

ANALYSIS OF RAINFALL CHARACTERISTICS OF NORTHEAST REGION OF BANGLADESH



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ANALYSIS OF RAINFALL CHARACTERISTICS OF NORTHEAST REGION OF BANGLADESH

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We hereby recommend that the project report prepared

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entitled "**Analysis of Rainfall Characteristics of Northeast Region of Bangladesh**" be accepted as fulfilling this part of the requirements for the degree of Master of Engineering (Water Resources).



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The aim of this study is to summarise the changing behaviour of rainfall in space and time over the northeast region of Bangladesh. During the study various rainfall parameters were investigated and mathematical relationships were established.

Updated isohyetal maps of mean monthly, monsoon (June-September) and annual rainfall were constructed for the study region. Spatial distribution of mean monthly, monsoon and annual number of rainy days were investigated. Normal monsoon rainfall of selected 32 stations within the region have been estimated and normal annual rainfall chart has been updated. Temporal variability of rainfall and number of rainy days over the region has been investigated. Moving average and percent departure of rainfall for every year with reference to the normal rainfall were worked out for this purpose.

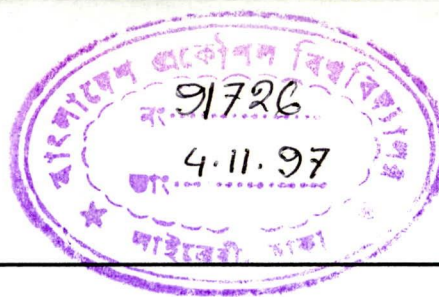
Attempts were made to establish mathematical relationships between number of rainy days and monsoon rainfall total and between mean daily rainfall intensity and monsoon rainfall total. Various forms of equations were examined.

Analytical probability distributions were fitted to 1-, 2-, 3-, 5-, 7- and 10-day maximum rainfall values. Normal, lognormal and Gumbel (EV1) distributions were examined and all of them were found good for maximum rainfall values. Gumbel distribution was found to be better. Pattern of Gumbel parameters over the region for 1-, 3-, 5- and 7-day maximum rainfall were presented on the base maps. Binomial and Poisson discrete probability models were tested to monsoon and annual number of rainy days. Normal approximation to Poisson distribution was found suitable to describe monsoon and annual number of rainy days.

HYMOS (HYdrological MOdelling System), developed at Delft Hydraulics, the Netherlands, has been extensively used for probability distribution and other analysis in performing the study.

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1.1 IMPORTANCE OF RAINFALL STUDIES

In Bangladesh, agriculture sector plays a major role in economic growth and its food production depends on the timely arrival and subsequent distribution of rainfall. But sometimes, severe rainfall causes devastating floods resulting heavy damages to lives and property. So, the management of water resources gets high priority in developmental activities of the country. Analysis of rainfall characteristics plays an important role in any project dealing with water resources providing basic information essential for project planning and design.

Hydrological parameters are the basic inputs in the evaluation of water resources. Among various hydrologic parameters, rainfall is of greatest concern to the people of Bangladesh. Rainfall observations are important in assessing the amount of water available to meet the requirements of agriculture, industry, generation of hydroelectricity and other human activities. Such data are frequently used to estimate streamflow and groundwater accretion and historic trend of these factors are used in the preparation of flood and water supply forecasting. So knowledge of spatial and temporal distributions of rainfall are indispensable to hydrological study for water management.

Water management problems are of continuing nature and their solutions require hydrologic analysis of historic data. Rainfall is a dominant input to the hydrologic system and consequently the characteristics of rainfall plays a major role in any hydrologic studies relating water resources management activities.

Analysis of rainfall records may be concerned with the following aspects: the spatial and temporal distribution of mean rainfall as well as number of rainy days, frequency analysis of extreme rainfall values, establishment of relationships between different rainfall parameters, etc. Irrigation engineers and agriculturists are interested in distributions of mean rainfall as well as number of rainy days for irrigation and drainage practices. Planning and design engineers prefer the results of frequency analysis of extreme rainfall values. Climatologists prefer maps which depicts distribution of various rainfall parameters.

On this background the present study is undertaken to analyse rainfall characteristics of northeast region of Bangladesh with a broader scope and with updated rainfall records which will enable engineers, agriculturists and climatologists to have up-to-date information regarding rainfall pattern over the region.

1.2 SUMMARY OF PREVIOUS STUDIES

A considerable number of rainfall studies have been conducted in many parts of the world. Prasad et al. (1991) conducted a hydrometeorological study over Teesta basin in north Bengal of India based on data of 40 rainfall stations within and in the neighbourhood of the basin. In his study, hydrometeorological information on the spatial distribution of monthly rainfall, number of rainy days and extreme rainfall distribution over the basin have been determined and presented on basin maps. The average monthly areal precipitation depth as well as extreme areal precipitation depth for a day have also been discussed and pentad rainfall for 22 stations in the catchment have been evaluated and discussed.

Mukherjee et al. (1987) studied the applicability of extreme value type I (EV1) distribution to annual maximum rainfall series over different parts of India. Method of maximum likelihood for parameter estimation and Gringorton's (1963) formula for plotting positions stated in Eq. 1.1 were used. In this study it is observed that EV1 distribution is generally applicable to annual maximum rainfall in major parts of India.

$$T = \frac{N+0.12}{m-0.44} \quad (1.1)$$

where, T is return period, N is total number of data item, and m is position of item in the rank.

Singh (1987) performed a study for Bombay, the west coast of Indian Peninsula, regarding the problem of flooding in the city due to intense rainfall which causes dislocation of normal life. He conducted frequency analysis with short duration rainfall (1-, 2-, 3-, 6-, 12-, 24-, 36- and 48-hr rainfall) to estimate design value for a suitable drainage system. Gumbel and gamma distributions both were fitted with moments and maximum likelihood methods and were found equally satisfactory. The results were presented on extreme value probability paper giving rainfall depth-duration-frequency (DDF) relationships. Relationship between mean annual maximum rainfall and the duration has also been obtained in order to simplify the understanding of extreme rainfall amount and duration.

Lakshmanaswamy and Jindal (1990) investigated the variability of area-weighted annual and monsoon rainfall for the 35 meteorological sub-divisions of India for the period from 1901 to 1988. They estimated decadal means of monsoon and annual rainfall to examine decadal percentage variations. They also examined percentage departure of monsoon and annual rainfall from their respective normal values. Area-weighted means and standard deviations of monsoon rainfall during three sub-periods were also investigated. In their study 11-year moving average of rainfall over India indicates a steady increase up to 1958, a gradual decrease up to 1969 and a slight increase thereafter with minor fluctuations. No definite periodicity in the occurrence of rainfall over India during 1901 to 1988 was identified.

Saxena and Agrawal (1990) studied the association between seasonal rainfall, corresponding number of rainy days and mean daily intensity for Maharashtra region of India for the monsoon period. They examined several polynomials to establish relationships of the later two parameters with rainfall magnitude. They found that the number of rainy days have a better relationship with rainfall total than does the mean daily rainfall intensity.

Yarnell (1935), U.S. Weather Bureau (1955) and others provided information on rainfall frequency for periods of five minutes to 24 hours. Huff and Neill (1959) performed analysis to determine the return period of heavy rainfall amounts encompassing periods of one to 10 days. The frequency distribution functions tested include the lognormal, log-skew (Chow, 1954), Gumbel, Frechet (Gumbel, 1958) and Jenkinson (1955). Results from those studies indicated no remarkable superiority to any of the five distributions.

A number of rainfall studies have been undertaken in Bangladesh. International Bank for Reconstruction and Development (IBRD, 1972) studied 36 years of rainfall data for the period 1934 to 1969 for agricultural planning and drainage design purposes. In this study rainfall intensity-duration-frequency relationships and probability profiles of reaching or exceeding specified rainfall amounts in any week were estimated for nine rainfall stations (Barisal, Bogra, Chittagong, Comilla, Dhaka, Khulna, Mymensingh, Rangpur and Rajshahi) for the determination of drainage requirements. For these purposes 1-, 2-, 3-, 5-, 7-, 10- and 15-consecutive days maximum rainfall were considered.

Manalo (1976) carried out a detailed study of rainfall and other climatic parameters using available data up to the period 1974 for climatic stations in 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 results of the study were presented in the form of isohyetal maps representing mean annual rainfall, mean monthly rainfall, mean seasonal (June-October) rainfall, number of months with rainfall between 100 mm to 200 mm, etc. He also prepared histograms of the monthly rainfall for various regions of the country.

Khan (1976) estimated rainfall probabilities for 2-week running period using daily rainfall data with 36 years of records for the period 1934 to 1969 from 13 different locations. This study was directed towards agricultural applications, e.g. designing of proper cropping pattern and for determination of the capacity of supplementary irrigation system.

A joint study by Bangladesh Water Development Board and United Nations Development Programme was performed (BWDB and UNDP, 1982) for eight climatic stations over the country to determine the probability of heavy rainfall to be used for drainage design in Bangladesh. This study included the analysis of 1 to 6-day rainfall data for the period 1947 to 1980. Six-day duration was selected as an upper limit because this period is consistent with the critical period of inundation of the rice crop. The data source was the daily rainfall data from Bangladesh Meteorological Division (BMD). Probability plotting position was evaluated with Blom formula as stated below.

$$p = 1 - \frac{m - 0.375}{n + 0.25} \quad (1.2)$$

where, m is position of item in the rank, n is total number of data item, and p is probability of rainfall greater than a critical value.

Later, Matin (1984) studied the short-duration rainfall data of northeastern region of Bangladesh and developed a generalised intensity-duration-frequency curve of the region. He analysed extreme rainfall value derived for such periods as 5, 10, 15, 30 minutes, 1 hour and 2 hours using empirical approaches developed for the United States (Hershfield, 1962) and prepared isohyetal maps on the basis of US depth-duration ratio and Hershfield-Wilson's Diagram. In his study prediction equations were developed, using EV1 (Gumbel) distribution, for 1-day maximum rainfall corresponding to return periods of 2, 5, 10, 20, 30 and 100 years.

Ahmed (1986) conducted a study for the northwest region of Bangladesh using long duration rainfall data. He used 1-, 2-, 3-, 5-, 7-, 10- and 15-day maximum rainfall data

of Dinajpur, Rangpur, Rajshahi, Bogra and Pabna. He tested gamma and Gumbel (EV1) distribution to select suitable frequency distribution. He showed that Gumbel distribution fitted the long duration rainfall data better. He prepared Isohyetal maps of 1-, 2-, 3-, 5-, 7-, 10- and 15-day rainfall having 2-year return period in his study. He also proposed a generalised depth-duration-frequency relationships of the region and developed an empirical method to determine the long duration probable maximum rainfall (PMP).

Akhter (1992) performed an exhaustive study to investigate the suitability of commonly used statistical distributions for estimating the magnitude of point rainfall extremes in the south eastern part of Bangladesh. In this study five distributions, viz., normal, lognormal, Gumbel, Pearson type-III and log-Pearson type-III were compared for their ability to fit annual maximum rainfall values of duration from 1 to 3 days. Her study indicated that Gumbel, lognormal and normal distributions fitted rainfall data better than others. Gumbel distribution seems to be better. To find out suitable parameter estimation method she compared method of moments, maximum likelihood method and probability weighted method and found the maximum likelihood method as better. She also compared different plotting position formulae and opined that Weibull formula is suitable for fitting empirical distribution to extreme rainfall values.

Ahmed et al. (1992) undertook a study to investigate the recent possible changes that might have occurred in rainfall, water level and discharge within the country. The study on rainfall data illustrates that there exists no significant trend in rainfall within the country. Among 53 stations considered for this study, two stations show increasing trend while two stations show decreasing trend in annual rainfall. In this study statistical t-test, 3-point moving median test and graphical methods were used to investigate the trend of rainfall data.

Siddiqui (1993) carried out the analysis of extreme value rainfall data of seven urban stations. The stations were Dhaka, Mymensingh, Tangail, Rajshahi, Khulna, Sylhet and Chittagong. Daily rainfall data for a period of 32 years were analysed to determine a suitable frequency distribution. Five probability distribution functions: normal, two parameter lognormal, Pearson type III, log-Pearson type III and Gumbel distribution were selected to test the goodness of fit. Gumbel distribution was recommended as appropriate for annual extreme rainfall analysis. Method of moment was used for parameter estimation in frequency analysis. Short duration rainfall data, i.e., 5-, 10-, 15-, 30-min, 1-hr and 2-hr data, were calculated having 2 year return period on the

basis of United States Weather Bureau (USWB) depth duration ratio and Hershfield-Wilson diagram and I-D-F curves were proposed for short duration rainfall of all the seven stations considered in this study.

Mamtaz (1993) performed another study covering the whole of Bangladesh to develop a correlation between 24-hour rainfall and short duration rainfall. She also developed a design chart for estimation of short duration rainfall potential anywhere within the country. She established depth-duration-frequency equation as shown in Eq. 1.3 which can be used to estimate maximum daily rainfall for short duration.

$$P_t^T = 0.53 T^{0.453} t^{0.249} [P_{24}^{10}]^{0.453} \quad (1.3)$$

Where, P_t^T = t -min T -yr rainfall in mm, T = return period in years for short duration rainfall ($2 \leq T \leq 50$), t = duration of rainfall in minutes ($5 \leq t \leq 120$), and P_{24}^{10} = 24-hr 10-yr rainfall in mm.

The intensity-duration-frequency form of the equation was expressed as follows:

$$I_t^T = 0.53 T^{0.453} t^{-0.751} [P_{24}^{10}]^{0.453} \quad (1.4)$$

Where, P_t^T = Intensity t -min T -yr rainfall in mm/min.

In performing her study, Mamtaz (1993) undertook frequency analysis on annual maximum one-day rainfall data from 319 point rainfall stations. She compared EV1, log-Pearson and lognormal distribution and found EV1 as most appropriate probability distribution function for frequency analysis of annual maximum rainfall in Bangladesh.

Alam (1994) conducted a study to investigate the statistical characteristics of climatic drought of North West region of Bangladesh. His study involved five selected stations in the Teesta Barrage project area and 20 years of rainfall and evaporation data. He investigated the climatic drought for Kharif-II crop, generally grow between June and November and perform statistical analysis of dry-day sequences. Empirical and theoretical distributions were fitted to drought maxima of growing period (15 July to 15 November) and critical growing period (15 October to 15 November) which needs supplementary irrigation. Extreme value type I (EV1) distribution exhibited reasonably good fit to 10-day drought maxima. He also extended his study to fit empirical and theoretical distribution to annual number of non-rainy or dry days and length of dry-day sequences. In his study normal plots reveals that the dry-day sequences appears to be approximated by a normal distribution.

Among the studies so far conducted in Bangladesh, the one by Manalo (1976) was quite exhaustive. Other studies were limited in scope and applicability. Specially, monthly and seasonal parameters did not get much attention and other two parameters of rainfall, viz., number of rainy days and mean daily rainfall intensity, which are very useful in analysing draught and wetness characteristics of a region, did not get any importance in those studies. However, since Manalo (1976) about two decades have passed and numerous new data have become available during this period, so it is worthwhile to carry out further analysis with updated data and information.

1.3 OBJECTIVES OF THE STUDY

The main objective of this study is to characterize the changing behaviour of rainfall in space and time over the northeast region of Bangladesh. In this study, various rainfall parameters were investigated and mathematical relationships were established. The specific objectives of this study are as follows:

- (i) To investigate the spatial and temporal variability of rainfall and number of rainy days over northeast region of Bangladesh;
- (ii) To develop relationships between (a) monsoon rainfall total and corresponding number of rainy days, and (b) monsoon rainfall total and mean daily rainfall intensity; and
- (iii) To conduct frequency analysis of annual maximum rainfall values of different durations and to test discrete probability models to monsoon and annual number of rainy days.

The study of variations in the rainfall over a region is of utmost importance in water resources management for the purpose of irrigation, flood control, water supply for household activities, etc. Inter-annual fluctuations in rainfall have a profound socio-economic impact. For instance, deficit in rainfall are associated with drought, crop failure and in extreme cases famine while heavy rainfall are associated with devastating floods and accompanying loss of life, property and crops. A very few research workers in Bangladesh have devoted their attentions to spacial distribution of rainfall depth and no significant study has been carried out regarding temporal distribution of rainfall. On this background, the *first objective* has been undertaken. In this study spatial distribution of rainfall magnitudes over the study region was investigated with isohyetal

maps for mean monthly and monsoon rainfall values and for normal (1961-90) annual rainfall values. Maps showing isolines (Prasad et al., 1991) of having equal values of mean monthly, monsoon and annual number of rainy days were constructed to observe their spatial distribution. Temporal variability of area-weighted rainfall and number of rainy days over the region were examined by moving average technique. Pattern of rainfall over the region in time scale was also investigated by analysing percentage departure of area-weighted rainfall for each year from 1961 to 1994 with reference to the normal rainfall values.

Number of rainy days and mean daily rainfall intensity are two important parameters in the studies of rainfall climatology as well as hydrological and agricultural investigation. They are closely associated with rainfall distribution and provide a better picture of tropical rainfall conditions than the rainfall magnitudes alone. A number of studies of these two parameters have been carried out for various parts of the world (Ananthakrishnan and Soman, 1989; Soman and Kumar, 1990; Jackson, 1986; Saxena and Agrawal, 1990), including their relationship with rainfall totals. But they did not get much attention in the previous studies carried out in Bangladesh. So the *second objective* has been incorporated to establish relationships for normal monsoon rainfall with corresponding number of rainy days and mean daily intensity using different polynomials. The analysis was limited to the monsoon period, June to September, as the region receives the major part of annual rainfall during this period.

The *third objective* has been considered in order to examine the suitability of commonly used statistical distributions for estimating the magnitudes of point rainfall maximums and to test discrete probability models to number of rainy days to find a suitable probability distribution to describe monsoon and annual number of rainy days. The amount of rainfall that can be expected to occur in a given period of time on the average once every so many years (frequency) is an important design variable for many hydraulic structures. Inappropriate frequency analysis can often lead to overdesign of project resulting in high cost or underdesign of project resulting in failure of the project. In Bangladesh the commonly used probability distribution models for extreme rainfall values are: normal, lognormal, log Pearson, gamma and Gumbel distribution. Among them Gumbel distribution are recommended to be better (Ahmed 1986; Akhter 1992; Siddiqui 1993; Mamtaz 1993). In this study three distributions: normal, lognormal and Gumbel are examined for point rainfall maximums. Binomial and Poisson distributions were tested to monsoon and annual number of rainy days.

2.1 GENERAL

The analyses to be carried out in this study include characterizing of spatial and temporal distribution of rainfall and number of rainy days; fitting of selected analytical probability distributions (such as, normal, lognormal, Gumbel, binomial and Poisson) and related goodness of fit tests; and regression analysis involving monsoon rainfall, corresponding number of rainy days and mean daily intensity. In this chapter related theoretical considerations are presented.

Spatial distribution of rainfall are generally presented on maps called isohyetal map. Distributions of other rainfall parameters are also presented with maps of lines having equal values which are often called isolines (Prasad et al., 1991). Temporal distribution of rainfall over the region is investigated by moving average and other statistical approaches.

Frequency analysis is merely a procedure for estimating the frequency of occurrence of past and/or future events. Thus probability plotting with or without any distributional assumptions is a method of frequency analysis. Frequency analysis may be carried out graphically or analytically. In the former approach, the observed data are plotted on probability paper and a frequency curve is drawn subsequently. In the later approach, probability distribution is fitted analytically to the observed data and events corresponding to selected probability can be estimated. Among several approaches of analytical probability distributions, some commonly used approaches: normal, lognormal, Gumbel or extreme value type I (EV1), binomial and Poisson are used in this study and discussed in this chapter.

2.2 PREPARATION OF DATA

Before using any hydrological data for analysis, it is necessary to check the data first for continuity and consistency. The continuity of a series may be broken with missing data due to many reasons, such as damage or fault in a raingauge during a period. In estimating missing records the *normal* rainfall is used as standard of comparison. The

normal is the average value for a particular date, month, season, or for the year as a whole over a specific 30-year period (Linsley et al., 1982). The 30-year normals are recomputed every decade dropping off the first 10 years and adding the most recent 10 years.

Missing rainfall values are usually estimated from data at neighbouring stations as close to and as evenly spaced around the station with missing record as possible. Two generally used approaches to estimate the missing data are *arithmetic average method* and *normal ratio method*. If the normal rainfall at each of the index stations is within 10 percent of that for the station with missing records, a simple arithmetic average of the rainfall at index stations provides the estimated amount. If the normal rainfall at any of the index stations differs from that at the station with missing records by more than 10 percent the normal ratio method, as stated in the following formula, is used to estimate the missing rainfall, P_x .

$$P_x = \frac{N_x}{M} \left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \dots + \frac{P_M}{N_M} \right] \quad (2.1)$$

where, $N_1, N_2, \dots, N_M$ are the normal rainfall at the index stations and N_x is the normal rainfall at the station under consideration.

Inconsistency in the rainfall data at a raingauge station would arise if the conditions relevant to the recording of a station have undergone a significant change during the period of record. Test for consistency of record is usually done by the *double-mass curve analysis*. The analysis is based on the principle that when each recorded data comes from the same parent population, they are consistent.

2.3 DEFINITION OF RAINY DAY

A day is considered as rainy if it experiences the amount of rainfall greater than or equal to a threshold value (Jackson, 1986). This threshold value is not a constant one. In different parts of the world different threshold values are being used.

Indian Practice: According to the definition of rainy day given by Indian Meteorological Department the threshold value is 2.5 mm.

BWDB practice: In Bangladesh, BWDB uses rainfall amounts of 0.2 mm as threshold value for rainy day.

2.4 MEAN AREAL RAINFALL OVER AN AREA

Hydrologic analysis requires the knowledge of the rainfall over an area, such as over a catchment or a region. To convert the point rainfall values at various stations into an average value over an area the following three approaches are used.

- (a) Arithmetic Average Method
- (b) Thiessen Method
- (c) Isohyetal Method

In the present study Thiessen method was used to estimate area-weighted rainfall. In this method the rainfall recorded at each station is given a weightage on the basis of an area closest to the station. The area is drawn first. Then stations are marked on it and joined to form a network of triangles. Perpendicular bisectors for each of the sides of the triangles are drawn. These bisectors form a polygon around each station. Then the area of the polygons are determined. If $P_1, P_2, \dots, P_m$ are the rainfall magnitudes recorded at the stations 1, 2, ..., m respectively and $A_1, A_2, \dots, A_m$ are the respective areas of the polygons, then the average rainfall P over the area is given by the following formula,

$$P = \frac{\sum_{i=1}^M P_i A_i}{A} = \sum_{i=1}^m P_i \frac{A_i}{A} \quad (2.2)$$

where A is the total area and the ratio A_i/A is the weightage factor for each station.

2.5 MOVING AVERAGE

To investigate the long-term trend or variability in rainfall series moving average curves are useful. A moving average series Y_i of series X_i is derived as follows:

$$Y_i = \frac{1}{2M+1} \sum_{j=i-M}^{i+M} X_j \quad (2.3)$$

where average takes place over $2M+1$ elements. An element of the moving average series gets a missing value if one of the X_i is missing. The original series can be plotted together with the moving average series.

2.6 PROBABILITY PLOTTING

A probability plotting is a plot of the magnitude of an event versus its probability. Numerous methods have been proposed for the determination of plotting position, most of which are empirical. Some of the formulae have been described below. In all cases, the exceedance probability of the m th largest value, x_m is calculated where n is the total number of values by descending order of magnitude.

The California Formula is the oldest and simplest of all the methods. This formula is given, for large n , as

$$p(x \geq x_m) = \frac{m}{n} \quad (2.4)$$

This formula produces a probability of 1 for $m=n$ and 0 for $m=1$ which may not be easily plotted on probability paper.

Hazen (1930) proposed a formula which is a modified form of California formula as

$$p(x \geq x_m) = \frac{m-0.5}{n} \quad (2.5)$$

One objection of this formula is that the return period for the largest event is twice of the record length.

For extreme value events Weibull (1939) introduced a formula with more statistical justification as

$$p(x \geq x_m) = \frac{m}{(n+1)} \quad (2.6)$$

For the largest value ($m=1$) it produces a return period 1 year longer than the period of record.

The Weibull formula is widely used in practice and offers a statistical justification. In Bangladesh, Akhter (1992) carried out a comparative study among different formulae of plotting position and recommended the Weibull formula for use.

2.7 CONTINUOUS PROBABILITY DISTRIBUTIONS

2.7.1 Normal Distribution

The normal distribution, also known as Gaussian distribution, arises from the central limit theorem. It is a symmetrical, bell-shaped two parameter distribution. The probability distribution function is given by the following formula.

$$p(x) = \frac{1}{\sigma_x \sqrt{2\pi}} e^{-\frac{(x-\mu_x)^2}{2\sigma_x^2}} \quad (2.7)$$

where,

μ_x = mean of X , and

σ_x = standard deviation of X .

A common notation for indicating that a random variable is normally distributed with mean μ and variance σ^2 is $N(\mu, \sigma^2)$. To evaluate Eq. 2.7 a linear transformation $Z = (X-\mu)/\sigma$ is used where the random variable Z will be $N(0, 1)$.

According to Chow (1951) the magnitude X_T of the event having a return period T can be estimated using the formula

$$X_T = \mu + K_T \sigma \quad (2.8)$$

K_T is the frequency factor and its value is the same as the standard normal variate z . The main limitation of the normal distribution for describing hydrologic variables is that it varies over a constant range $-\infty$ to $+\infty$, while most hydrologic variables are non-negative and they tend to be skewed.

2.7.2 Two-Parameter Lognormal Distribution

If the random variable $y = \ln x$ is normally distributed, then x is said to be logarithmic normally distributed. This is a two parameter distribution. The probability density function is given below.

$$p(x) = \frac{1}{x\sigma_y\sqrt{2\pi}} e^{-\frac{(\ln x - \mu_y)^2}{2\sigma_y^2}} \quad \text{for } x > 0 \quad (2.9)$$

where,

$$y = \ln x,$$

$$\mu_y = \text{mean of } y, \text{ and}$$

$$\sigma_y = \text{standard deviation of } y.$$

The frequency factor K_T can be estimated following the same procedure as in normal distribution. But in this case K_T is applied to the logarithms of variables and parameters.

Chow (1954) advocated in support of lognormal distribution for hydrological data analysis. Hydrological variables vary multiplicatively rather than additively and for this reason logarithms of these variables will satisfy the basic condition of normal distribution. Lognormal distribution has the advantage over the normal distribution that it is bounded by $x > 0$ and that the logarithmic transformation tends to reduce the positive skewness commonly found in hydrologic data.

2.7.3 Gumbel Distribution

Gumbel distribution, also known as extreme value type I (EV1) distribution, results from initial distribution of the exponential type. The probability distribution function is as follows.

$$p(x) = \frac{1}{\beta} e^{\left\{-\frac{x-X_o}{\beta} - e^{-\frac{x-X_o}{\beta}}\right\}} \quad \text{for } -\infty < x < \infty \quad (2.10)$$

where,

$$\beta = \text{scale parameter,}$$

$$X_o = \text{location parameter,}$$

and,

$$\text{mean } \mu = X_o + 0.5772\beta \text{ and Standard deviation } \sigma = \pi\beta\sqrt{6}.$$

Chow (1951) presented the following relationship for the frequency factor for Gumbel distribution.

$$K_T = -\frac{\sqrt{6}}{\pi} [0.5772 + \ln[\ln(\frac{T}{T-1})]] \quad (2.11)$$

2.8 DISCRETE PROBABILITY DISTRIBUTIONS

2.8.1 Binomial Distribution

In binomial distribution the probability of $X = x$ occurrences of an event in n independent trials if p is the probability of an occurrence in a single trial is given by

$$f_x(x;n,p) = {}^nC_x p^x q^{n-x} \quad (2.12)$$

where, $x = 0, 1, 2, \dots, n$, and $q = \text{probability of nonoccurrence} = 1-p$. n and p are two independent parameters of binomial distribution. The mean and variance of the distribution are $E(X) = np$ and $Var(X) = npq$.

If n is too large, normal distribution can be approximated to binomial distribution. Thus as n gets large the distribution of

$$Z = \frac{(X - np)}{\sqrt{npq}} \quad (2.13)$$

approaches a $N(0, 1)$.

2.8.2 Poisson Distribution

Poisson probability distribution function is given by the following formula.

$$p(x) = \frac{\lambda^x e^{-\lambda}}{x!} \quad (2.14)$$

where, the constant λ is the only parameter of the distribution, x is the number of occurrences of an event of the given small probability, p , in a large number of trial, n , and $p(x)$ is the probability of $x = 0, 1, 2, \dots, \infty$. The mean and variance of Poisson distribution are, $E(X) = \lambda$ and $Var(X) = \lambda$.

Poisson distribution converges to normal or the normal probability function fits discrete points of $p(x)$ of Eq. 2.14, when λ gets large. In this case the distribution of

$$Z = \frac{(X - \lambda)}{\sqrt{\lambda}} \quad (2.15)$$

approaches a $N(0, 1)$.

2.9 SELECTION OF PROBABILITY DISTRIBUTION

Tests of goodness of fit are commonly used approach of selecting probability distribution. These tests are generally based on the differences between observed or calculated frequency of events and the expected or theoretical frequency of the events for given distribution. Two ways of judging whether or not a particular distribution adequately describes a set of observations are,

- (a) Graphical comparison and
- (b) Statistical tests.

One of the most commonly used test for goodness of fit of empirical data to specified theoretical distribution is *Chi-square test*. The chi-square test makes a comparison between the actual number of observations and the expected number of observations (expected according to the distribution under test). The expected numbers are calculated by multiplying the expected relative frequency by the total number of observations. The test statistics is calculated from the following relationship.

$$\chi_c^2 = \sum_{j=1}^k \frac{(O_j - E_j)^2}{E_j} \quad (2.16)$$

where,

k = number of class intervals,

O_j = Observed frequency of each class, and

E_j = Expected number of observations.

The estimated χ_c^2 value is compared with a limiting value, $\chi_{1-\alpha, v}^2$, determined from the χ^2 distribution with v degrees of freedom and having a significance level of $1-\alpha$ where α is called *confidence level*. In the χ^2 test $v=k-p-1$, where k is the number of classes and p is the number of parameters used in fitting the proposed distribution. In the test the fit is deemed inadequate if the value of χ_c^2 is larger than the limiting value.

Akhter (1992) conducted a comparison study on the suitability of the test of goodness of fit for rainfall frequency analysis. In addition to chi-square and Kolmogrov-Smirnov test, she also examined three other tests introduced by Stephens (1977) namely A^2 -, U^2 - and W^2 - test. She found that the chi-square test was a reliable tool for the test of goodness of fit of rainfall data.

2.10 REGRESSION ANALYSIS

Possibly the most common model used in hydrology is based on the assumption of a linear relationship between two variables. Generally the objective of such a model is to provide a means of predicting or estimating one variable, the dependent variable, from knowledge of a second variable, the independent variable.

In this study regression analysis was performed to investigate the association between monsoon rainfall total with corresponding number of rainy days and mean daily rainfall intensity. HYMOS (Delft Hydraulics, 1992) has been used to carry out the analysis. The types of equations available in HYMOS are listed below.

1. Polynomial

$$Y = \sum_{j=0}^n C_j X^j \quad (2.17)$$

where, n = degree of polynomial ≤ 9 , and C_j = coefficient

2. Simple linear

$$Y = A + BX \quad (2.18)$$

3.1 Exponential

$$Y = A \exp(BX) \quad (2.19)$$

3.2 Exponential

$$Y = A \exp\left(\frac{B}{X}\right) \quad (2.20)$$

4. Power

$$Y = AX^B \quad (2.21)$$

5. Logarithmic

$$Y = A + B \ln(X) \quad (2.22)$$

6. Hyperbolic

$$Y = A \frac{B}{X} \quad (2.23)$$

7. Multiple Linear

$$Y = C_o + \sum C_j X_j \quad (2.24)$$

where, n = number of series on independent variable, $n \leq 10$ and C_j = coefficient.

In Eqs. 2.17 to 2.24 A and B are coefficients and all coefficients are determined by the least square method.

3.2 STUDY AREA

Rainfall data from northeast region of Bangladesh will be used for analysis in the study. Northeast region, as shown in Figure 3.1, is one of the six hydrologic regions of the country as demarcated by Water Resources Planning Organization (WARPO). This region comprises the districts of Sylhet, Sunamganj, Moulvi Bazar, Srimangal, Netrokona, Kishoreganj and part of Sherpur, Mymensingh and Brahmanbaria. The north and eastern part of the region is bounded by the international border of India and Bangladesh.

The topography of this region consists of a large depression called Sylhet Depression flanked by lowland floodplain, then gently piedmont floodplain and bordered distally by alluvial fans, terraces and uplands extending into India. Land elevations of this region ranges between 9 and 24 meters.

The northeast region experiences the highest precipitation of Bangladesh. Cherrapunji in Meghalaya of India, the wettest place on the earth, is located near this region. The rainfall over this region lasts for about seven months, viz., April to October of the year in average. About 70 percent of total annual rainfall occurs during southwest monsoon (June to September). Because of its special topography and hydrological conditions northeast region can be regarded as "unique" in Bangladesh (CIDA, 1993).

3.1 SOURCES OF RAINFALL DATA

The main sources of rainfall data in Bangladesh are Bangladesh Water Development Board (BWDB) and Bangladesh Meteorological Department (BMD). BWDB collects rainfall data through a country-wide raingauge network which comprises about 256 manually operated raingauges and about 24 recording raingauges. The data collection activities are conducted by Surface Water Hydrology-I (SWH-I) while Surface Water Hydrology-II (SWH-II) processes and stores the data in a computer based integrated data bank along with other hydrological data. SWH-II also preserves rainfall data in

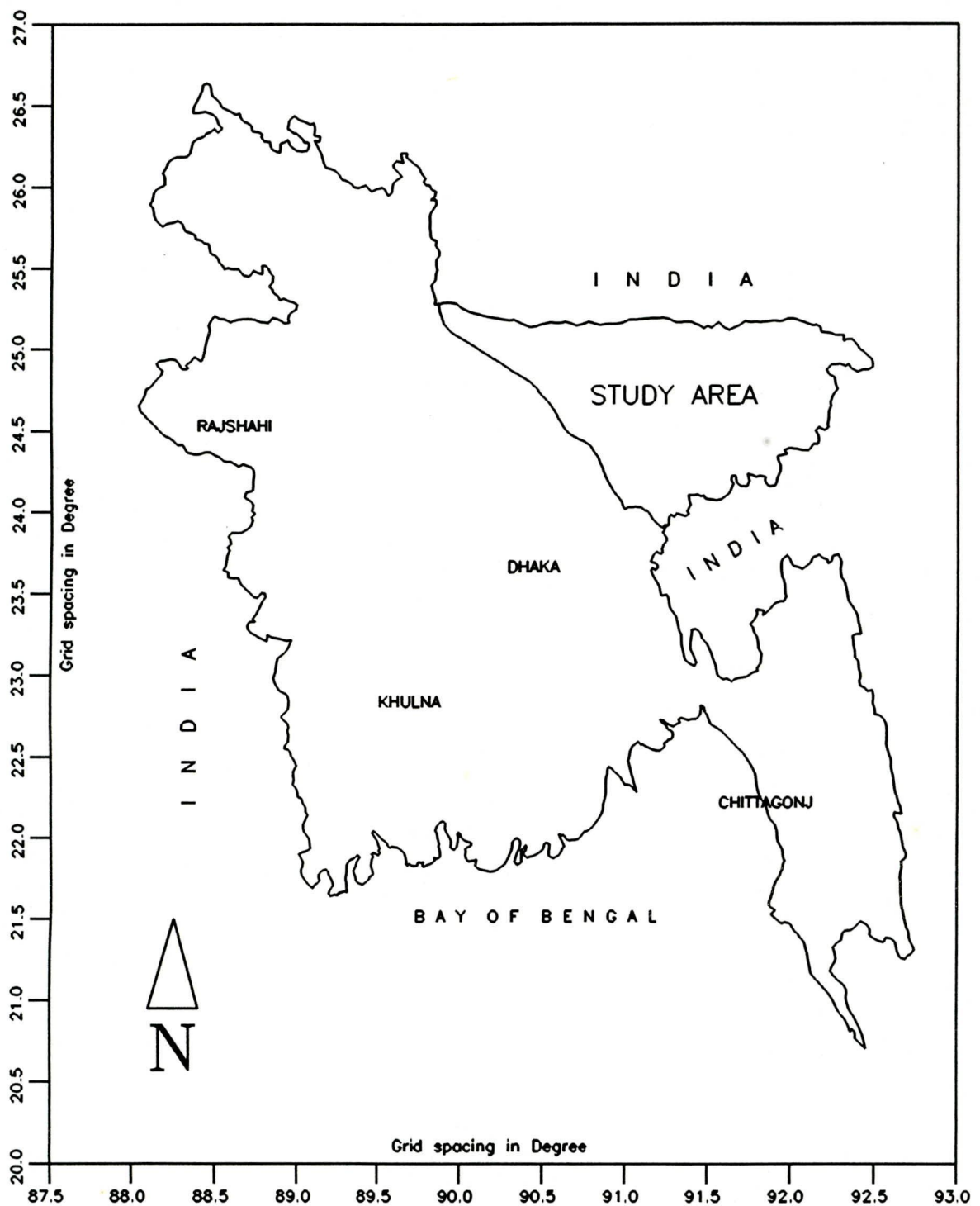
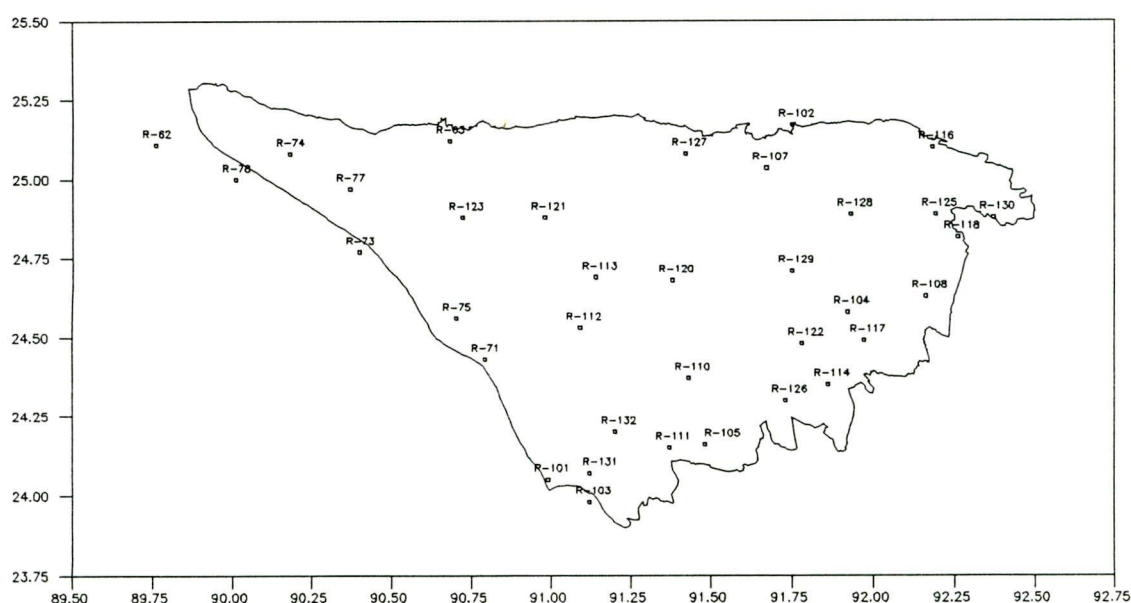


Figure 3.1 Map showing the study area within Bangladesh

the form of '*Index Card*' which contains daily rainfall values and some of their statistics.

3.3 DATA COLLECTION



34 years. The locations of the stations were extracted from *BWDB Index of Hydrological Observation Stations* in geographical co-ordinate system as given in Table A.1 in Appendix A. The regional boundary was collected from SWMC. The digitized boundary data included the geographical co-ordinates of boundary points.

In addition to the available software, some computer programs were also developed for this study to process and summarise the data. All the programs were coded in C language.

Table 3.1 List of raingauge stations selected for this study

Station code	Station name	Period of record
R-62	Dewanganj	1961 - 1994
R-63	Durgapur	1961 - 1994
R-71	Kishoreganj	1961 - 1994
R-73	Mymensingh	1961 - 1994
R-74	Nalitabari	1962 - 1994
R-75	Nandail	1963 - 1994
R-77	Phulpur	1962 - 1994
R-78	Sherpur Town	1961 - 1994
R-101	Bhairab Bazar	1961 - 1994
R-102	Bholaganj	1961 - 1994
R-103	Brahmanbaria	1961 - 1994
R-104	Chandbugh	1965 - 1994
R-105	Chandpur Bagan	1964 - 1994
R-107	Chatak	1963 - 1994
R-108	Dakhinbagh	1962 - 1994
R-110	Habiganj	1961 - 1994
R-111	Itakhola	1961 - 1994
R-112	Itna	1970 - 1994
R-113	Khaliaghuri	1962 - 1994
R-114	Kamalganj	1962 - 1994
R-116	Lallakhal	1962 - 1994
R-117	Langla	1963 - 1994
R-118	Latu	1962 - 1994
R-120	Markuli	1972 - 1994
R-121	Mohonganj	1962 - 1994
R-122	Moulvi Bazar	1961 - 1994
R-123	Netrokona	1961 - 1994
R-125	Sheola	1961 - 1994
R-126	Srimangal	1961 - 1994
R-127	Sunamganj	1961 - 1994
R-128	Sylhet	1961 - 1994
R-129	Tajpur	1962 - 1994
R-130	Zakiganj	1965 - 1994
R-131	Sarail	1962 - 1994
R-132	Nasirnagar	1962 - 1994

3.4 ESTIMATION OF MISSING DATA AND TEST FOR CONSISTENCY

After collection, all data were checked to fill the missing records and remove inconsistency in the daily rainfall series as stated in Sec. 2.2. Missing data were found at five raingauge stations, viz., Dewanganj, Sherpur Town, Brahmanbaria, Moulvi Bazar and Sheola. Normal annual rainfall of surrounding stations were compared with that at the stations in question. Missing values for Sherpur Town and Sheola were filled using *normal ration method*. For remaining three stations simple *arithmetic average method* was applied.

Consistency of data were tested at seven randomly selected stations, viz., Kishoreganj, Bhairab Bazar, Habiganj, Khaliaghuri, Netrokona, Sunamganj and Sylhet, using *double-mass technique*. No remarkable inconsistency in rainfall data was found at any of the above stations.

3.5 EXTRACTION OF DATA SERIES

3.5.1 Rainfall Data Series

After filling the missing records *daily rainfall values* were used to extract the following rainfall data series.

- i) Monthly rainfall totals of all the selected stations for each months of the year for each year of available records.
- ii) Monsoon (June-September) rainfall total for each station for each year of records.
- iii) Annual rainfall total for each station for each year of records.
- iv) Annual maximum rainfall of 1-, 2-, 3-, 5-, 7-, and 10-consecutive day for each station for the entire length of available records.

Monthly rainfall totals for some stations are given in Appendix D. Running total technique (1961; Chow, 1964) was considered to compute annual maximum rainfall series. All the series were extracted with computer programs developed for this study.

From the above series, averages of monthly, monsoon and annual rainfall values for all stations were computed and presented in Tables A.3 and A.5 in Appendix A.

Normal annual rainfall values were estimated for 32 selected stations for the period from 1961 to 1990 as per definition stated in Sec. 2.2. The updated normal annual rainfall values are given in Table 3.2 with that of estimated by BWDB for the period

Table 3.2 Comparison of normal annual rainfall (1961-90) estimated in this study with that of estimated by BWDB (1951-80)

Station code	Station name	Normal annual rainfall (mm)		
		BWDB (1951-80)	This Study (1961-90)	% Deviation
R-62	Dewanganj	1963	2223	13.25
R-63	Durgapur	3987	3568	-10.51
R-71	Kishoreganj	2263	2273	0.44
R-73	Mymensingh	2351	2454	4.38
R-74	Nalitabari	2381	2602	9.28
R-75	Nandail	2691	2721	1.11
R-77	Phulpur	2457	2558	4.11
R-78	Sherpur Town	2102	2170	3.24
R-101	Bhairab Bazar	2196	2169	-1.23
R-102	Bholaganj	5636	5417	-3.89
R-103	Brahmanbaria	2039	2113	3.63
R-105	Chandpur Bagan	2369	2333	-1.52
R-107	Chatak	5322	5348	0.49
R-108	Dakhinbagh	3232	3337	3.25
R-110	Habiganj	2531	2534	0.12
R-111	Itakhola	2260	2250	-0.44
R-113	Khali ajhuri	3316	3396	2.41
R-114	Kamalganj	2457	2519	2.52
R-116	Lallakhal	5858	5976	2.01
R-117	Langla	2628	2805	6.74
R-118	Latu	3414	3495	2.37
R-121	Mohonganj	3889	3740	-3.83
R-122	Moulvi Bazar	2618	2673	2.10
R-123	Netrokona	2719	2948	8.42
R-125	Sheola	4115	4096	-0.46
R-126	Srimangal	2483	2441	-1.69
R-127	Sunamganj	5573	5553	-0.36
R-128	Sylhet	3995	4301	7.66
R-129	Tajpur	3681	3896	5.84
R-130	Zakiganj	3787	4193	10.72
R-131	Sarail	2271	2201	-3.08
R-132	Nasirnagar	2372	2433	2.57
Average Deviation :				2.18

from 1951 to 1980. Normal monsoon rainfall chart was prepared for the same stations and shown in Table 3.3. Recorded maximum rainfall of 1-, 2-, 3-, 5-, 7- and 10-consecutive day for the entire length of records were also extracted and presented in Table A.6 in Appendix A.

All the extreme event series were converted into HYMOS database format as the entire frequency analysis was carried out by HYMOS.

3.5.2 Number of Rainy Day Series

In the present study BWDB practice has been considered for compilation of number of rainy days. The following series were extracted for number of rainy days.

- i) Monthly number of rainy days of all the selected stations for each month of the year for each year of available records.
- ii) Number of rainy days during monsoon for each station for each year of records.
- iii) Annual number of rainy days for each station for each year of records.

From the above series, mean values of monthly, monsoon and annual number of rainy days were estimated and presented in Tables A.4 and A.5 in Appendix A. Normal values of number of rainy days of 32 selected stations during monsoon for the period from 1961 to 1990 were computed and shown in Table 3.3.

3.5.3 Mean Daily Rainfall Intensity for Monsoon

Mean daily rainfall intensity during monsoon for 32 selected raingauge stations were estimated for each year from 1961 to 1990 by simply dividing the monsoon rainfall totals with corresponding number of rainy days. Then the averages of mean daily intensity for the selected stations were computed and given in Table 3.3.

3.5.4 Computation of Area-weighted Rainfall Parameters

Area-weighted monsoon and annual rainfall totals and number of rainy days to be used in examining the temporal variability in rainfall and number of rainy days over the study region were estimated by Thiessen method as stated in Sec. 2.4. 12 raingauge stations sporadically located over the region were considered and 12 polygons were formed as shown in Figure 3.3. Then mean regional parameters were estimated and presented in Table 3.4 using Eq. 2.2.

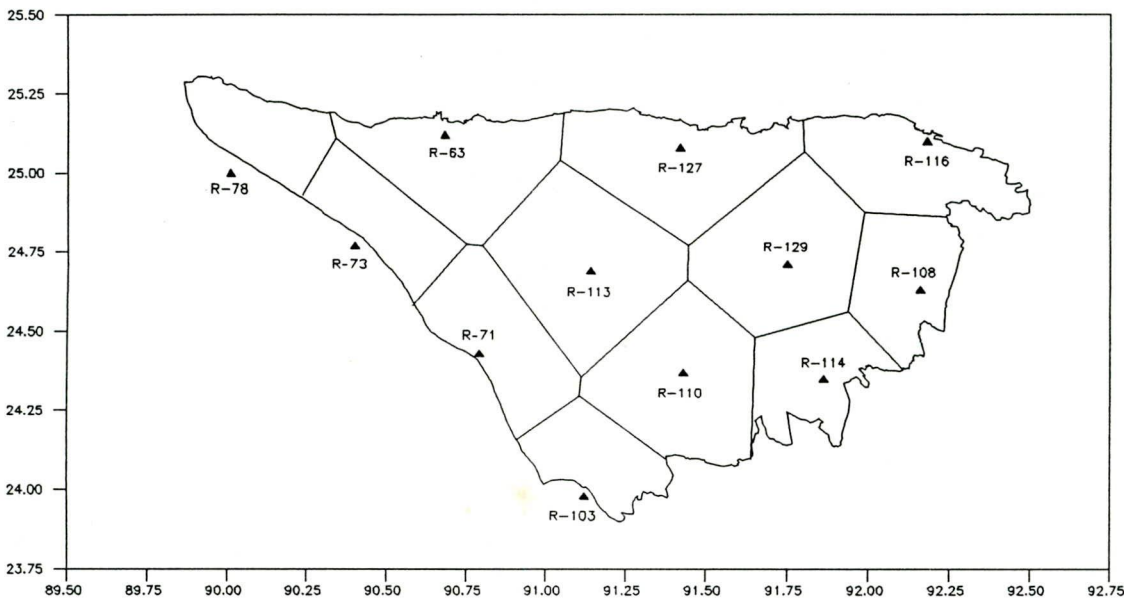


Figure 3.3 Thiessen polygons to compute area-weighted rainfall parameters.

Table 3.3 Normal monsoon rainfall, number of rainy days and mean daily intensity computed for the period 1961-90

Station code	Station name	Monsoon rainfall (mm)	Number of rainy days	Mean daily intensity (mm/day)
R-62	Dewanganj	1563	69	22.7
R-63	Durgapur	2682	86	31.2
R-71	Kishoreganj	1523	68	22.4
R-73	Mymensingh	1706	84	20.3
R-74	Nalitabari	1822	75	24.3
R-75	Nandail	1868	67	27.9
R-77	Phulpur	1864	68	27.4
R-78	Sherpur Town	1545	66	23.4
R-101	Bhairab Bazar	1406	61	23.0
R-102	Bholaganj	4009	94	42.6
R-103	Brahmanbaria	1294	66	19.6
R-105	Chandpur Bagan	1409	79	17.8
R-107	Chatak	3910	96	40.7
R-108	Dakhinbagh	2088	87	24.0
R-110	Habiganj	1574	78	20.2
R-111	Itakhola	1406	70	20.1
R-113	Khaliaghuri	2371	81	29.3
R-114	Kamalganj	1483	81	18.3
R-116	Lallakhal	4126	98	42.1
R-117	Langla	1706	80	21.3
R-118	Latu	2265	88	25.7
R-121	Mohonganj	2731	90	30.3
R-122	Moulvi Bazar	1671	83	20.1
R-123	Netrokona	2060	80	25.8
R-125	Sheola	2698	90	30.0
R-126	Srimangal	1419	78	18.2
R-127	Sunamganj	4301	96	44.8
R-128	Sylhet	2915	93	31.3
R-129	Tajpur	2629	84	31.3
R-130	Zakiganj	2667	86	31.0
R-131	Sarail	1395	64	21.8
R-132	Nasirnagar	1480	74	20.0

Table 3.4 Area-weighted rainfall and number of rainy days over northeast region

Year	Monsoon		Annual	
	Rainfall (mm)	Number of rainy days	Rainfall (mm)	Number of rainy days
1961	2045	83	2867	125
1962	2193	68	3015	104
1963	2597	83	3514	127
1964	2826	87	4238	144
1965	2367	81	3034	117
1966	2447	88	3404	126
1967	2378	86	3168	117
1968	2372	89	3413	132
1969	2346	84	3073	120
1970	2493	87	3595	121
1971	2349	77	3684	128
1972	2288	73	3159	107
1973	2707	86	4236	136
1974	2263	72	3376	111
1975	2089	64	3181	103
1976	2944	73	3750	102
1977	2081	81	3561	135
1978	2005	70	3484	110
1979	2738	73	3351	108
1980	1772	88	3088	138
1981	2240	80	3241	125
1982	2851	79	3707	119
1983	2543	79	3664	124
1984	2361	87	3856	142
1985	2243	88	2932	122
1986	2117	83	3340	136
1987	2579	87	3472	135
1988	2965	81	4632	128
1989	2728	87	3980	132
1990	2584	86	3900	134
1991	2319	88	4270	148
1992	2040	82	2967	121
1993	3197	92	4540	145
1994	1726	79	2639	128
Mean (61-94)	2406	81	3510	125

Analysis performed in this study include: investigation of spatial and temporal distribution of rainfall and number of rainy days; establishment of relationships between rainy days, mean daily intensity and monsoon rainfall totals; fitting continuous probability distributions to annual maximum rainfall values of different durations and fitting discrete probability models to monsoon and annual number of rainy days. SURFER, a surface mapping system developed by Golden Software Incorporation, USA, has been used to prepare isoline maps for conducting spatial distribution analysis. Steps of analysis and subsequent results are stated below.

4.1 SPATIAL DISTRIBUTION OF RAINFALL AND NUMBER OF RAINY DAYS

4.1.1 Spatial Distribution of Rainfall

Spatial distribution of rainfall over the study area was investigated by examining isohyetal maps for normal and mean rainfall values. Annual isohyetal map was constructed with normal (1961-90) annual rainfall values of 32 selected stations and shown in Figure 4.1. Monthly isohyetal maps for months of April to October were prepared with mean monthly rainfall values of all the selected stations and shown in Figures B.1 to B.7 in Appendix B. Isohyetal map for monsoon rainfall was also constructed and shown in Figure B.8 in Appendix B.

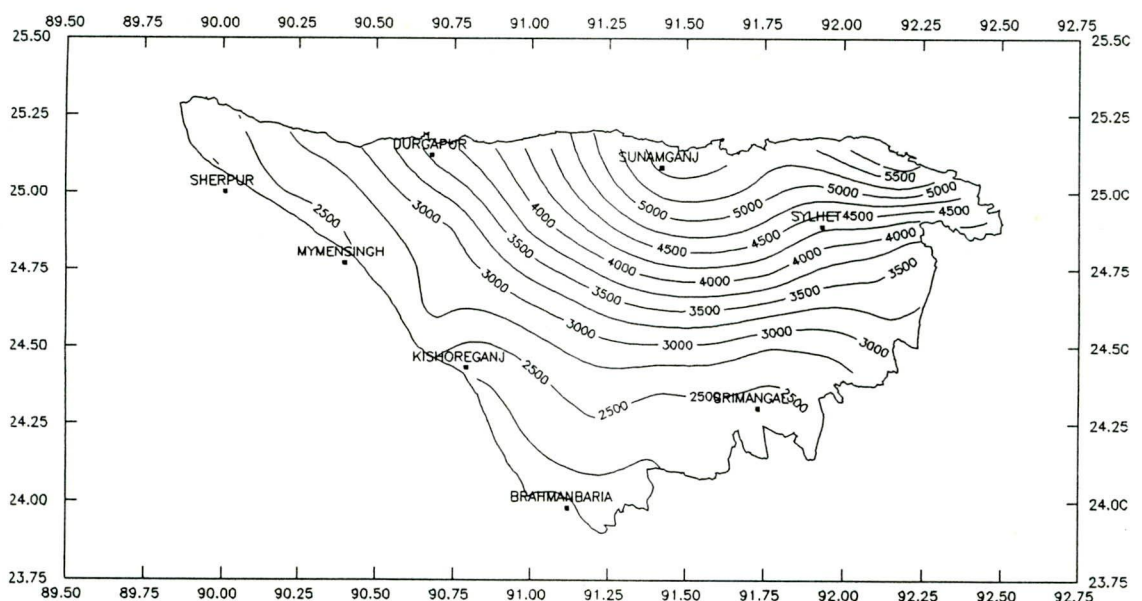


Figure 4.1 Isohyetal map of normal (1961-90) annual rainfall over northeast region.

The salient features as seen from these maps and related tables are as follows:

- (a) The northeastern part of the study area, i.e. Sunamganj district and northeastern part of Sylhet district, experiences the highest rainfall.
- (b) Rainfall is seen to have a steep decrease from north to south and the extreme south and western part receive the lowest rainfall.
- (c) Normal annual rainfall over the region varies between 2200 mm and 6000 mm and normal monsoon rainfall varies from 1250 mm to 4400 mm.
- (d) The highest monthly rainfall over the region occurs in the month of July and the mean monthly rainfall in July varies between 330 mm and 1450 mm.
- (e) The maximum monthly rainfall of 3085 mm was recorded (at Bholaganj) in the northeastern part of the region in the month of July.
- (f) The highest annual rainfall was recorded 9966 mm (at Zakiganj) in the northeastern part and the lowest was recorded 1069 mm (at Phulpur) in the western part of the region. The spatial variation in annual rainfall over the region is remarkably high.
- (g) The highest monsoon (June to September) rainfall was registered 8123 mm (at Tajpur) in the northeastern part and the lowest was recorded 642 mm (at Chandpur Bagan) in the southern part of the region. Again the variation in monsoon rainfall over the region is very large.

4.1.2 Spatial Distribution of Number of Rainy Days

The spatial distribution of number of rainy days over the region was studied by investigating the maps depicting lines, known as isolines (Prasad et al., 1991), having equal number of rainy days. The maps were constructed with mean monthly, monsoon and annual number of rainy days of all the selected stations within the study area. Isoline map of annual number of rainy days is shown in Figure 4.2. Isoline maps of monthly number of rainy days for months of April to October are as shown in Figures B.9 to B.15 and the same for number of rainy days during monsoon is shown in Figure B.16 in Appendix B.

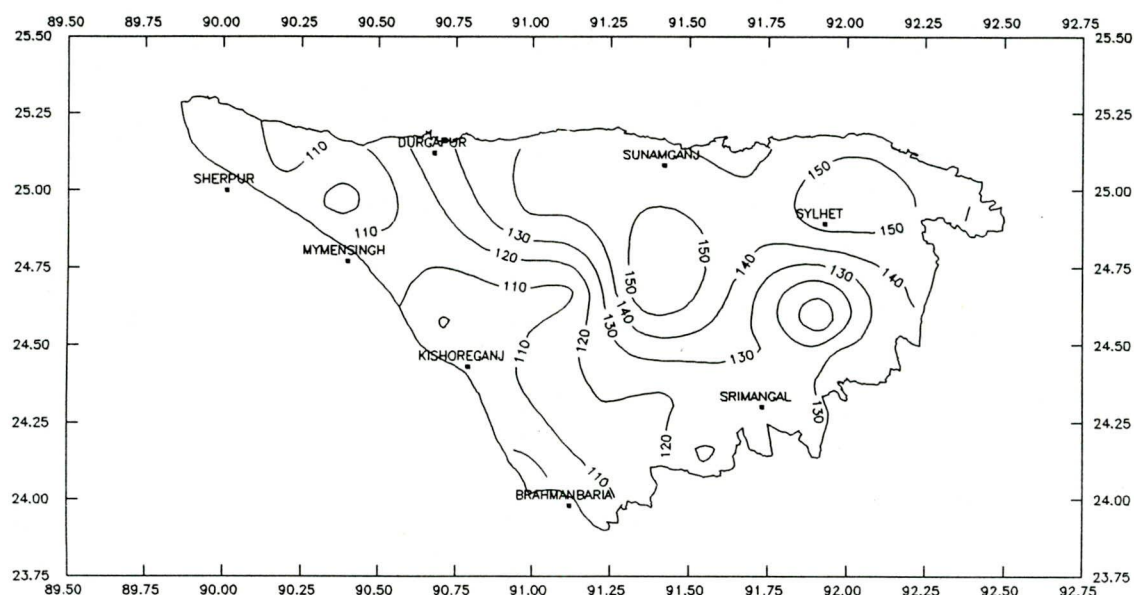


Figure 4.2 Distribution of mean annual number of rainy days.

The main features found in those maps are stated below:

- (a) Distributions of number of rainy days are not uniform like that of rainfall values.
- (b) On the average, number of rainy days is highest in the northeastern part of the region.
- (c) Average annual number of rainy days over the study region varies between 95 and 160.
- (d) The recorded highest annual number of rainy days was found 190 (at Markuli) in the northeastern part and lowest was found 48 (at Phulpur) in the western part of the region.
- (e) The recorded highest number of rainy days during monsoon was found 111 (at Sunamganj) in the northeastern part and lowest was found 36 (at Sherpur Town) in the western part of the region.

4.2 TEMPORAL VARIABILITY OF RAINFALL AND NUMBER OF RAINY DAYS

4.2.1 Temporal Variability of Rainfall

Temporal variability of area-weighted monsoon and annual rainfall over the northeast region of Bangladesh was studied in the following three ways:

- (a) examining the moving averages,
- (b) investigating percent departure from normal values, and
- (c) comparing sub-period statistics.

The moving averages of area-weighted monsoon and annual rainfall series were calculated using Eq. 2.3 with time span of 11 years. Then the derived series were plotted with their respective parent series as shown in Figures 4.3 and 4.4 to examine whether any trend or periodicity can be found in the rainfall series.

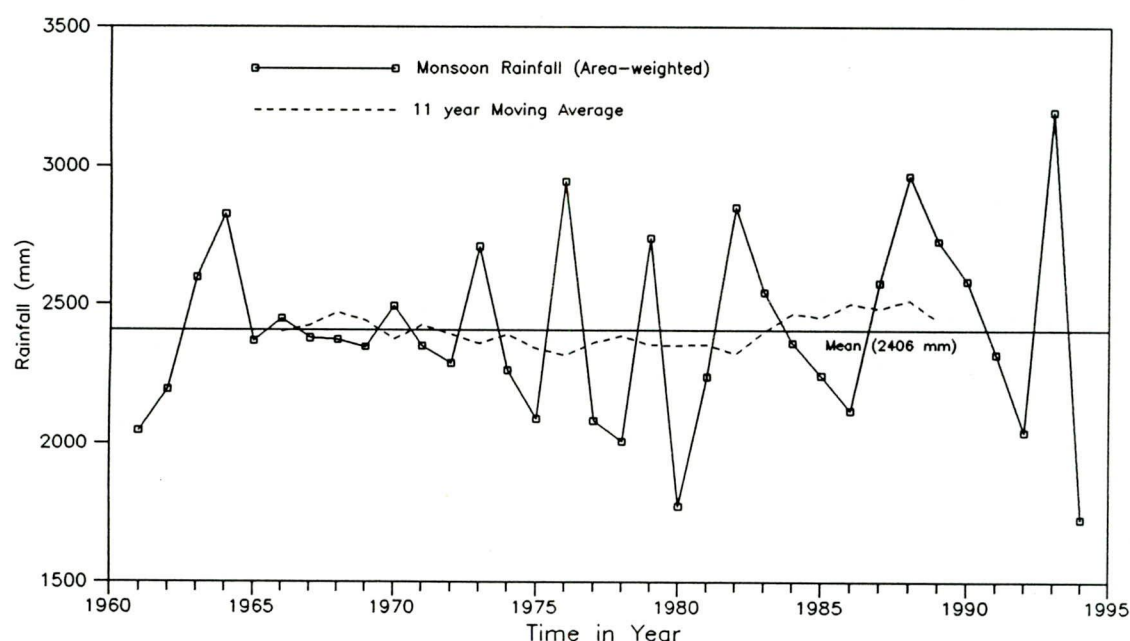


Figure 4.3 Monsoon rainfall series and 11-year moving averages

The changing behaviour of rainfall in time scale were also examined by investigating the percentage increase or decrease of monsoon and annual rainfall for every year with reference to their respective normal rainfall as shown in Figures 4.5 and 4.6. In these two figures the deviations of minus 10 percent or less are treated as deficit years and those with plus 10 percent or more are treated as excess years.

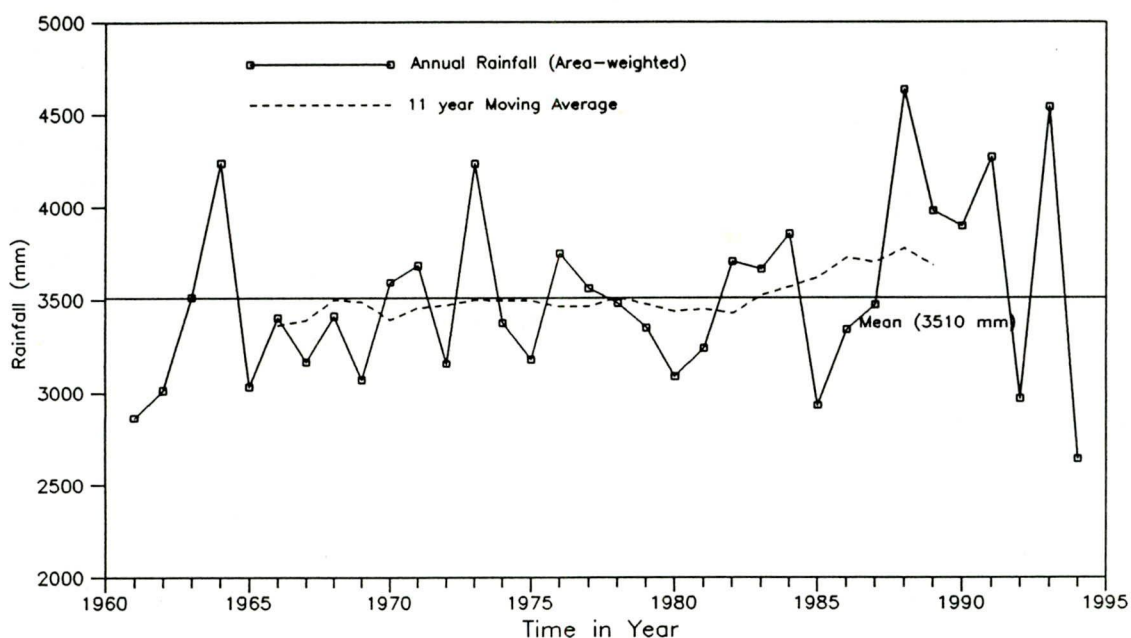


Figure 4.4 Annual rainfall series and 11-year moving averages

Further study has been conducted to investigate the temporal distribution of rainfall over the region by comparing sub-period statistics. The entire period from 1961 to 1994 has been divided into three sub-periods of 12, 11, and 11 years. Then area-weighted mean, standard deviations and coefficients of variation for the monsoon and annual rainfall for each sub-period were calculated and given in Table 4.1.

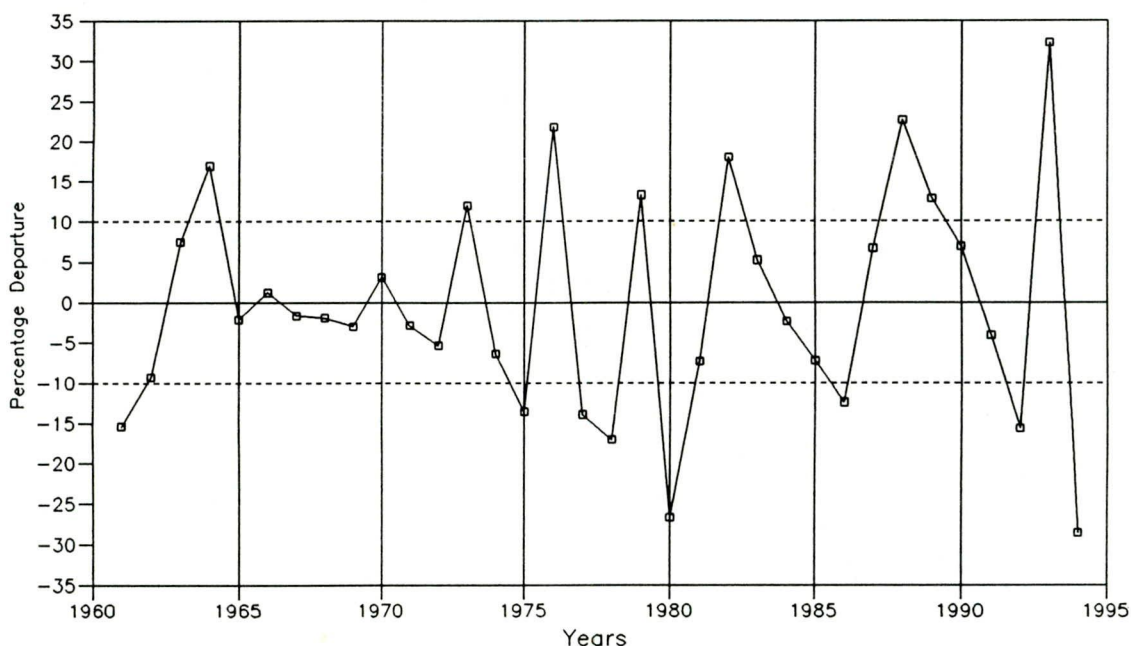


Figure 4.5 Percentage departure of area-weighted monsoon rainfall

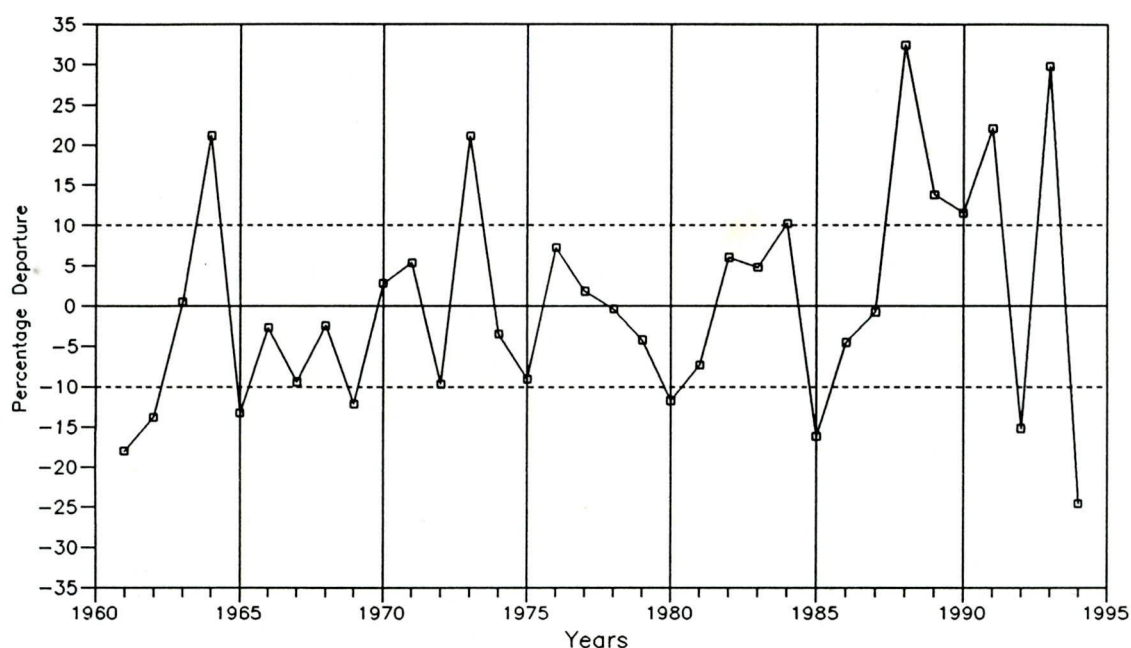


Figure 4.6 Percentage departure of area-weighted annual rainfall

Table 4.1 Sub-period statistics of area-weighted rainfall values

Sub-period (Year)	Monsoon rainfall			Annual rainfall		
	Mean (mm)	Standard deviation (mm)	Coefficient of variation	Mean (mm)	Standard deviation (mm)	Coefficient of variation
1961-72	2392	195	0.08	3347	380	0.11
1973-83	2385	390	0.16	3513	324	0.09
1984-94	2442	425	0.17	3684	669	0.18

The following findings can be noted from the above figures and related table.

- There are no significant periodicity in the occurrence of rainfall from 1961 to 1994 over the northeast region of Bangladesh.
- The 11-year moving averages indicate no significant change in trend during the period from 1961 to 1982 and thereafter an increasing trend in monsoon and annual rainfall over the region.

- (c) The highest and lowest area-weighted annual rainfall occurred in 1988 (4632 mm) and 1994 (2639 mm) respectively. The recorded highest area-weighted monsoon rainfall occurred in 1993 (3197 mm) and 1994 (1726 mm) respectively.
- (d) During 1961 to 1994, number of years with deficit in rainfall was eight and number of years with excess in rainfall was also eight. But it cannot be concluded if there is an excess rainfall in one year, there will be deficient rain in the next year and *vice versa*.
- (e) Sub-period statistics exhibit that the means of area-weighted monsoon and annual rainfall for the third sub-period, viz., 1984 to 1994 are highest and they are also higher than their respective normal values (2417 mm and 3497 mm).
- (f) Standard deviations of area-weighted annual rainfall for the third sub-period is remarkably higher than other sub-periods which indicates a greater inter-annual fluctuations in rainfall in the recent years.
- (g) Coefficients of variations for different sub-periods exhibit that area-weighted rainfall varies within the range of 18 percent of mean values.

4.2.2 Temporal Variability of Number of Rainy Days

Temporal variability of number of rainy days over the study area was investigated by (a) examining the moving averages and (b) comparing sub-period statistics of area-weighted monsoon and annual number of rainy days. The moving averages with 11-year time span were computed using Eq. 2.3 and plotted with their respective parent series as shown in Figures 4.7 and 4.8. Sub-period statistics of number of rainy days were estimated as described in Sec. 4.2.1 and shown in Table 4.2.

Table 4.2 Sub-period statistics of area-weighted number of rainy days

Sub-period (Year)	Number of rainy days during monsoon			Annual number of rainy days		
	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
1961-72	82	6	0.07	122	11	0.09
1973-83	77	7	0.09	119	13	0.11
1984-94	85	4	0.05	134	9	0.07

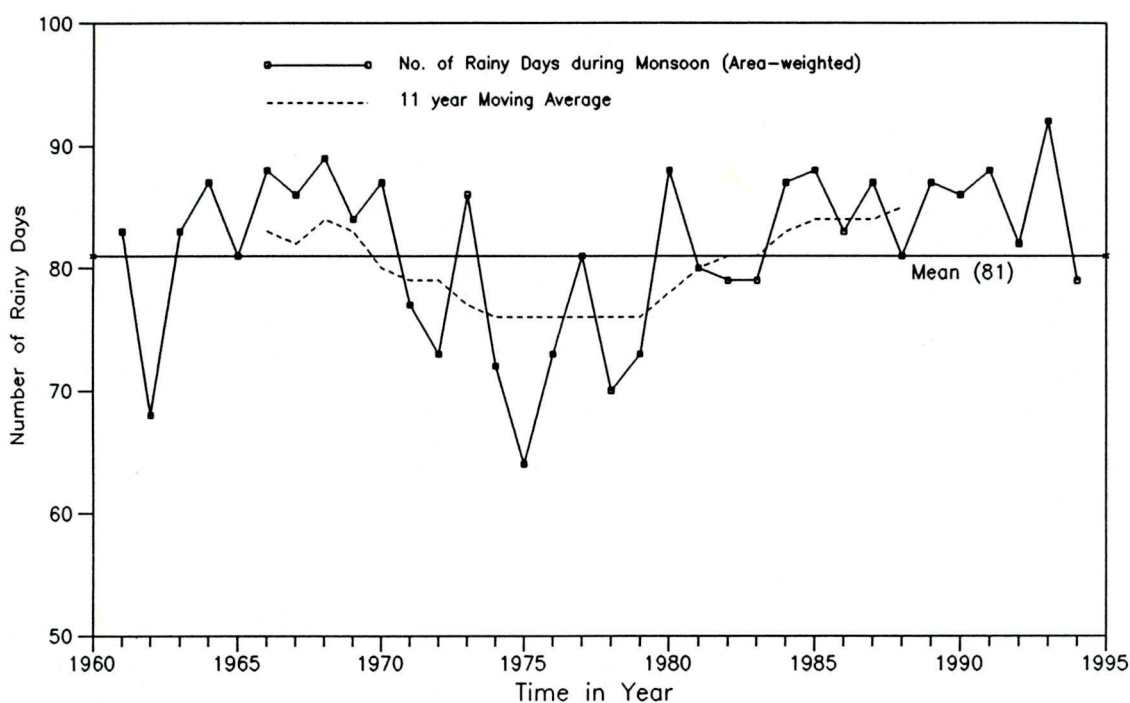


Figure 4.7 Number of rainy days during monsoon and 11 year moving averages.

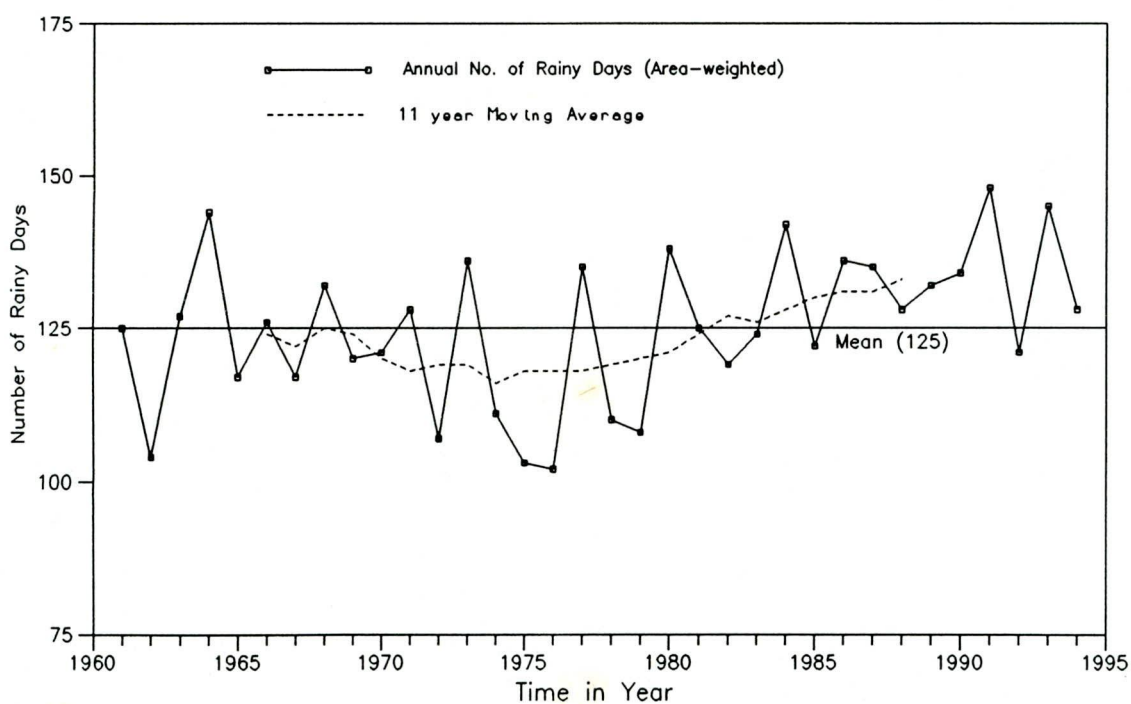


Figure 4.8 Annual number of rainy days and 11 year moving averages.

The following remarks can be made from the figures and related table.

- (a) No definite periodicity was seen in the occurrence of number of rainy days over the study area.
- (b) 11-year moving averages indicate a decreasing trend upto 1975 and thereafter an increasing trend in the occurrence of monsoon and annual number of rainy days.
- (c) It is seen from the sub-period statistics that the mean has increased while the standard deviation has decreased from first sub-period to second sub-period and *vice versa* from second sub-period to third sub-period. So the standard deviation and hence inter-annual fluctuation in the occurrence of number of rainy days exhibits an opposite pattern to the mean.

4.3 RELATIONSHIP BETWEEN RAINY DAYS, MEAN DAILY INTENSITY AND MONSOON RAINFALL

Normal values of monsoon rainfall and corresponding number of rainy days of 32 selected stations as listed in Table 3.3 have been utilized for this analysis. Mean daily rainfall intensity were obtained by dividing monsoon rainfall by corresponding number of rainy days as stated in Sec. 3.5.3. Four polynomials as given in Eqs. 18, 19, 21 and 24 were examined.

The variable Y is the number of rainy days or mean daily rainfall intensity and X is the monsoon rainfall. The constant A and B were worked out for the two sets of relationship i.e. (i) between number of rainy days and monsoon rainfall totals and, (ii) between mean daily intensity and monsoon rainfall totals.

To assess the degree of relationship of two parameters with rainfall, the R^2 value, the maximum absolute deviation and the standard error of estimate S_e were worked out. The S_e between the actual and derived values indicates the closeness of fit of the relationship of two parameters. Here R^2 denotes correlation between the actual values of Y and those predicted by the polynomials.

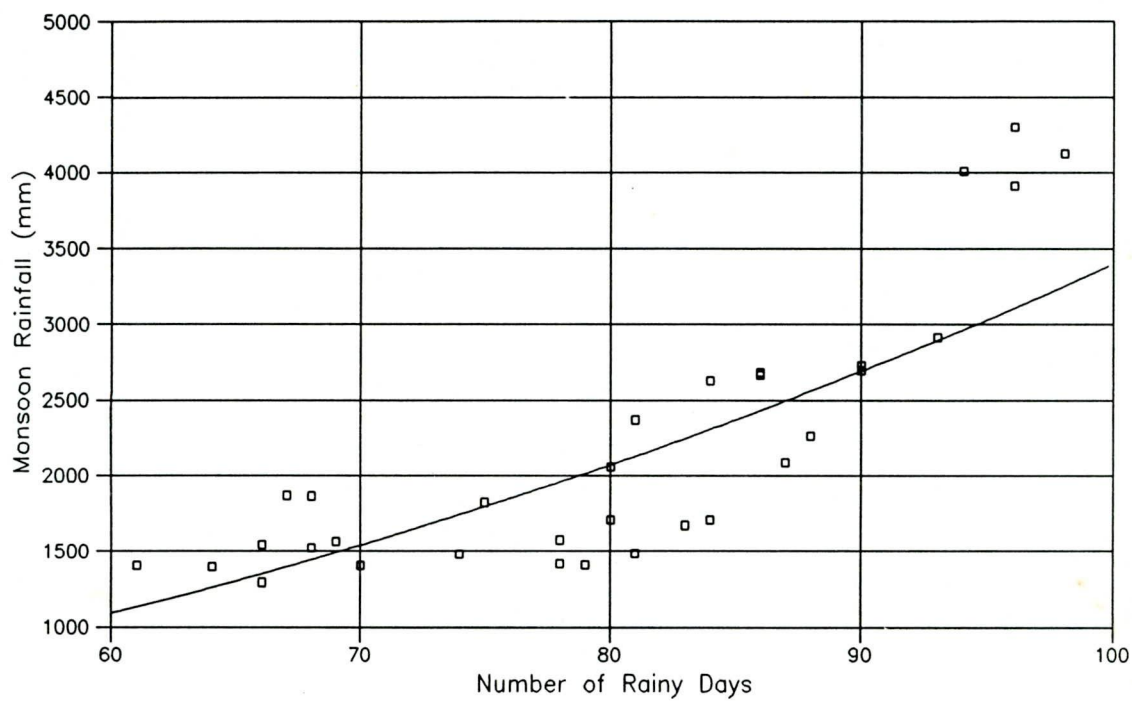


Figure 4.9 Monsoon rainfall and number of rainy days.

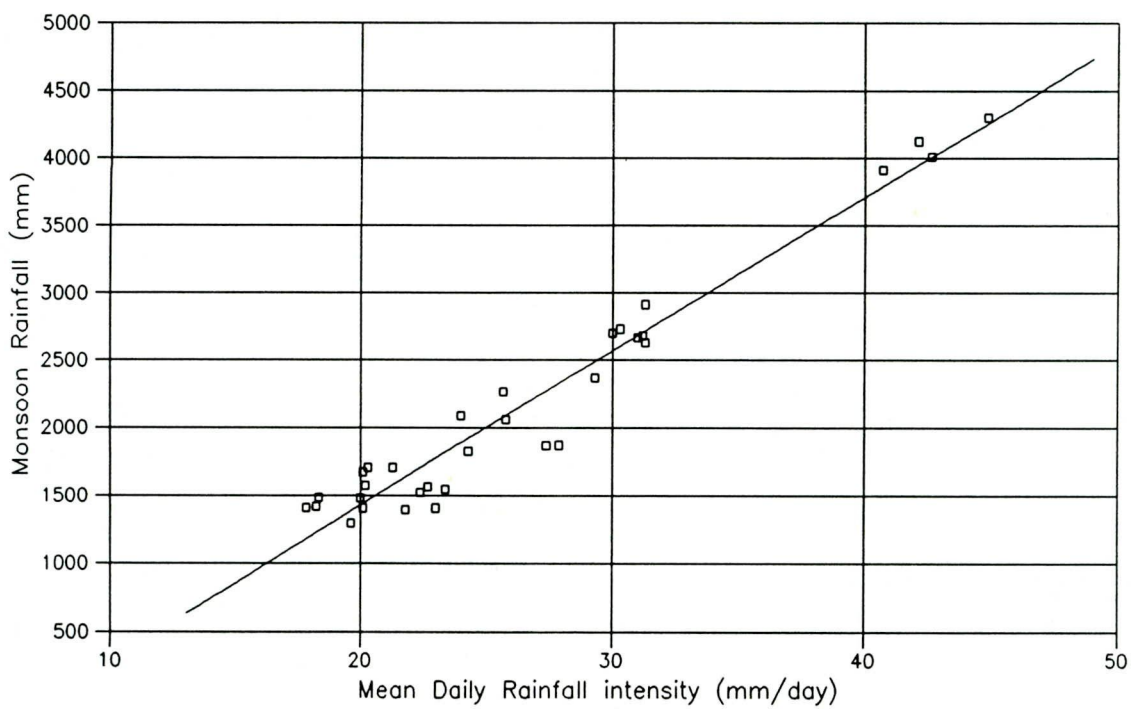


Figure 4.10 Monsoon rainfall and mean daily intensity.

Table 4.3 Results of regression analysis between monsoon rainfall and number of rainy days

Polynomials	Coefficients		R^2	Standard error of estimate	Maximum absolute deviation
	A	B			
$Y = A + BX$	58.6125	0.009835	0.682	4.95	11.44
$Y = A e^{BX}$	61.0092	0.000121	0.663	5.31	11.32
$Y = A X^B$	7.8094	0.304340	0.740	4.86	10.31
$Y = A + B \log X$	-107.4780	24.612100	0.716	4.79	10.92
$X = \text{Monsoon rainfall (mm)}$			$Y = \text{Number of rainy days}$		

Table 4.4 Results of regression analysis between monsoon rainfall and mean daily intensity

Polynomials	Coefficients		R^2	Standard error of estimate	Maximum absolute deviation
	A	B			
$Y = A + BX$	8.443	0.008320	0.948	1.693	3.62
$Y = A e^{BX}$	13.840	0.000283	0.937	1.941	4.20
$Y = A X^B$	0.128	0.695450	0.945	1.711	3.75
$Y = A + B \log X$	-125.985	20.021900	0.923	2.046	3.86
$X = \text{Monsoon rainfall (mm)}$			$Y = \text{Mean daily rainfall intensity (mm/day)}$		

The results of regression analysis are given in Tables 4.3 and 4.4. The tables show the values of the constants A and B as well as the values of R^2 , standard errors of estimate, S_e and maximum absolute deviations between actual and derived values. The following remarks can be made from these results:

- Table 4.3 gives the highest R^2 value 0.74 which indicates poor association of rainy day with monsoon rainfall total. However, the table shows that the relationship is better in the form of $Y = A X^B$ (Figure 4.9).
- Table 4.4 gives highest R^2 (0.948) value, least standard error of estimate (1.693) and reasonable maximum deviation (3.62) for the equation $Y = A + BX$ which indicates that mean daily rainfall intensity is linearly associated with monsoon rainfall total (Figure 4.10). The value of coefficients A in equation $Y = A + BX$ exhibits that the equation can be applied when mean daily intensity is higher than 8.443 mm/day.
- Mean daily intensity has better relationship with monsoon rainfall total than corresponding number of rainy days does.

4.4 FITTING DISTRIBUTIONS TO MAXIMUM RAINFALL VALUES AND NUMBER OF DAILY DAYS

4.4.1 Fitting Distributions to Maximum Rainfall Values

Three probability distributions - normal, lognormal and Gumbel or extreme value type I (EV1) were chosen for fitting annual series of 1-, 2-, 3-, 5-, 7- and 10-day maximum rainfall values of all the selected stations of the study area. This choice of distributions was based on the findings of Akhter (1992) who fitted normal, lognormal, Gumbel, Pearson type-III and log-Pearson type-III distributions to 1-, 2- and 3-day maximum rainfall of southeastern area and concluded that normal, lognormal and Gumbel were suitable for maximum rainfall frequency analysis in Bangladesh. HYMOS has been used for this part of the analysis. Parameters were estimated using maximum likelihood method. Weibull formula was used for plotting positions. Goodness of fit of the distributions were tested by inspecting probability plots and chi-square test results. As samples, some probability plots with plotting positions and their best fit lines are shown in Figure 4.11 and Figures C.1a to C.5c in Appendix C. Results of chi-square test for some selected stations are given in Table C.1 in Appendix C.

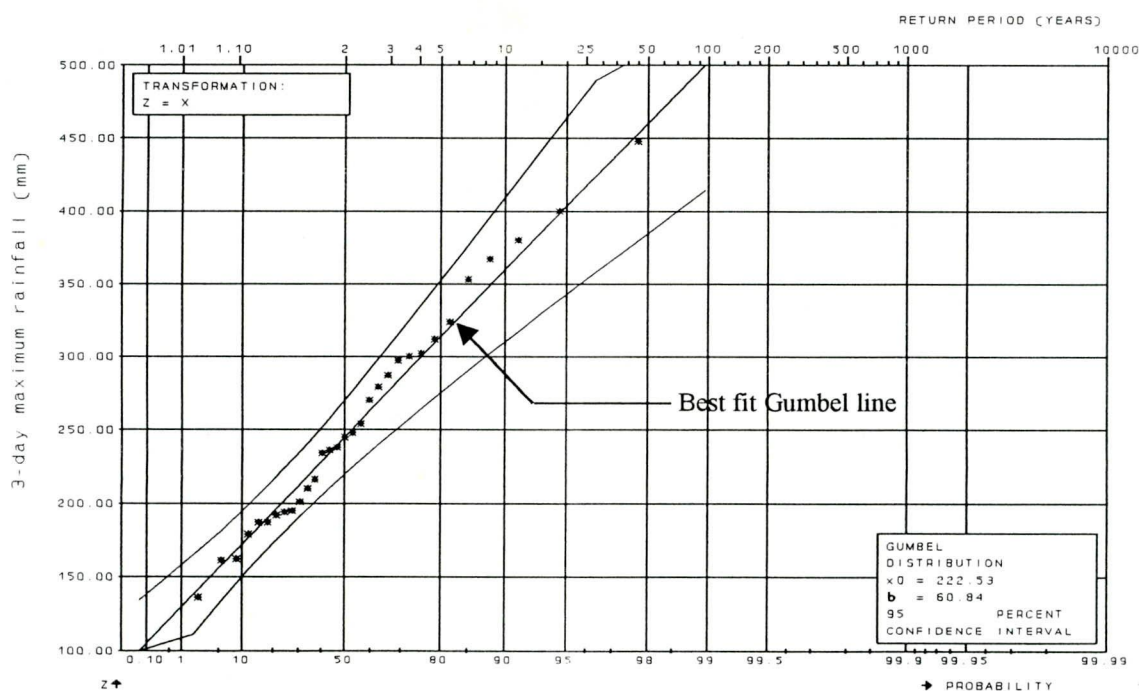


Figure 4.11 Gumbel probability plot of 3-day maximum rainfall at Habiganj.

On the basis of Chi-square test (Sec. 2.9) and visual judgement of probability plots, all three distributions were found satisfactory to fit annual maximum rainfall of different durations over northeast region of Bangladesh and Gumbel distribution was found to be the most suitable.

Gumbel parameters were plotted on maps and lines of isovalues were drawn for 1-, 3-, 5- and 7-day maximum rainfall as shown in Figures C.6a to C.9b in Appendix C.

Maximum rainfall values of different durations corresponding to return periods of 5, 10, 20, 25, 30, 50 and 100 years were also calculated using the chosen distributions and the results are given in Appendix C (Table C.2).

4.4.2 Fitting Distributions to Number of Rainy Days

Six representative stations were selected for this analysis. Appropriateness of binomial and Poisson discrete probability functions were examined for describing monsoon and annual number of rainy days. Parameters of distributions were estimated using method of moments. As stated in Sec. 2.8 for large values of n and λ binomial and Poisson distributions can be approximated by normal probability density function. Accordingly normal approximation to binomial and Poisson distribution were applied to monsoon and annual number of rainy days at six selected stations located over the region.

To judge the goodness of fit of both the distributions chi-square tests were carried out and comparison of the observed relative frequency curve with the theoretical relative frequency curve were done. The chi-square tests were conducted considering six classes. The class intervals were defined in such a ways so that the expected number of observations in each class is the same. The calculated χ_c^2 values and the limiting χ^2 values (Sec. 2.9) having 95 percent confidence interval are given in Tables 4.6 and 4.7. Some probability distribution plots are shown in Figure 4.12 and in Figures C.10 to C.17 in Appendix C.

From the figures and tables it is seen that normal approximation to Poisson distribution adequately describe annual number of rainy days over northeast region of Bangladesh and it gives satisfactory fit to number of rainy days during monsoon.

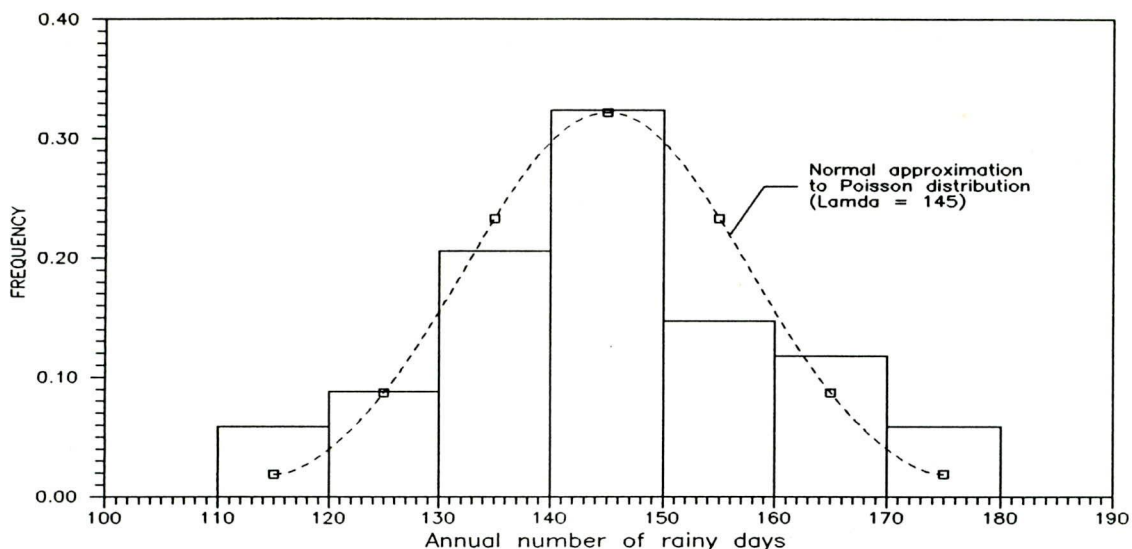


Figure 4.12 Probability distribution of annual number of rainy days at Sunamganj.

Table 4.6 Results of χ^2 test on annual number of rainy days

Raingauge stations	Normal approximation to Poisson distribution		Normal approximation to binomial distribution	
	χ^2_c (calculated)	$\chi^2_{0.95,4}$ (limiting)	χ^2_c (calculated)	$\chi^2_{0.95,3}$ (limiting)
R-63 Durgapur	3.763	9.45	11.523	7.81
R-71 Kishoreganj	5.879	9.45	12.227	7.81
R-101 Bhairab Bazar	1.749	9.45	6.252	7.81
R-110 Habiganj	7.240	9.45	13.642	7.81
R-127 Sunamganj	0.940	9.45	6.231	7.81
R-128 Sylhet	3.409	9.45	5.522	7.81

Table 4.7 Results of χ^2 test on number of rainy days during monsoon

Raingauge stations	Normal approximation to Poisson distribution		Normal approximation to binomial distribution	
	χ^2_c (calculated)	$\chi^2_{0.95,4}$ (limiting)	χ^2_c (calculated)	$\chi^2_{0.95,3}$ (limiting)
R-63 Durgapur	7.289	9.45	8.347	7.81
R-71 Kishoreganj	1.293	9.45	15.049	7.81
R-101 Bhairab Bazar	2.126	9.45	9.256	7.81
R-110 Habiganj	1.998	9.45	13.285	7.81
R-127 Sunamganj	2.351	9.45	16.460	7.81
R-128 Sylhet	9.406	9.45	10.110	7.81

5.1 CONCLUSIONS

The present study was undertaken with the goal of characterizing the changing behaviour of rainfall in space and time over the northeast region of Bangladesh. The analysis performed herein involves distribution of rainfall and number of rainy days in space and time, regression analysis to relate rainy days and mean daily intensity with monsoon rainfall totals, fitting of continuous probability distributions to annual maximum rainfall values and fitting of discrete probability models to monsoon and annual number of rainy days.

The following conclusions can be drawn from the analysis performed and the results obtained.

- (a) Northeastern part of the study area experiences the highest rainfall. Rainfall decreases sharply towards south and west. Extreme south and western parts receive the lowest rainfall of the region (Sec 4.1).
- (b) No definite trend in areal distribution of number of rainy days was found in the study region. However, on the average, number of rainy days is also highest over northeastern part of the region (Sec 4.1).
- (c) The deviation of updated (1961-1990) normal annual rainfall from that of estimated by BWDB (1951-1980) are within the range of 13 percent. On the average normal annual rainfall have increased 2 percent in the gap of 10 years (Table 3.2).
- (d) No significant trend or periodicity in the occurrence of monsoon and annual rainfall from 1961 to 1994 over the study region was found (Sec 4.2).
- (e) Inter annual fluctuations in rainfall magnitudes is remarkably high during the recent years than previous three decades.

- (f) Number of rainy days does not show any definite trend during 1961 to 1994 but it exhibits a slight increasing trend after mid-seventies.

Engineers, agriculturists and climatologists can extract information for their respective fields from the results of the analysis of spatial and temporal variability of rainfall over northeast region with updated rainfall records. Updated isohyetal maps will be useful to meteorological forecasters as a reference to study the variations in rainfall over the northeast region of Bangladesh.

- (g) Mean daily rainfall intensity has better linear relationship with monsoon (June-September) rainfall than does the number of rainy days (Eq 5.1, Sec. 4.3).

$$Y = 8.443 + 0.00832 X \quad (5.1)$$

where, Y = mean daily rainfall intensity (mm/day), and X = monsoon rainfall total (mm). The relationship is valid when mean daily intensity is higher than 8.443 mm/day.

Saxena and Agrawal (1990) conducted a similar study with seasonal (monsoon) rainfall, number of rainy days and mean daily intensity for Maharashtra region of India. They found that number of rainy days has a better relationship with rainfall than does the mean daily intensity and the relation was linear.

- (h) Gumbel or extreme value type I (EV1) was found to be the most appropriate distribution function for frequency analysis of annual maximum rainfall of different durations over northeastern area of Bangladesh (Sec 4.4).

The same conclusion was drawn by Ahmed (1986) for northwest region, Akhter (1992) for southeast region and Siddiqui(1993) for seven selected stations.

Similar studies were also carried out in many parts of the world with extreme rainfall events. In U.S.A, Reich (1963) carried out a frequency analysis with short duration rainfall. In India, Singh (1987) undertaken a comparison study using Gumbel extreme value type I and gamma distribution and Mukherjee et al. (1987) performed another study for annual maximum series. They all advocated in favour of Gumbel distribution as suitable for rainfall frequency analysis.

Isoline maps with Gumbel parameters for 1-, 3-, 5- and 7-day maximum rainfall have been available. So it is now convenient to estimate point rainfall maximums for different return periods at any location of northeast region of Bangladesh even if there is no raingauge at the location under considered.

- (i) Normal approximation to Poisson distribution fits satisfactorily to monsoon and annual number of rainy days over northeast region of Bangladesh.

5.2 RECOMMENDATIONS

Frequency analysis performed during this study was based solely on annual series of rainfall data. Analysis of partial series was not considered which tend to consider multiple extreme events of the same series as independent events. However, it is recommended to undertake further studies using partial series.

The investigation of temporal variability of rainfall conducted in this study was done with data of 34 years and the study was limited to area-weighted rainfall values. But to get a long-term trend or periodicity, it is necessary to extend the study with longer period of records (where available or effort may be made to use synthetically generated data). This study may also be extended with point rainfall.

In the present study, attempts were made to establish relationships between number of rainy days, mean daily intensity and rainfall amounts. It was a preliminary one and was limited to seasonal (monsoon) parameters only. But one single relationship for each of the two parameters with monsoon rainfall does not hold good for different types of rainfall parameters (Such as, monthly and annual parameters). So it is recommended to extend the study in greater detail with monthly and annual parameters.

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APPENDIX A
Tables Referred to the Text

Table A.1 List of raingauge stations in northeast region maintained by BWDB

Station code	Station name	Raingauge location			
		Latitude		Longitude	
		deg	min	deg	min
R-62	Dewanganj	25	06.5 N	89	45.7 E
R-63	Durgapur	25	07.0 N	90	40.5 E
R-65	Goaripur	24	43.3 N	90	34.5 E
R-68	Jaria-jhanjail	25	00.5 N	90	39.3 E
R-71	Kishoreganj	24	26.0 N	90	47.5 E
R-72	Muktagacha	24	45.0 N	90	16.0 E
R-73	Mymensingh	24	46.0 N	90	24.0 E
R-74	Nalitabari	25	04.5 N	90	11.0 E
R-75	Nandail	24	33.8 N	90	42.0 E
R-77	Phulpur	24	58.0 N	90	22.0 E
R-78	Sherpur town	25	00.0 N	90	00.8 E
R-79	Shibpur	24	01.5 N	90	46.0 E
R-101	Bhairab Bazar	24	02.7 N	90	59.3 E
R-102	Bholaganj	25	09.9 N	91	45.1 E
R-103	Brahmanbaria	23	58.7 N	91	07.0 E
R-104	Chandbugh	24	34.8 N	91	55.2 E
R-105	Chandpur Bagan	24	09.3 N	91	29.0 E
R-107	Chatak	25	02.1 N	91	40.2 E
R-108	Dakhinbagh	24	38.0 N	92	09.7 E
R-109	Gobindaganj	24	55.7 N	91	41.7 E
R-110	Habiganj	24	22.0 N	91	25.5 E
R-111	Itakhola	24	09.0 N	91	22.0 E
R-112	Itna	24	31.5 N	91	05.5 E
R-113	Khaliaghuri	24	41.5 N	91	08.5 E
R-114	Kamalganj	24	21.0 N	91	51.5 E
R-115	Kendua	24	39.6 N	90	50.5 E
R-116	Lallakhal	25	06.0 N	92	11.0 E
R-117	Langla	24	29.5 N	91	58.0 E
R-118	Latu	24	49.0 N	92	15.5 E
R-119	Manumukh	24	35.5 N	91	43.5 E
R-120	Markuli	24	41.0 N	91	23.0 E
R-121	Mohonganj	24	52.5 N	90	58.8 E
R-122	Moulvi Bazar	24	28.5 N	91	46.8 E
R-123	Netrokona	24	53.0 N	90	43.0 E
R-125	Sheola	24	53.1 N	92	11.3 E

Table A.1 (Continued)

List of raingauge stations in northeast region maintained by BWDB

Station code	Station name	Raingauge location			
		Latitude		Longitude	
		deg	min	deg	min
R-126	Srimangal	24	18.2 N	91	44.0 E
R-127	Sunamganj	25	04.5 N	91	25.0 E
R-128	Sylhet	24	53.4 N	91	55.5 E
R-129	Tajpur	24	42.5 N	91	44.8 E
R-130	Zakiganj	24	52.8 N	91	22.0 E
R-131	Sarail	24	04.3 N	91	07.0 E
R-132	Nasirnagar	24	11.8 N	91	12.0 E
R-227	Nakuagaon				
R-228	Kanairghat				

Table A.2 List of raingauge stations in northeast region maintained by BMD

Station code	Station name	Raingauge location			
		Latitude		Longitude	
		deg	min	deg	min
	Mymensingh	24	46 N	90	24 E
	Srimangal	24	18 N	91	44 E
	Sylhet	24	54 N	91	53 E

Table A.3 Mean monthly rainfall for indicated months at selected stations in northeast region

Station code	Station name	Mean monthly rainfall (mm)						
		April	may	June	July	August	September	October
R-62	Dewanganj	112	329	430	508	326	314	167
R-63	Durgapur	169	446	693	841	604	583	223
R-71	Kishoreganj	141	336	425	417	380	327	178
R-73	Mymensingh	131	353	477	550	355	402	220
R-74	Nalitabari	148	370	488	584	358	382	167
R-75	Nandail	165	388	500	516	436	422	185
R-77	Phulpur	98	357	480	606	385	403	200
R-78	Sherpur town	116	313	443	470	313	322	142
R-101	Bhairab Bazar	170	348	366	394	315	295	169
R-102	Bholaganj	386	597	1040	1269	962	704	233
R-103	Brahmanbaria	188	390	349	390	284	248	153
R-104	Chandbugh	330	526	645	554	486	393	194
R-105	Chandpur Bagan	237	420	431	337	321	269	150
R-107	Chatak	386	582	1077	1182	854	757	280
R-108	Dakhinbagh	353	543	678	564	451	372	178
R-110	Habiganj	221	470	469	420	385	295	165
R-111	Itakhola	197	367	423	380	328	266	157
R-112	Itna	256	549	527	646	452	537	197
R-113	Khali ajhuri	215	441	571	562	588	625	238
R-114	Kamalganj	265	489	499	374	346	273	159
R-116	Lallakhal	552	754	1165	1267	884	756	276
R-117	Langla	303	496	550	429	406	313	167
R-118	Latu	370	484	767	644	465	410	191
R-120	Markuli	422	670	789	772	414	399	187
R-121	Mohonganj	227	426	699	772	647	632	240
R-122	Moulvi Bazar	276	467	518	437	386	305	146
R-123	Netrokona	177	398	615	621	465	444	228
R-125	Sheola	387	574	878	750	584	528	230
R-126	Srimangal	276	468	475	369	347	275	156
R-127	Sunamganj	315	593	1095	1436	1101	826	279
R-128	Sylhet	399	574	898	863	614	575	246
R-129	Tajpur	328	557	813	729	560	446	200
R-130	Zakiganj	430	622	815	796	589	477	223
R-131	Sarail	176	355	398	378	318	266	162
R-132	Nasirnagar	200	407	392	391	367	284	172

Table A.4 Mean monthly number of rainy days for indicated months at selected stations in northeast region

Station code	Station name	Mean monthly number of rainy days						
		April	May	June	July	August	September	October
R-62	Dewanganj	6	14	16	21	17	16	6
R-63	Durgapur	9	16	21	25	22	18	7
R-71	Kishoreganj	8	14	16	19	19	14	7
R-73	Mymensingh	9	16	21	24	21	18	8
R-74	Nalitabari	7	14	18	22	19	16	7
R-75	Nandail	8	13	16	18	17	14	6
R-77	Phulpur	5	12	15	20	16	14	6
R-78	Sherpur town	6	13	16	19	17	14	6
R-101	Bhairab Bazar	8	12	16	17	15	13	6
R-102	Bholaganj	14	17	22	25	23	18	8
R-103	Brahmanbaria	9	14	17	19	17	14	7
R-104	Chandbugh	12	13	18	17	15	12	5
R-105	Chandpur Bagan	11	17	21	21	21	16	8
R-107	Chatak	14	18	22	26	22	18	8
R-108	Dakhinbagh	14	18	22	25	23	18	8
R-110	Habiganj	10	15	20	22	22	16	7
R-111	Itakhola	10	14	18	19	19	15	8
R-112	Itna	12	17	27	20	18	17	8
R-113	Khaliaghuri	9	14	17	19	18	16	7
R-114	Kamalganj	11	17	21	23	21	17	8
R-116	Lallakhal	16	18	23	26	23	19	8
R-117	Langla	13	17	21	23	21	16	7
R-118	Latu	15	17	22	26	22	18	9
R-120	Markuli	16	22	24	28	25	21	10
R-121	Mohonganj	11	17	23	26	24	20	8
R-122	Moulvi Bazar	11	16	21	23	21	17	7
R-123	Netrokona	9	15	19	29	20	16	7
R-125	Sheola	16	19	24	27	23	20	9
R-126	Srimangal	12	16	20	21	20	16	8
R-127	Sunamganj	13	19	24	27	23	19	8
R-128	Sylhet	15	20	24	27	24	20	9
R-129	Tajpur	13	17	20	23	21	16	7
R-130	Zakiganj	15	18	22	25	22	18	7
R-131	Sarail	9	14	16	17	17	14	8
R-132	Nasirnagar	10	15	18	20	19	17	8

Table A.5 Mean monsoon and annual rainfall and number of rainy days

Station code	Station name	Monsoon		Annual	
		Rainfall (mm)	Number of rainy days	Rainfall (mm)	Number of rainy Days
R-62	Dewanganj	1524	69	2253	104
R-63	Durgapur	2682	86	3660	126
R-71	Kishoreganj	1517	68	2329	106
R-73	Mymensingh	1744	84	2585	124
R-74	Nalitabari	1811	75	2600	112
R-75	Nandail	1874	65	2739	99
R-77	Phulpur	1874	65	2602	95
R-78	Sherpur town	1517	66	2196	97
R-101	Bhairab Bazar	1375	61	2171	95
R-102	Bholaganj	3976	88	5387	138
R-103	Brahmanbaria	1261	66	2103	104
R-104	Chandbugh	2078	61	3361	103
R-105	Chandpur Bagan	1357	79	2306	129
R-107	Chatak	3871	88	5315	140
R-108	Dakhinbagh	2066	88	3330	139
R-110	Habiganj	1569	79	2566	120
R-111	Itakhola	1398	71	2270	112
R-112	Itna	2161	74	3329	116
R-113	Khali ajhuri	2346	70	3380	110
R-114	Kamalganj	1492	82	2589	128
R-116	Lallakhal	4073	90	5971	147
R-117	Langla	1698	80	2839	130
R-118	Latu	2286	87	3562	142
R-120	Markuli	2374	98	3825	161
R-121	Mohonganj	2749	93	3772	137
R-122	Moulvi Bazar	1619	83	2659	129
R-123	Netrokona	2114	78	3024	118
R-125	Sheola	2722	93	4191	151
R-126	Srimangal	1439	78	2511	124
R-127	Sunamganj	4365	93	5672	144
R-128	Sylhet	2811	95	4415	154
R-129	Tajpur	2548	81	3816	129
R-130	Zakiganj	2677	86	4300	140
R-131	Sarail	1359	65	2186	105
R-132	Nasirnagar	1435	73	2374	118

Table A.6 Recorded maximum rainfall of indicated durations at selected stations

station code	Station code	Annual maximum rainfall (mm)					
		1-day	2-day	3-day	5-day	7-day	10-day
R-62	Dewanganj	336	466	610	677	759	996
R-63	Durgapur	330	508	684	784	864	983
R-71	Kishoreganj	297	515	541	596	597	658
R-73	Mymensingh	298	541	559	560	647	714
R-74	Nalitabari	355	450	450	595	746	843
R-75	Nandail	415	443	467	529	691	850
R-77	Phulpur	304	533	660	767	901	983
R-78	Sherpur town	378	452	506	530	598	702
R-101	Bhairab Bazar	292	503	533	554	561	567
R-102	Bholaganj	315	619	838	1289	1562	1754
R-103	Brahmanbaria	279	304	474	593	608	608
R-104	Chandbugh	222	392	582	867	921	977
R-105	Chandpur Bagan	296	392	415	533	632	771
R-107	Chatak	558	863	1194	1372	1570	1822
R-108	Dakhinbagh	254	444	543	724	748	833
R-110	Habiganj	269	383	448	519	615	689
R-111	Itakhola	287	397	498	556	617	651
R-112	Itna	222	337	423	654	865	1118
R-113	Khaliaghuri	585	661	845	1101	1195	1252
R-114	Kamalganj	354	438	520	685	762	920
R-116	Lallakhal	330	533	865	1054	1141	1301
R-117	Langla	294	495	636	674	744	907
R-118	Latu	280	400	487	792	1003	1064
R-120	Markuli	305	593	861	1102	1182	1259
R-121	Mohonganj	280	435	597	740	819	895
R-122	Moulvi Bazar	245	418	548	592	756	785
R-123	Netrokona	267	462	513	708	838	878
R-125	Sheola	507	702	743	928	1009	1114
R-126	Srimangal	532	606	664	771	862	940
R-127	Sunamganj	383	650	777	914	1005	1393
R-128	Sylhet	436	579	638	826	1009	1187
R-129	Tajpur	310	497	720	924	1105	1530
R-130	Zakiganj	374	622	784	945	1061	1174
R-131	Sarail	302	376	395	535	598	613
R-132	Nasirnagar	205	304	394	495	567	789



Figure B.1 Distribution of mean monthly rainfall (mm) for April

APPENDIX B

Figures Relating Spatial and Temporal Distributions of Rainfall and Number of Rainy Days



Figure B.2 Distribution of mean monthly rainfall (mm) for May

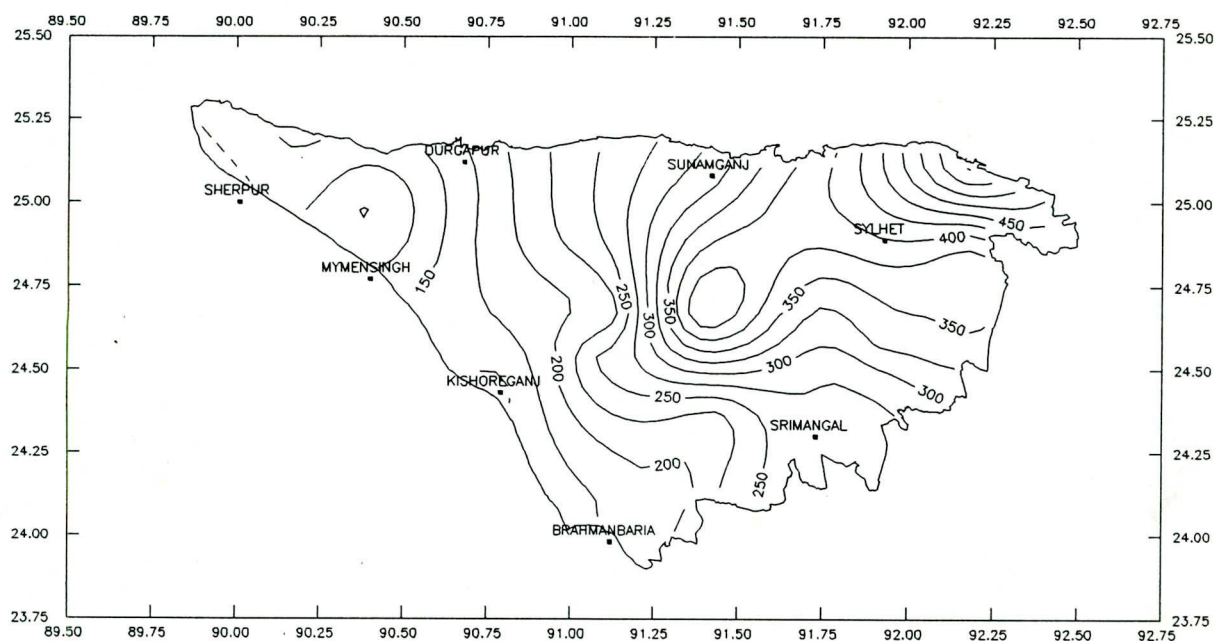


Figure B.1 Distribution of mean monthly rainfall (mm) for April.

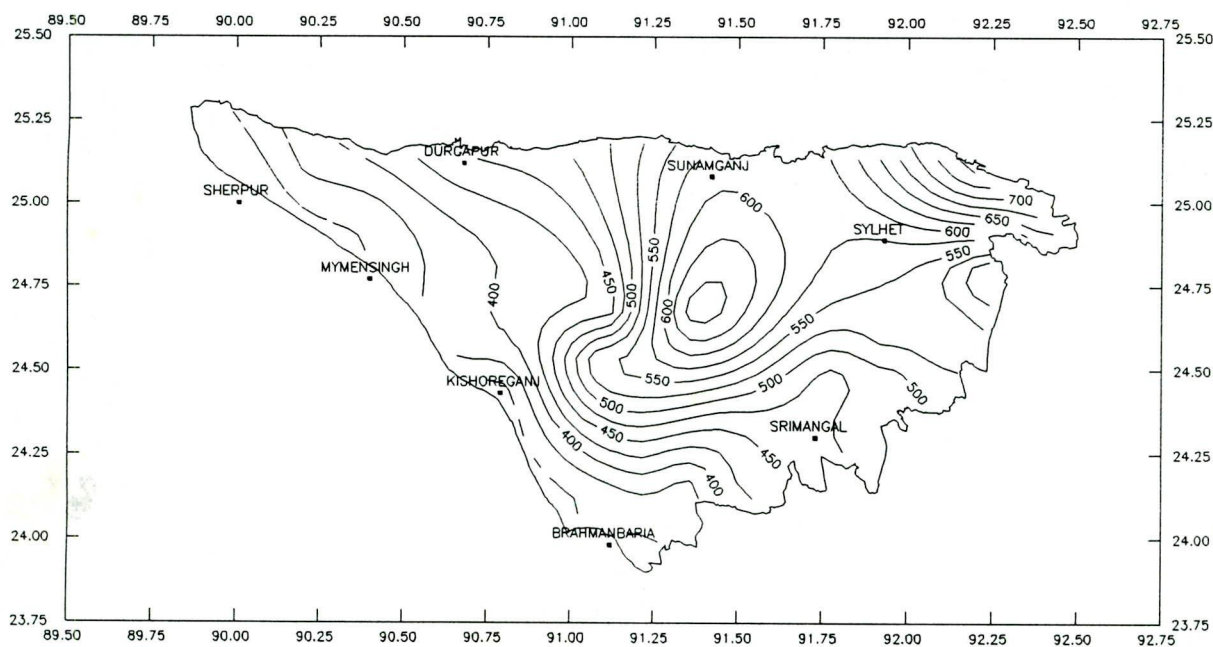


Figure B.2 Distribution of mean monthly rainfall (mm) for May.

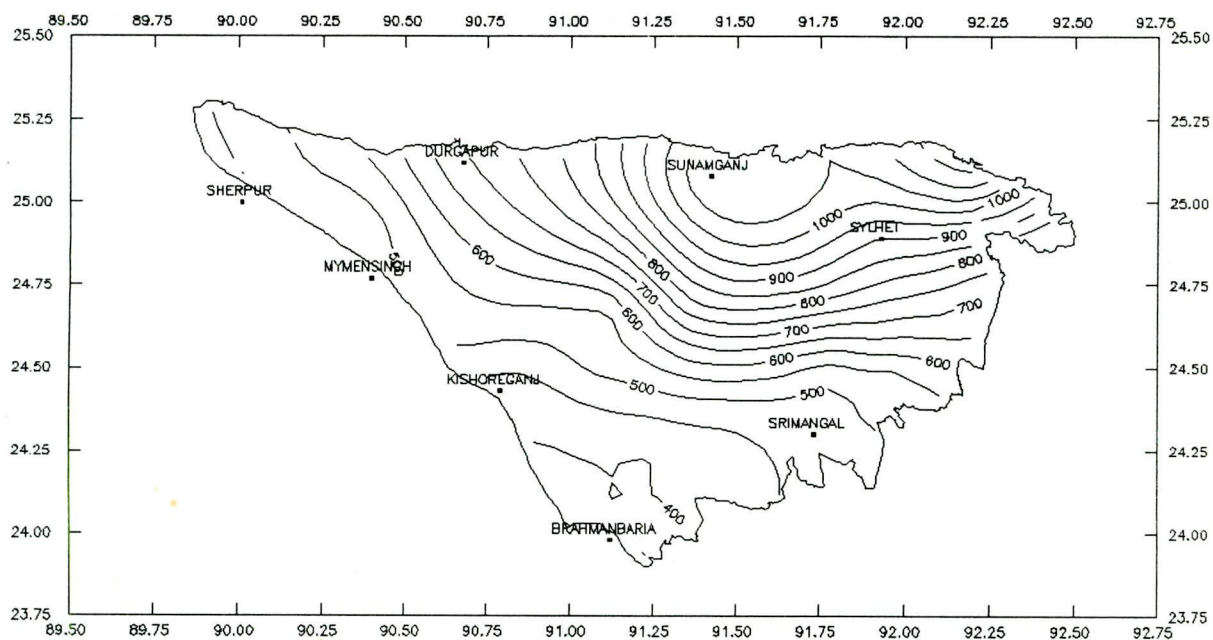


Figure B.3 Distribution of mean monthly rainfall (mm) for June.

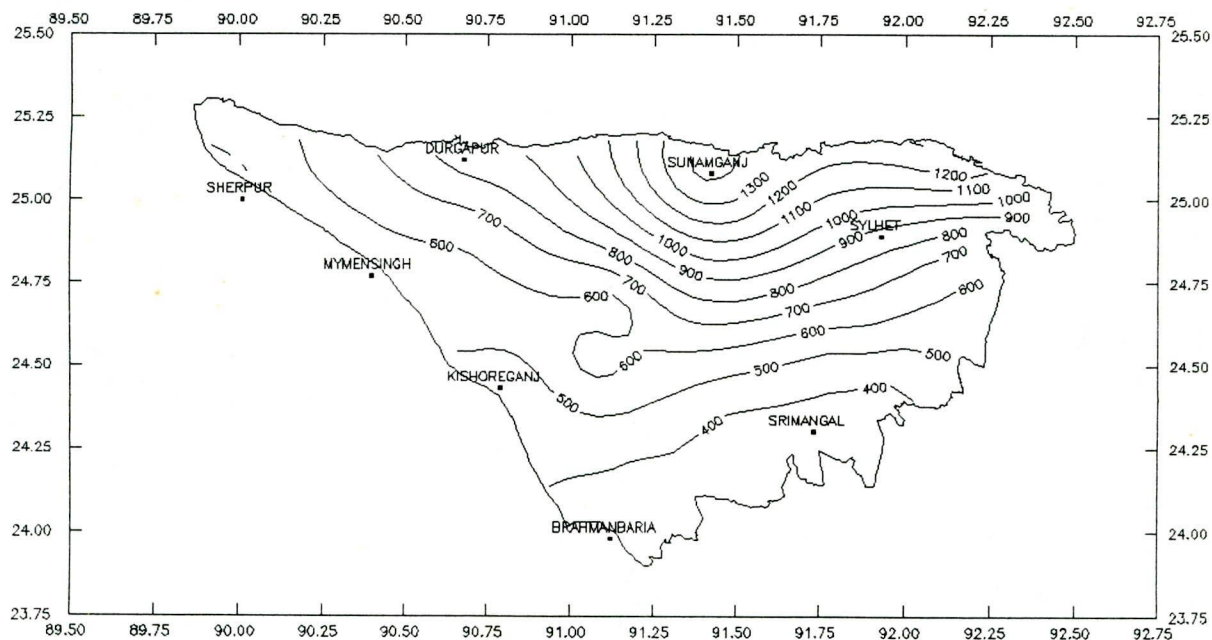


Figure B.4 Distribution of mean monthly rainfall (mm) for July.

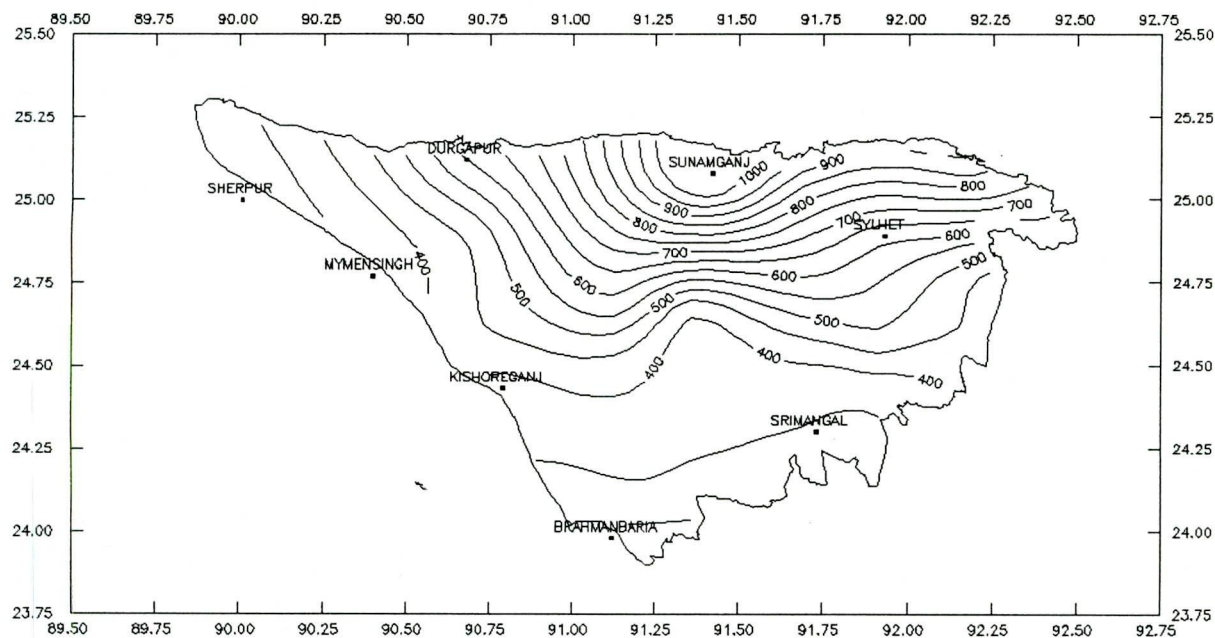


Figure B.5 Distribution of mean monthly rainfall (mm) for August.

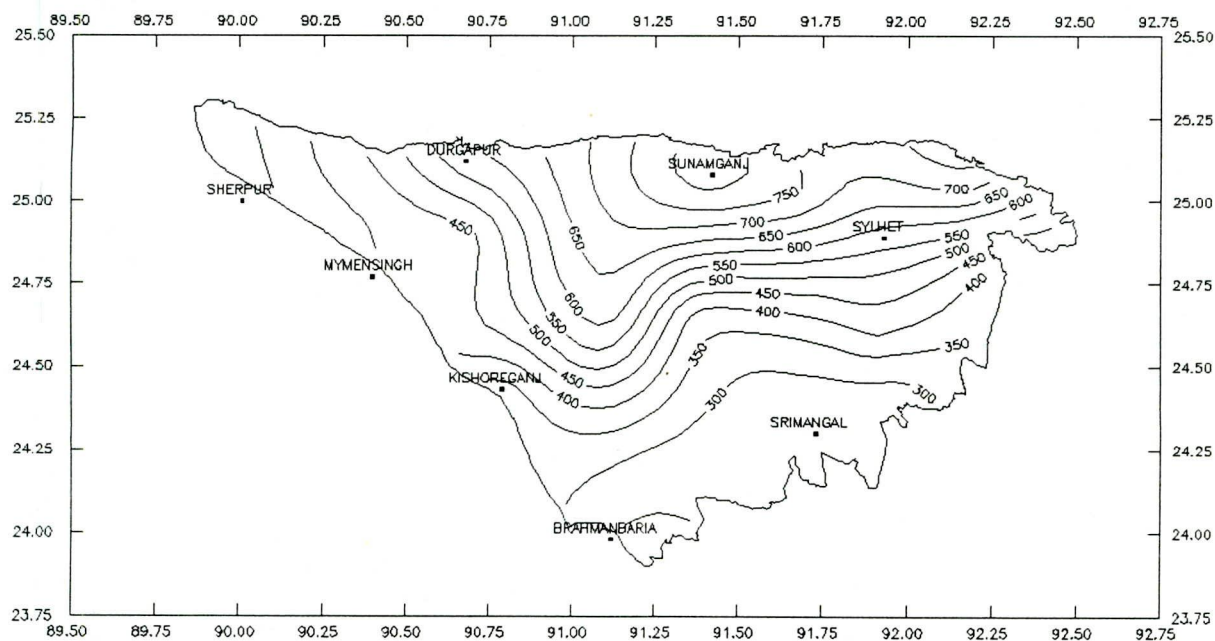


Figure B.6 Distribution of mean monthly rainfall (mm) for September.

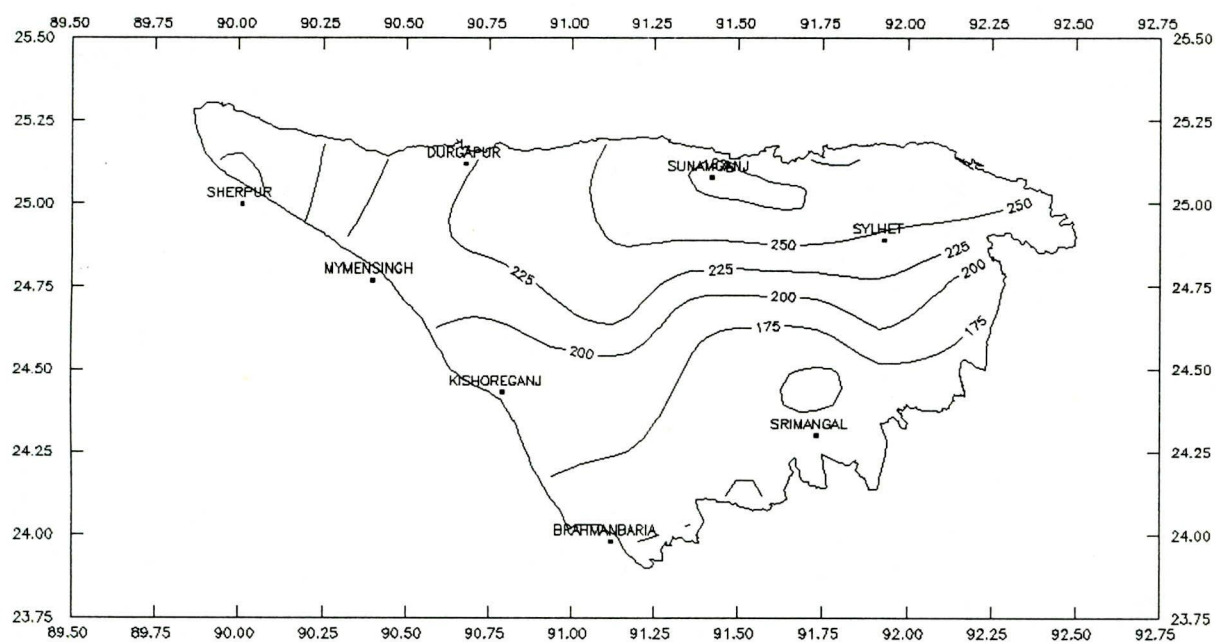


Figure B.7 Distribution of mean monthly rainfall (mm) for October.

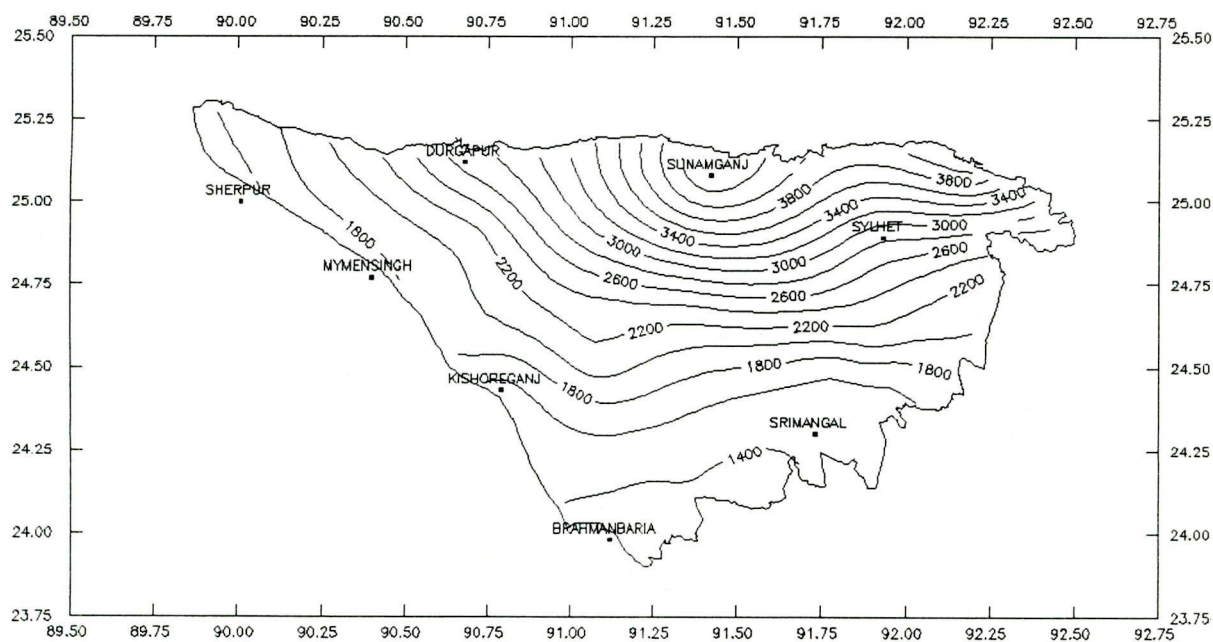


Figure B.8 Distribution of mean monsoon rainfall (mm).

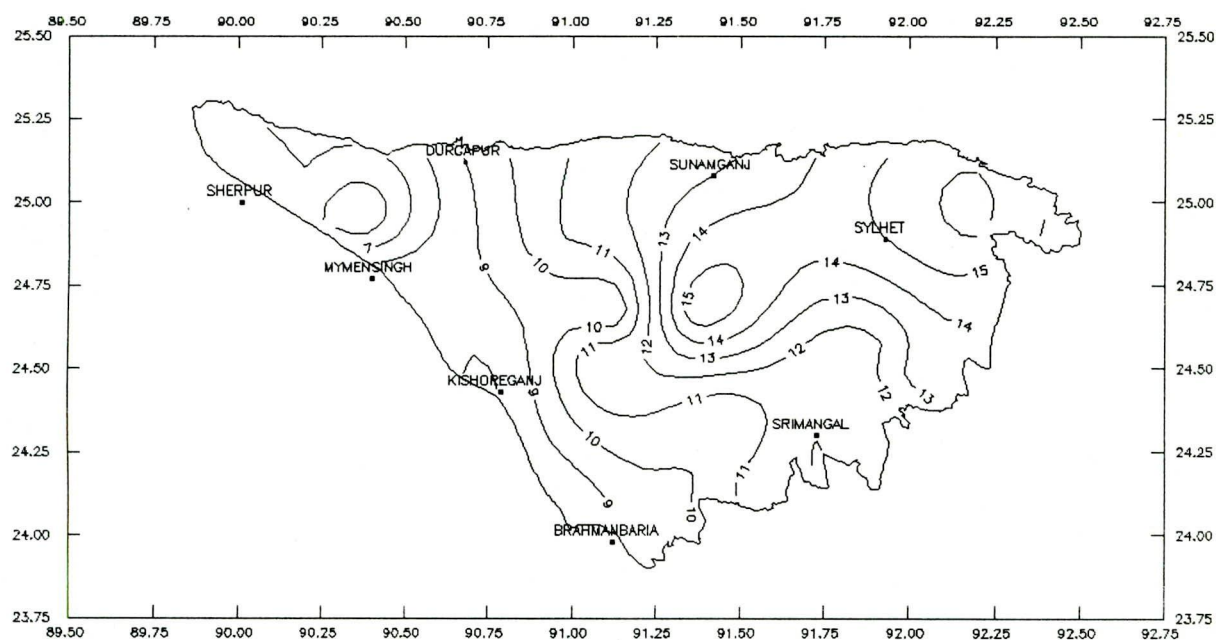


Figure B.9 Distribution of mean monthly number of rainy days for April.

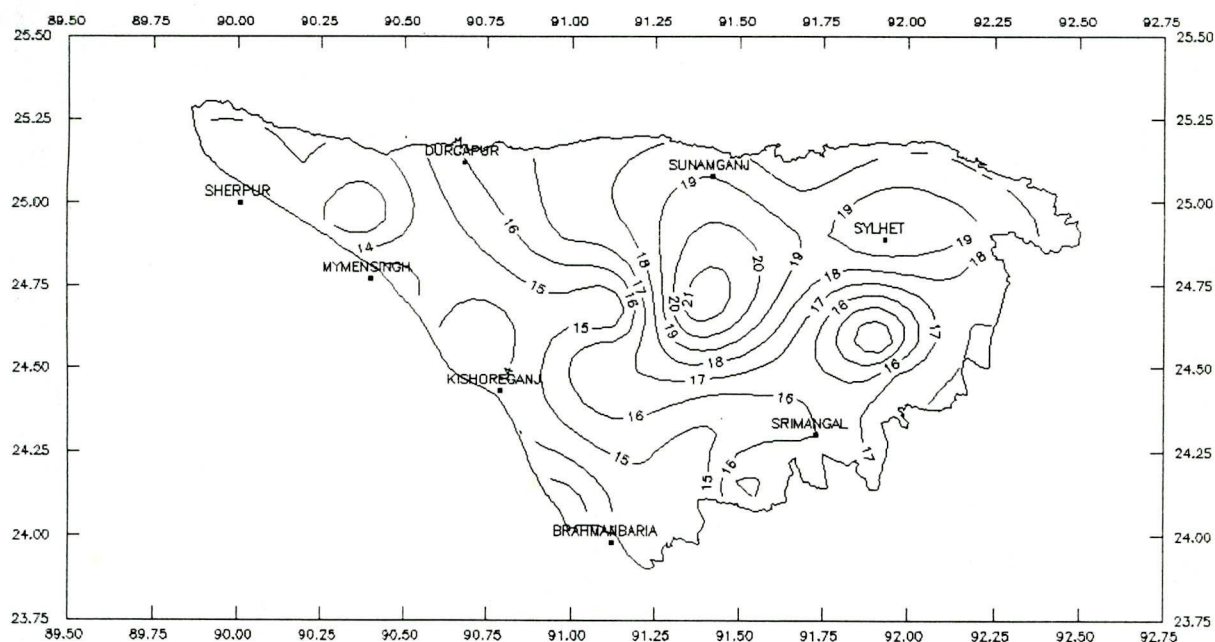


Figure B.10 Distribution of mean monthly number of rainy days for May.

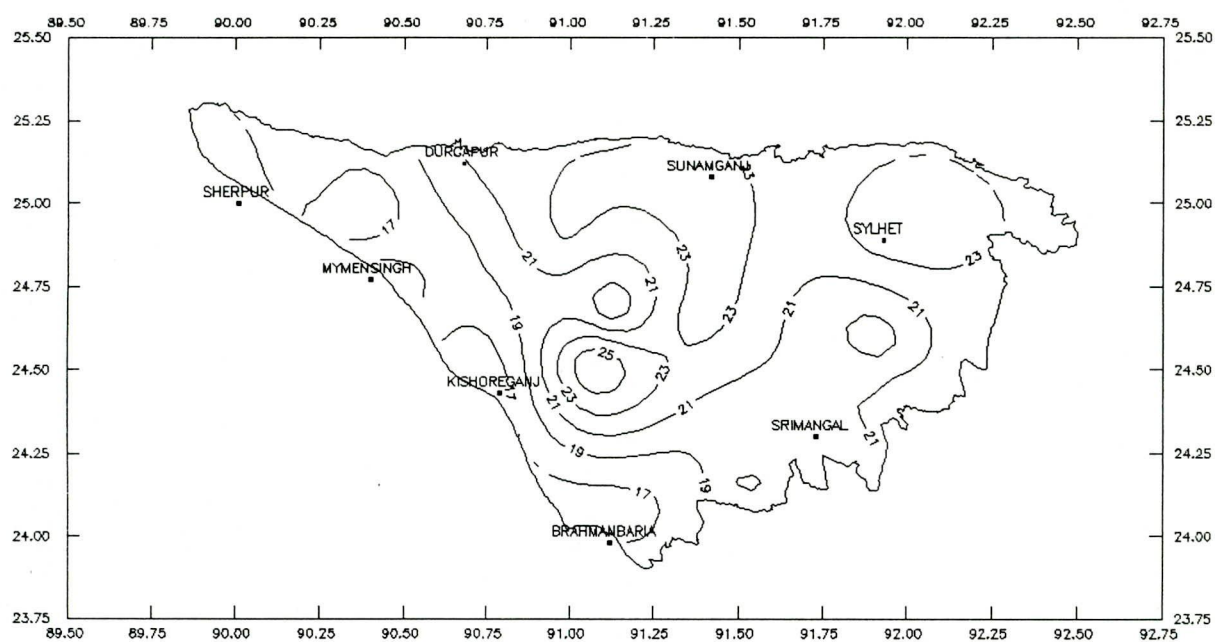


Figure B.11 Distribution of mean monthly number of rainy days for June.

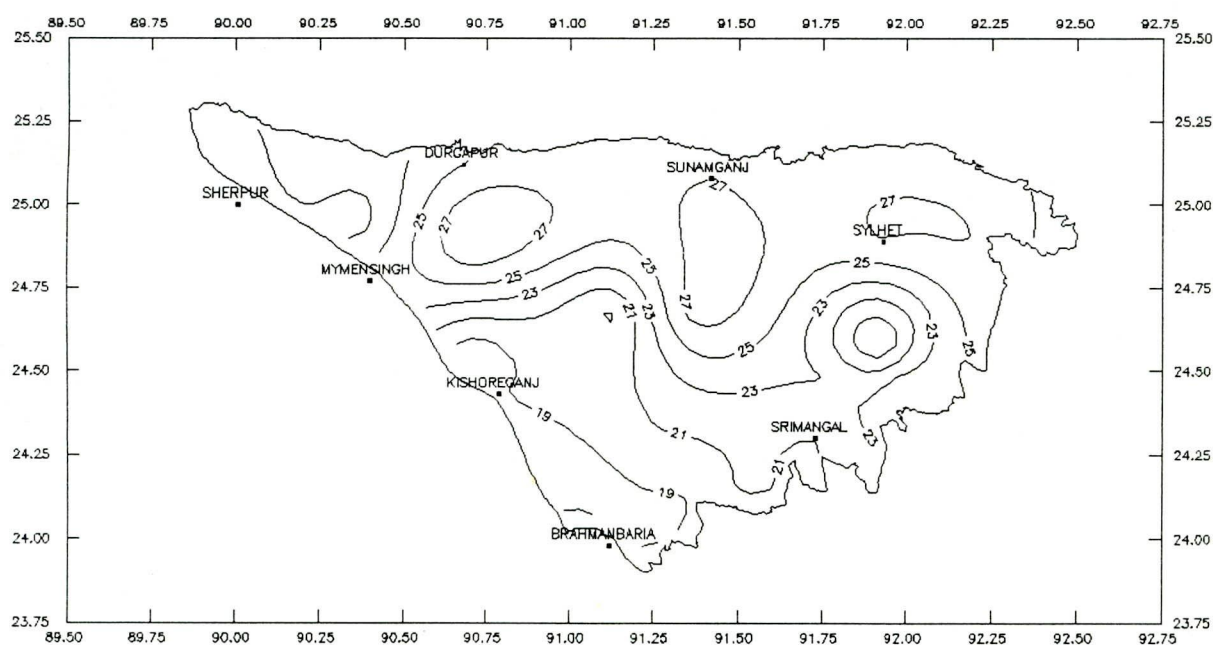


Figure B.12 Distribution of mean monthly number of rainy days for July.

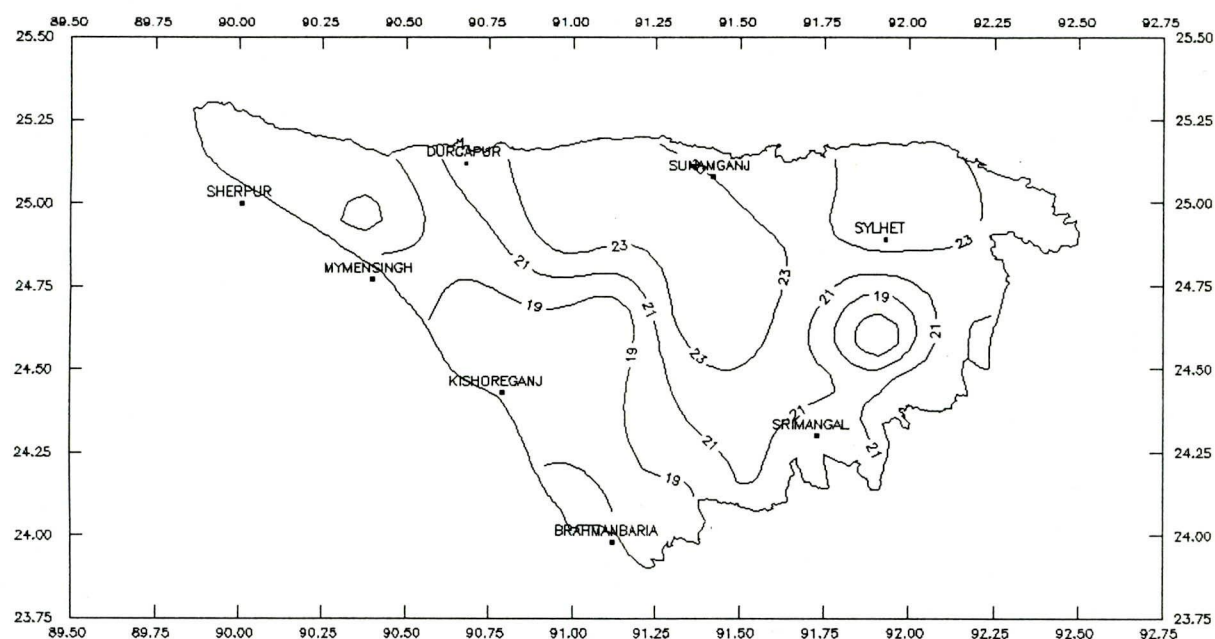


Figure B.13 Distribution of mean monthly number of rainy days for August.

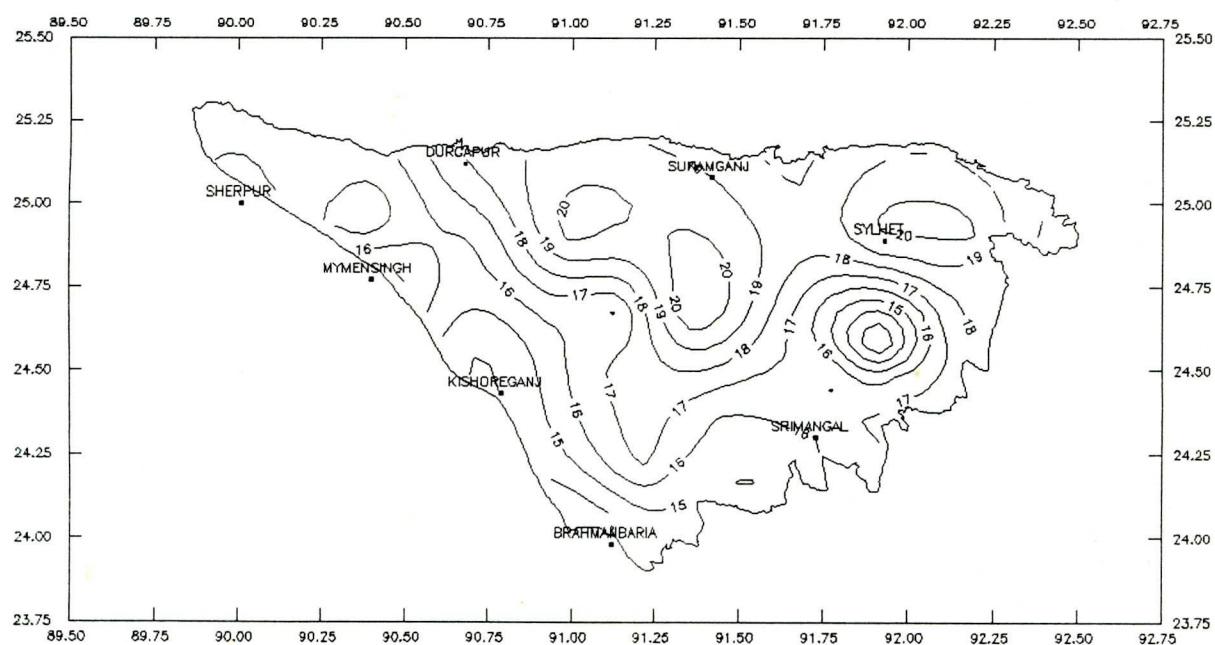


Figure B.14 Distribution of mean monthly number of rainy days for September.

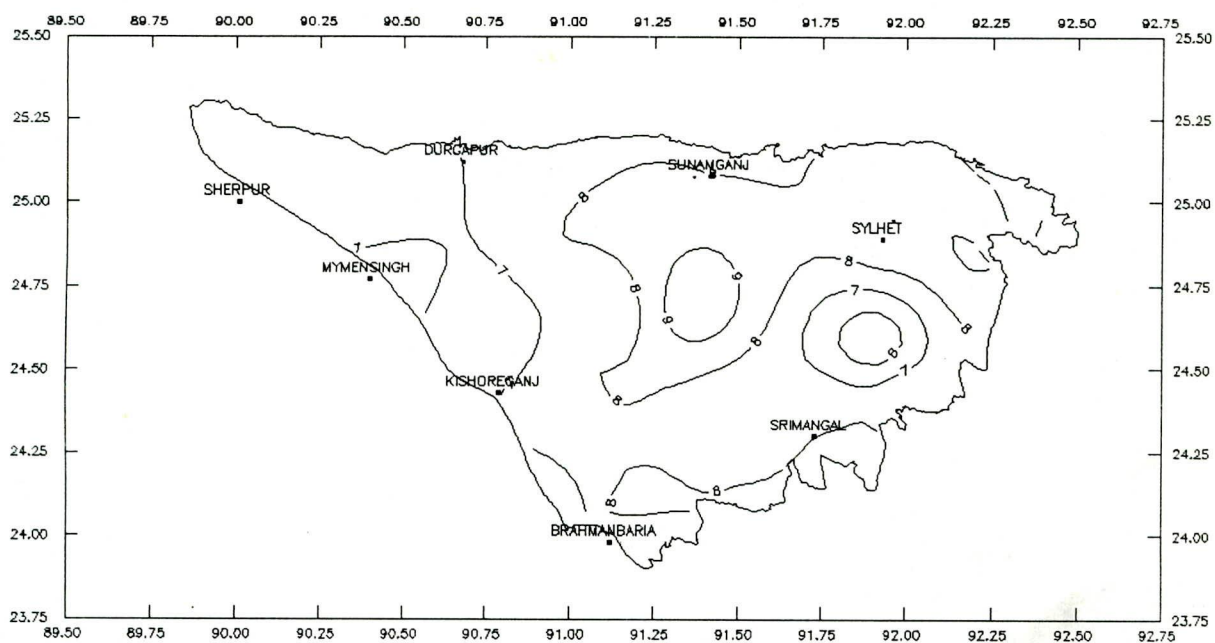


Figure B.15 Distribution of mean monthly number of rainy days for October.

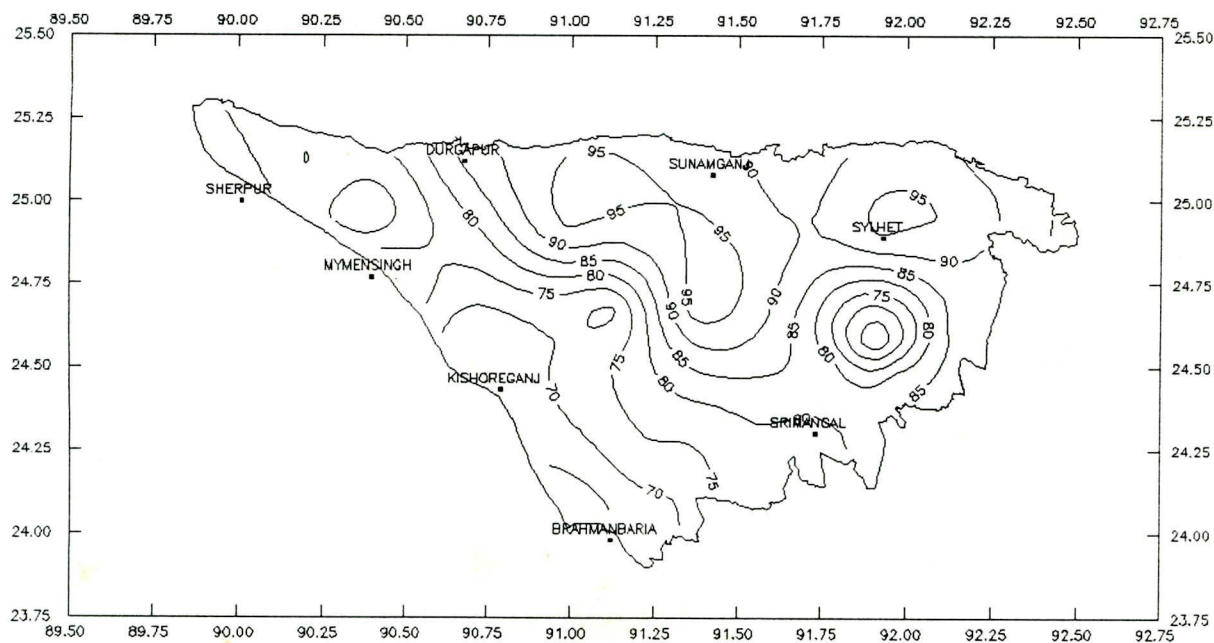


Figure B.16 Distribution of mean number of rainy days for monsoon.

APPENDIX C

Figures and Tables Relating Fitting Probability Distributions to Rainfall and Number of Rainy days

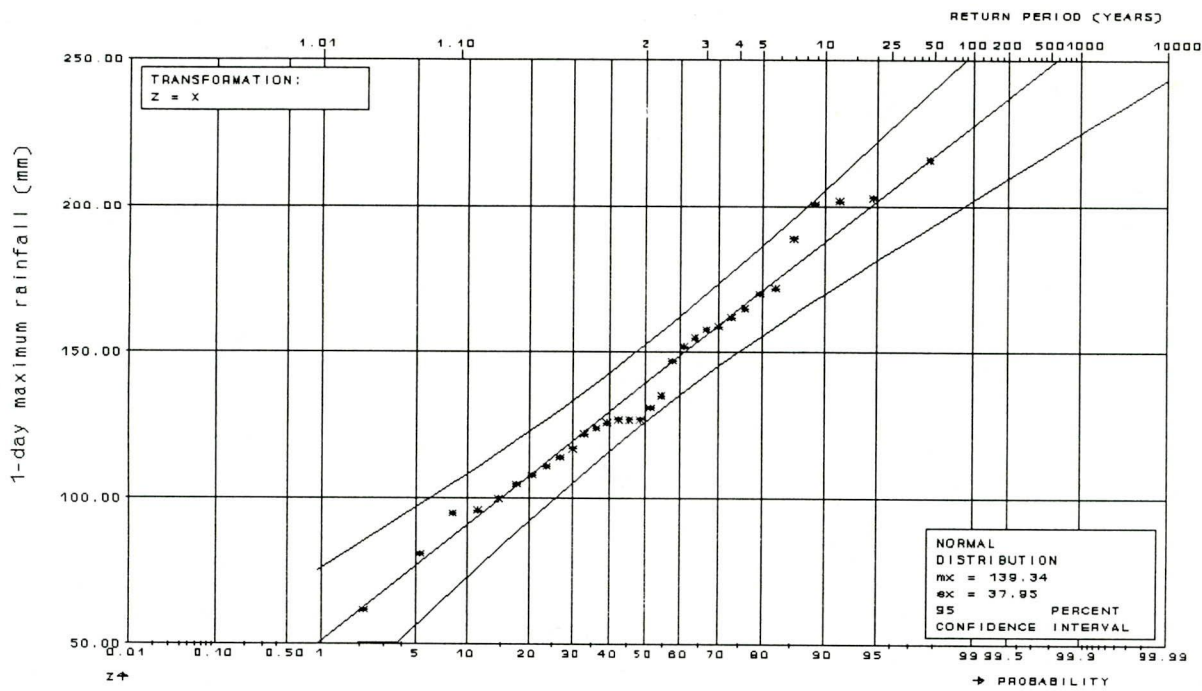


Figure C.1a Normal probability plot of 1-day maximum rainfall at Srimangal.

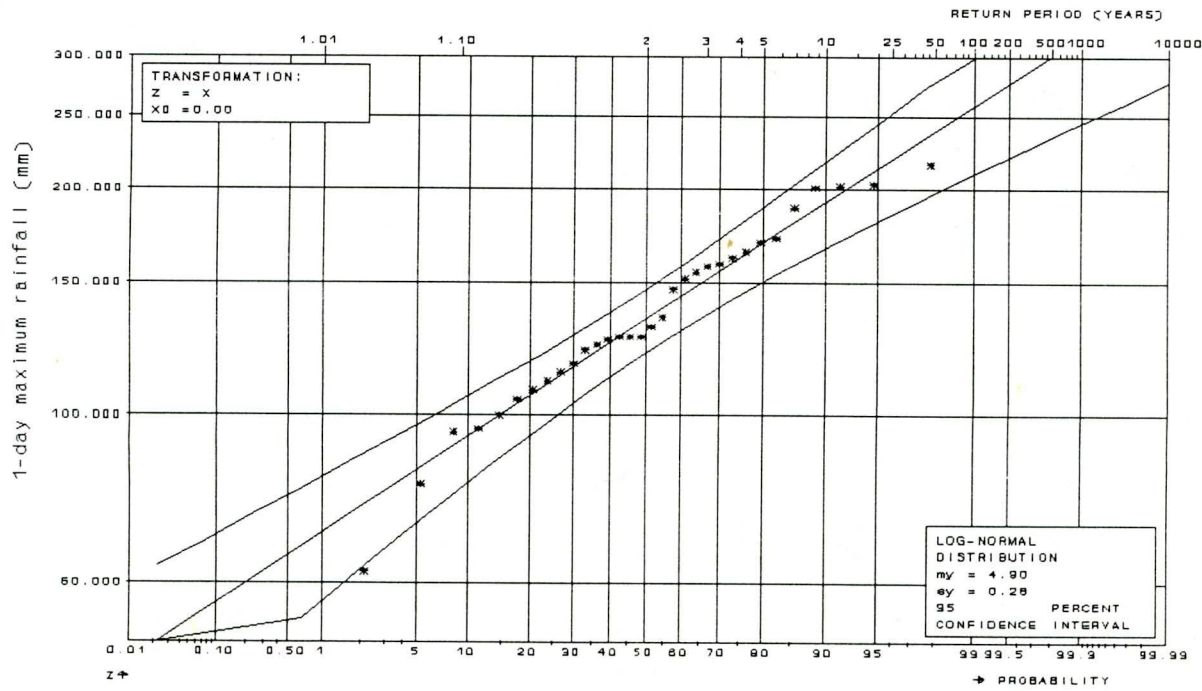


Figure C.1b Lognormal probability plot of 1-day maximum rainfall at Srimangal.

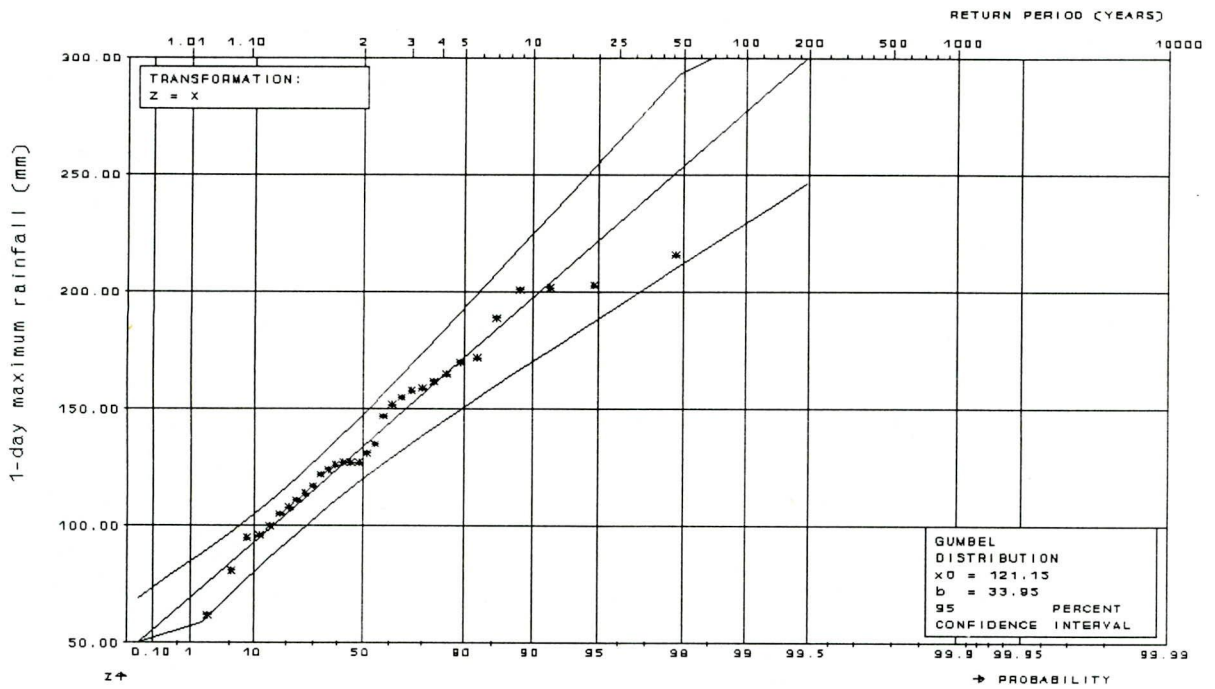


Figure C.1c Gumbel probability plot of 1-day maximum rainfall at Srimangal.

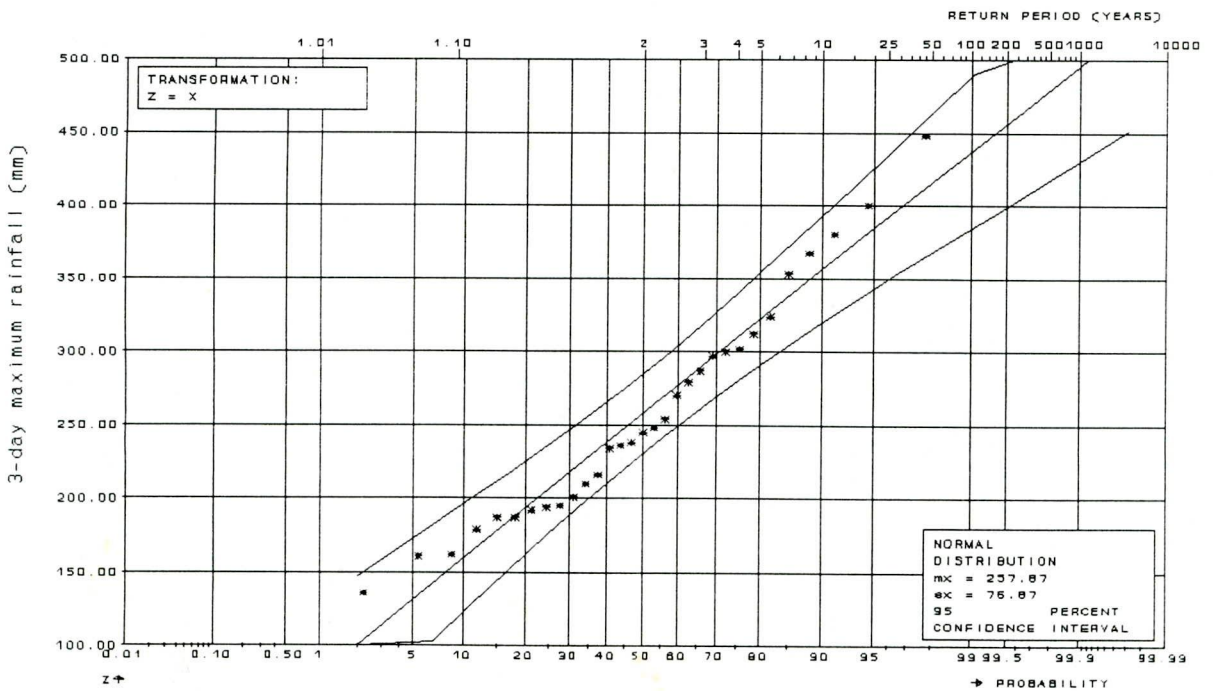


Figure C.2a Normal probability plot of 3-day maximum rainfall at Habiganj.

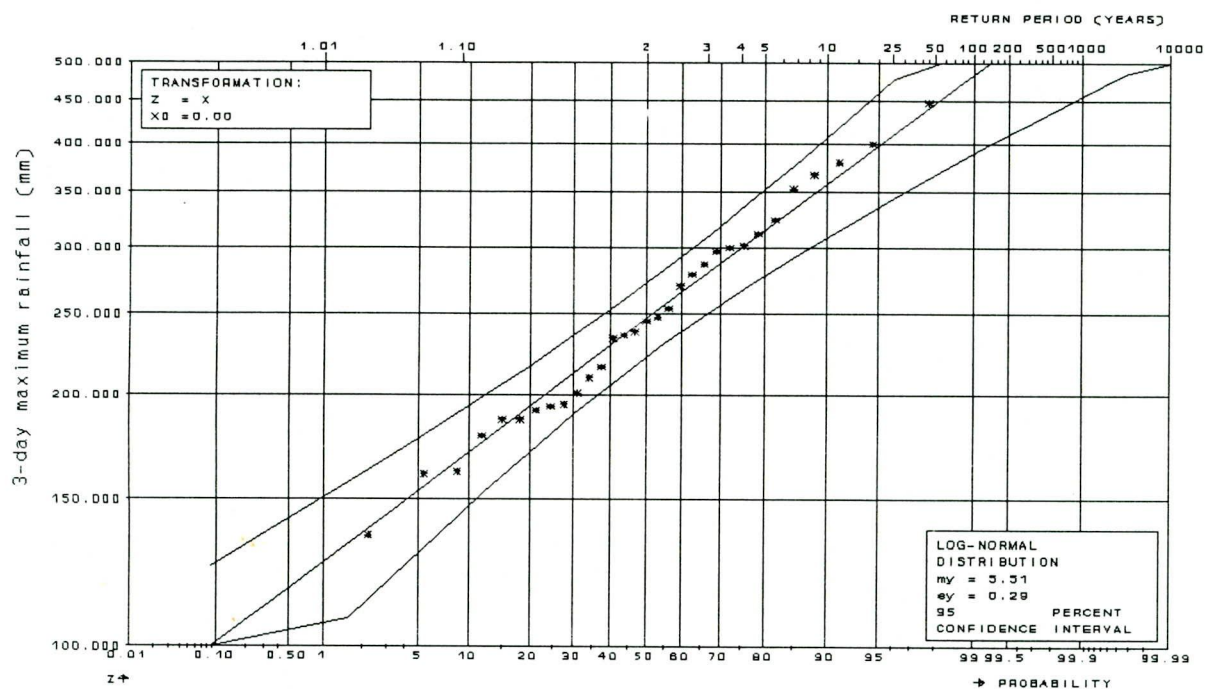


Figure C.2b Lognormal probability plot of 3-day maximum rainfall at Habiganj.

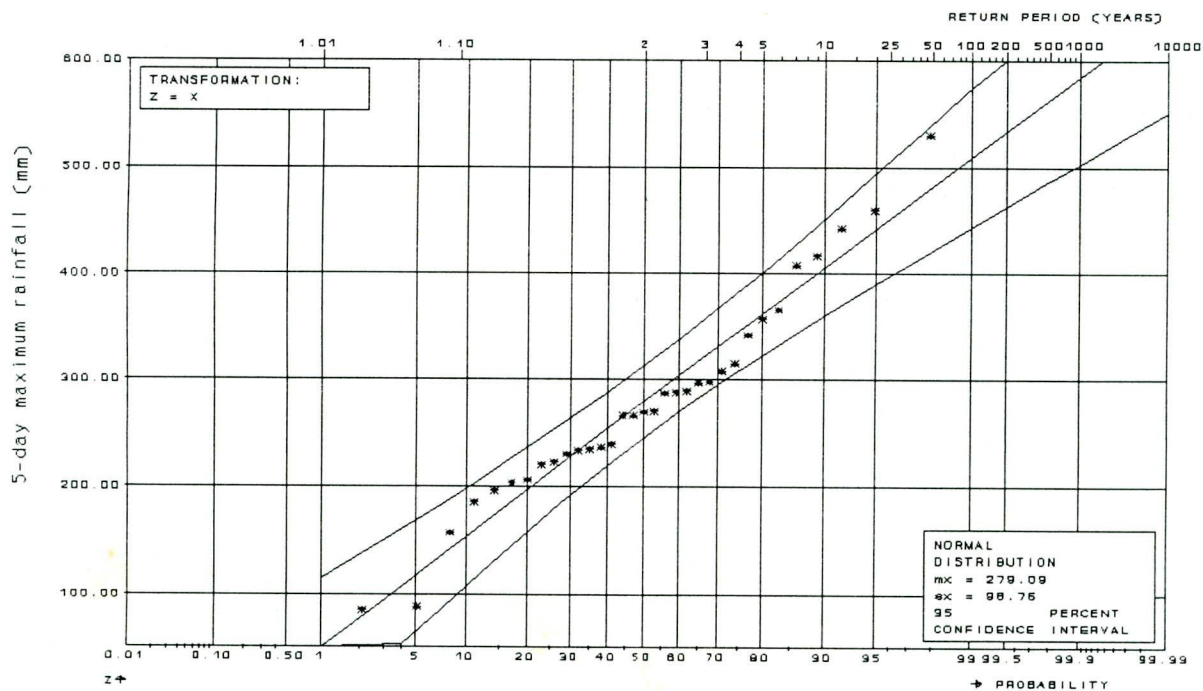


Figure C.3a Normal probability plot of 5-day maximum rainfall at Sherpur.

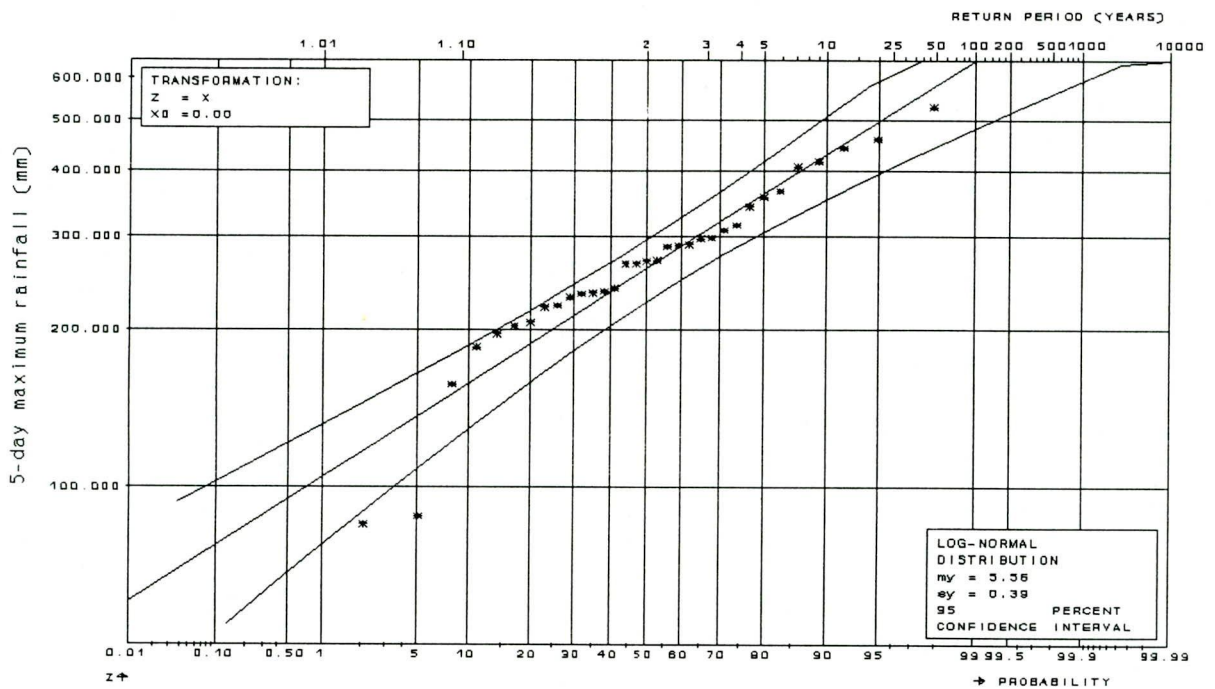


Figure C.3b Lognormal probability plot of 5-day maximum rainfall at Sherpur.

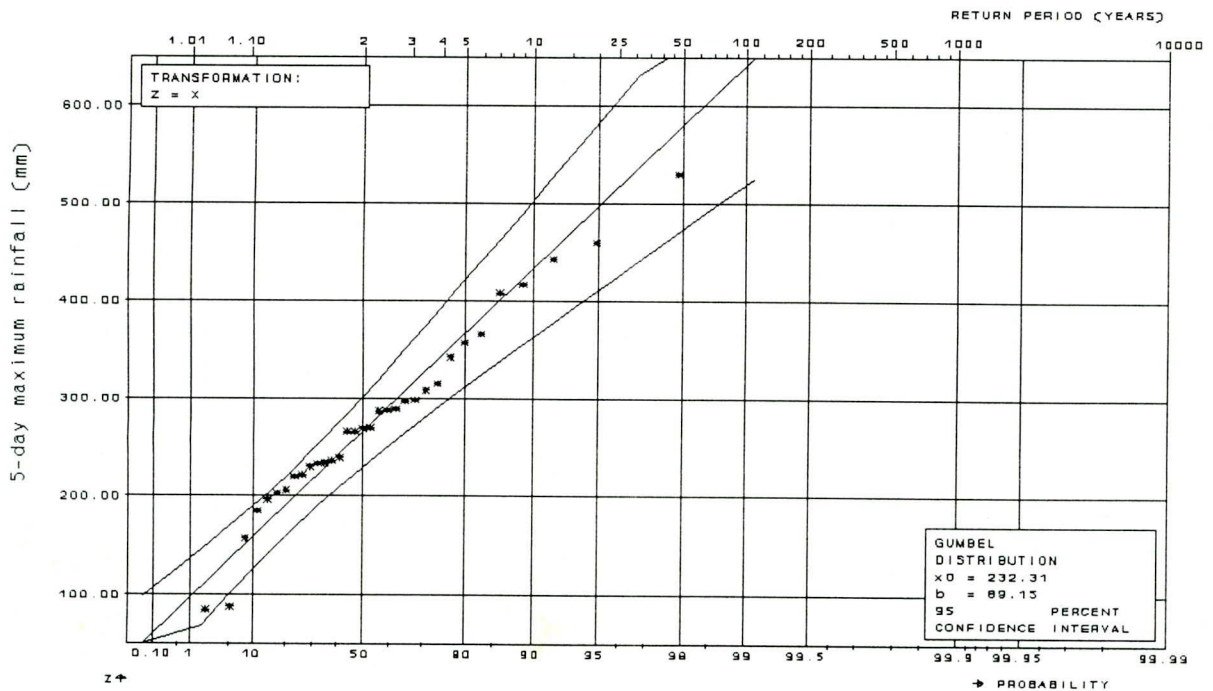


Figure C.3c Gumbel probability plot of 5-day maximum rainfall at Sherpur.

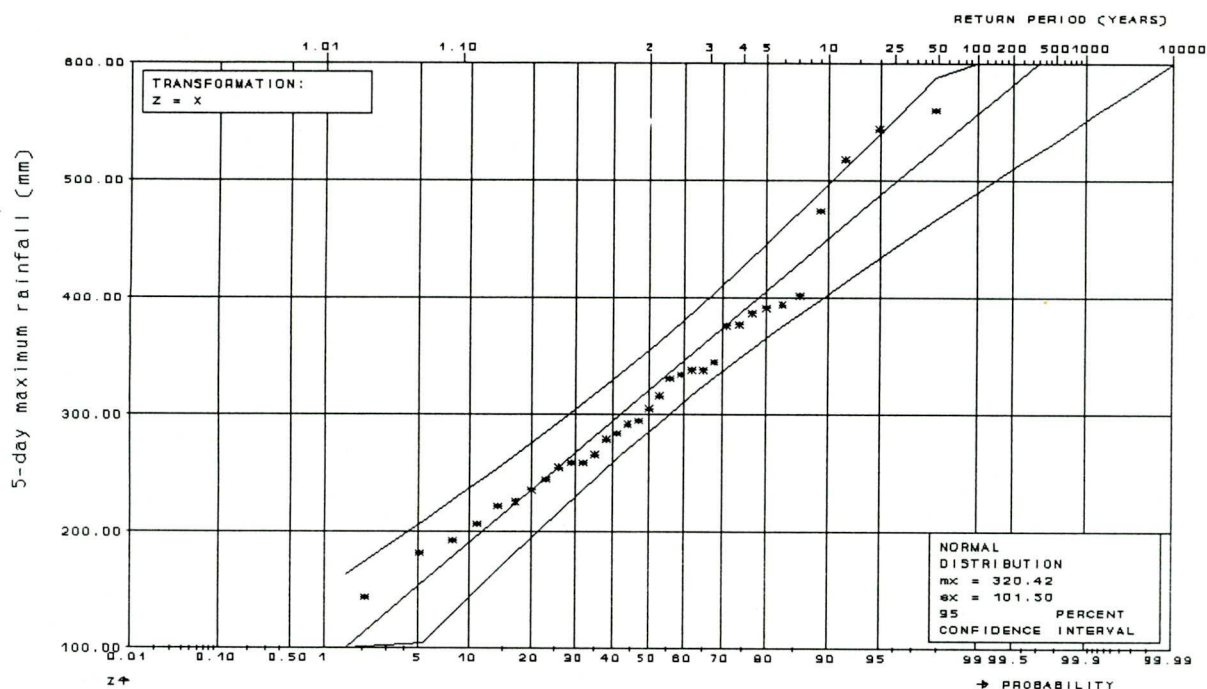


Figure C.4a Normal probability plot of 5-day maximum rainfall at Mymensingh.

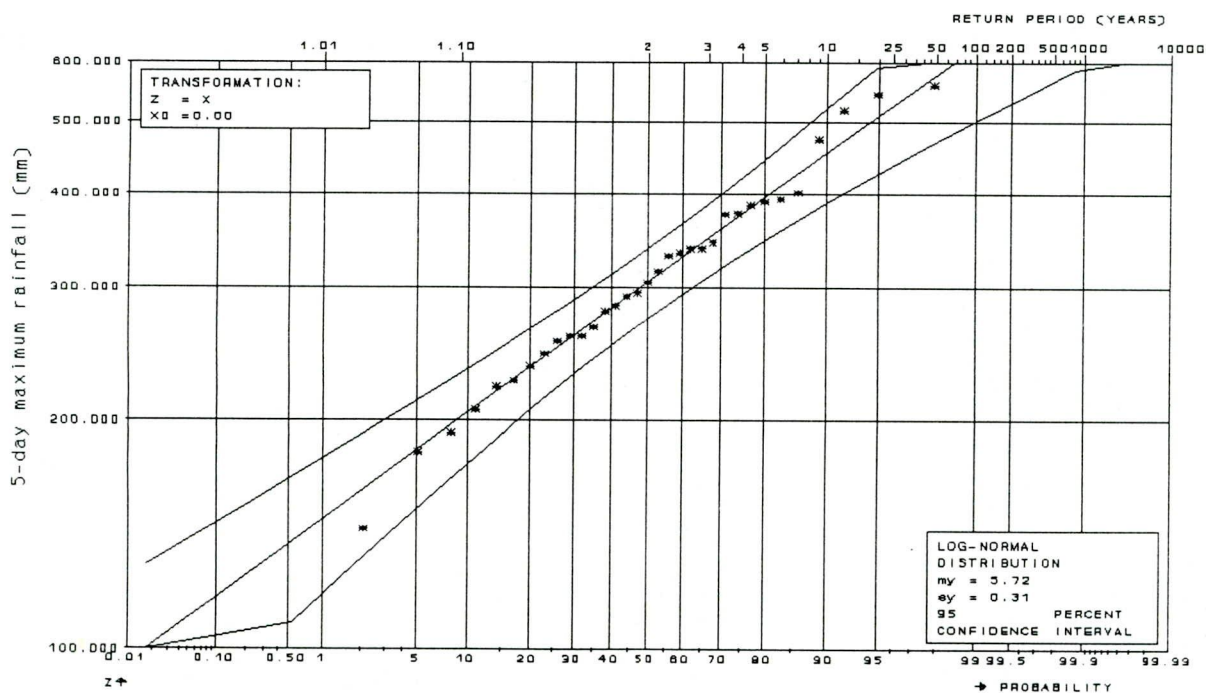


Figure C.4b Lognormal probability plot of 5-day maximum rainfall at Mymensingh.

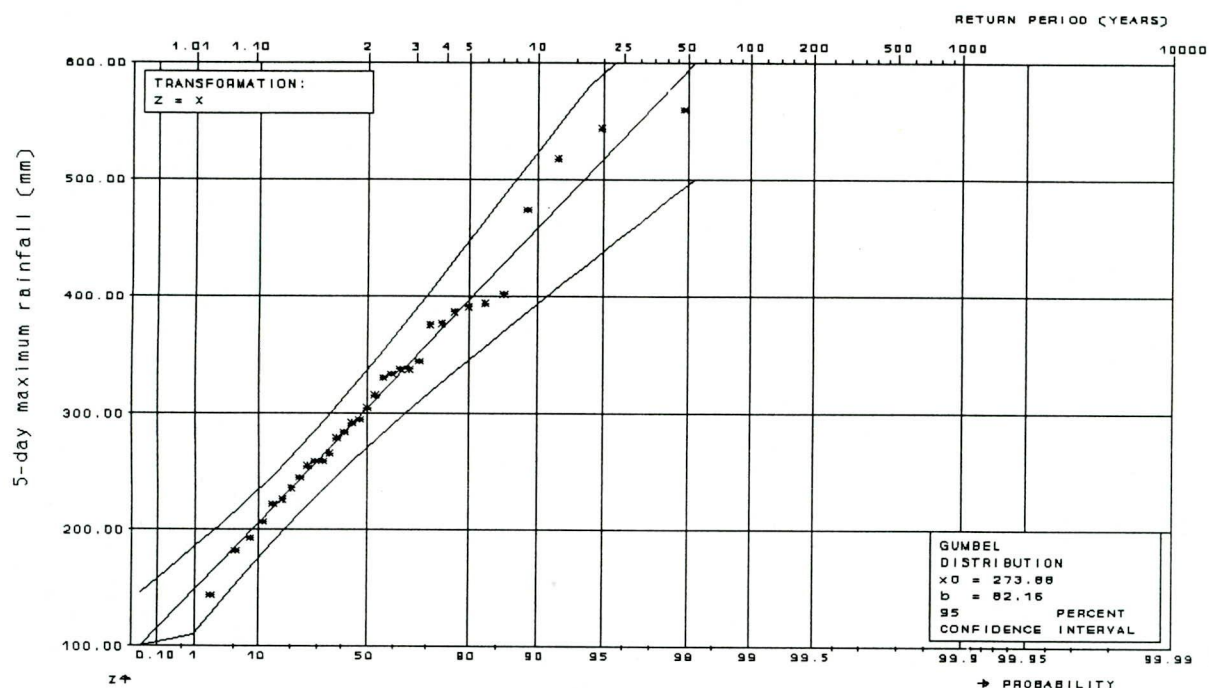


Figure C.4c Gumbel probability plot of 5-day maximum rainfall at Mymensingh.

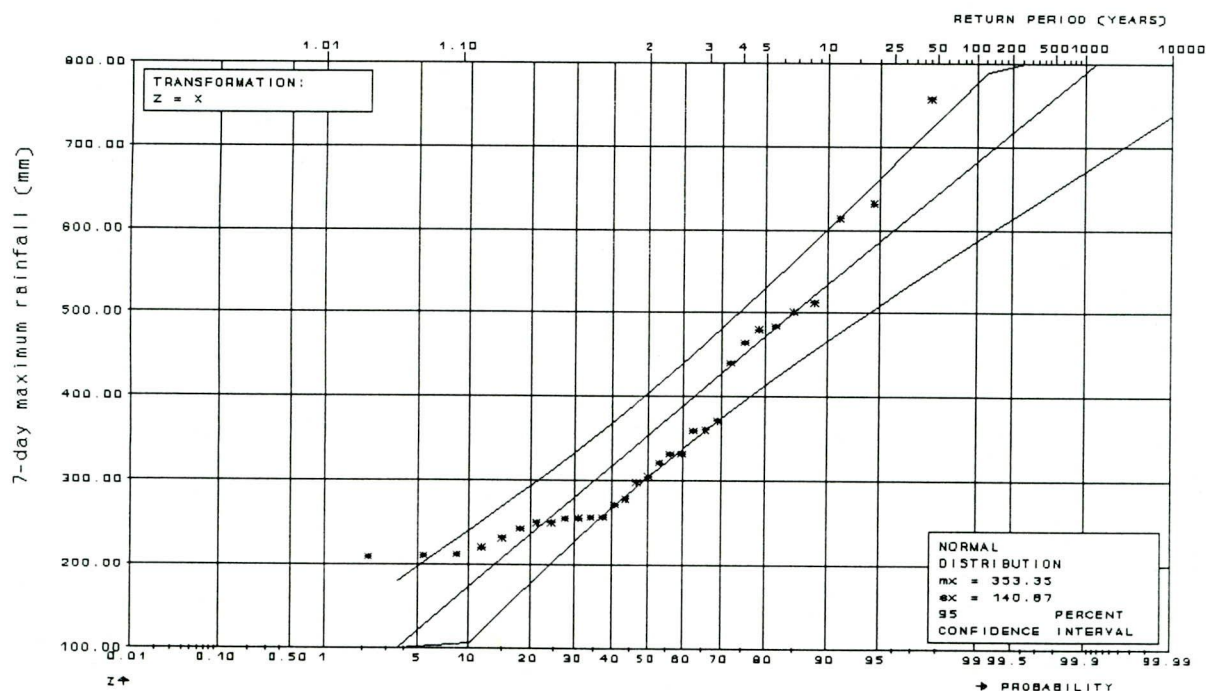


Figure C.5a Normal probability plot of 7-day maximum rainfall at Moulvi Bazar.

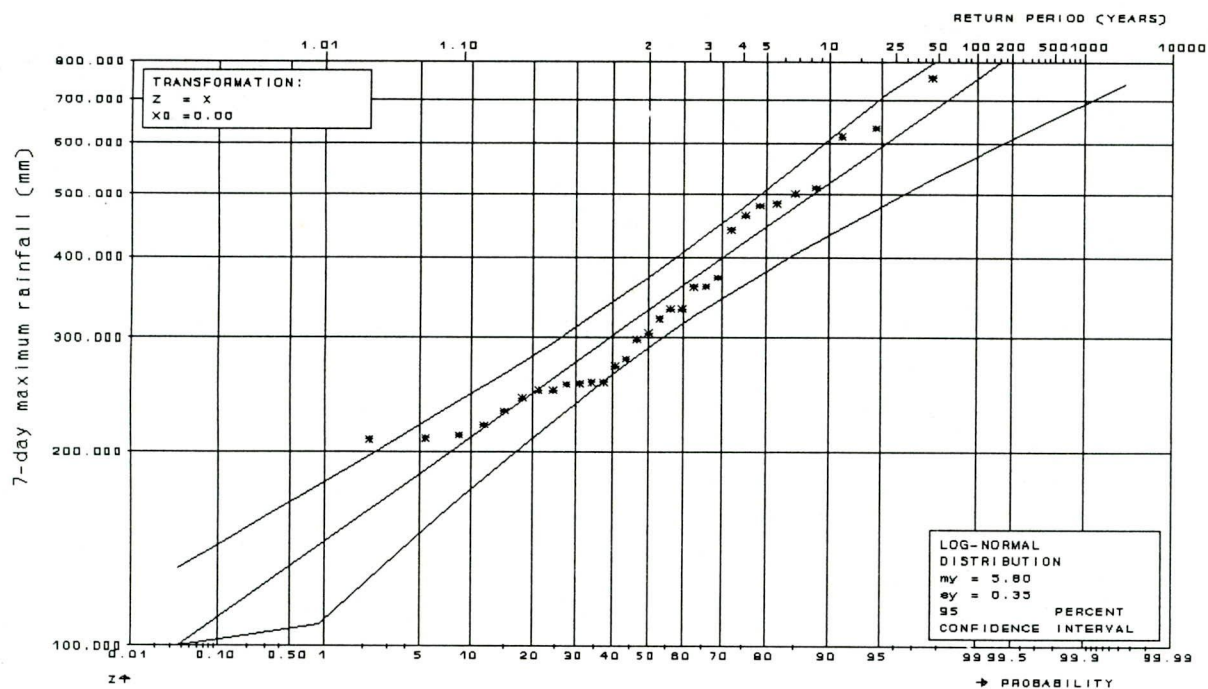


Figure C.5b Lognormal probability plot of 7-day maximum rainfall at Moulvi Bazar.

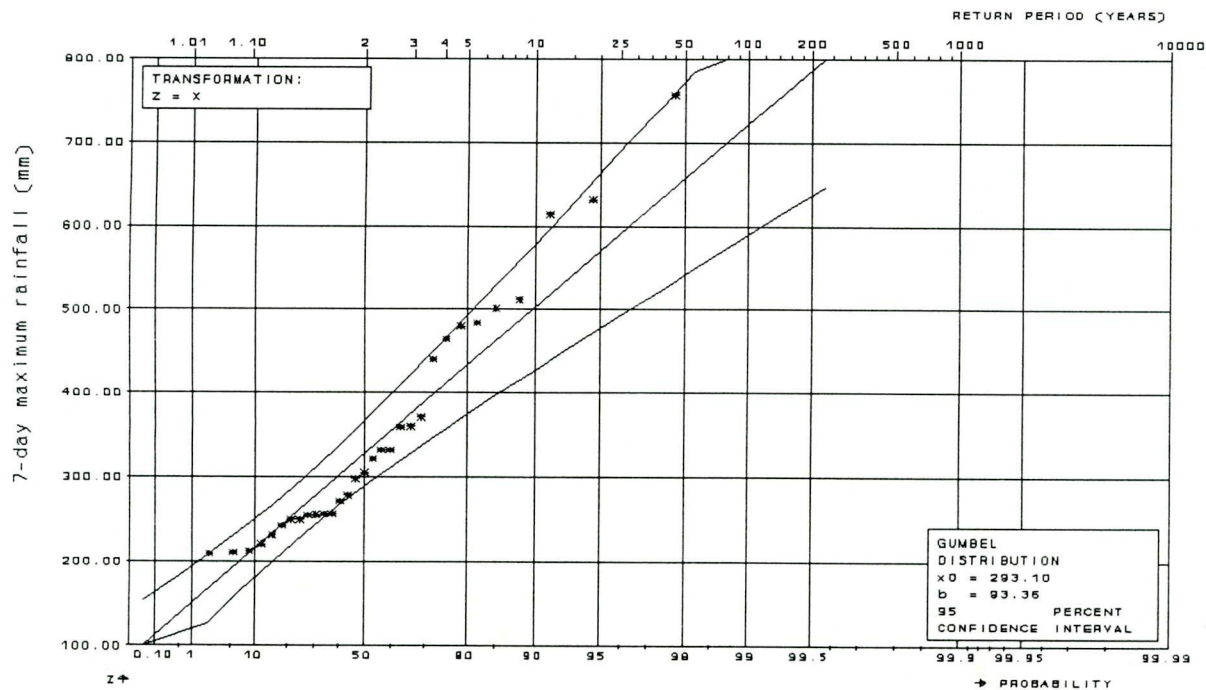


Figure C.5c Gumbel probability plot of 7-day maximum rainfall at Moulvi Bazar.

Table C.1 Results of χ^2 -test on maximum rainfall values of different durations at some selected stations

Raingauge station	Duration	Probability distribution		
		Normal	Lognormal	Gumbel
R-63 Durgapur	1-day	8.000	4.471	3.412
R-71 Kishoreganj	1-day	5.236	9.568	7.646
R-78 Sherpur Town	1-day	3.365	0.609	1.837
R-102 Bholaganj	1-day	5.326	3.871	2.198
R-103 Brahmanbaria	1-day	8.267	6.393	1.949
R-110 Habiganj	1-day	3.856	6.707	4.165
R-125 Sheola	1-day	6.687	12.442	4.836
R-126 Srimangal	1-day	1.750	4.000	4.000
R-128 Sylhet	1-day	9.265	12.06	5.740
R-103 Brahmanbaria	2-day	2.484	2.484	5.968
R-110 Habiganj	2-day	2.484	2.097	0.935
R-125 sheola	2-day	13.323	1.710	6.903
R-127 Sunamganj	2-day	4.471	2.706	4.824
R-63 Durgapur	3-day	0.235	0.941	2.353
R-103 Brahmanbaria	3-day	2.484	3.387	3.645
R-110 Habiganj	3-day	2.871	2.484	2.097
R-125 Sheola	3-day	9.839	6.742	6.742
R-127 Sunamganj	3-day	4.118	2.706	2.353
R-128 Sylhet	3-day	5.882	6.941	7.647
R-73 Mymensingh	5-day	1.000	1.727	1.364
R-78 Sherpur Town	5-day	5.128	5.503	5.879
R-103 Brahmanbaria	5-day	0.548	3.258	2.097
R-125 Sheola	5-day	13.710	4.806	3.645
R-127 Sunamganj	5-day	5.882	5.529	2.000
R-128 Sylhet	5-day	7.270	5.973	2.081
R-103 Brahmanbaria	7-day	2.097	3.258	3.258
R-122 Moulavi Bazar	7-day	8.677	8.672	7.672
R-126 Srimangal	7-day	1.000	4.636	3.908
R-128 Sylhet	7-day	5.000	6.946	4.351
R-103 Brahmanbaria	10-day	2.484	10.226	0.548
R-127 Sunamganj	10-day	3.765	11.882	6.235

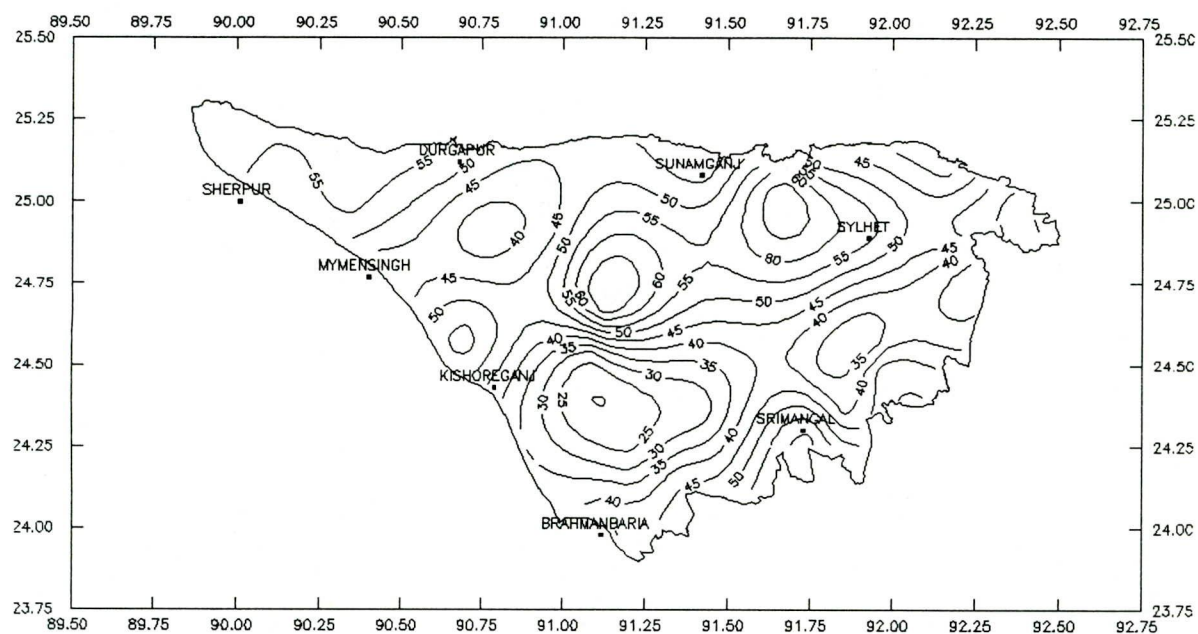


Figure C.6a Distribution of Gumbel Parameter β (Scale) for 1-day maximum rainfall.

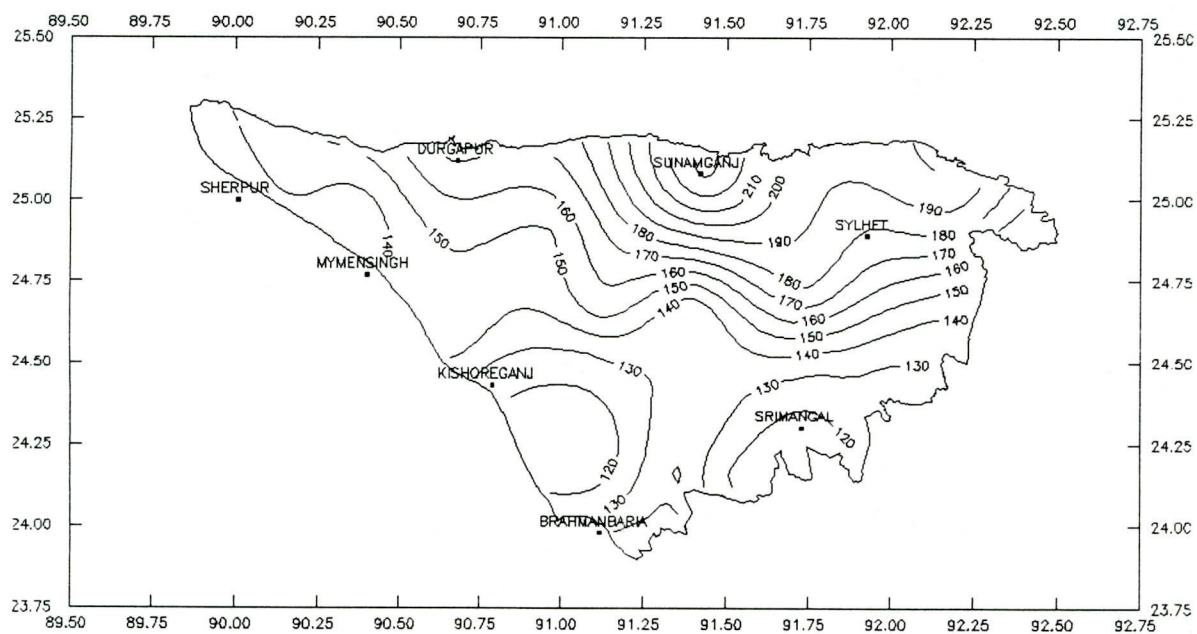


Figure C.6b Distribution of Gumbel parameter X_0 (location) for 1-day maximum rainfall.

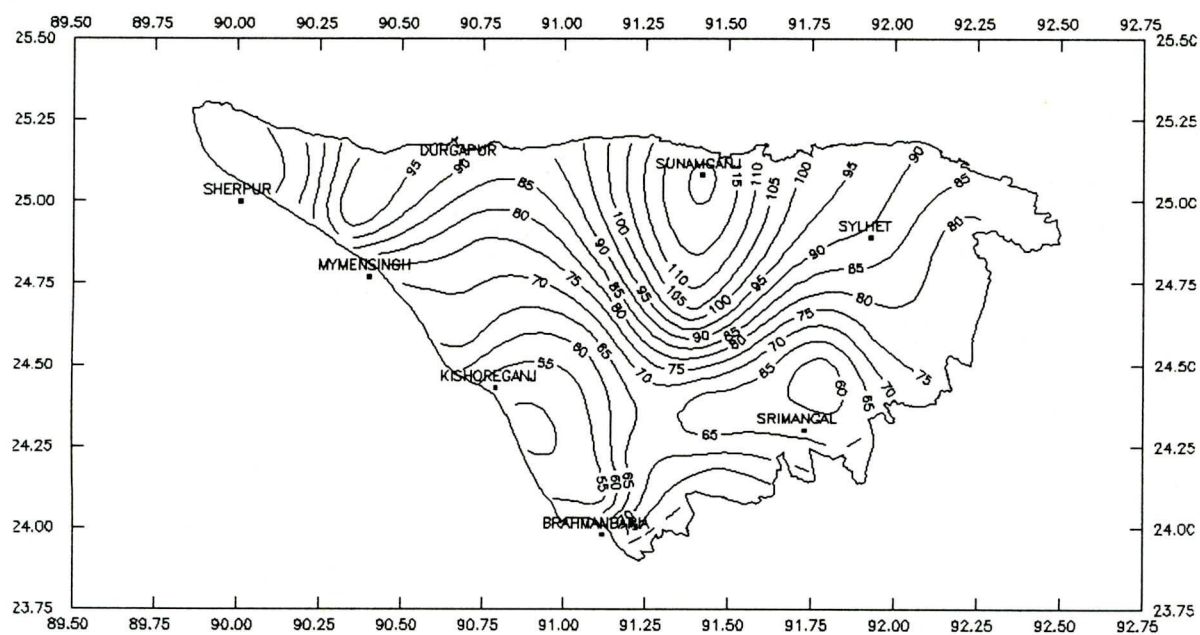


Figure C.7a Distribution of Gumbel parameter β (scale) for 3-day maximum rainfall.

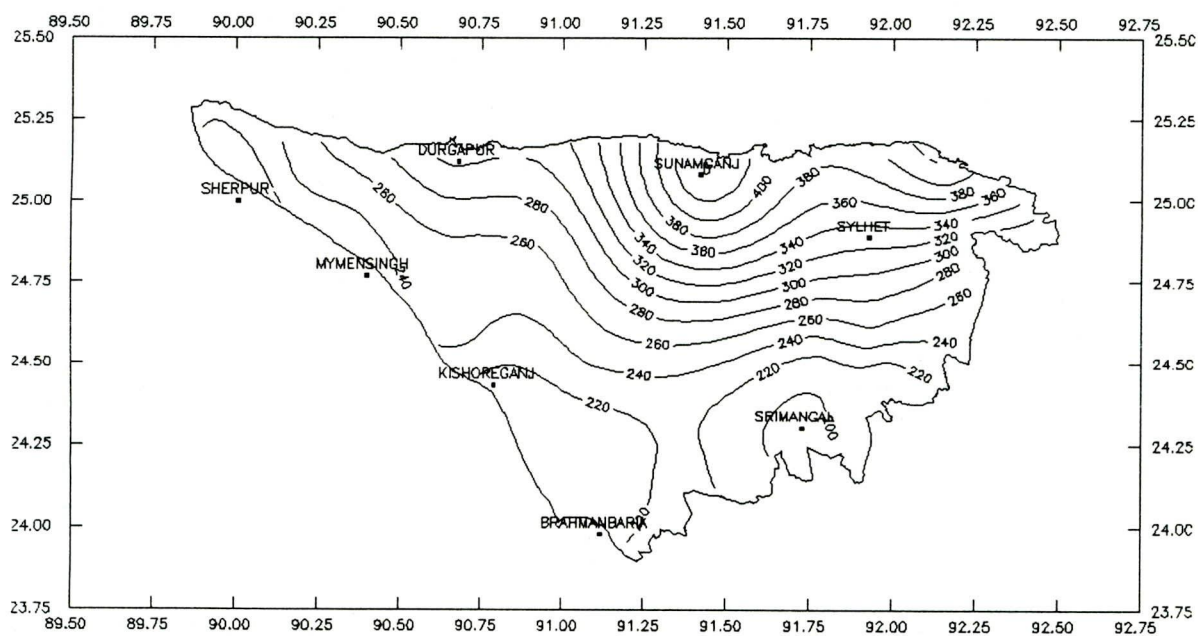


Figure C.7b Distribution of Gumbel parameter X_0 (location) for 3-day maximum rainfall.

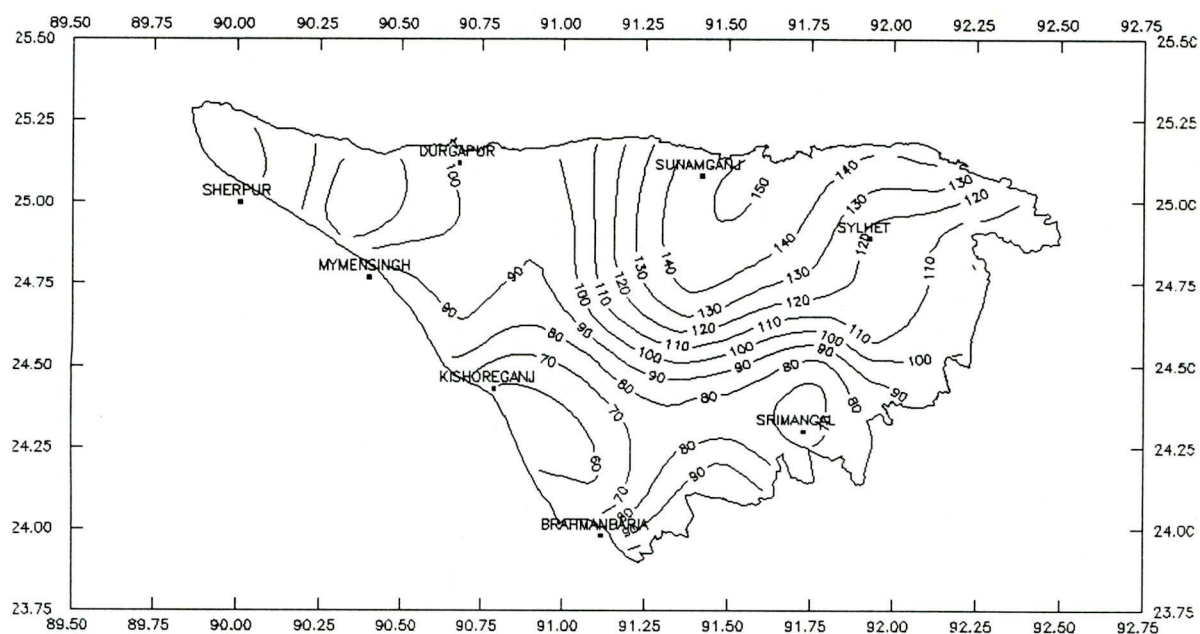


Figure C.8a Distribution of Gumbel parameter β (scale) for 5-day maximum rainfall.

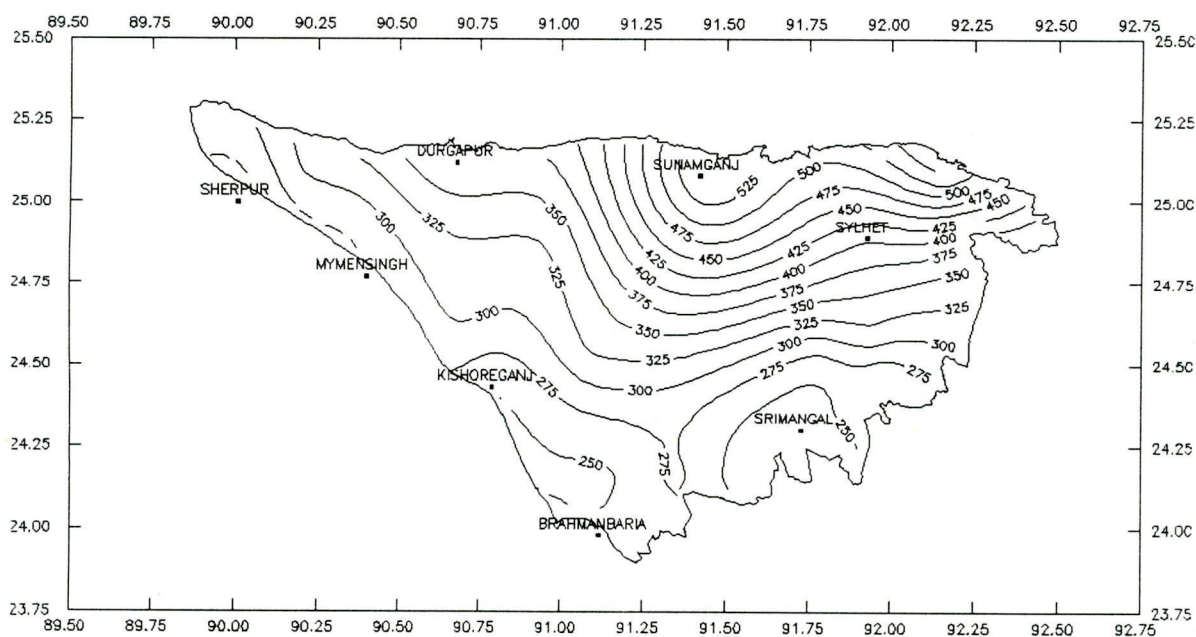


Figure C.8b Distribution of Gumbel parameter X_0 (location) for 5-day maximum rainfall.

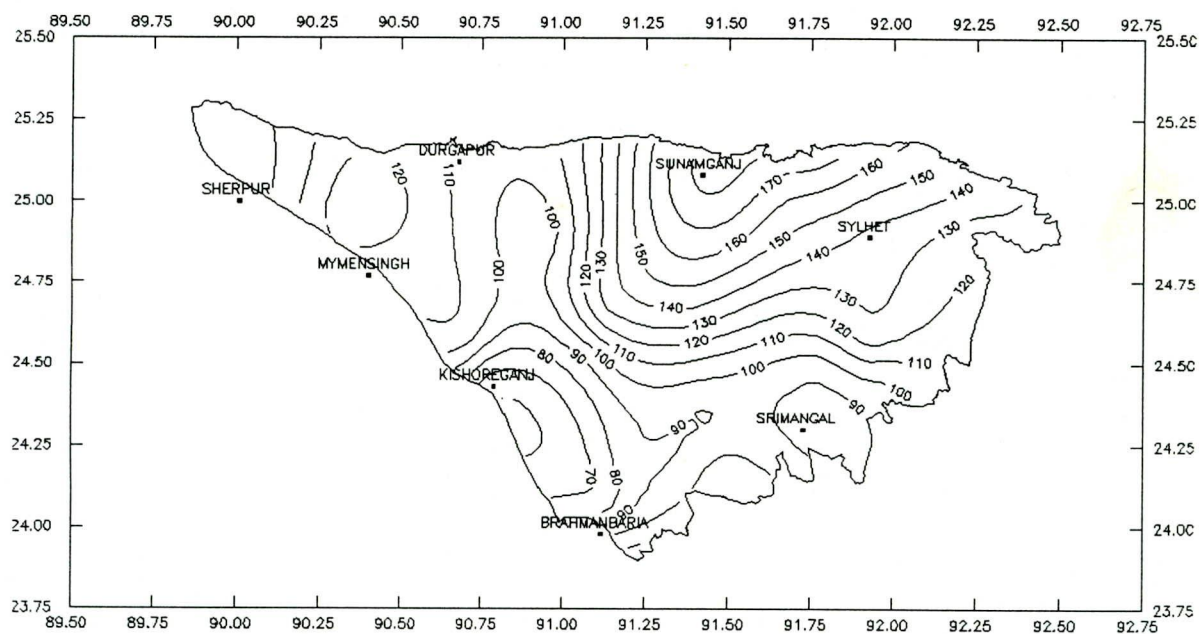


Figure C.9a Distribution of Gumbel Parameter β (Scale) for 7-day maximum rainfall.

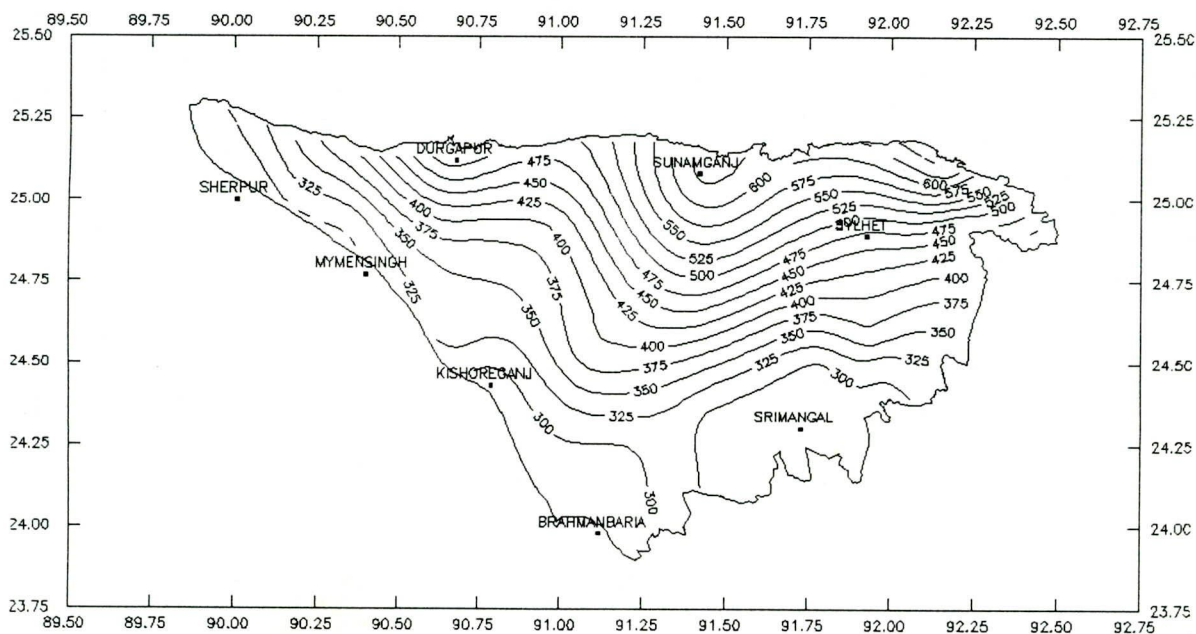


Figure C.9b Distribution of Gumbel parameter X_0 (location) for 7-day maximum rainfall.

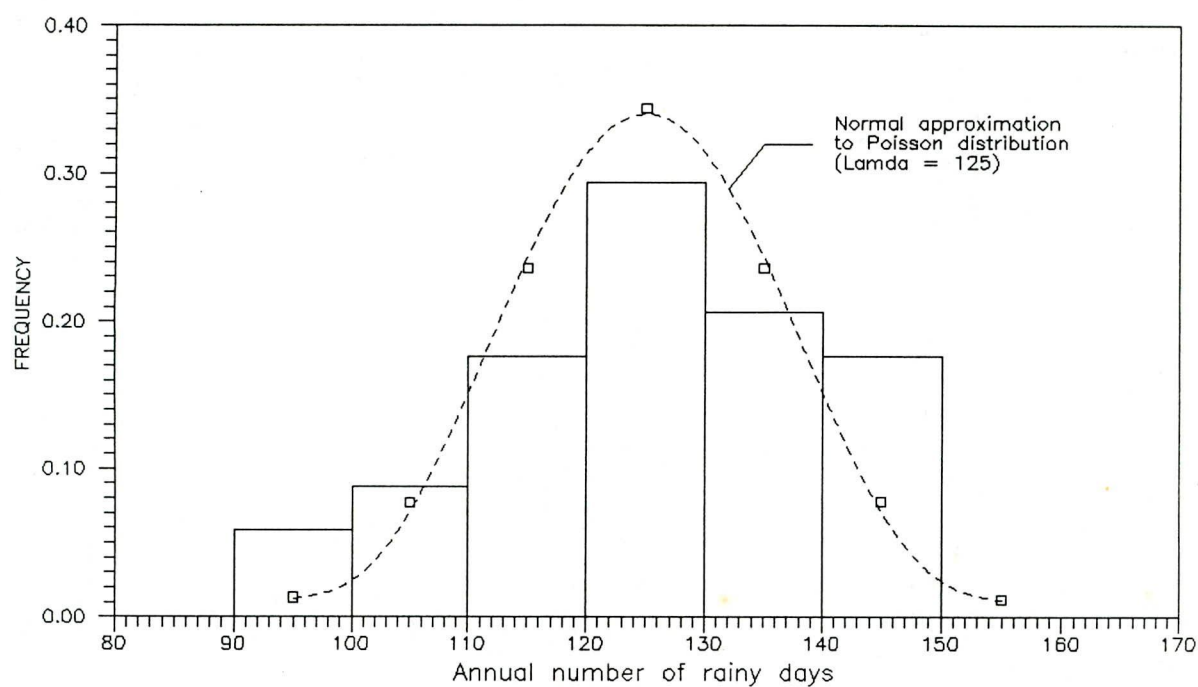


Figure C.10 Probability distributin of annual number of rainy days at Durgapur.

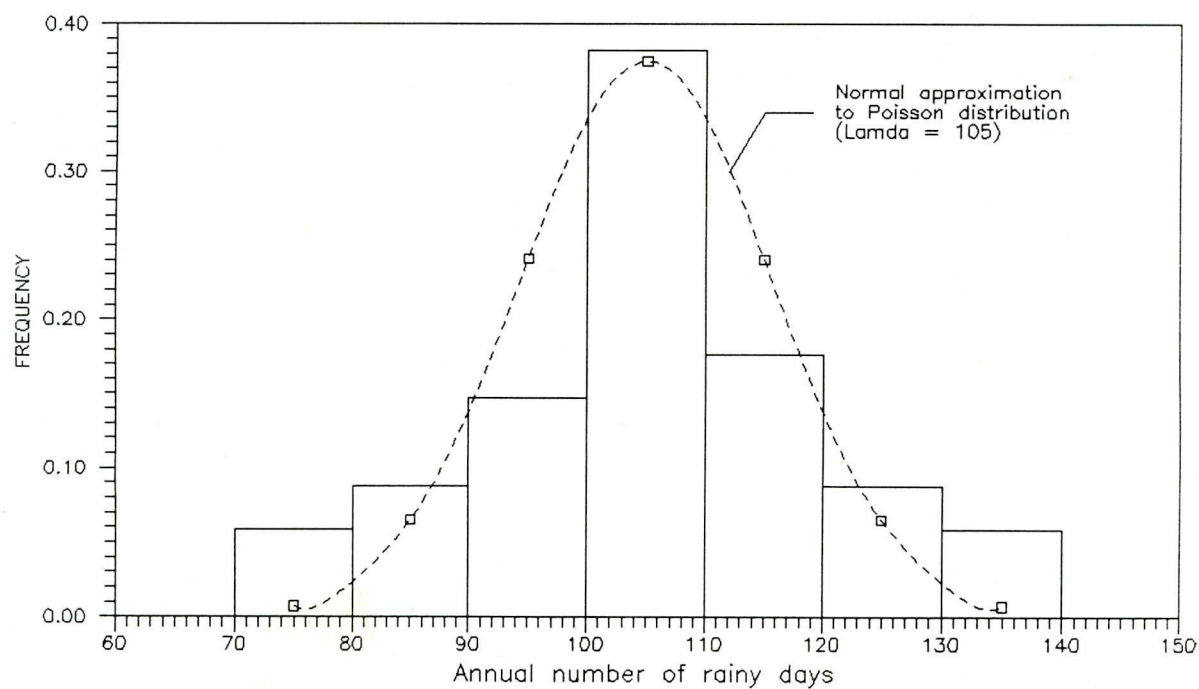


Figure C.11 Probability distribution of annual number of rainy days at Kishorganj.

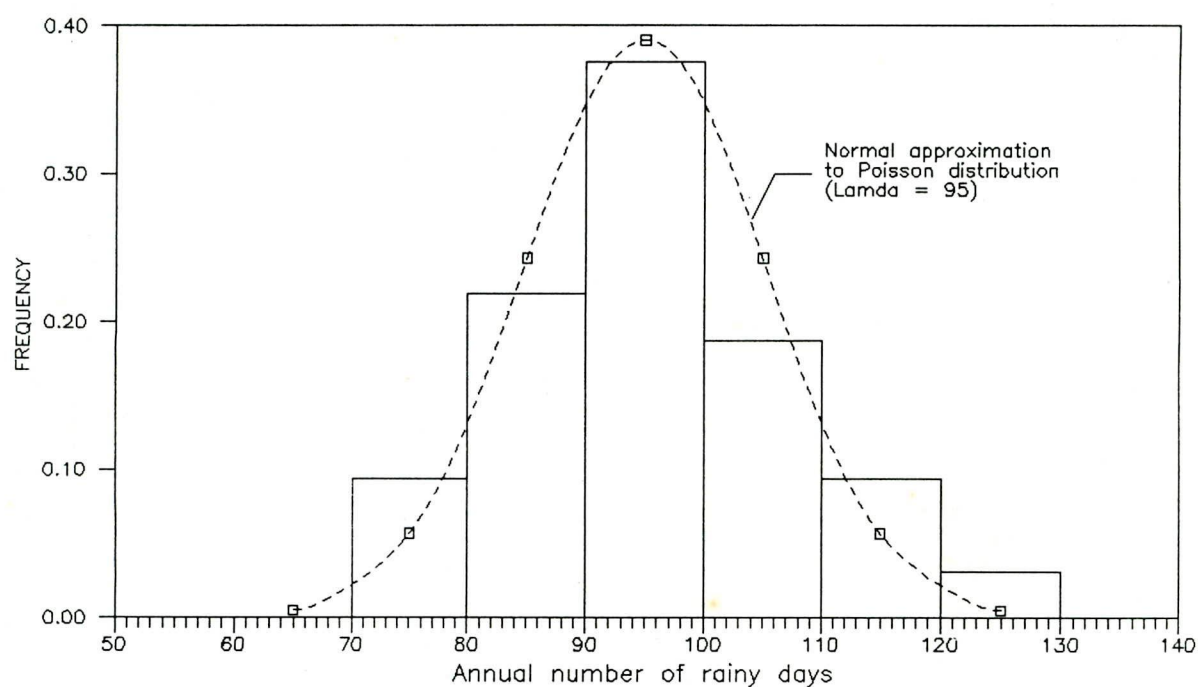


Figure C.12 Probability distribution of annual number of rainy days at Bhairab Bazar.

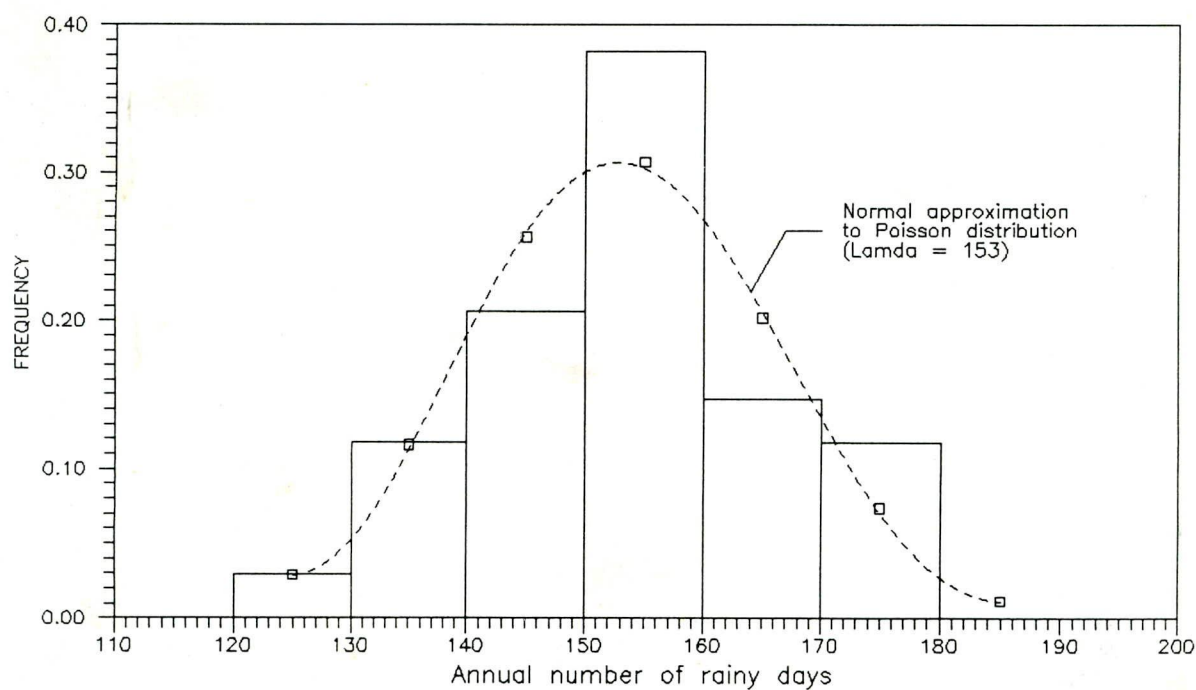


Figure C.13 Probability distribution of annual number of rainy days at Sylhet.

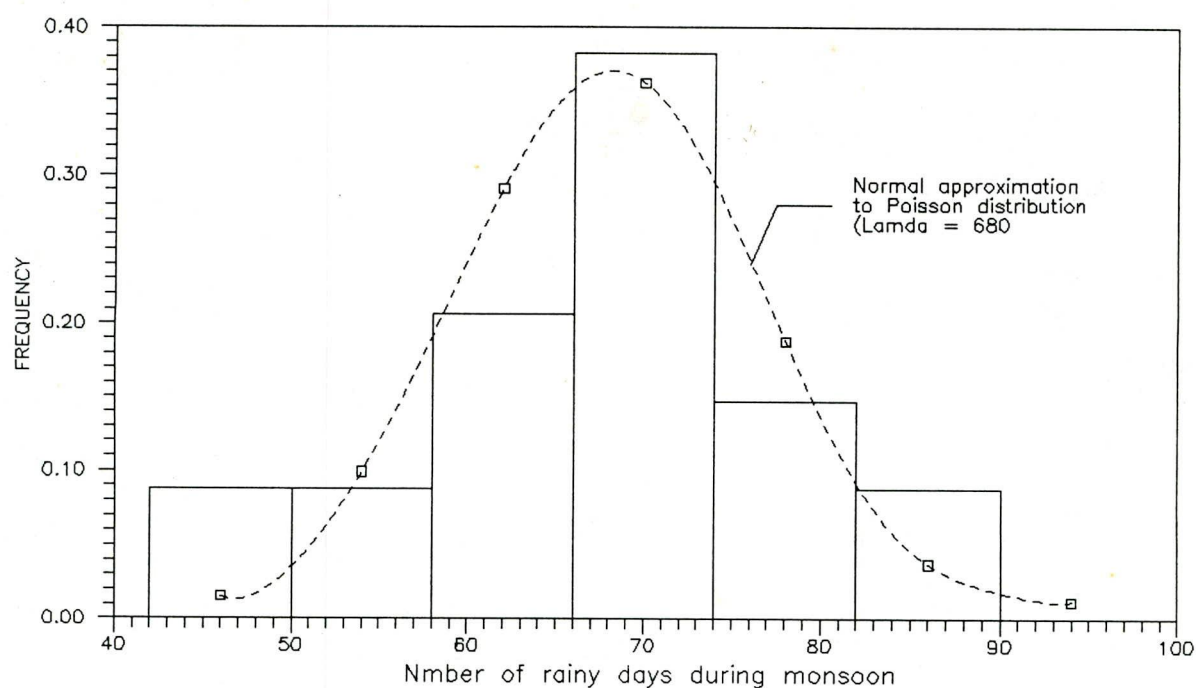


Figure C.14 Probability distribution of number of rainy days during monsoon at Kishorganj.

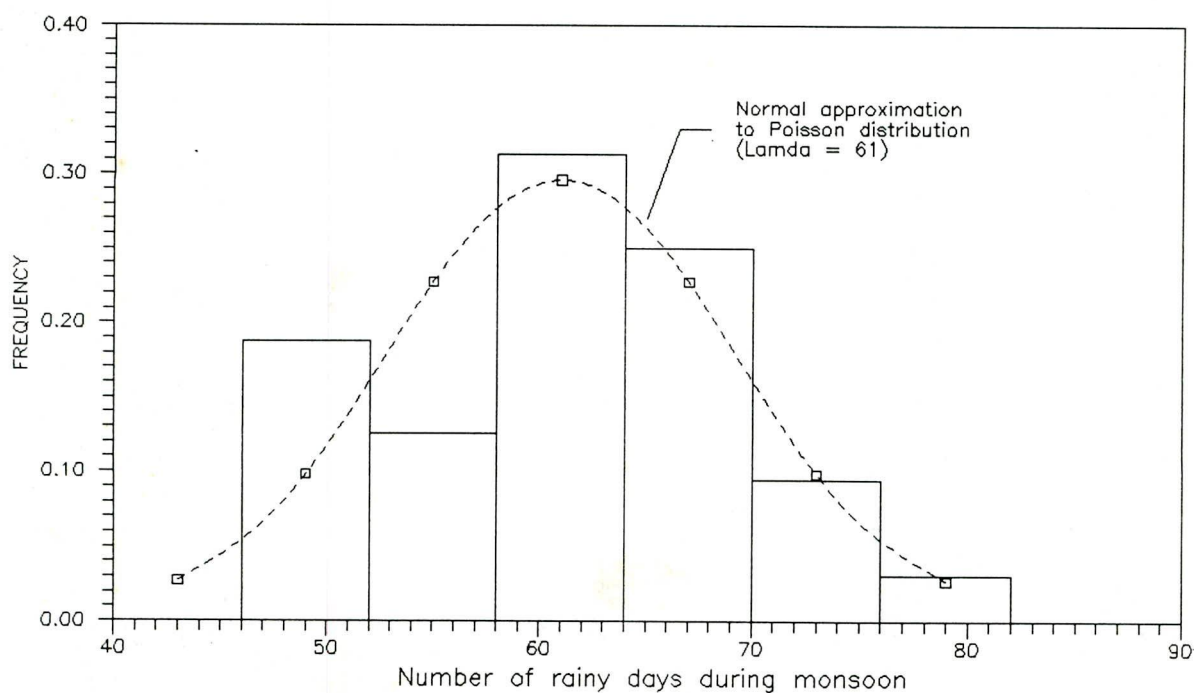


Figure C.15 Probability distribution of number of rainy days during monsoon at Bhairab Bazar.

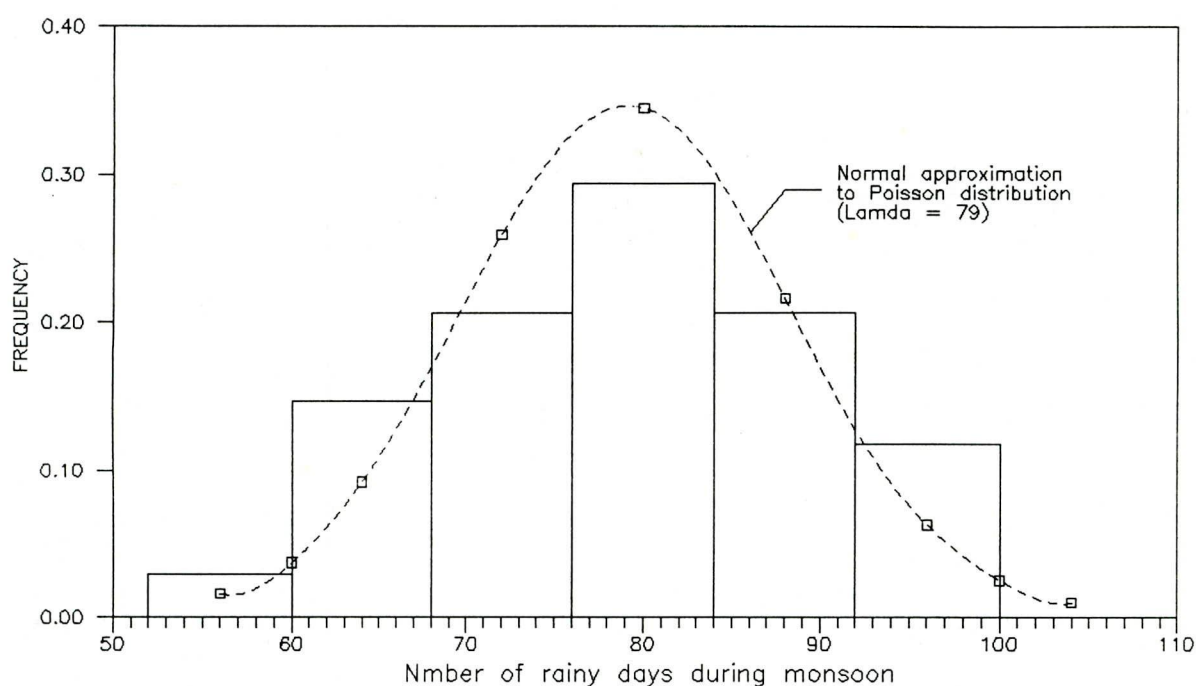


Figure C.16 Probability distribution of number of rainy days during monsoon at Habiganj.

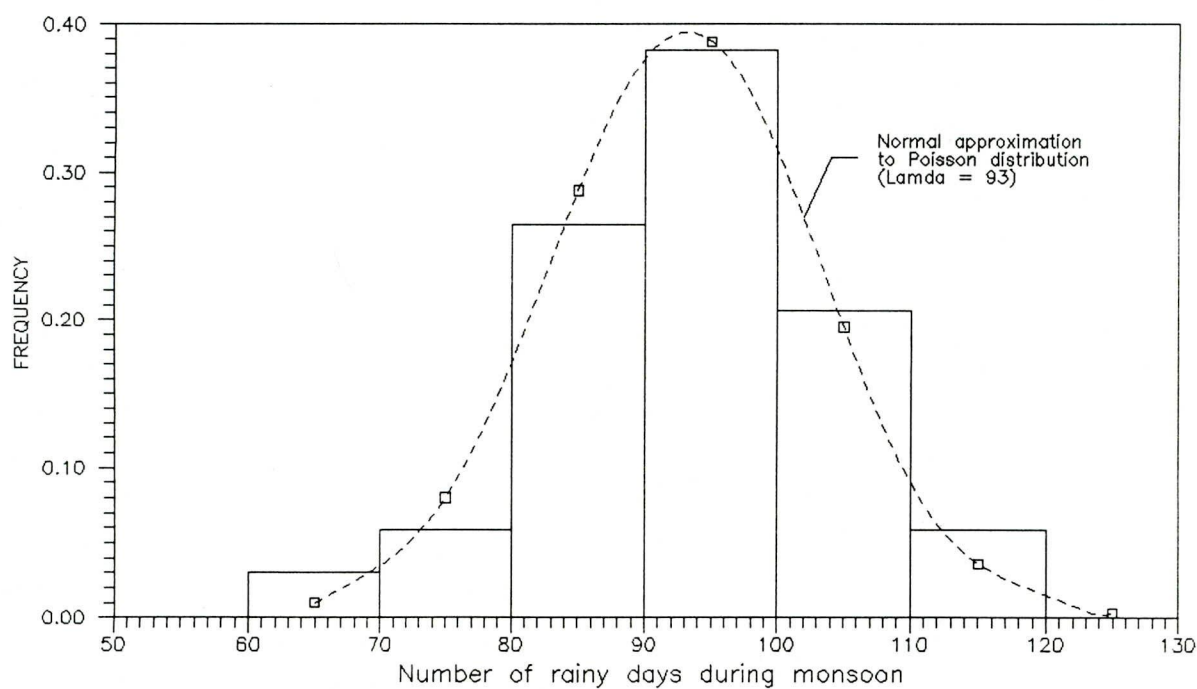


Figure C.17 Probability distribution of number of rainy days during monsoon at Sunamganj.

Table C.2
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
R-63 Durgapur 1-day Rainfall (mm)				
5	251	250	252	258
10	302	289	292	288
20	354	327	329	312
25	371	339	341	320
30	384	349	350	325
50	423	376	377	340
100	474	413	412	358
R-71 Muktagacha 1-day Rainfall				
5	190	188	186	194
10	234	220	217	219
20	277	251	246	238
25	291	260	255	244
30	303	268	263	249
50	335	290	284	261
100	379	320	312	276
R-73 Mymensingh 1-day Rainfall				
5	196	197	196	200
10	235	227	225	222
20	273	256	253	240
25	285	265	262	245
30	295	272	269	250
50	323	293	289	261
100	362	321	315	274
R-78 Sherpur 1-day Rainfall				
5	217	215	215	223
10	272	255	259	254
20	327	295	301	279
25	345	307	315	287
30	359	317	326	292
50	400	345	358	308
100	455	383	401	327

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
R-103 Brahmanbaria 1-day Rainfall (mm)				
5	198	196	199	202
10	236	225	228	224
20	275	253	255	242
25	287	262	263	247
30	297	269	270	251
50	326	289	288	262
100	364	315	314	275
R-110 Habiganj 1-day Rainfall				
5	181	180	180	184
10	209	200	198	200
20	237	220	214	212
25	246	227	219	216
30	254	232	223	219
50	275	246	234	227
100	303	266	248	237
R-116 Lallakhal 1-day Rainfall				
5	260	258	261	264
10	299	287	288	286
20	338	315	311	304
25	350	323	319	309
30	360	331	324	313
50	389	350	340	324
100	428	377	361	337
R-125 Sheola 1-day Rainfall				
5	256	257	248	265
10	303	295	276	294
20	351	332	301	317
25	366	343	309	324
30	378	353	315	330
50	413	379	332	344
100	461	415	354	362

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
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R-126 Srimangal 1-day Rainfall (mm)

5	167	172	170	171
10	196	198	192	188
20	225	222	213	202
25	235	230	219	206
30	242	236	225	209
50	264	254	239	217
100	293	284	258	228

R-127 Sunamganj 1-day Rainfall

5	298	296	299	303
10	341	329	328	327
20	384	360	354	348
25	398	370	361	353
30	409	378	368	358
50	441	400	385	370
100	484	430	407	385

R-128 Sylhet 1-day Rainfall

5	264	263	264	271
10	320	305	305	303
20	376	346	344	329
25	394	359	356	337
30	408	369	366	343
50	449	398	393	359
100	505	437	430	379

R-63 Durgapur 2-day Rainfall

5	362	359	360	370
10	438	415	414	413
20	514	469	465	448
25	538	486	482	458
30	558	500	495	466
50	614	539	531	487
100	690	592	579	514

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
R-71 Muktagacha 2-day Rainfall (mm)				
5	265	263	255	272
10	325	308	292	306
20	385	351	326	334
25	404	365	337	342
30	420	376	345	349
50	464	407	369	366
100	523	449	401	387
R-73 Mymensingh 2-day Rainfall				
5	288	286	286	299
10	351	333	332	337
20	415	379	375	368
25	435	393	389	377
30	452	405	400	384
50	499	437	431	403
100	562	481	472	426
R-78 Sherpur 2-day Rainfall				
5	269	267	270	276
10	332	313	321	312
20	394	358	369	341
25	414	372	384	349
30	431	384	397	356
50	477	416	432	373
100	540	459	480	395
R-103 Brahmanbaria 2-day Rainfall				
5	255	255	261	262
10	300	290	297	289
20	345	324	331	311
25	359	335	342	317
30	371	344	350	323
50	404	368	374	336
100	449	401	406	352

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
R-110 Habiganj 2-day Rainfall (mm)				
5	271	268	267	276
10	325	307	302	305
20	378	344	335	330
25	395	356	345	337
30	409	366	353	342
50	448	393	375	357
100	502	429	405	375
R-116 Lallakhal 2-day Rainfall (mm)				
5	418	417	424	426
10	481	464	468	462
20	544	509	509	492
25	564	524	522	500
30	580	536	532	507
50	626	568	559	525
100	689	612	595	547
R-125 Sheola 2-day Rainfall (mm)				
5	366	363	352	376
10	443	422	398	420
20	521	478	440	456
25	546	496	453	467
30	567	511	464	475
50	624	551	493	497
100	702	606	531	525
R-126 Srimangal 2-day Rainfall (mm)				
5	261	263	228	230
10	325	315	258	252
20	390	364	286	270
25	410	380	294	276
30	427	393	301	280
50	474	429	320	291
100	539	476	346	305

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
R-127 Sunamganj 2-day Rainfall (mm)				
5	473	472	479	484
10	550	530	534	528
20	626	586	585	564
25	651	603	600	574
30	671	618	613	582
50	727	658	647	604
100	804	711	692	631
R-128 Sylhet 2-day Rainfall (mm)				
5	392	389	389	402
10	475	451	448	449
20	558	511	504	487
25	585	530	521	498
30	606	545	535	507
50	668	588	574	531
100	751	645	627	559
R-63 Durgapur 3-day Rainfall (mm)				
5	444	440	442	454
10	535	508	507	504
20	627	573	568	546
25	656	594	587	559
30	680	611	603	568
50	748	658	645	594
100	839	721	703	625
R-71 Muktagacha 3-day Rainfall (mm)				
5	303	289	295	307
10	365	328	333	341
20	428	365	369	369
25	448	377	380	377
30	464	386	389	383
50	510	413	414	400
100	573	449	446	421

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
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R-73 Mymensingh 3-day Rainfall (mm)

5	328	334	330	337
10	393	386	379	374
20	458	437	425	405
25	479	453	439	414
30	496	466	450	421
50	544	502	482	439
100	609	551	525	462

R-78 Sherpur 3-day Rainfall (mm)

5	301	306	304	310
10	370	361	360	349
20	440	413	414	381
25	462	430	432	390
30	480	444	446	398
50	531	482	485	417
100	600	533	539	441

R-103 Brahmanbaria 3-day Rainfall (mm)

5	321	322	322	329
10	391	377	375	367
20	460	429	426	399
25	482	446	442	409
30	501	459	455	416
50	552	497	491	435
100	621	547	540	459

R-110 Habiganj 3-day Rainfall (mm)

5	316	314	316	323
10	378	359	358	356
20	439	403	398	384
25	459	417	410	392
30	475	428	420	399
50	520	460	448	416
100	581	502	485	437

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
R-116 Lallakhal 3-day Rainfall (mm)				
5	563	549	556	571
10	659	614	615	623
20	755	677	669	667
25	786	697	686	679
30	811	713	699	689
50	882	758	735	716
100	977	818	783	748
R-125 Sheola 3-day Rainfall (mm)				
5	457	432	445	466
10	553	490	504	519
20	649	546	559	563
25	680	564	577	575
30	705	578	590	585
50	776	618	629	612
100	872	672	679	644
R-126 Srimangal 3-day Rainfall (mm)				
5	298	289	267	267
10	369	337	305	293
20	441	383	339	315
25	463	397	350	321
30	482	409	359	326
50	535	442	383	339
100	606	487	416	356
R-127 Sunamganj 3-day Rainfall (mm)				
5	606	623	617	622
10	710	714	698	682
20	814	801	772	732
25	848	829	795	747
30	875	852	814	758
50	952	914	865	788
100	1056	999	934	826

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
R-128 Sylhet 3-day Rainfall (mm)				
5	470	462	468	484
10	563	529	533	537
20	656	593	593	581
25	686	614	612	593
30	711	630	627	603
50	779	676	669	630
100	872	738	725	663
R-63 Durgapur 5-day Rainfall (mm)				
5	526	520	522	537
10	627	594	591	594
20	728	664	654	640
25	760	687	674	654
30	787	705	690	664
50	861	756	734	692
100	962	824	792	727
R-71 Muktagacha 5-day Rainfall (mm)				
5	357	338	348	364
10	430	382	392	404
20	502	424	433	437
25	526	437	446	447
30	545	448	457	455
50	598	478	485	475
100	671	519	522	500
R-73 Mymensingh 5-day Rainfall (mm)				
5	397	397	397	406
10	476	459	455	451
20	556	518	510	487
25	582	537	527	498
30	603	552	540	507
50	662	594	579	529
100	742	652	630	557

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
R-78 Sherpur				
		5-day	Rainfall (mm)	
5	352	366	362	362
10	429	433	431	406
20	505	497	497	442
25	530	517	518	452
30	550	534	535	460
50	606	580	583	482
100	683	642	649	509
R-103 Brahmanbaria				
		5-day	Rainfall (mm)	
5	387	390	389	397
10	470	456	454	444
20	553	520	515	482
25	579	540	535	494
30	601	556	550	502
50	662	602	594	526
100	745	663	653	554
R-110 Habiganj				
		5-day	Rainfall (mm)	
5	388	387	388	396
10	461	443	440	437
20	534	497	488	470
25	557	515	503	480
30	577	529	515	488
50	630	567	549	508
100	703	620	593	534
R-116 Lallakhal				
		5-day	Rainfall (mm)	
5	762	767	764	775
10	894	872	856	848
20	1026	972	940	908
25	1069	1004	966	925
30	1103	1030	987	939
50	1201	1102	1044	976
100	1333	1199	1120	1021

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
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R-125 Sheola 5-day Rainfall (mm)

5	583	549	566	593
10	711	627	647	663
20	839	702	722	721
25	880	726	746	737
30	914	745	765	751
50	1008	799	818	785
100	1136	871	888	829

R-126 Srimangal 5-day Rainfall (mm)

5	365	335	329	331
10	449	385	372	362
20	534	433	412	388
25	561	449	425	396
30	583	461	435	402
50	645	495	462	418
100	729	542	499	438

R-127 Sunamganj 5-day Rainfall (mm)

5	743	769	761	765
10	864	880	857	836
20	985	986	945	895
25	1024	1020	972	913
30	1056	1047	995	926
50	1145	1124	1055	962
100	1266	1227	1136	1006

R-128 Sylhet 5-day Rainfall (mm)

5	588	579	585	606
10	710	667	671	675
20	832	751	751	732
25	871	778	776	749
30	903	800	797	762
50	993	860	853	796
100	1114	942	929	839

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
R-73 Mymensingh 7-day Rainfall (mm)				
5	448	463	460	454
10	535	547	546	507
20	623	627	629	550
25	651	652	655	563
30	674	673	677	573
50	739	730	737	599
100	826	808	820	632
R-78 Sherpur 7-day Rainfall (mm)				
5	401	404	403	411
10	489	474	472	461
20	577	541	539	502
25	606	562	560	513
30	629	580	577	523
50	694	628	624	547
100	782	693	689	578
R-103 Brahmanbaria 7-day Rainfall (mm)				
5	430	436	435	442
10	521	510	507	493
20	611	581	576	535
25	640	603	597	548
30	664	622	615	557
50	731	673	664	583
100	821	741	730	614
R-110 Habiganj 7-day Rainfall (mm)				
5	443	441	443	453
10	532	508	507	502
20	621	573	567	543
25	649	593	586	555
30	673	610	601	565
50	738	656	643	589
100	827	719	699	620

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
R-126 Srimangal 7-day Rainfall (mm)				
5	420	412	383	384
10	514	477	433	420
20	607	540	479	450
25	637	560	493	459
30	662	576	505	465
50	730	621	536	483
100	824	682	579	506
R-127 Sunamganj 7-day Rainfall (mm)				
5	854	907	888	884
10	988	1045	1006	967
20	1122	1177	1116	1036
25	1166	1219	1150	1056
30	1201	1253	1177	1071
50	1300	1348	1253	1113
100	1434	1476	1354	1164
R-128 Sylhet 7-day Rainfall (mm)				
5	675	673	675	695
10	814	776	774	774
20	952	874	866	838
25	997	906	895	857
30	1033	931	918	872
50	1135	1002	983	911
100	1274	1098	1070	959
R-78 Sherpur 10-day Rainfall (mm)				
5	468	477	474	481
10	571	561	559	539
20	674	641	639	587
25	707	667	665	601
30	734	688	686	612
50	810	746	744	641
100	913	824	823	677

Table C.2 (Continued)
Rainfall Values for Different Return Periods using Selected Distributions

Return Period (Year)	Plotting Position	Gumbel	Lognormal	Normal
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R-103 Brahmanbaria 10-day Rainfall (mm)

5	465	474	472	477
10	555	550	543	529
20	646	622	609	571
25	675	646	630	583
30	698	664	646	593
50	765	716	693	619
100	855	787	756	651

R-116 Lallakhal 10-day Rainfall (mm)

5	1008	1008	1010	1026
10	1159	1126	1111	1111
20	1310	1239	1202	1182
25	1359	1274	1229	1203
30	1398	1304	1252	1219
50	1510	1385	1313	1261
100	1661	1494	1392	1314

R-127 Sunamganj 10-day Rainfall (mm)

5	1076	1126	1108	1109
10	1260	1299	1261	1218
20	1444	1466	1403	1308
25	1503	1518	1448	1334
30	1552	1561	1484	1355
50	1687	1681	1583	1409
100	1871	1842	1715	1477

Appendix D

Monthly and Annual Rainfall Values for Some Selected Raingauge Stations

R-63 Durgapur

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1961	92	468	730	544	510	183	273	16	0	13	31	5	2865
1962	93	545	483	517	539	64	221	0	0	0	0	56	2518
1963	152	281	716	916	483	545	182	0	0	4	13	43	3335
1964	215	401	745	1210	469	576	615	0	0	0	64	52	4347
1965	62	386	619	790	657	395	52	14	0	15	0	5	2995
1966	125	510	497	673	686	410	104	17	9	9	0	76	3116
1967	127	542	566	846	600	489	74	0	0	0	0	46	3290
1968	64	407	816	899	496	414	141	5	0	0	0	95	3337
1969	203	333	888	530	1025	283	9	0	0	43	6	26	3346
1970	71	138	777	703	581	769	488	3	0	0	0	24	3554
1971	271	269	1140	726	889	572	188	67	0	0	0	51	4173
1972	246	278	858	678	698	546	50	0	0	0	42	0	3396
1973	127	912	1041	822	354	1525	228	64	38	0	0	68	5179
1974	197	313	584	1238	506	497	290	16	0	0	7	57	3705
1975	338	463	150	776	466	552	155	0	0	0	41	49	2990
1976	171	156	841	612	914	232	75	8	0	0	0	16	3025
1977	297	413	1062	783	343	263	374	82	7	0	0	36	3660
1978	201	521	969	586	385	694	43	8	0	0	5	0	3412
1979	86	161	457	1862	415	489	234	19	91	2	34	9	3859
1980	97	550	772	465	742	290	398	0	0	2	13	33	3362
1981	415	590	370	850	420	706	7	0	84	0	10	68	3520
1982	188	275	969	582	782	294	28	0	0	4	8	30	3160
1983	51	389	381	761	1078	862	475	0	28	8	0	28	4061
1984	152	474	876	1057	459	706	178	0	24	6	8	84	4024
1985	38	256	520	686	496	533	74	0	19	1	0	0	2623
1986	171	317	552	793	351	579	353	28	8	2	10	61	3225
1987	208	304	741	918	659	630	196	12	0	0	18	51	3737
1988	170	734	792	921	1340	514	296	107	1	1	45	0	4921
1989	30	610	484	1382	561	836	277	0	0	0	41	0	4221
1990	401	730	632	718	319	913	345	0	0	0	9	7	4074
1991	268	858	483	623	572	898	565	0	62	3	30	32	4394
1992	67	495	656	753	488	697	78	4	0	67	12	42	3359
1993	130	549	929	1149	626	636	327	0	0	16	22	111	4495
1994	140	300	765	572	632	248	159	4	0	11	40	18	2889

R-71 Muktagacha

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1961	13	370	465	220	252	94	87	9	0	8	18	30	1566
1962	258	368	245	64	408	9	51	0	0	0	0	19	1422
1963	175	334	650	410	164	411	141	19	0	1	3	36	2344
1964	148	270	477	549	248	534	419	5	0	0	14	49	2713
1965	46	272	580	418	598	284	78	50	6	26	0	51	2409
1966	103	143	371	337	576	271	175	10	14	16	0	118	2134
1967	90	148	237	392	390	288	78	0	0	0	2	21	1646
1968	99	222	454	375	330	293	62	8	0	6	3	103	1955
1969	212	193	629	288	690	198	57	7	0	47	3	38	2362
1970	103	153	491	650	241	201	471	22	0	16	36	8	2392
1971	338	417	278	452	616	382	174	81	0	0	20	37	2795
1972	102	196	485	312	215	178	70	0	0	28	27	11	1624
1973	313	730	575	306	539	737	98	36	74	1	0	107	3516
1974	127	456	320	874	139	455	246	0	0	0	6	28	2651
1975	150	360	107	546	386	320	123	15	0	0	14	13	2034
1976	110	325	600	449	399	65	94	20	0	4	55	2	2123
1977	295	263	651	375	200	50	270	82	34	0	12	48	2280
1978	109	485	442	332	293	182	71	8	0	4	14	65	2005
1979	100	120	561	596	435	272	75	2	38	0	2	17	2218
1980	93	688	340	290	304	200	172	0	0	15	39	16	2157
1981	368	281	73	440	402	200	45	0	35	0	17	56	1917
1982	87	172	591	192	582	209	34	8	0	8	15	188	2086
1983	153	212	200	292	871	350	272	0	29	6	0	19	2404
1984	64	686	473	494	212	634	61	0	0	0	34	56	2714
1985	70	320	471	132	274	294	64	0	9	4	0	6	1644
1986	385	189	174	312	292	471	354	143	0	0	0	98	2418
1987	147	169	245	443	523	411	36	7	14	0	55	111	2161
1988	53	876	443	563	503	402	422	66	15	0	0	0	3343
1989	70	384	509	532	307	409	417	0	3	0	75	35	2741
1990	113	303	400	625	319	399	201	16	0	6	18	32	2432
1991	169	632	382	191	228	459	309	0	79	0	52	0	2501
1992	60	154	178	528	158	385	204	8	0	2	125	156	1958
1993	177	496	1072	532	356	462	300	0	0	15	21	82	3513
1994	110	190	206	138	400	186	68	0	0	10	38	18	1364

R-73 Mymensingh

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1961	41	256	481	297	199	154	107	12	0	12	22	0	1581
1962	134	432	480	394	381	223	123	0	0	0	0	37	2204
1963	72	258	483	450	331	160	161	12	2	14	41	26	2010
1964	103	400	651	527	240	511	427	0	0	0	15	28	2902
1965	64	216	544	671	668	328	78	39	3	29	0	6	2646
1966	140	129	276	359	528	240	199	14	0	15	0	54	1954
1967	119	295	243	468	402	305	186	24	0	7	3	36	2088
1968	68	295	439	766	169	363	142	8	0	3	2	147	2402
1969	176	151	398	335	633	315	52	8	0	55	11	27	2161
1970	131	161	586	522	227	251	299	7	0	17	0	15	2216
1971	0	0	588	407	397	373	79	47	0	0	0	0	1891
1972	100	118	584	283	164	251	217	0	0	14	201	6	1938
1973	192	329	538	527	217	714	56	38	58	0	0	21	2690
1974	169	347	621	860	282	420	408	4	0	0	0	5	3116
1975	127	292	98	800	531	290	241	23	0	0	10	5	2417
1976	138	248	625	635	490	257	190	4	0	0	50	2	2639
1977	236	490	889	336	241	144	270	37	25	0	5	45	2718
1978	126	530	798	381	146	318	30	2	0	0	8	7	2346
1979	61	213	425	704	436	413	205	10	32	3	33	12	2547
1980	92	630	276	413	394	239	239	0	0	15	48	9	2355
1981	291	372	154	767	320	278	34	0	94	0	2	69	2381
1982	155	221	551	470	283	235	29	10	0	23	6	83	2066
1983	154	513	139	428	908	389	444	0	16	13	2	17	3023
1984	73	568	555	681	219	320	206	0	0	12	51	2	2687
1985	56	292	505	357	310	345	138	0	3	1	5	1	2013
1986	244	150	284	571	320	748	403	71	12	0	0	30	2833
1987	170	313	423	408	517	407	88	14	14	0	70	65	2489
1988	98	662	662	654	399	406	190	147	20	3	25	2	3268
1989	24	365	333	743	160	550	242	0	4	0	111	38	2570
1990	186	463	540	679	250	468	252	14	0	2	22	34	2910
1991	80	794	591	357	269	1257	591	0	97	0	30	0	4066
1992	5	199	302	762	229	459	277	2	0	79	2	52	2368
1993	228	533	953	702	392	544	269	2	0	18	56	155	3852
1994	116	290	324	336	294	296	189	0	0	8	10	20	1883

R-78 Shergpur Town

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1961	58	309	424	196	317	59	215	23	0	6	0	2	1609
1962	0	411	368	334	452	204	0	0	0	0	0	34	1803
1963	42	184	261	463	306	258	210	32	2	2	5	4	1769
1964	151	269	632	605	220	628	192	0	0	5	13	29	2744
1965	39	176	558	586	420	160	48	36	3	26	0	7	2059
1966	10	186	170	440	495	280	196	22	0	9	0	103	1911
1967	201	289	256	512	440	256	55	0	0	0	0	53	2062
1968	63	239	389	426	234	196	219	0	0	3	0	66	1835
1969	215	101	385	323	507	344	49	6	0	25	14	31	2000
1970	62	114	412	390	223	184	133	8	0	4	0	0	1530
1972	154	80	610	46	130	266	290	0	0	0	68	11	1655
1973	170	415	842	376	363	873	84	57	38	5	0	72	3295
1974	201	324	410	818	199	499	343	0	0	0	9	2	2805
1975	123	161	148	330	241	170	136	2	0	0	6	7	1324
1976	161	217	692	547	368	227	31	2	0	3	18	0	2266
1977	174	399	689	332	245	133	171	50	0	0	5	6	2204
1978	126	463	626	195	175	138	57	8	0	0	28	41	1857
1979	55	162	206	774	380	274	114	0	41	11	11	9	2037
1980	44	293	270	458	289	306	259	0	0	71	22	16	2028
1981	273	527	160	594	239	205	0	0	91	0	7	26	2122
1982	159	126	880	374	417	146	50	1	0	4	21	57	2235
1983	82	261	166	433	464	446	388	0	18	7	0	8	2273
1984	58	478	559	474	210	331	185	10	11	0	35	4	2355
1985	95	252	403	409	221	248	48	0	3	1	2	1	1683
1986	222	256	374	367	361	406	354	49	13	0	0	43	2445
1987	181	245	322	833	539	407	85	22	6	0	18	31	2689
1988	122	463	689	442	585	248	136	100	0	6	17	22	2830
1989	6	536	326	985	68	325	101	0	25	0	35	20	2427
1990	105	617	624	615	190	370	185	0	0	0	25	29	2760
1991	15	886	406	352	194	477	93	19	114	0	36	12	2604
1992	21	292	278	366	251	463	120	18	0	80	10	8	1907
1993	85	410	528	533	540	491	25	0	0	17	23	26	2678
1994	109	159	268	159	188	148	123	3	0	11	21	50	1239

R-102 Bholaganj

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1964	739	770	1596	3085	1391	1105	595	0	0	0	156	80	9517
1965	342	502	1401	1239	1205	638	117	157	8	21	0	67	5697
1966	410	701	2239	1583	1632	854	192	30	10	27	18	128	7824
1967	622	433	1884	2902	1176	1106	328	0	0	14	58	107	8630
1968	403	738	903	1067	708	438	27	2	0	15	0	143	4444
1969	301	465	692	470	1478	270	85	16	0	40	95	135	4047
1970	311	773	597	820	677	684	409	12	0	10	20	18	4331
1971	311	773	597	820	677	684	409	12	0	10	20	18	4331
1972	330	1000	1562	1532	717	226	29	0	0	9	64	2	5471
1973	617	760	1270	929	803	410	10	106	37	51	0	57	5050
1974	564	538	591	1969	348	367	244	16	0	0	89	125	4851
1976	227	317	781	548	950	391	47	7	0	0	12	216	3496
1977	561	798	1180	1350	1145	206	339	192	4	0	3	8	5786
1978	164	549	725	1179	849	344	321	10	0	0	0	24	4165
1979	59	412	656	1475	708	744	164	12	43	0	19	62	4354
1980	359	591	728	794	1010	239	213	0	0	51	4	16	4005
1981	249	412	398	1631	1064	1510	114	0	20	0	12	66	5476
1982	495	227	1344	1438	816	666	70	30	0	13	43	249	5391
1983	340	438	597	871	1732	1079	323	0	18	12	13	0	5423
1984	374	859	711	1093	570	903	326	8	53	0	66	183	5146
1985	305	287	836	1351	397	591	69	0	13	0	0	20	3869
1986	464	262	720	1364	828	432	508	117	0	0	30	183	4908
1987	544	216	1214	1164	632	1201	102	13	30	10	71	132	5329
1988	348	771	787	1162	1638	1117	636	165	0	0	117	8	6749
1989	483	877	1536	1734	1229	959	430	12	0	1	54	141	7456
1990	794	555	939	637	1050	946	130	13	0	2	6	27	5099
1991	145	1183	1051	455	867	987	212	0	23	0	38	170	5131
1992	239	448	1212	1267	876	880	159	3	7	52	277	133	5553
1993	251	800	1512	1241	955	626	126	0	0	15	57	339	5922
1994	220	457	946	905	741	531	257	17	0	6	32	39	4151

R-103 Brahmanbaria

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1961	52	227	538	362	226	88	59	0	0	5	5	6	1568
1962	134	361	292	312	268	66	119	0	0	0	0	1	1553
1965	25	132	639	306	433	216	124	10	4	13	0	54	1956
1966	102	282	369	373	261	199	446	77	23	55	0	103	2290
1967	198	210	260	400	291	450	104	0	0	0	9	34	1956
1968	190	234	515	675	333	204	18	22	0	0	0	127	2318
1969	254	44	497	241	438	188	86	28	0	29	1	76	1882
1970	128	142	365	369	223	162	224	24	0	3	15	0	1655
1972	106	281	440	350	160	160	29	0	0	13	12	40	1591
1973	250	923	459	322	278	266	56	121	117	0	0	51	2843
1974	288	560	362	460	463	119	92	5	0	0	29	2	2380
1975	79	381	229	733	228	216	118	78	0	0	20	34	2116
1976	150	283	419	419	334	65	38	5	0	0	19	0	1732
1977	543	278	333	268	220	96	424	29	20	0	2	41	2254
1978	196	947	487	310	211	140	41	4	0	14	1	91	2442
1979	37	119	245	635	300	382	63	3	51	0	33	59	1927
1980	107	762	213	503	235	203	469	0	0	34	34	53	2613
1981	488	377	84	542	271	74	16	0	14	0	42	56	1964
1982	126	263	305	248	291	144	0	23	0	12	28	179	1619
1983	145	257	350	279	706	309	112	0	28	0	0	14	2200
1984	90	723	398	501	434	491	116	0	2	0	23	47	2825
1985	230	235	399	221	113	286	42	0	30	3	0	20	1579
1986	484	367	205	397	279	411	333	163	0	0	1	44	2684
1987	187	156	304	380	359	195	154	8	18	0	61	118	1940
1988	137	719	738	559	145	465	264	61	8	0	51	15	3162
1989	132	244	358	292	231	269	152	0	2	0	36	246	1962
1990	216	386	193	362	236	290	218	37	7	20	10	61	2036
1991	198	934	106	68	121	394	304	16	130	0	90	0	2361
1992	59	272	164	293	157	135	114	2	1	4	149	28	1378
1993	209	560	557	606	209	567	110	54	0	8	50	125	3055
1994	112	239	139	194	277	96	181	1	0	3	21	76	1339

R-107 Chatak

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1967	317	358	1143	1249	622	489	62	0	0	4	0	86	4330
1968	315	623	890	1025	695	816	125	5	0	21	0	249	4764
1969	414	335	1565	1277	1681	205	180	6	0	6	0	71	5740
1970	403	798	1215	1063	1083	833	429	18	0	8	16	111	5977
1972	361	708	1369	1623	455	366	234	0	0	2	132	3	5253
1973	448	809	2024	610	707	861	95	88	46	10	0	17	5715
1974	774	447	992	1768	860	1200	747	28	0	0	50	64	6930
1975	392	533	563	1414	992	715	447	65	0	0	11	499	5631
1976	339	518	2677	1745	1517	300	138	23	0	1	36	186	7480
1977	708	645	824	797	848	391	430	74	13	0	0	30	4760
1978	104	526	804	1048	257	801	217	10	0	0	11	24	3802
1979	96	492	957	1792	851	666	305	14	22	0	48	56	5299
1980	520	700	579	510	762	682	313	0	0	22	22	46	4156
1981	226	520	368	1449	745	1049	32	0	28	0	0	39	4456
1982	537	208	1242	1041	784	626	112	11	0	5	16	200	4782
1983	237	467	568	947	1123	931	412	0	11	13	0	64	4773
1984	332	1321	829	1217	552	1067	261	2	18	8	23	348	5978
1985	457	320	1274	954	464	855	6	0	13	0	0	8	4351
1986	601	212	578	850	975	434	584	76	2	0	11	127	4450
1987	487	231	1483	1433	728	1328	86	15	10	3	37	112	5953
1988	329	1138	1002	1203	1586	1320	467	140	0	0	66	14	7265
1989	389	732	1003	1367	696	1108	481	0	0	0	78	137	5991
1990	545	507	777	851	1099	852	333	50	0	0	62	71	5147
1991	440	1364	1500	888	757	1017	305	0	72	0	31	278	6652
1992	175	445	952	1686	694	643	128	0	5	48	165	85	5026
1993	249	600	1606	1263	810	447	79	0	0	3	57	289	5403
1994	233	144	296	850	726	442	559	3	0	16	36	123	3428

R-110 Habiganj

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1961	221	372	458	324	332	285	100	3	0	9	18	1	2123
1962	226	352	536	341	514	123	164	0	0	0	0	85	2341
1964	307	325	444	816	265	228	320	7	0	0	29	63	2804
1965	45	307	553	139	319	246	115	26	0	28	0	23	1801
1966	167	416	526	342	578	134	242	36	16	35	0	61	2553
1967	223	169	238	341	369	489	138	0	0	4	0	21	1992
1968	231	476	355	240	113	73	4	2	0	90	0	114	1698
1969	306	126	574	225	467	221	30	9	0	13	1	50	2022
1970	62	360	814	674	509	291	389	34	0	23	86	16	3258
1971	348	749	810	760	956	141	246	17	0	0	20	196	4243
1972	175	203	572	467	294	230	48	0	0	13	166	14	2182
1973	225	783	502	474	403	281	83	117	147	0	16	9	3040
1974	311	651	520	672	255	193	184	20	0	0	0	20	2826
1975	305	486	392	455	395	273	43	0	0	0	3	0	2352
1976	100	511	987	423	308	280	47	20	0	1	51	112	2840
1977	614	612	578	259	216	213	206	76	0	0	0	6	2780
1978	186	799	337	276	213	190	52	0	0	0	9	62	2124
1979	86	99	572	504	235	498	114	15	36	0	10	24	2193
1980	140	726	342	344	351	184	212	0	0	127	38	37	2501
1981	509	378	93	441	473	159	10	0	18	0	23	30	2134
1982	267	300	447	450	403	368	18	14	0	4	29	29	2329
1983	249	316	408	360	784	388	186	0	24	0	0	38	2753
1984	53	939	368	358	312	565	139	0	0	14	36	179	2963
1985	194	284	656	166	226	442	90	0	9	2	0	7	2076
1986	371	350	339	262	316	273	292	140	1	8	0	36	2388
1987	295	254	361	549	446	276	72	28	12	0	66	56	2415
1988	125	782	587	584	561	331	242	133	7	0	21	24	3397
1989	47	388	352	460	443	259	321	0	2	0	45	118	2435
1990	212	523	329	311	400	498	217	82	5	11	64	6	2658
1991	411	997	81	750	332	304	646	27	389	0	50	0	3987
1992	82	393	207	372	233	306	172	0	2	14	58	49	1888
1993	116	490	866	771	372	532	148	57	0	2	16	194	3564
1994	165	243	308	186	274	216	242	0	0	4	46	86	1770

R-116 Lallakhal

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1964	676	552	1480	1864	689	1348	443	2	0	0	178	94	7326
1965	451	535	1156	1194	1174	524	168	69	5	16	0	36	5328
1966	546	637	1734	1406	1346	402	195	42	0	17	14	83	6422
1967	442	584	1620	1405	532	531	178	2	0	0	22	135	5451
1968	520	968	941	1119	1014	598	146	17	0	49	0	189	5561
1969	314	591	1402	1065	1386	204	64	28	0	47	93	313	5507
1970	415	1140	1219	1585	730	654	440	59	0	46	7	0	6295
1972	603	930	1599	1026	507	371	478	0	3	4	80	24	5625
1973	918	726	1861	1071	758	725	85	129	69	0	2	104	6448
1974	649	513	1074	1526	973	820	440	10	0	0	22	36	6063
1975	607	710	486	1364	992	750	222	105	0	0	45	520	5801
1976	563	358	2036	1602	1124	915	119	23	0	2	38	377	7157
1977	1039	846	1179	946	776	287	52	90	0	0	0	6	5221
1978	185	613	1102	1002	408	704	239	72	0	0	2	240	4567
1979	110	672	1080	1746	1174	1116	279	39	16	1	78	93	6404
1980	723	865	743	1010	649	703	411	0	0	101	33	292	5530
1981	286	742	576	1575	861	960	141	18	23	0	30	42	5254
1982	834	384	1243	1663	720	340	33	64	0	25	38	156	5500
1983	509	676	772	1281	1503	739	439	0	36	43	0	155	6153
1984	539	1730	665	1486	481	1204	386	20	81	5	56	512	7165
1985	559	655	1241	1262	963	620	132	0	17	0	0	85	5534
1986	746	203	912	734	989	659	480	119	0	0	4	194	5040
1987	730	568	1128	1335	615	820	194	151	18	0	60	176	5795
1988	300	1272	844	1269	1456	1326	622	146	36	0	77	78	7426
1989	855	681	1166	1664	849	1095	447	0	0	40	48	129	6974
1990	962	669	953	845	764	1160	263	63	0	5	19	66	5769
1991	431	1535	1010	598	805	1317	396	0	81	0	113	514	6800
1992	479	500	925	1210	606	664	202	0	50	52	399	269	5356
1993	223	852	1611	1201	860	660	185	20	0	26	63	622	6323
1994	359	901	1179	966	825	478	392	22	0	8	57	93	5280

R-122 Moulvi Bazar

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1961	131	350	389	300	292	354	157	0	0	11	28	1	2013
1962	148	252	541	406	485	111	162	0	0	0	0	139	2244
1963	223		584	389	275	208	262	0	0	4	60	117	2494
1964	395	380	550	623	283	250	252	14	0	0	64	62	2873
1965	105	274	567	463	512	237	37	66	7	51	0	34	2353
1966	195	369	505	365	552	415	244	50	53	53	0	141	2942
1967	318	284	350	390	317	482	104	2	0	14	20	118	2399
1968	260	488	551	673	283	339	25	39	0	6	105	105	2874
1969	331	280	522	389	528	111	105	13	0	27	67	28	2401
1970	157	182	708	724	367	312	230	43	0	6	8	44	2781
1972	219	190	529	568	382	136	54	2	5	21	163	21	2290
1973	326	565	611	536	501	213	28	55	88	2	7	28	2960
1974	320	375	547	469	283	189	135	17	0	0	0	0	2335
1975	266	441	333	365	375	196	58	57	0	0	20	53	2164
1976	206	528	1261	584	310	325	160	36	0	12	88	10	3520
1977	801	616	697	355	468	90	288	34	0	0	6	25	3380
1978	268	841	448	271	171	396	72	0	0	0	10	87	2564
1979	100	153	678	475	300	401	50	1	29	0	2	122	2311
1980	275	597	375	468	323	322	179	0	0	0	34	96	2669
1982	202	235	531	432	629	193	4	10	0	25	27	261	2549
1983	345	654	361	386	716	351	186	0	36	0	0	12	3047
1984	134	1236	390	339	316	523	135	4	0	13	22	191	3303
1985	256	218	836	295	155	427	29	2	2	0	2	0	2222
1986	252	189	200	416	262	283	381	131	0	0	2	48	2164
1987	284	170	779	534	440	210	151	16	9	0	33	75	2701
1988	352	883	460	373	667	207	214	67	0	2	1	4	3230
1989	199	376	250	428	463	487	386	0	0	0	10	201	2800
1990	388	590	428	355	562	467	280	43	5	9	102	27	3256
1991	355	935	334	135	105	368	147	0	129	0	52	113	2673
1992	63	437	216	290	281	291	91	2	0	34	114	100	1919
1993	302	843	757	769	329	463	32	8	0	7	30	378	3918
1994	322	222	245	196	312	148	172	0	0	1	35	76	1729

R-123 Netrokona

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1961	129	394	556	434	369	189	144	28	0	10	49	6	2308
1962	189	438	596	296	609	205	152	0	0	0	0	73	2558
1963	164	251	697	386	282	174	144	52	2	2	2	47	2203
1964	228	308	688	620	289	628	383	0	0	0	47	89	3280
1965	22	291	407	671	836	293	66	52	2	19	0	10	2669
1966	96	326	513	511	630	454	164	20	12	23	0	104	2853
1967	115	235	456	585	568	326	76	10	0	8	0	31	2410
1968	175	326	580	720	435	447	204	27	0	6	0	180	3100
1969	226	186	696	272	798	85	35	9	0	48	27	36	2418
1970	72	112	569	645	296	509	626	1	0	1	0	41	2872
1971	196	316	420	260	501	559	361	0	0	0	0	0	2613
1972	0	94	823	584	275	314	185	0	0	0	53	13	2341
1973	147	562	1487	603	520	534	74	84	23	0	0	0	4034
1974	270	444	681	435	416	495	386	0	0	0	0	0	3127
1975	348	513	132	726	589	435	244	13	0	0	0	0	3000
1976	61	226	1104	602	825	179	94	36	2	2	23	51	3205
1977	490	518	1486	754	194	170	282	18	9	0	8	37	3966
1978	147	642	1088	389	289	394	0	0	0	0	6	9	2964
1979	96	336	399	791	324	483	75	41	57	2	51	28	2683
1980	86	436	314	264	265	162	291	0	0	15	25	69	1927
1981	227	473	234	594	316	332	51	0	127	0	47	104	2505
1983	100	380	262	456	949	749	451	0	16	16	1	23	3403
1985	115	355	428	603	225	342	72	0	38	8	2	1	2189
1986	414	267	272	768	230	585	377	127	11	0	10	37	3098
1987	122	225	476	917	636	706	102	32	30	0	51	66	3363
1988	260	867	588	756	456	719	370	184	10	18	16	0	4244
1989	78	514	479	1025	350	539	350	0	3	0	46	92	3476
1990	347	842	564	592	415	520	302	2	0	0	23	23	3630
1991	236	845	570	526	550	842	524	0	80	0	26	34	4233
1992	98	433	461	1165	486	540	126	5	0	50	15	46	3425
1993	265	342	979	927	492	619	236	4	0	19	65	132	4080
1994	114	284	590	494	520	201	195	2	0	18	23	48	2489

R-125 Sheola

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1963	192	639	1130	427	426	205	265	0	0	8	24	89	3405
1964	409	536	1454	1070	518	538	304	1	0	0	152	51	5033
1965	298	466	992	457	628	582	43	67	3	32	0	92	3660
1966	160	673	1714	979	746	476	258	31	12	20	22	175	5266
1967	278	328	869	616	346	563	124	0	0	9	3	97	3233
1968	156	773	839	772	754	671	147	46	24	6	2	147	4337
1969	254	190	900	656	851	108	170	55	0	65	82	77	3408
1970	303	639	856	900	606	386	625	75	0	14	9	53	4466
1971	347	701	414	575	419	282	173	105	0	6	32	133	3187
1973	541	681	1190	596	533	397	70	88	120	0	25	186	4427
1974	557	469	823	886	494	364	277	13	0	0	73	56	4012
1975	290	617	273	910	813	448	245	69	0	0	3	400	4068
1976	256	381	1442	1070	607	317	140	41	0	16	50	100	4420
1977	995	661	830	542	545	217	250	51	15	0	0	62	4168
1978	211	517	1040	693	279	408	111	19	0	0	0	130	3408
1979	161	324	830	840	327	647	296	0	18	0	54	64	3561
1980	537	686	638	471	410	484	351	0	0	28	43	118	3766
1981	327	678	220	792	581	267	37	9	10	0	69	118	3108
1982	759	425	729	954	824	356	4	8	0	21	27	405	4512
1983	390	318	693	805	695	603	223	2	23	0	0	36	3788
1984	313	914	624	635	490	788	265	0	50	0	44	472	4595
1985	570	403	1331	521	543	613	31	0	6	0	0	87	4105
1986	447	128	470	602	465	289	445	112	0	14	4	181	3157
1987	463	156	876	796	449	807	88	38	15	0	54	92	3834
1988	298	1201	1074	519	816	621	370	122	46	18	43	34	5162
1989	303	625	960	1146	524	853	692	8	0	0	36	111	5258
1990	767	570	730	785	670	1232	231	65	10	10	61	102	5233
1991	389	1324	1090	393	703	1012	283	12	120	0	64	230	5620
1992	192	616	684	761	791	540	333	3	3	44	241	191	4399
1993	254	741	1064	1057	442	637	63	6	0	32	38	512	4846
1994	385	481	700	691	643	342	249	0	0	4	45	138	3678

R-126 Srimangal

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1961	67	320	364	211	412	226	97	19	0	15	58	2	1791
1962	116	266	679	375	322	18	115	0	0	0	0	110	2001
1963	0	420	496	310	283	225	448	0	0	9	81	138	2410
1964	526	391	427	443	272	189	331	49	0	0	79	86	2793
1965	92	298	694	385	332	261	63	68	7	2	0	128	2330
1966	194	450	634	559	395	207	222	39	48	44	0	163	2955
1967	253	178	272	360	290	352	79	0	0	1	19	96	1900
1968	189	493	448	573	500	299	98	23	0	67	0	82	2772
1969	351	47	452	246	448	124	102	32	0	40	0	77	1919
1970	78	255	453	613	256	379	226	26	0	5	24	0	2315
1971	0	98	327	229	261	160	230	96	0	1	44	98	1544
1972	197	309	527	477	192	178	30	4	0	21	99	16	2050
1973	354	730	573	402	324	168	96	143	97	9	0	60	2956
1974	304	550	554	471	209	181	92	34	0	0	8	7	2410
1975	315	327	339	386	391	200	105	79	0	0	20	60	2222
1977	801	544	585	152	341	137	299	96	17	0	0	20	2992
1978	194	774	723	261	280	204	58	2	0	0	11	52	2559
1979	50	156	419	351	299	286	45	19	71	1	2	113	1812
1980	245	687	346	268	187	327	237	0	15	26	70	139	2547
1981	518	472	212	476	417	126	10	0	8	0	80	32	2351
1982	344	223	449	392	491	263	32	11	0	2	25	351	2583
1983	414	594	489	194	577	381	127	2	47	0	0	12	2837
1984	107	1298	424	231	419	646	171	6	0	4	46	124	3476
1985	222	418	924	186	213	327	44	0	11	7	10	19	2381
1986	526	167	383	201	270	268	400	189	0	5	3	48	2460
1987	333	175	269	412	356	223	138	25	9	0	46	196	2182
1988	187	918	353	516	464	291	198	155	0	0	19	33	3134
1989	135	273	380	423	272	305	273	15	2	0	20	193	2291
1990	290	608	403	268	321	441	253	66	15	18	96	34	2813
1991	261	1132	594	270	218	512	309	0	210	0	43	41	3590
1992	148	394	305	314	401	208	196	6	0	5	114	56	2147
1993	160	436	902	609	442	346	140	48	0	11	58	254	3406
1994	210	287	244	269	492	142	146	11	0	6	40	94	1941

R-127 Sunamganj

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1961	104	490	856	854	626	353	250	5	0	13	47	11	3609
1962	140	503	904	790	1026	151	115	1	0	0	23	35	3688
1963	0	493	1578	1375	1253	408	187	11	0	15	29	78	5427
1964	387	516	1042	2113	1009	1130	607	2	0	0	125	85	7016
1965	213	396	1122	1235	1504	652	71	50	3	12	0	35	5293
1966	207	555	1028	1815	1370	557	91	18	6	4	0	121	5772
1967	271	522	1330	1416	1056	821	119	2	0	6	2	53	5598
1968	134	578	1139	1556	739	679	169	0	0	24	0	221	5239
1969	279	255	1339	887	1294	419	80	0	0	40	22	26	4641
1970	256	1218	1116	1306	1022	732	473	11	0	6	0	93	6233
1971	417	322	801	560	661	652	288	84	0	0	45	84	3914
1972	248	583	1639	1205	556	438	210	0	0	4	76	0	4959
1973	343	835	2466	818	838	767	168	10	0	0	0	152	6397
1974	128	367	408	784	266	256	162	1	0	2	2	2	2378
1975	209	404	578	1731	798	696	268	41	0	0	27	146	4898
1976	136	499	1777	1387	2012	573	192	70	0	0	23	187	6856
1977	861	818	1192	1435	1401	413	520	52	9	0	16	20	6737
1978	332	667	1088	1497	679	686	225	11	0	0	4	25	5214
1979	62	323	988	2172	1221	820	456	18	71	2	40	63	6236
1980	370	738	771	703	768	610	230	0	0	31	15	35	4271
1981	207	542	249	1865	915	1472	16	0	43	0	48	69	5426
1982	533	336	1038	1480	627	523	58	18	0	3	20	122	4758
1983	225	528	719	1620	1522	862	333	0	90	10	0	90	5999
1984	272	831	852	1123	1127	1386	369	4	42	6	31	161	6204
1985	414	319	713	1986	1260	722	35	0	15	3	0	0	5467
1986	339	224	638	1596	1413	759	497	105	1	2	6	104	5684
1987	453	333	1054	1630	694	1651	111	2	14	0	38	94	6074
1988	372	1138	1001	1726	2515	1093	596	144	4	0	60	0	8649
1989	423	562	1303	1988	1399	963	677	0	0	0	88	146	7549
1990	554	521	1126	976	1298	1440	424	10	2	4	15	19	6389
1991	315	1174	1436	1244	858	1489	360	0	68	0	40	129	7113
1992	166	632	1393	1582	1024	826	240	3	0	73	212	96	6247
1993	259	851	1700	1755	1290	895	309	0	0	18	60	318	7455
1994	381	787	906	1334	1010	629	298	6	0	12	60	33	5456

R-128 Sylhet

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1961	199	593	919	465	474	673	81	0	0	7	56	3	3470
1962	256	397	981	375	740	158	127	1	0	0	16	62	3113
1963	0	575	1133	556	623	228	213	4	0	26	13	148	3519
1964	624	564	1155	1087	560	511	264	2	0	0	154	45	4966
1965	301	397	917	558	893	540	115	88	4	23	0	31	3867
1966	190	498	1230	819	552	394	156	9	13	28	53	124	4066
1967	286	320	1016	514	389	652	72	2	0	14	10	115	3390
1968	248	657	854	836	779	592	88	10	0	15	2	200	4281
1969	364	399	1008	648	849	173	62	58	0	55	83	53	3752
1970	379	742	813	967	654	426	555	44	0	26	6	67	4679
1971	237	243	503	518	595	361	274	92	0	10	36	118	2987
1972	484	498	1403	970	406	333	276	0	0	8	123	2	4503
1973	409	789	1222	752	443	651	59	92	74	0	0	108	4599
1974	740	452	1018	1184	940	478	386	7	0	0	0	0	5205
1975	323	574	445	1057	846	428	206	102	0	0	14	354	4349
1976	166	468	1610	1131	742	285	259	46	0	18	60	147	4932
1977	929	580	853	660	653	159	386	72	18	0	3	43	4356
1978	220	687	1002	658	226	473	165	19	0	0	2	66	3518
1979	127	349	855	1387	381	577	271	22	27	1	30	112	4139
1980	531	799	503	493	373	757	452	0	0	27	33	89	4057
1981	380	853	288	854	679	501	30	0	20	0	25	74	3704
1982	703	353	852	852	651	681	48	8	0	22	32	264	4466
1983	359	572	702	878	793	507	247	0	17	8	2	89	4174
1984	352	1019	615	840	305	1194	316	23	69	0	33	271	5037
1985	579	392	1106	719	485	603	122	0	24	0	1	36	4067
1986	405	163	424	701	496	452	484	108	1	0	33	142	3409
1987	423	219	845	1306	735	970	128	42	12	0	19	165	4864
1988	377	1196	1000	722	1138	604	699	179	46	5	34	11	6011
1989	322	506	908	1393	677	1220	552	0	12	0	37	174	5801
1990	602	542	685	827	743	1069	261	27	2	6	64	92	4920
1991	465	1270	1342	370	478	787	186	2	83	0	65	190	5238
1992	152	598	736	945	389	488	232	3	1	38	205	116	3903
1993	297	699	1229	1273	587	731	98	3	0	23	47	604	5591
1994	392	406	699	825	608	238	176	3	0	12	34	99	3492

R-129 Tajpur

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1965	87	424	780	533	660	433	166	182	6	32	0	20	3323
1966	316	427	553	641	685	421	295	38	25	45	0	136	3582
1967	341	504	1080	594	381	846	88	7	0	3	0	92	3936
1968	334	810	1140	897	544	672	159	30	0	26	0	220	4832
1969	425	285	965	597	762	170	99	32	0	74	48	14	3471
1970	261	458	934	915	446	431	561	60	0	13	3	139	4221
1971	369	412	523	662	494	466	280	62	0	3	9	91	3371
1972	316	456	797	690	431	193	138	0	0	2	80	3	3106
1973	224	656	494	529	399	351	51	60	82	0	22	126	2994
1974	473	371	693	703	504	452	587	16	0	0	25	31	3855
1975	457	800	565	990	831	427	428	62	0	0	23	201	4784
1976	50	275	1463	694	742	168	171	145	0	89	131	145	4073
1977	656	640	971	323	671	101	238	36	12	0	0	31	3679
1978	208	974	739	632	224	299	16	0	0	0	5	88	3185
1979	61	201	950	660	231	449	122	8	52	5	42	112	2893
1980	525	935	802	319	208	274	54	0	0	43	13	13	3186
1981	300	636	446	1531	781	338	9	0	8	0	5	39	4093
1982	854	321	2500	2516	2225	882	0	23	0	8	16	279	9624
1983	341	678	697	286	617	452	112	2	43	0	0	126	3354
1984	241	1025	320	555	275	802	297	1	38	0	44	123	3721
1985	334	319	987	387	365	549	10	0	16	0	0	0	2967
1986	392	186	274	661	415	365	401	65	2	8	13	148	2930
1987	392	222	1006	754	604	354	160	10	0	0	56	30	3588
1988	287	1224	803	830	612	399	282	156	23	30	5	0	4651
1989	329	691	720	1036	450	790	400	0	0	0	32	67	4515
1990	265	443	562	558	678	780	205	55	0	10	70	39	3665
1991	342	951	501	230	412	734	180	0	86	13	63	88	3600
1992	157	392	390	440	385	299	144	0	0	32	166	43	2448
1993	304	731	1144	1239	315	371	132	0	0	23	33	428	4720
1994	212	251	588	458	448	120	204	3	0	9	10	111	2414

R-130 Zakiganj

Rainfall in mm

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1964	469	504	981	1279	449	541	505	2	0	0	37	82	4849
1965	258	330	817	822	633	312	121	157	24	26	0	66	3566
1966	145	771	1552	630	549	311	88	36	0	34	14	100	4230
1967	278	316	861	980	425	289	6	0	0	0	77	221	3453
1968	596	1910	1795	2417	1382	1169	346	60	13	43	1	234	9966
1969	306	288	890	624	840	120	157	34	0	52	65	107	3483
1970	339	522	771	864	555	470	392	48	0	16	8	33	4018
1971	484	372	290	416	426	420	244	108	0	7	63	153	2983
1972	490	702	1212	771	360	142	177	0	0	2	98	5	3959
1973	599	555	970	621	557	176	109	76	122	0	22	304	4111
1974	378	716	738	733	538	364	230	29	0	0	53	194	3973
1975	466	682	158	861	604	382	122	66	0	1	10	318	3670
1976	224	481	1287	620	409	361	11	0	0	10	130	160	3693
1977	793	379	707	601	717	177	170	48	12	0	0	101	3705
1978	295	598	666	808	387	402	164	10	0	0	0	140	3470
1979	157	446	695	776	388	606	392	5	30	0	51	78	3624
1980	564	834	988	570	469	550	346	0	0	22	41	130	4514
1981	348	1006	300	1013	362	313	0	9	10	0	20	39	3420
1982	807	465	740	1103	596	340	59	11	0	4	47	483	4655
1983	488	390	564	543	1078	415	134	13	55	9	0	24	3713
1984	364	730	335	614	381	362	284	23	11	0	60	551	3715
1985	522	289	962	440	392	433	62	0	22	2	4	42	3170
1986	550	112	370	636	385	296	472	104	0	0	1	200	3126
1987	394	199	766	831	520	836	47	32	10	0	49	160	3844
1988	374	1164	698	640	950	800	423	112	28	33	58	89	5369
1989	393	824	661	1182	618	727	512	7	0	0	100	121	5145
1990	935	465	738	842	680	1288	258	57	0	10	73	69	5415
1991	421	1200	1221	489	559	578	256	20	97	0	73	217	5131
1992	201	680	688	563	594	394	387	0	0	36	279	274	4096
1993	270	968	1103	933	865	870	105	5	0	30	25	844	6018
1994	415	392	750	455	580	352	320	60	0	10	30	165	3529

