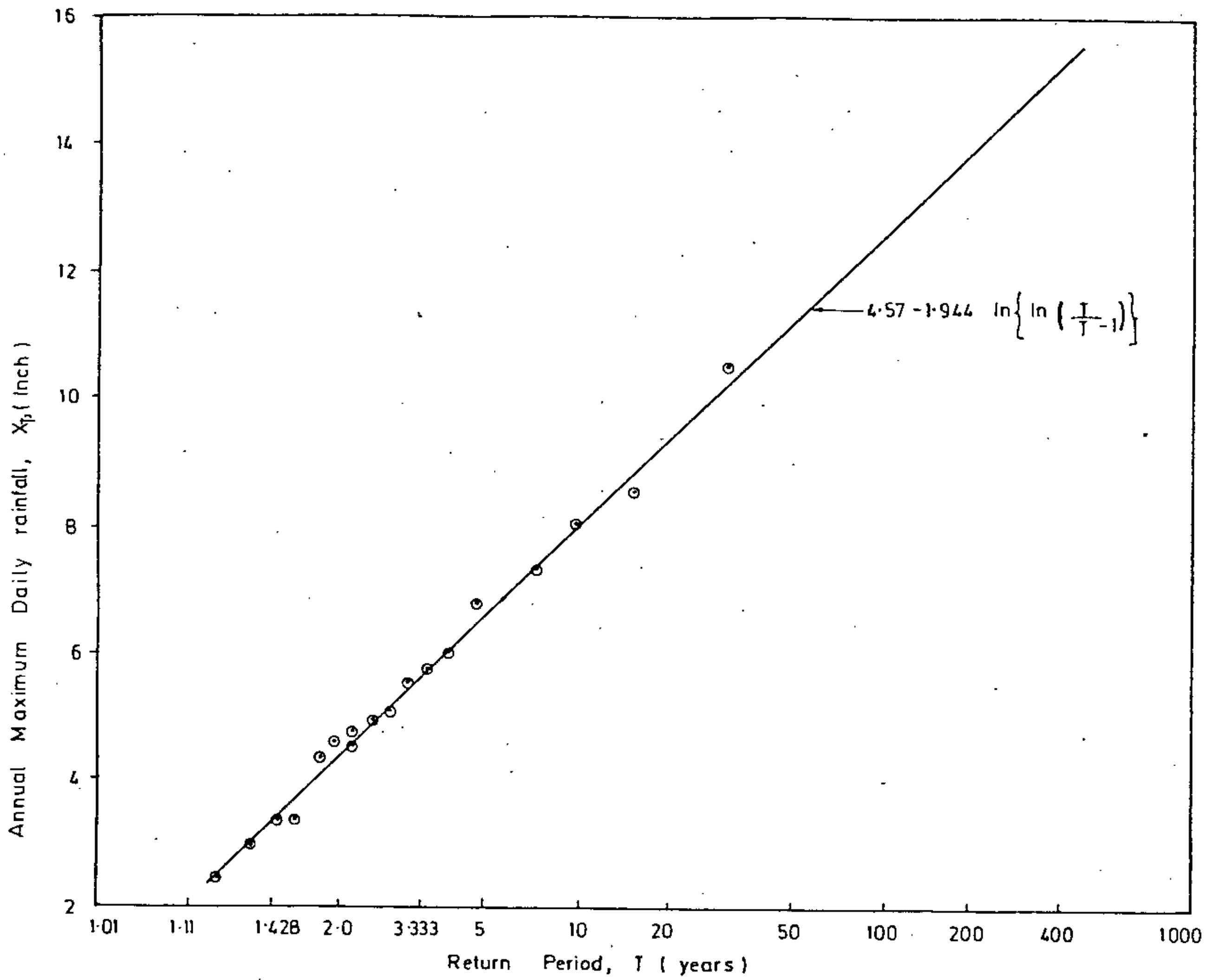


Fig. 19. Distribution of annual daily maximum rainfall for JAMALPUR Station

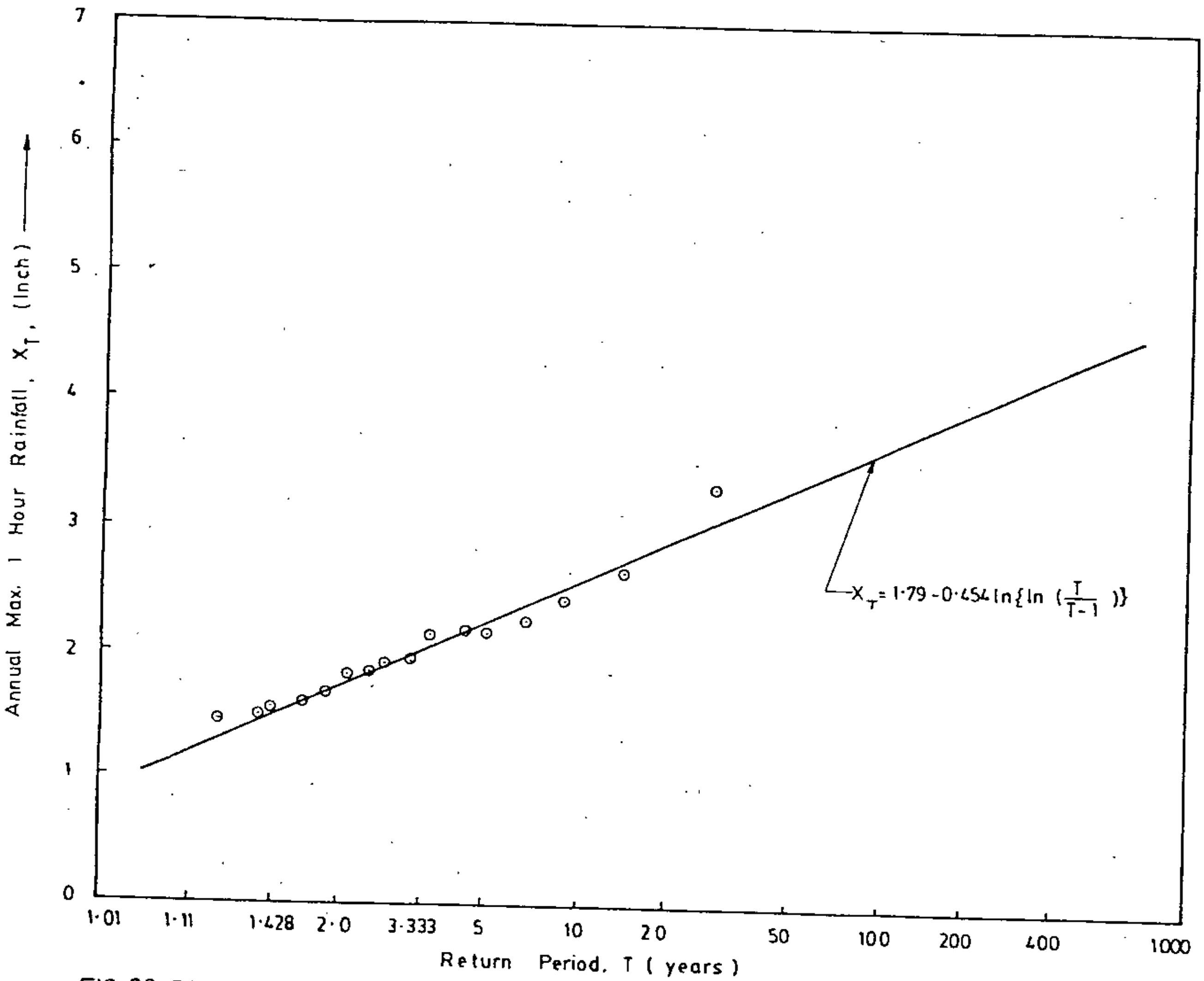


FIG. 20. Distribution of Annual Maximum 1-Hour Rainfall for Dhaka Station

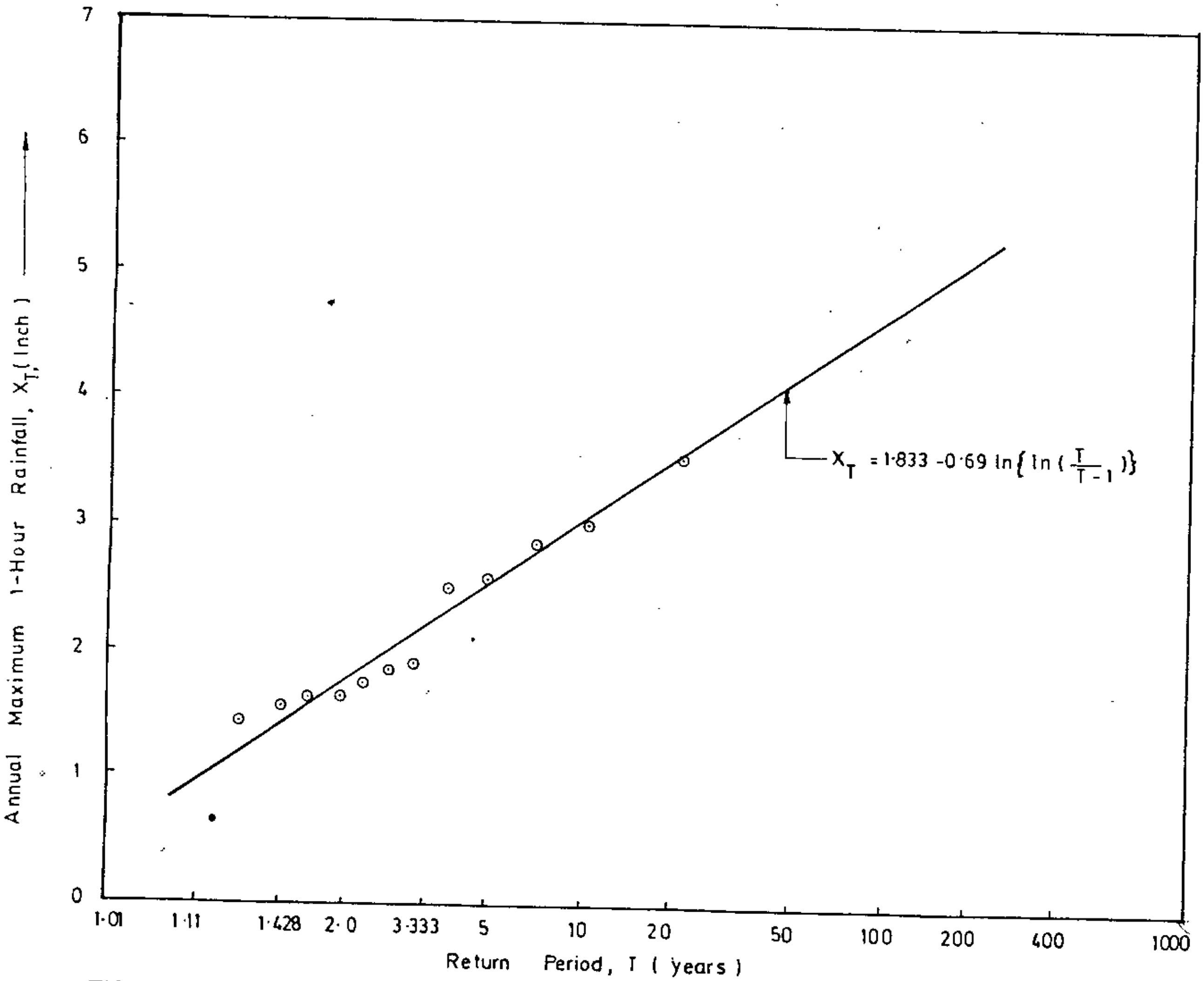


FIG. 21. Distribution of Annual Maximum 1-Hour Rainfall for Sylhet Station

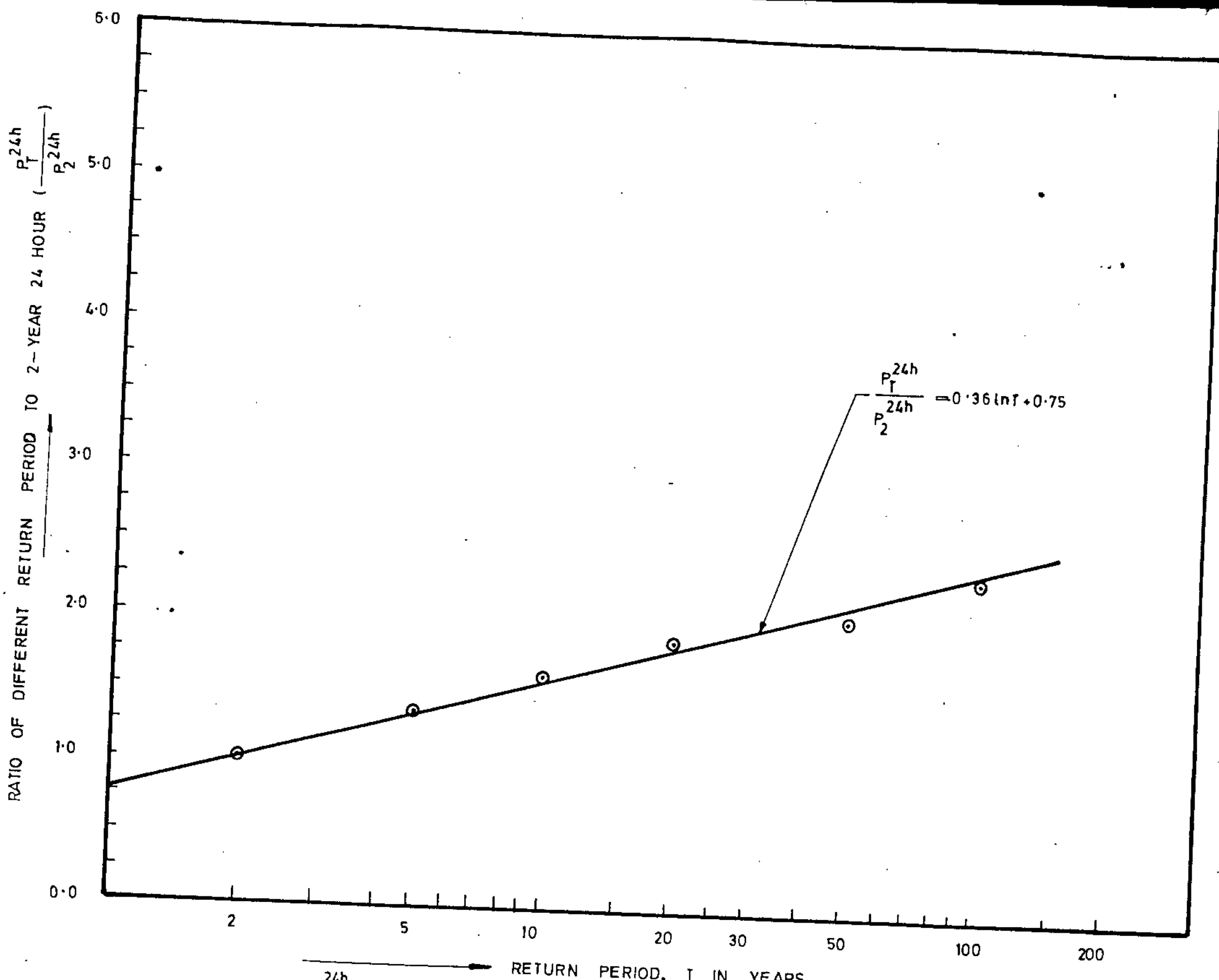


FIG. 22. RATIO OF $\frac{P_T^{24h}}{P_2^{24h}}$ AS A FUNCTION OF RETURN PERIOD

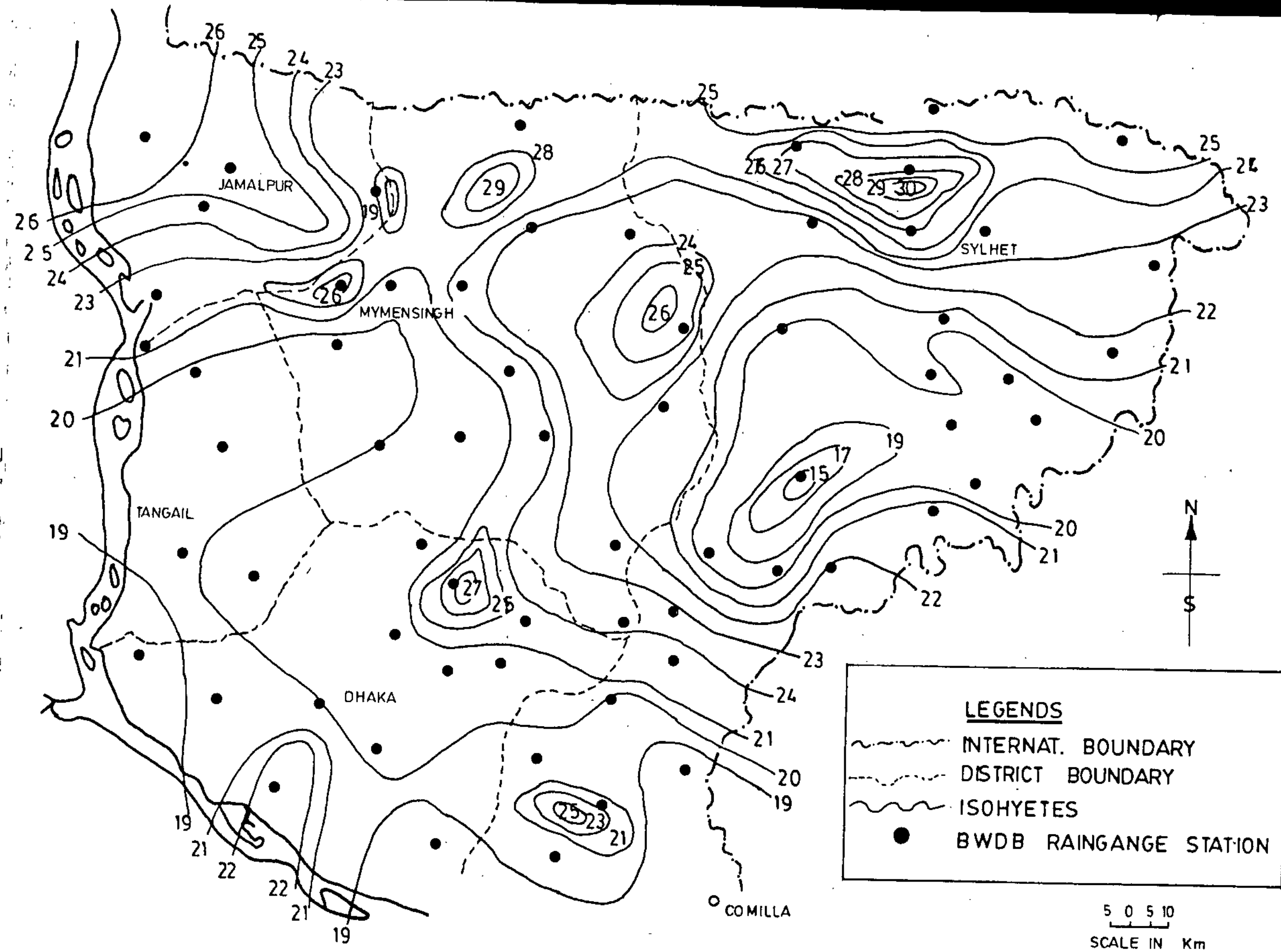


FIG. 23. GENERALIZED ISOHYETAL MAP FOR PROBABLE MAXIMUM ONE-DAY RAINFALL (INCHES)

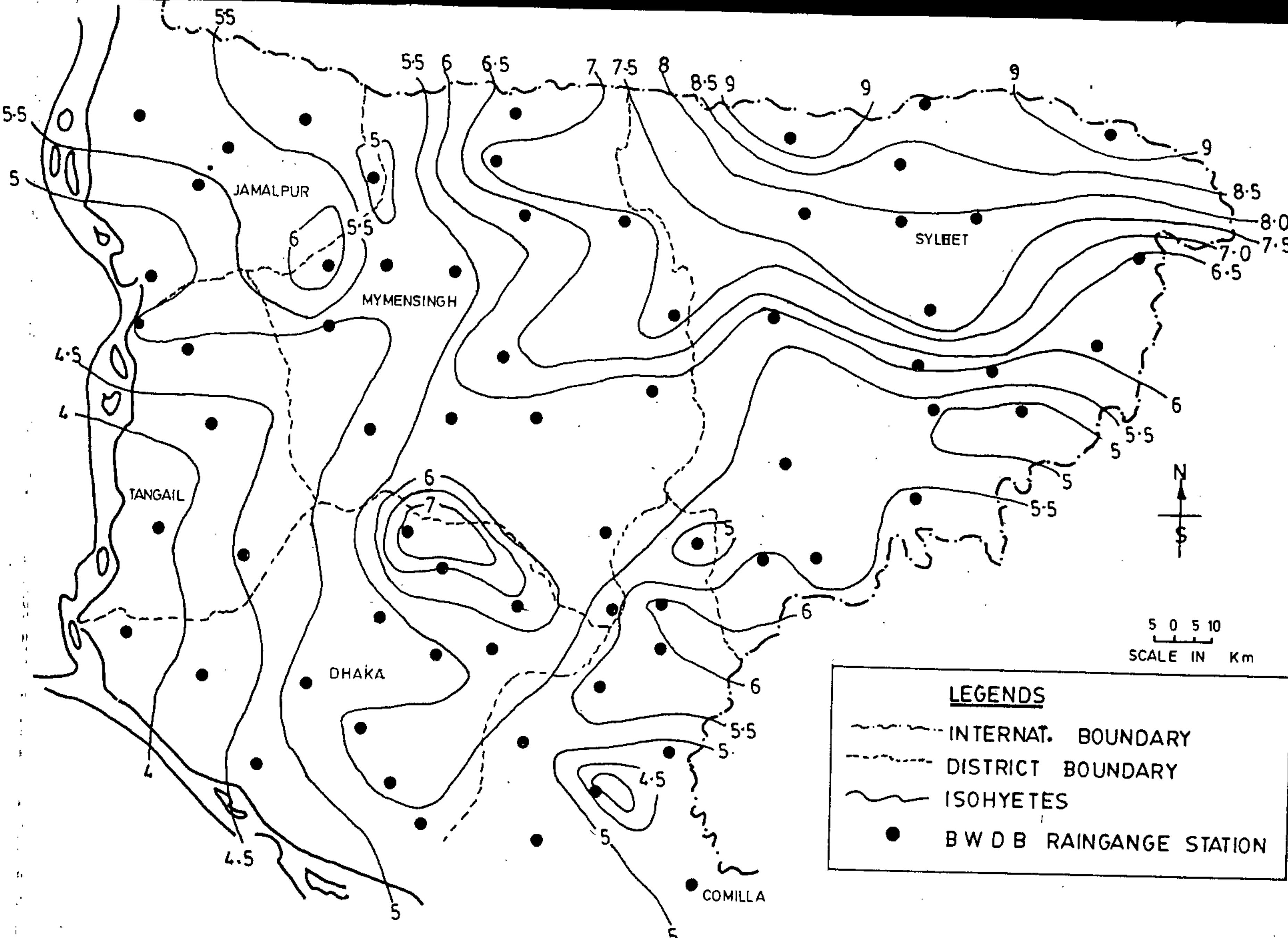
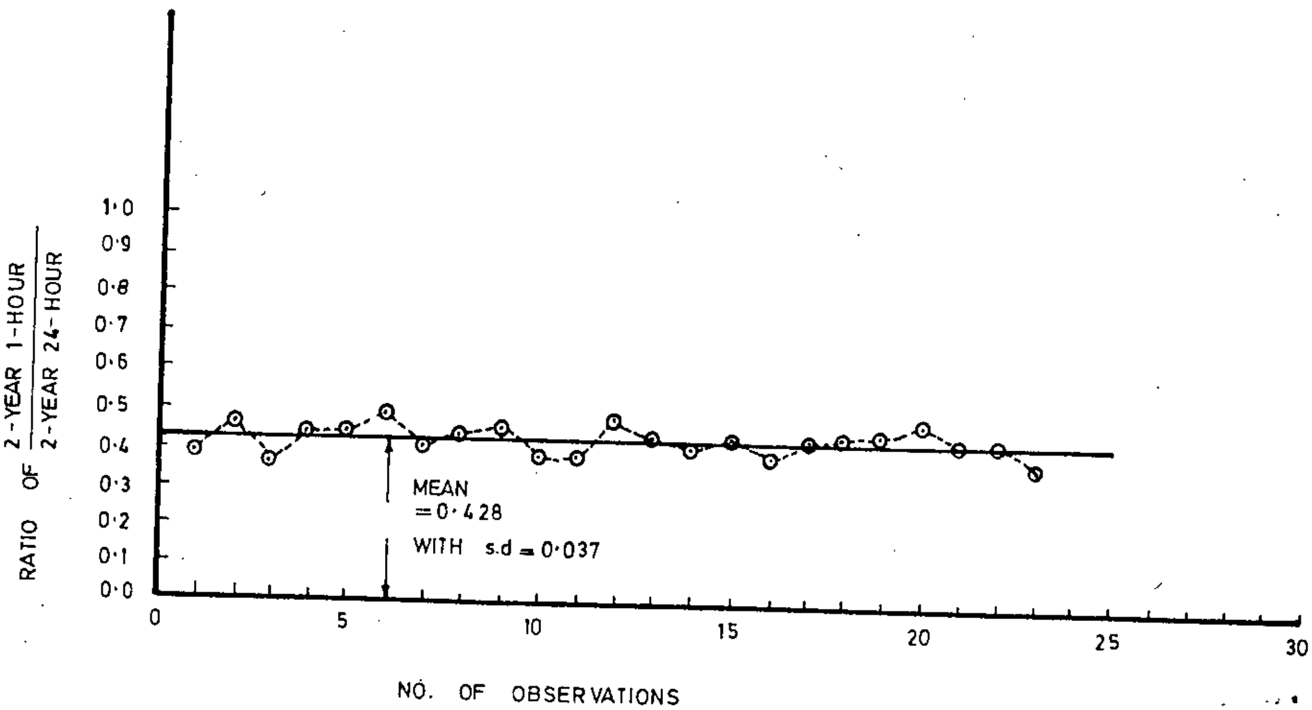


FIG. 24. GENERALIZED ISOHYETAL MAP FOR MAXIMUM ONE-DAY RAINFALL IN INCH HAVING 2-YEAY RETURN PERIOD



FIG·25. RATIOS OF 2-YEAR 1-HOUR TO 2-YEAR 24-HOUR RAINFALL

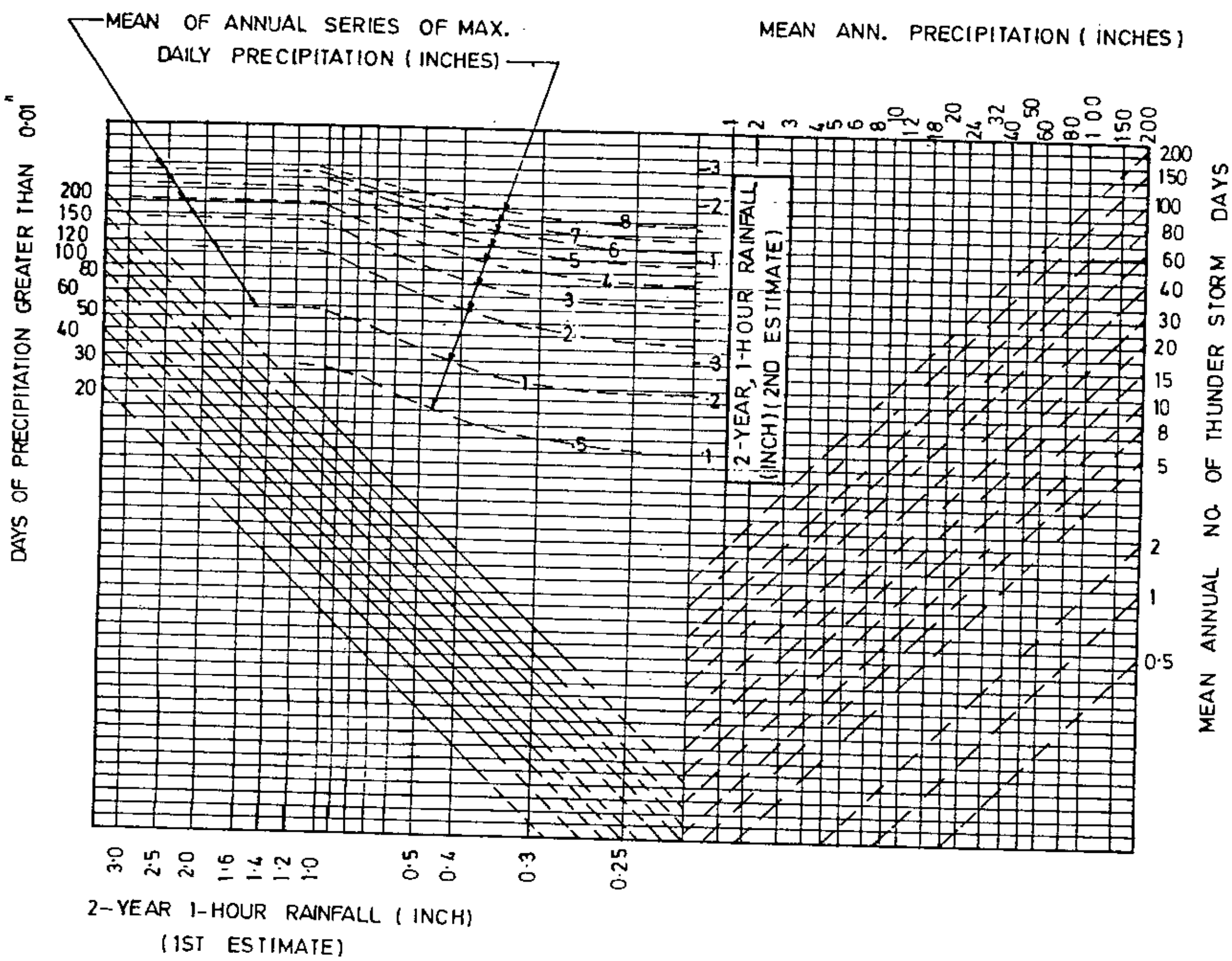


FIG.26. HERSHFIELD AND WILSON'S DIAGRAM FOR ESTIMATING 2-YEAR 1-HOUR RAINFALL

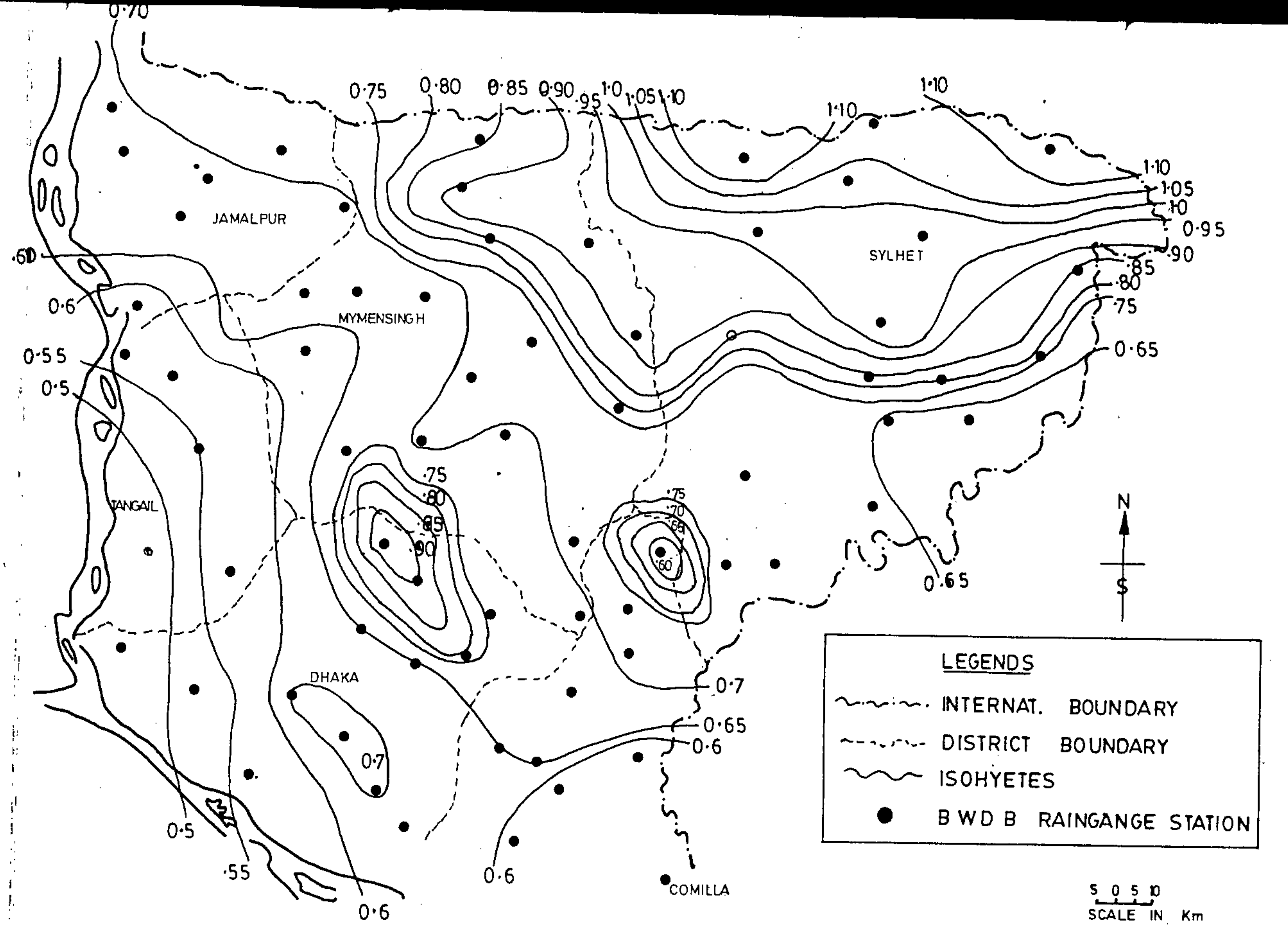


FIG. 27. GENERALIZED ISOHYETAL MAP FOR 5 MINUTE 2-YEAR RAINFALL (INCHES)

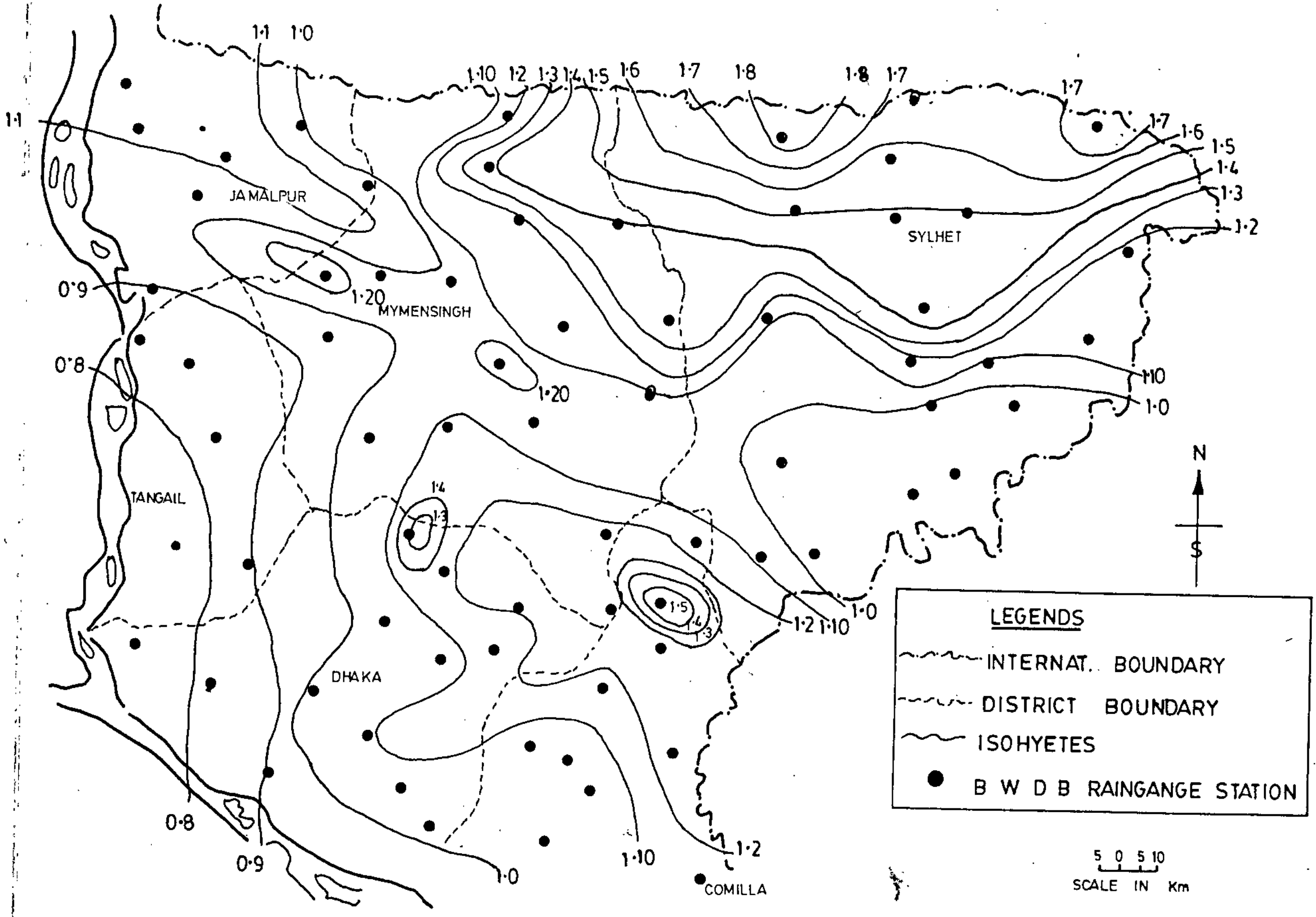


FIG. 28. GENERALIZED ISOHYETAL MAP FOR 10 MINIUTE - 2-YEAR RAINFALL (INCHES)

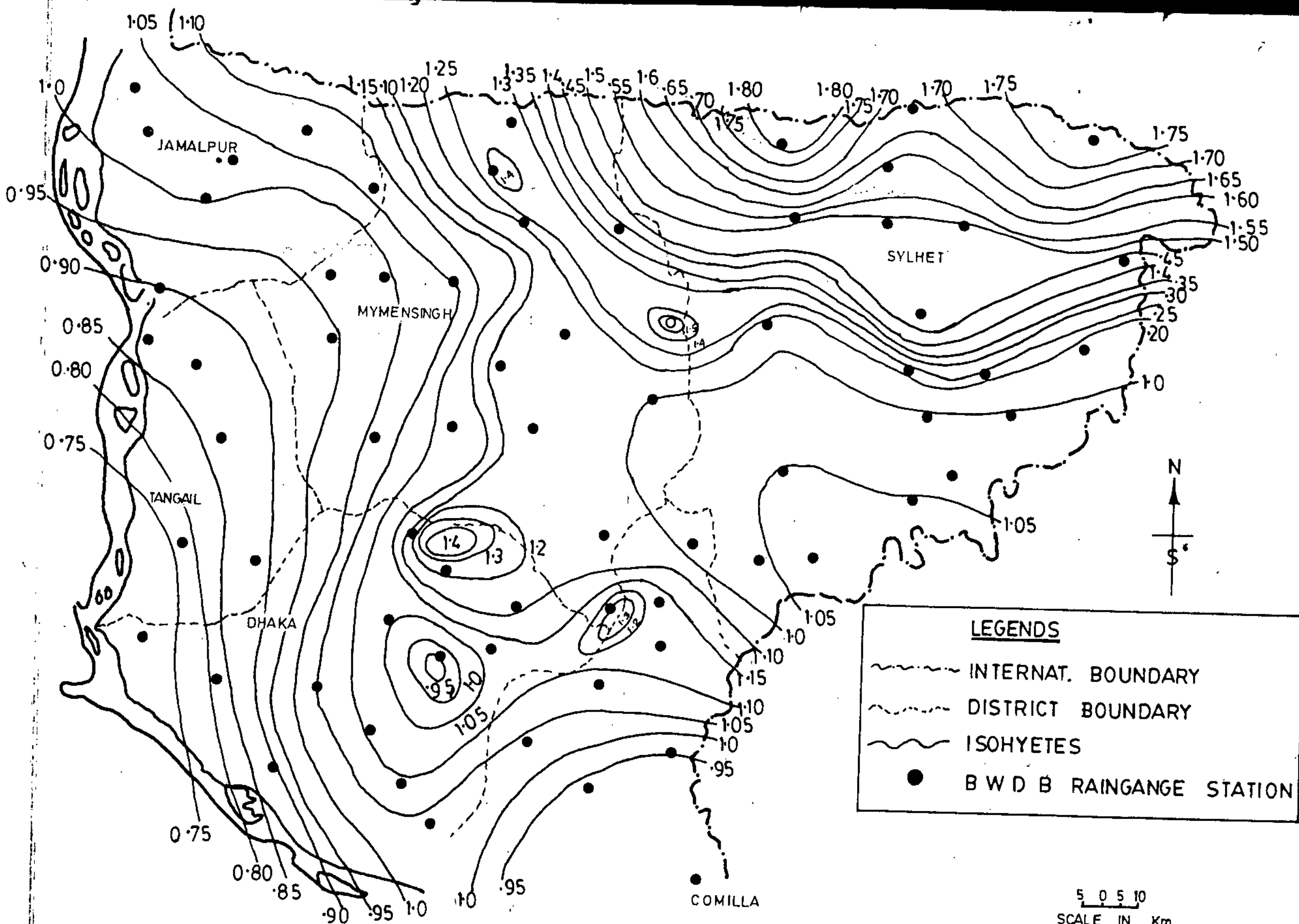


FIG. 29. GENERALIZED ISOHYETAL MAP FOR 15 MINUTE 2-YEAR RAINFALL (INCHES)

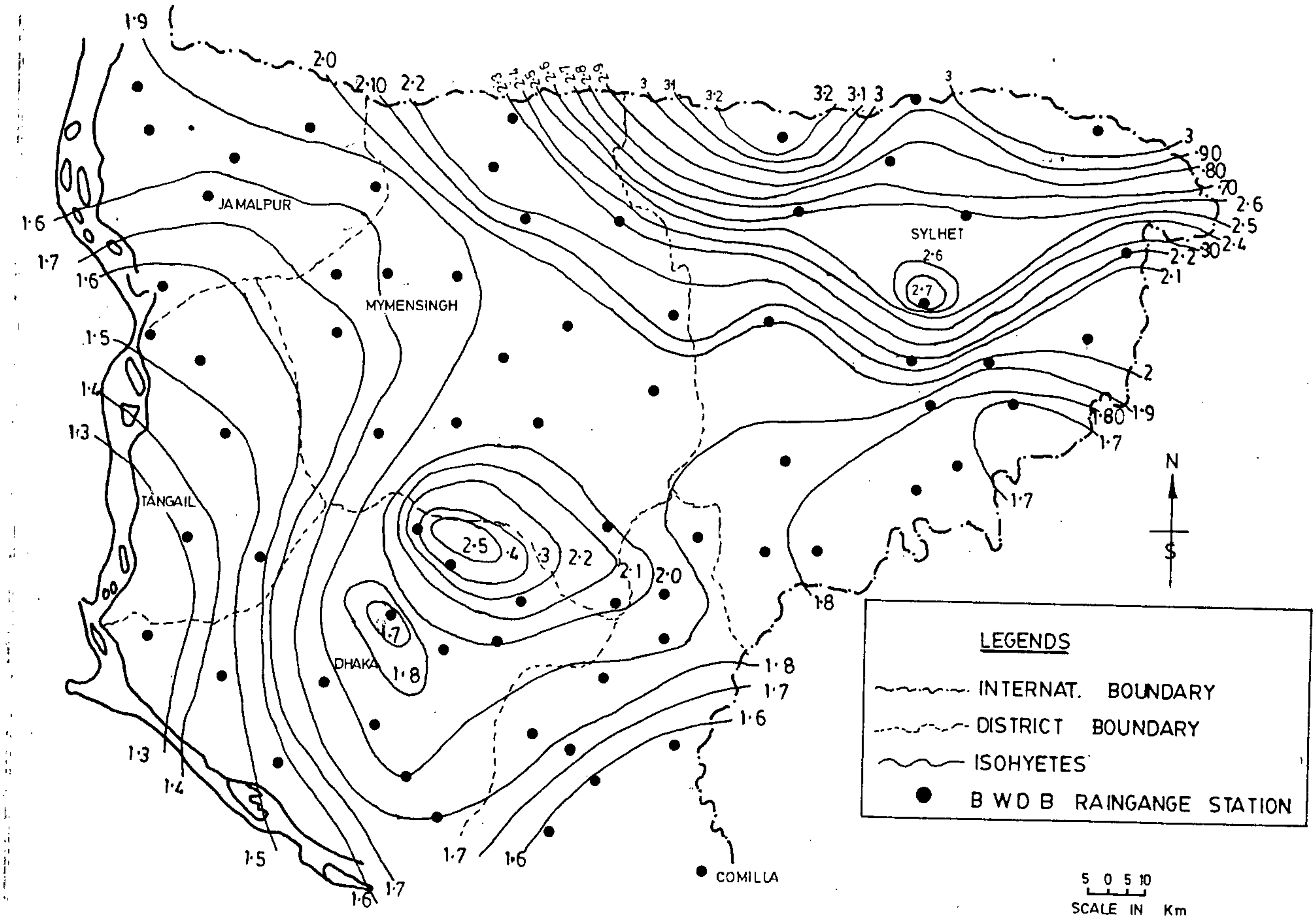


FIG. 30. GENERALIZED ISOHYETAL MAP FOR 30 MIN. 2-YEAR RAINFALL (INCHES)

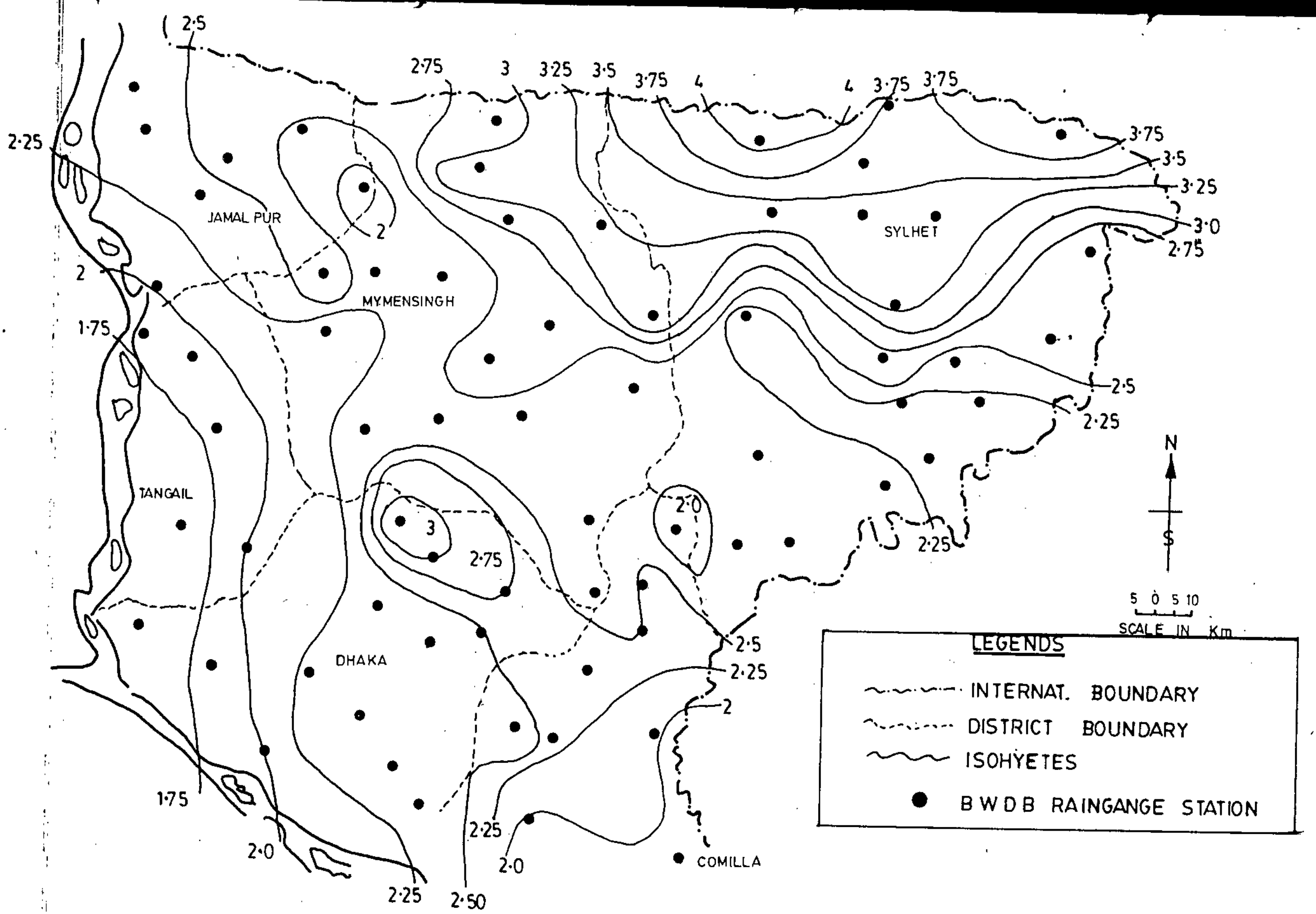


FIG. 31. GENERALIZED ISOHYETAL MAP FOR 1 HOUR 2-YEAR RAINFALL (INCHES)

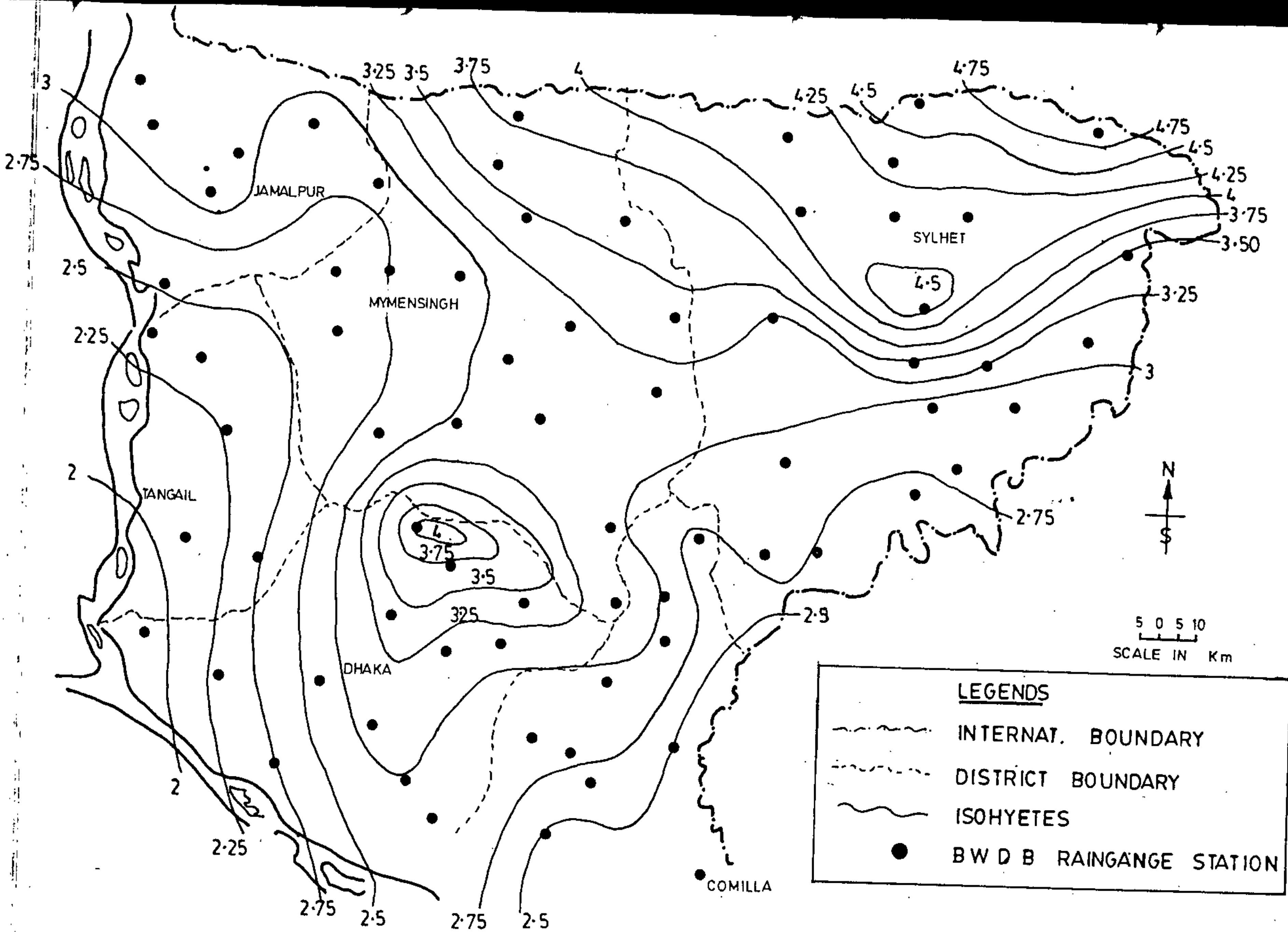


FIG. 32. GENERALIZED ISOHYETAL MAP FOR 2 HOUR 2-YEAR RAINFALL (INCHES)

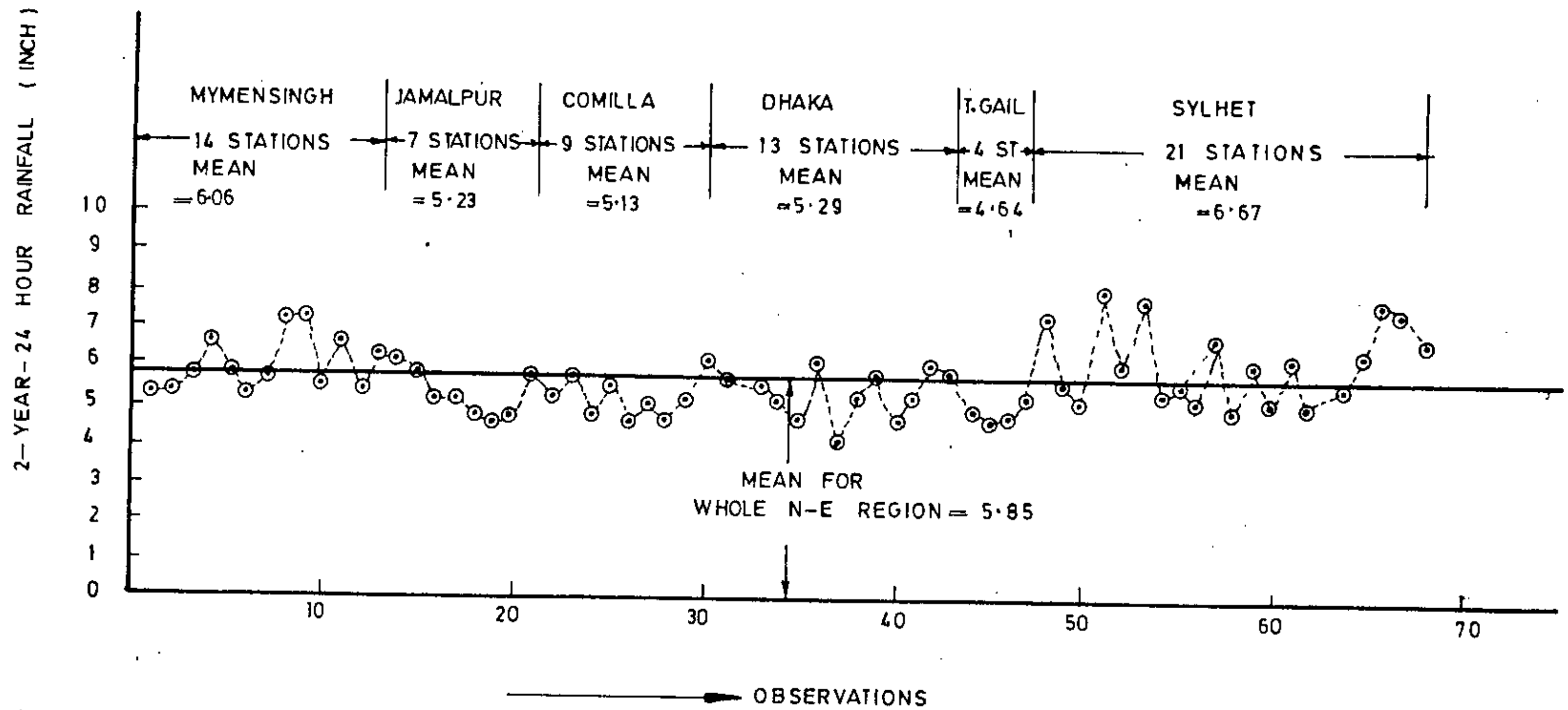


FIG. 33. 2-YEAR 24-HOUR RAINFALL (INCH)

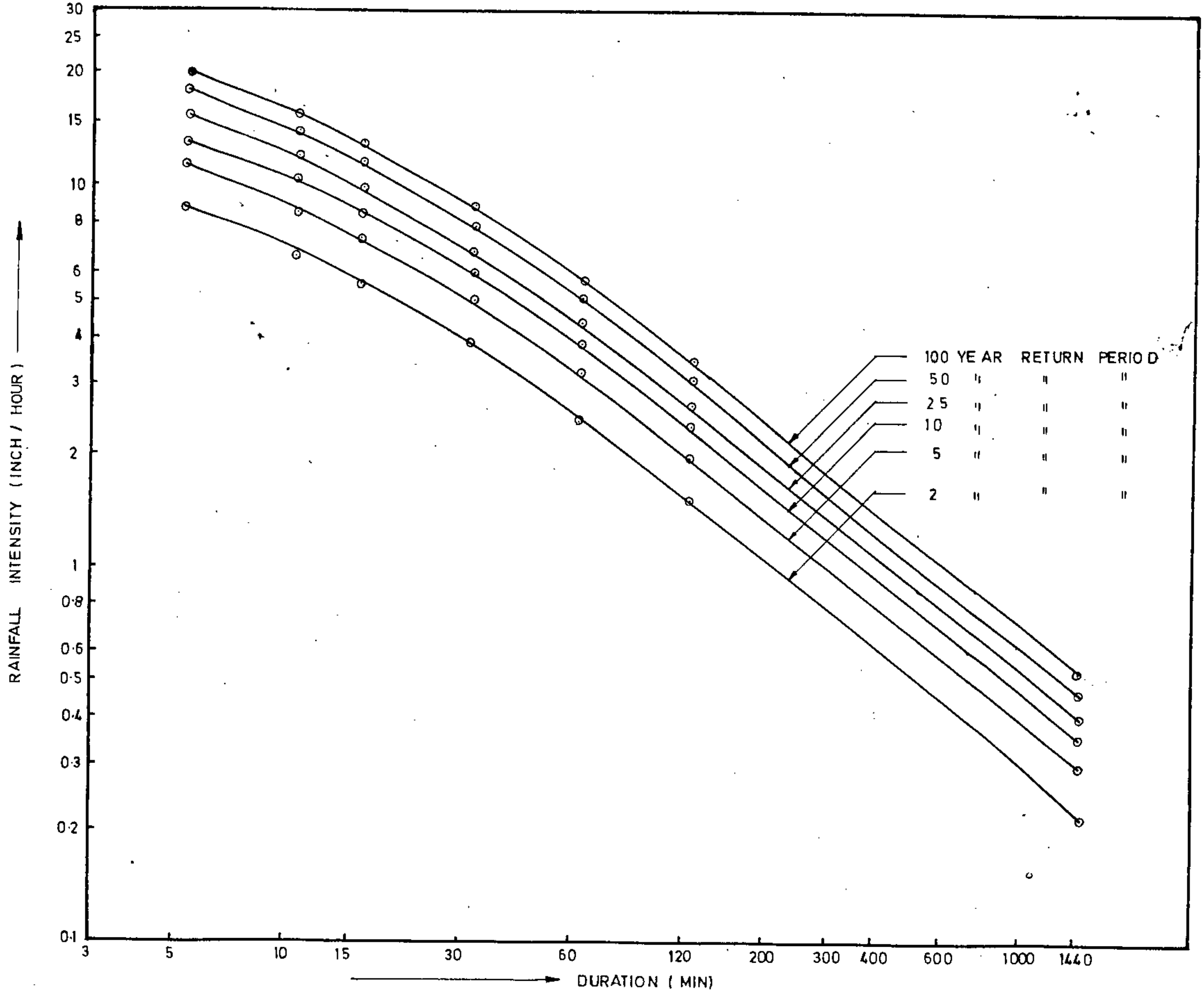


FIG. 34. GENERALIZED RAINFALL INTENSITY – DURATION – FREQUENCY CURVE FOR NORTH EASTERN ZONE OF BANGLADESH

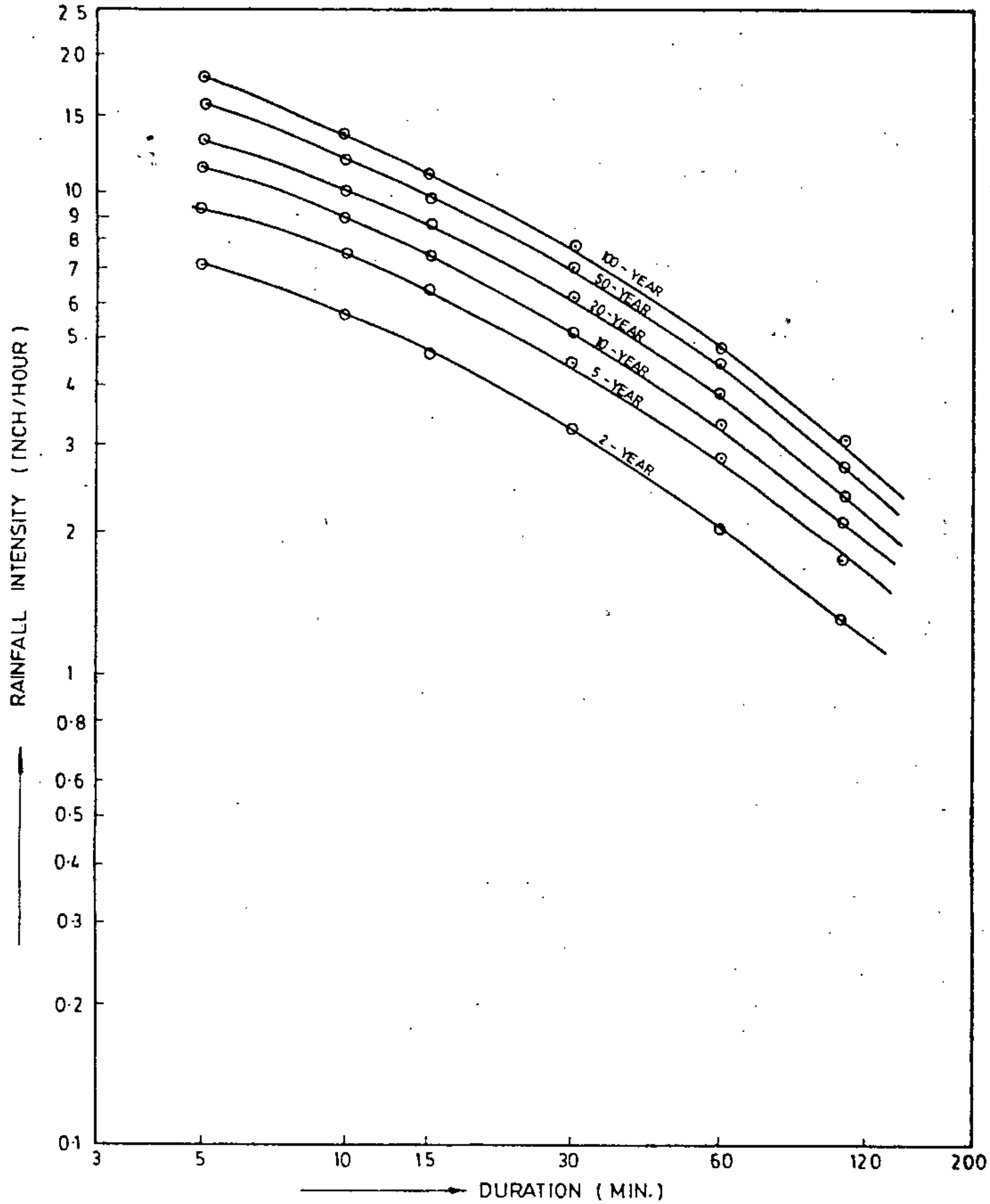


FIG. 35. POINT RAINFALL INTENSITY-DURATION-FREQUENCY CURVE FOR SYLHET

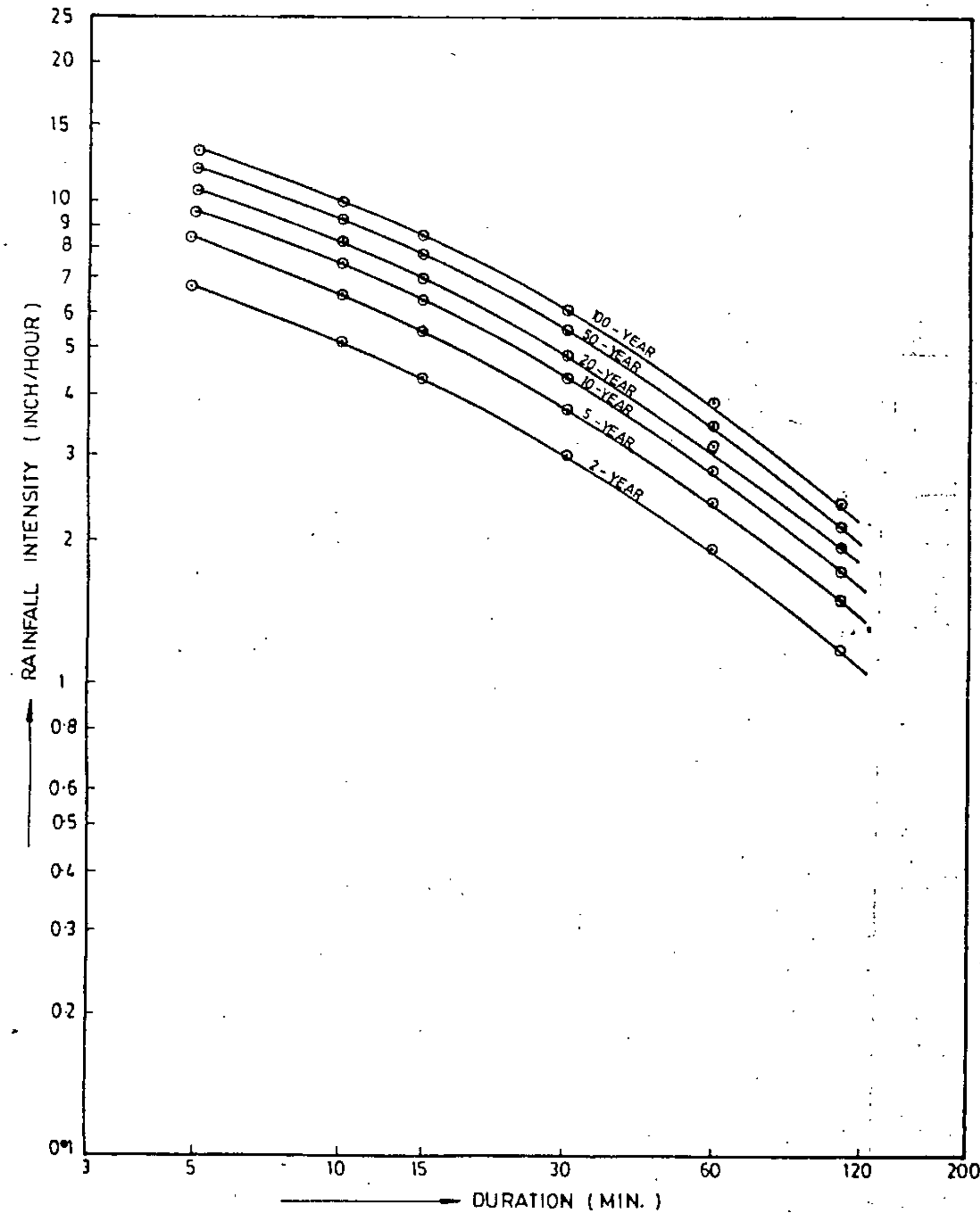


FIG.36. POINT RAINFALL INTENSITY – DURATION – FREQUENCY CURVE FOR DHAKA

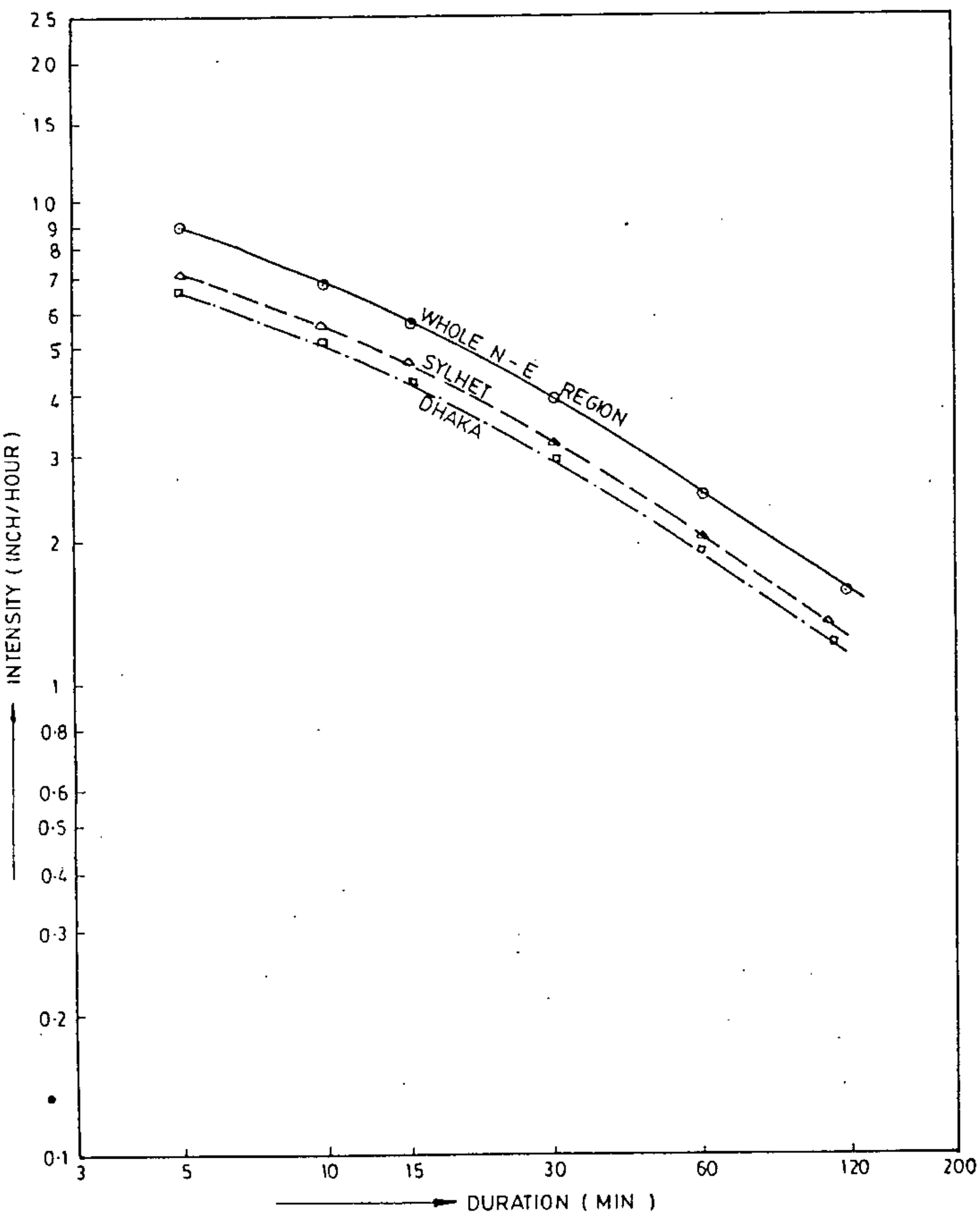


FIG. 37(a) RAINFALL INTENSITY - DURATION CURVES FOR 2-YEAR RETURN PERIOD

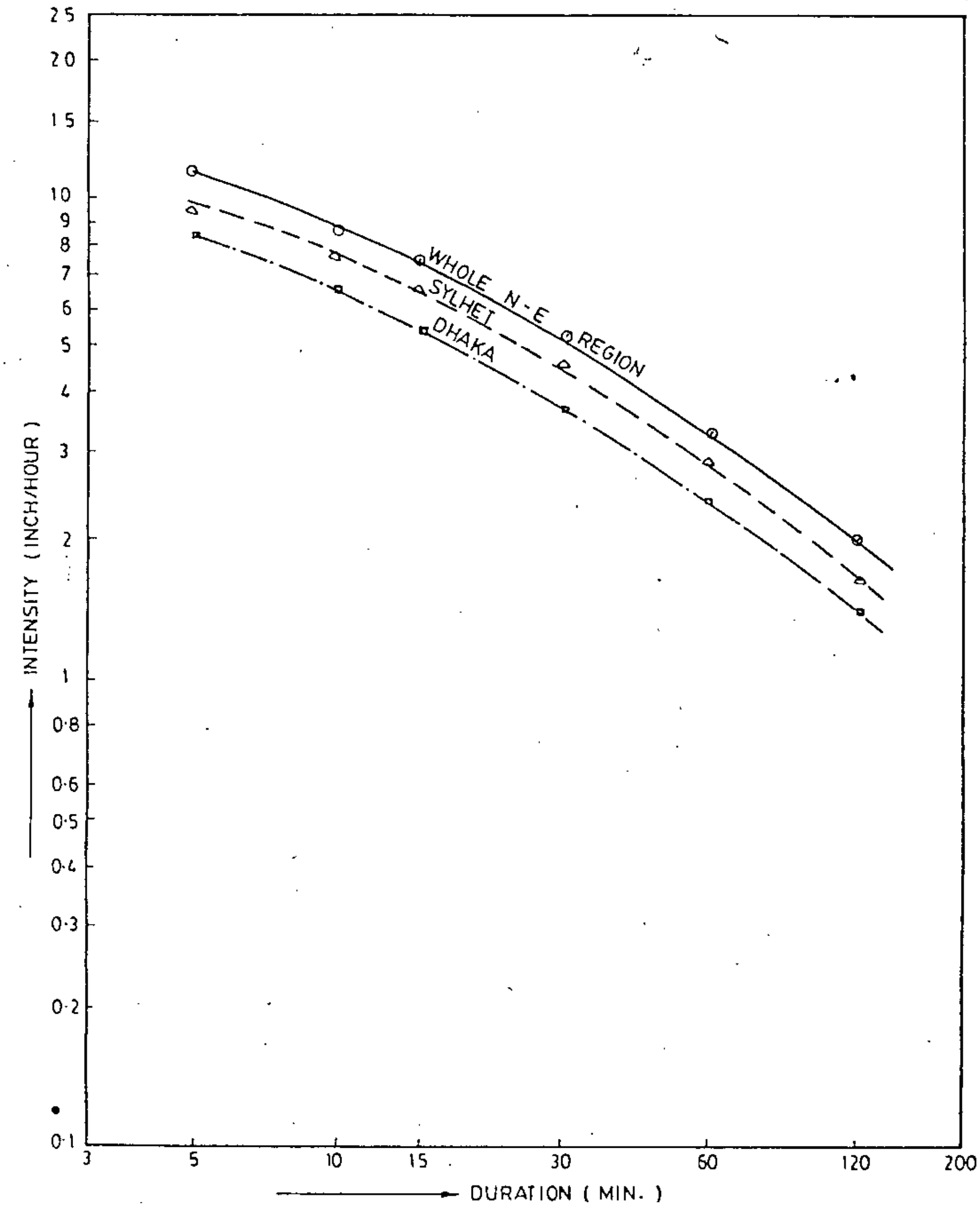


FIG. 37(b). RAINFALL INTENSITY-DURATION CURVES FOR 5 YEAR RETURN PERIOD

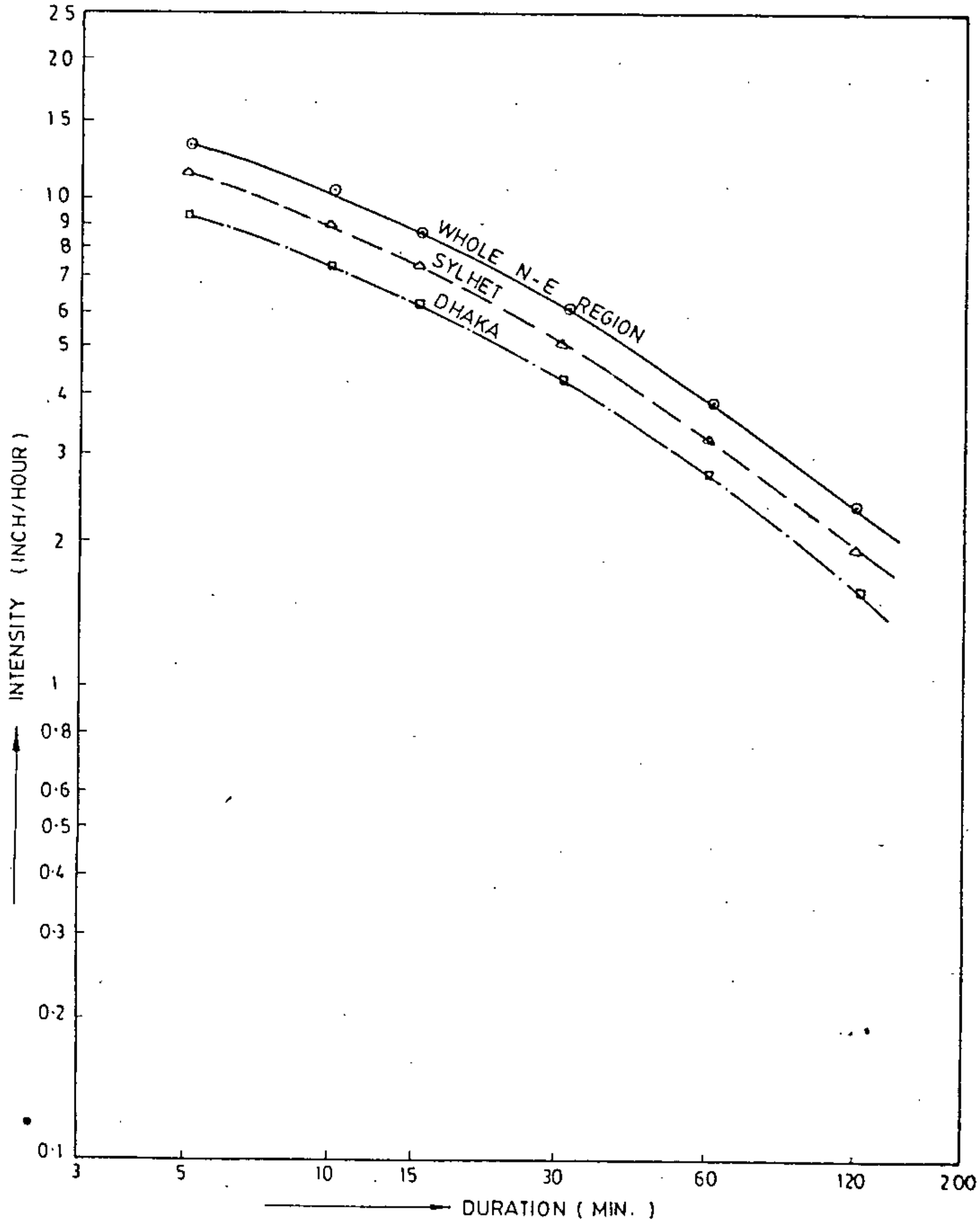


FIG. 37(c). RAINFALL INTENSITY-DURATION CURVES FOR 10-YEAR RETURN PERIOD

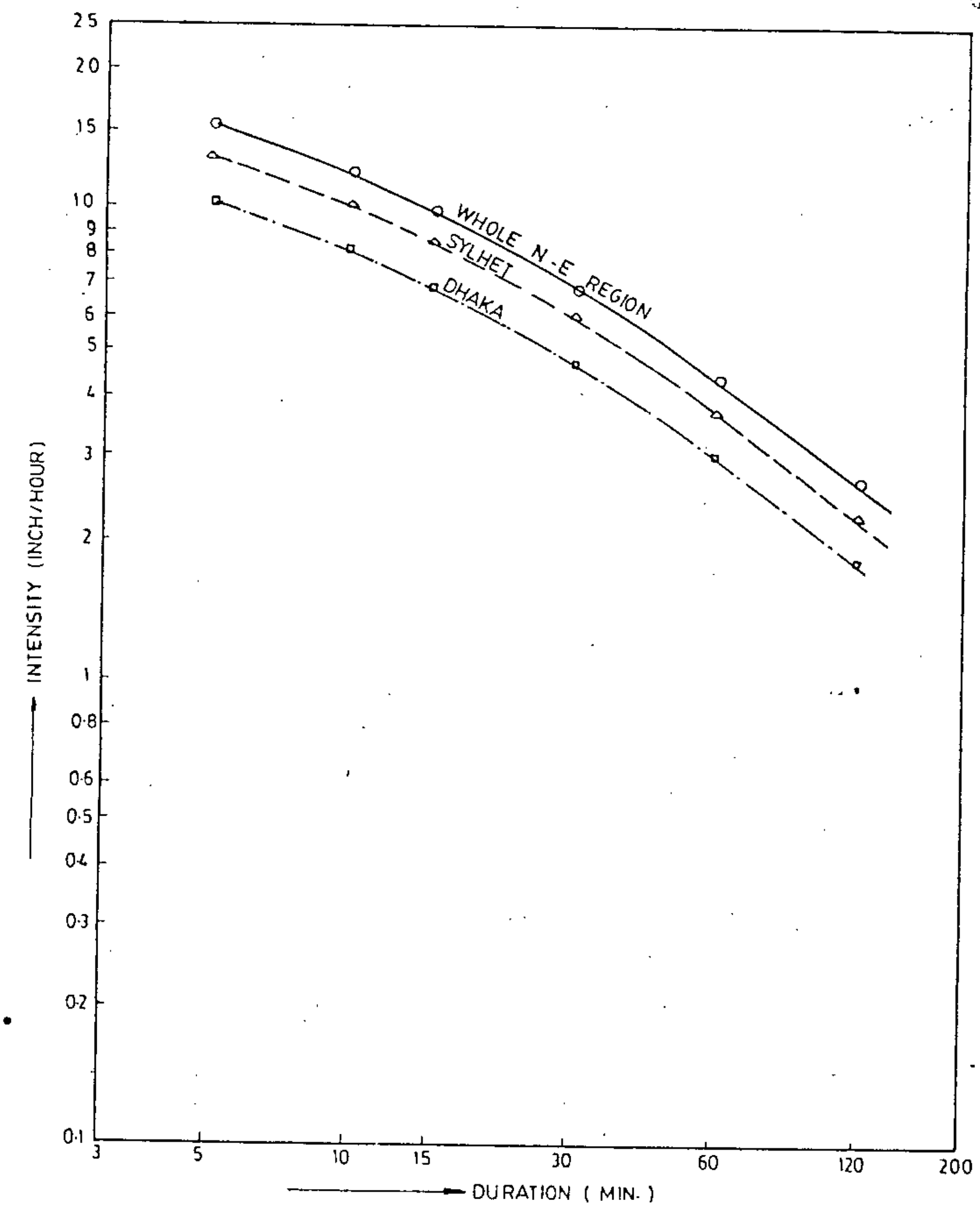


FIG. 37(d). RAINFALL INTENSITY - DURATION CURVES FOR 20 - YEAR RETURN PERIOD

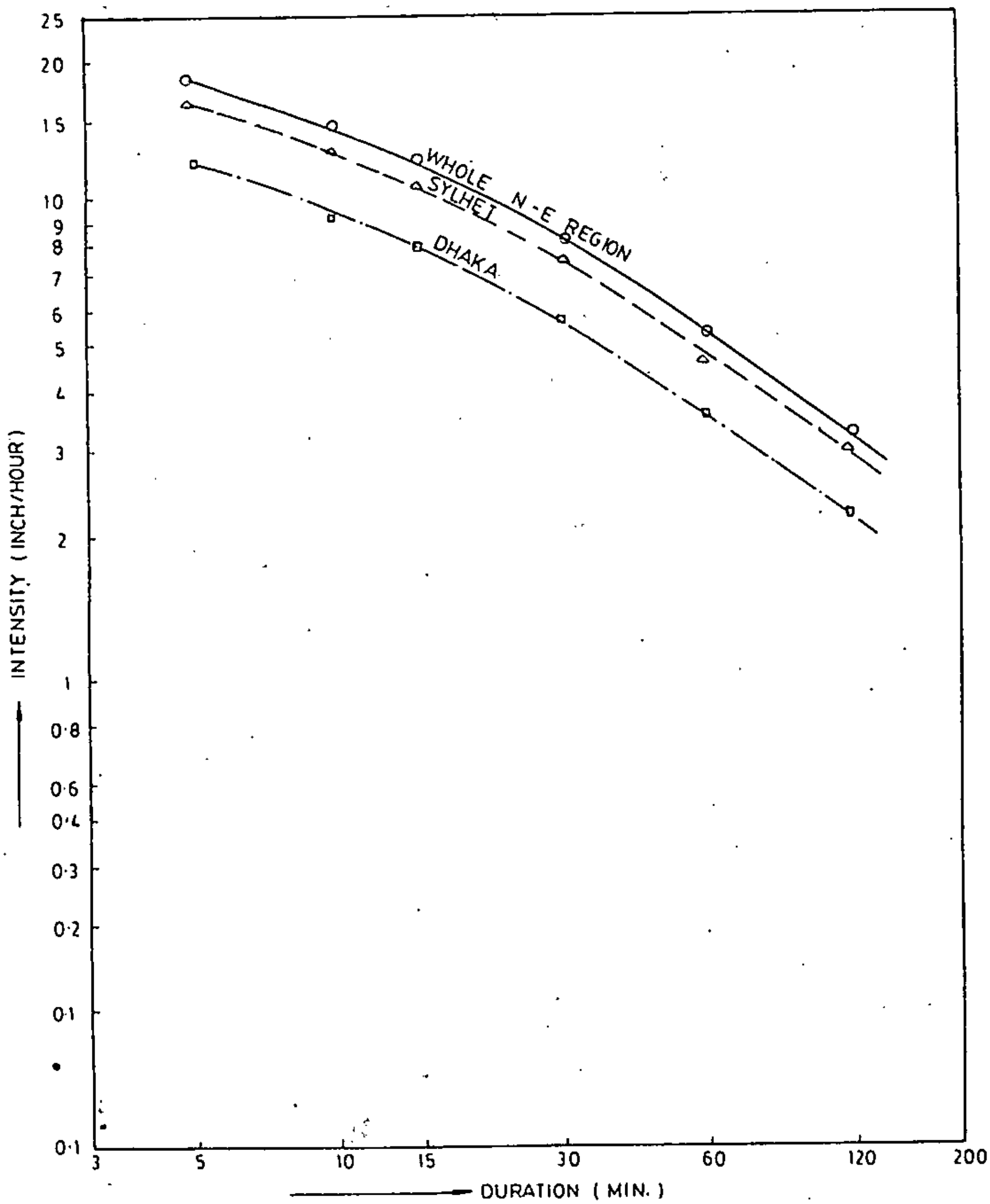


FIG. 37(e). RAINFALL INTENSITY-DURATION CURVES FOR 50-YEAR RETURN PERIOD

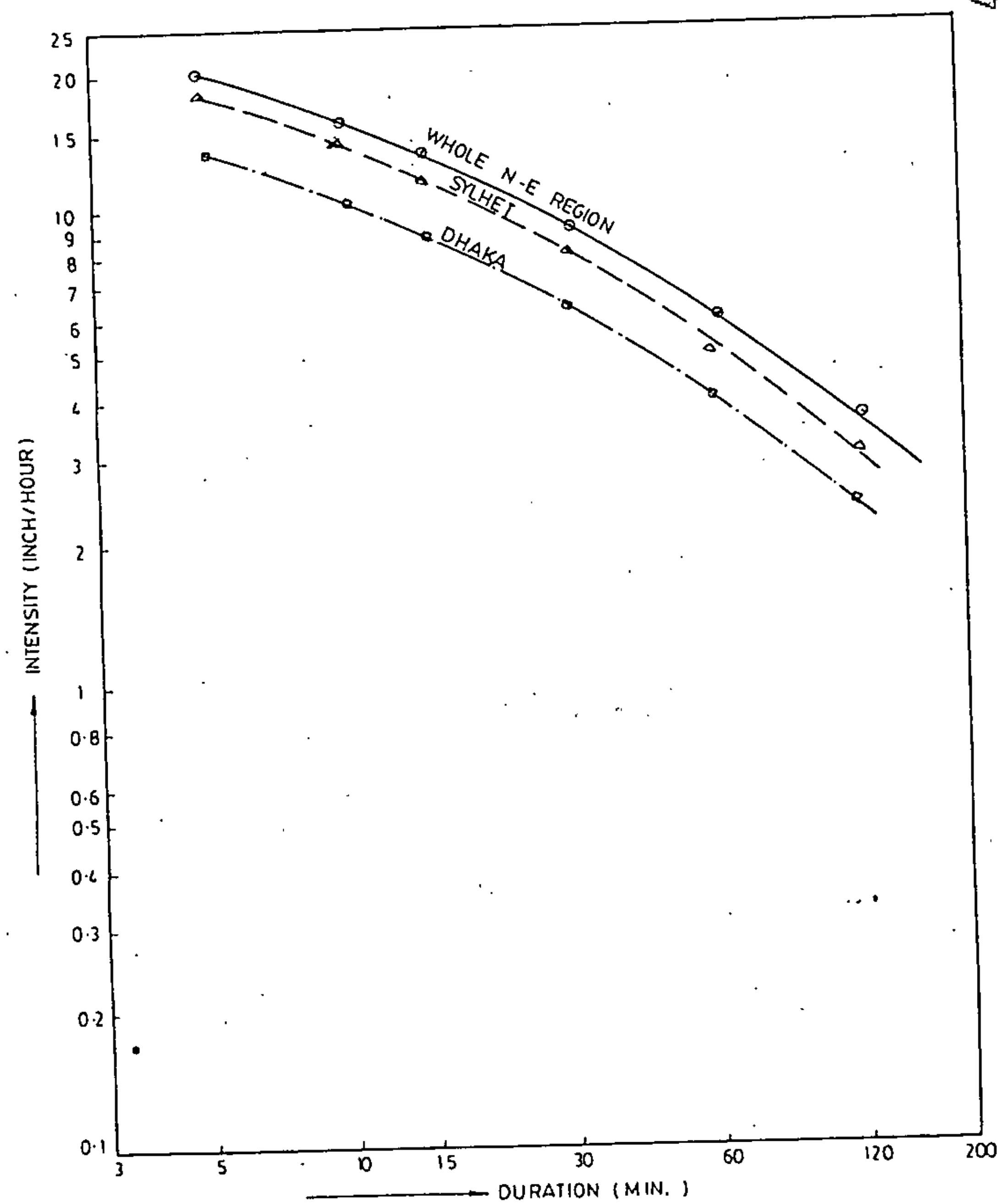


FIG. 37 (f). RAINFALL INTENSITY - DURATION CURVES FOR 100 -YEAR RETURN PERIOD