THESIS

DRAINAGE REQUIREMENT FOR SELECTED CROPS IN THE NORTH-EASTERN REGION OF BANGLADESH

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED BY MRS. SELINA BEGUM ENTITLED DRAINAGE REQUIREMENT FOR SELECTED CROPS IN THE NORTH-EASTERN REGION OF BANGLADESH BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING (WATER RESOURCES).

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ABSTRACT

Drainage coefficient has been determined to avoid crop damage from flooding caused by on-site rainfall for the North-eastern region of Bangladesh which has heaviest rainfall. Climatically the North-eastern region has been divided into three zones. Crops selected for the present analysis are Broadcast Aman, HYV Transplanted Aman, HYV Aus, HYV Boro and summer vegetables.

Daily rainfall data from 68 raingauge stations of the region have been used in the study. Probable maximum 3-day rainfall on the basis of running days has been calculated by Gumbel's Method using 10-years daily rainfall data for a return period of 10 years. Kolmogorov-Smirnov method has been used to test the goodness of fit of the data.

Potential evapotranspiration has been determined by the modified Penman equation as described by Doorenbos and Pruitt. Crops have been categorized under 5 different drainage classes considering the tolerance limit to submergence, duration of submergence, growth stage, plant height and physiological behavior. For each drainage class, water balance equation has been developed.

Maximum drainage coefficient was found for T. Aman (Transplanted Aman) in all the three climatic zones. These values are found to be 63.55 mm/day, 75.19 mm/day and

103.05 mm/day for the climatic zones I, II and III respectively. Drainage coefficient for Aus rice is 49.35 mm/day and 51.13 mm/day in the zone II and III respectively. Aus rice needs no drainage in zone I, because drainage is not acute due to small rainfall during that period. Boro rice can grow without any provision of drainage. On the other hand the requirement of drainage magnitude for upland crops (summer vegetables) is 1.5 times more than that of rice.

These drainage coefficients are applicable to the flood protection areas and to the areas where flood protection is under execution in the North-eastern region of Bangladesh. The cropping pattern to those areas can be improved if provision is made for drainage.

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NOTATIONS

N	-	Sample size
S_N	-	Standard deviation of sample
S_{N-1}	-	Standard deviation of series omitting highest value in the series
T	-	Return period in years
U	-	Mode or location parameter
x	-	Initial variate
$\bar{X}_N$	-	Sample mean
$\bar{X}_{N-1}$	-	Mean of the series omitting highest value- in the series
X_T	-	3-day maximum rainfall in mm
y	-	Reduced variate
$\bar{Y}_N$	-	Theoretical quantity
σ_N	-	Scale parameter which is analogous to standard deviation
Q	-	Drainage coefficient, mm/day
S	-	Seepage and percolation, mm/day
ET_c	-	Crop evapotranspiration, mm/day
PT	-	10-yr frequency, 3-day duration depth of rainfall, mm
F_{LT}	-	Long term flooding, mm

CHAPTER-1
INTRODUCTION

1.1 General

Bangladesh is one of the world's largest deltaic countries. It consists of the flood plains of three major rivers - the Ganges, the Brahmaputra, the Meghna and their tributaries and distributaries (Fig. 1). The land to the west of Brahmaputra is generally higher than that on the east. During the process of delta building, several depressions were formed as a result of geographical faults. The pronounced depressions are in the Northwest (Rajshahi, Pabna and Bogra districts), Northeast (Sylhet, Mymensingh Haor areas) and in the South (beel areas of Khulna, Faridpur and Barisal). These areas are inundated with the advent of monsoon and remain waterlogged to different depths until November.

The climate of Bangladesh is of the tropical monsoon variety, characterized by high temperature, heavy rainfall, excessive humidity and fairly marked seasonal variations. There are three distinct seasons, viz. the warm season from March through May, Monsoon season from June through October and the winter season from November through February. The average January temperature (winter season) varies from 19^{o}C in the southern parts of the country to 17^{o}C in the north. The average July temperature varies between 27^{o}C and 32^{o}C in the different parts of the country. The sky remains cloudy for long period and high humidity persists with high temperature.

There are three distinct rainfall periods in Bangladesh. The premonsoon, a norwesterperiod (March-May), monsoon period (June to October), and dry winter months (november to March) with very small amount of rainfall.

The distribution of rainfall throughout the year is not uniform. During monsoon period rainfall is heavy, while in winter months it is scanty. The mean annual rainfall in Bangladesh varies from 1400 mm in the west to over 5000 mm in the northeast[23/]. It is characterized by wide seasonal fluctuations, with about 90% of rainfall occuring in the six-month monsoon period (May-October). Hence plants get affected because of drought in one period and abundance of water in another period. Since the rain falls during the most active part of the growing season of major crops (e.g. rice) when the plants are susceptible to the effects of flooding, excess water must be removed within a specified time to prevent damage to crops.

1.2 Background and Statement of the Problem

Bangladesh, streching over 14.3 million hectares and having a population of 89.9 million peoples suffers from food grain deficiency every year. Of the land available for cultivation, 95 percent is under agricultural production. But crop yield is among the lowest in the world. Production is frequently reduced due to climatic extremes which ranges from flooding to drought.

Flooding may cause because of excess rainfall or spills from rivers (flood water). Excess soil water obstructs agricultural productivity in different ways.

If there is standing water over the land, the land becomes waterlogged. Because of lack of oxygen in the waterlogged condition most upland crops are injured and even die due to continued submergence. Though rice can survive under submerged condition but the extent to which it can survive depends on the variety and growth stage, duration of submergence, quality of water and other physiological factors.

The productivity of the land may become affected when the rootzones of the plant get flooded. The normal cultivation operation such as tilling, ploughing, transplanting etc. cannot be easily carried out in swampy land. There may be salinity problem if the land is waterlogged.

To avoid all these problem which hamper agricultural productivity, it is necessary to drain out excess water in proper time.

Drainage is the removal and disposal of excess water either from the surface or from beneath the surface. The main purpose of drainage is to provide a root environment that is suitable for optimum plant growth. It is related to the source of excess water, rate of flow of excess water through the soil, crop evapotranspiration and tolerence of crops to submergence. The amount of water to be removed from the watershed per day to provide a certain degree of crop protection is very important for the design of drainage system. The rate at which excess water must be removed is termed 'drainage coefficient', which is expressed either in mm/day or m^3/sec/ha.

Drains must be designed on the basis of drainage coefficient. Some empirical criteria are often used for design of drains in humid areas. Since empirical criteria are based on experience and assessment of numerious interrelating factors, care must be taken in their application from one locality to another.

In humid regions the major source of excess water that makes drainage necessary on parts of the irrigated land is due to on-site rainfall and its spatial distribution. Protection to prevent damages of crops from flooding caused by on-site rainfall has been considered here.

Lack of recognition of anticipated drainage caused failures of many irrigation projects. Provision for drainage not only boost up the agricultural production through avoiding water-logging or submergence but also add versatality in cropping pattern.

The cropping system in Bangladesh include some crops which are tolerant to poor drainage (like deep water rice) but some with very low tolerance (like vegetable crops, rabi crops). The adjustment in the cropping system or a new crop calendar can be made by choice of crops adapted to the conditions of drainage.

Until recently, drainage has not been given the importance as it deserves in the design and implementation of water resources development projects in Bangladesh. Only a few works have been taken in this direction. Very recently Bangladesh Master plan organization (abbreviated as MPO) experts have completed a brief report[24] to determine crop drainage requirement due to on-site rainfall. But studies involving detailed quantitative evaluation are lacking. The present study involving analysis of long term daily rainfall data will provide a reliable basis for design of drainage system.

1.3 Scope of Study

The Northeastern part of Bangladesh is one of the highest rainfall regions in the-country. The mean annual rainfall and the rainfall distribution during the monsoon period in the country is indicated by isohytes in Figs. 2 and 3[23]. Isohytes becoming progressively closer in the Norteast corner of the country. The Cherapungi (India) which is the rainiest place in the world is located near the northeast part of the country. Hence meteorologically it is seen that the Northeastern region of Bangladesh is comparatively wet over which the rainfall lasts for about seven months of the year in average. The present study has been confined to this region only.

The specific objectives of the present study are:

1) Identification and classification of drainage problem.

2) Rainfall frequency analysis on the basis of running days (using daily rainfall data) for the growing season of the selected crops.

3) Determination of drainage coefficient necessary to avoid damage from submergence caused by on-site rainfall for various crops.

CHAPTER-2

FACTORS CONTROLLING DRAINAGE COEFFICIENT

2.1 Introduction

The amount of water to be removed from the watershed per day to provide a certain degree of crop protection is related to the source of excess water, depth of water and its duration, tolerance of crops to submergence, growing season of the crop, crop evapotranspiration and the rate of flow of excess water through the soil. A detailed discussion about the factors that affect drainage coefficient is given here.

2.2 Source of Excess Water and Its Depth

2.2.1 Rainfall

The source of excess water is rainfall. The amount of rain that falls on the ground in a certain period is expressed as the depth (mm, inches etc.) to which it would cover a horizontal plane on the ground. As rainfall is extremely variable in time and space, the rainfall data covering long periods and recorded at various stations have to be studied. The rainfall depth may be considered a statistical variate, its value depends on the season of the year, the duration selected and the area under study. For the design of drainage works the amount of water that have to be discharged must be known from rainfall data analysis.

In a design the frequency, season and duration chosen depend on the type of problem under consideration.

2.2.2 Choice of a Design Frequency

The higher a rainfall, the less often it occurs. Consequently the higher the design rainfall, implying a more costly project but lesser risk of failure. There is however, a certain point at which the cost of ensuring more safety outweighs the benifits of a further reduction in the number of failures. Therefore the choice of a design frequency is an optimization problem. If failure is to be understood in an agricultural sense only i.e a loss or reduction in agricultural production as may occur in irrigation and drainage projects, an average failure of once in 5 or 10 years is generally accepted[15/]. For this study a design frequency of 1 in 10 years has been selected.

2.2.3 The Critical Season

The rainfall analysis for drainage design can be restricted to that part of the hydrological year during which excess rainfall may cause damage. When the drainage problem concerns surface drainage for crop protection, it is the growing season that may be critical. For Bangladesh, examination of the data showed that the extreme events of rainfall could occur any time within the period April to October, though there is a belief that highest frequency of occurence will occur in the main monsoon months of June, July and August[1/]. For this study the period, April to October was selected as the critical season.

2.2.4 The Critical Duration

The rainfall intensity is expressed as a depth per unit of time. This unit can be an hour, a day, a month or a year. The type of problem will decide the duration to be selected for analysis. In drainage studies, if it is related to prevent damage to crops, the duration which the crops can survive under a certain depth of submergence is also important.

In drainage design the critical duration is of the order of some days (successive day) or moving total[15/]. The advantage of the moving totals is that they take into consideration of all possible totals (say all consecutive 5-day totals) and do not result in an underestimation of high 5-day rainfalls. For this analysis critical duration has been selected as 3-day moving totals, since the crops selected for this study cannot survive under submergence of more than 3 days.

2.2.5 Net Work Density of Raingauges

The required network density of raingauges depends on the area variability of rainfall and the type of problem for which it is required. A network should be planned to yield a representive picture of the areal distribution of precipitation.

There should be no concentration of gages in heavy-rainfall areas, or vice-versa. A relatively sparse network of stations would suffice for studies of long-duration rainfalls (e.g. annual). A very dense network is required to determine the rainfall patterns of thunderstorms. The following minimum densities of precipitation networks[21] have been recommended for general hydrometeorological purposes:

1. For flat regions of temperate, mediterranean, and tropical zones, 600 to 900 km^2 per station.
2. For mountainous regions of temperate, mediterranean and tropical zones, 100 to 250 km^2 per station.

Total area[5] of the North-eastern region is 43211 km^2. The area of the climatic zone 1, 2 and 3 in the North-eastern region are 37363 km^2, 3117 km^2 and 2727 km^2 respectively[5]. According to the specifications recommended by World Metrological Organization, a network of 700 km^2 per station on an average was assumed for climatic zone 1 and 2. The stations available in zone 1 and 2 are 56 and 6 respectively (Fig. 14). This provides a network density of 667 km^2 and 520 km^2 per station for zone 1 and 2 respectively. Hence the network density for zone 1 and 2 is more than the specified density. Zone 3 is located near the hilly region of Sylhet. Hence a network of 300 km^2 per station was assumed for this zone. The number of stations available in this zone is 6 (Fig. 14). This provides a network density of one station per 303 km^2, which is slightly lower than the required density.

2.2.6 Area Averages of Rainfall

The analysis of rainfall is understood here to be the analysis of area averages of point rainfalls. There are several methods of computing area averages of rainfall. The methods are arithmetic mean, the Thiessen method and the Isohyetal method. An advantage of the arithmetic mean is its simplicity. The method can only be used in a relatively flat area, where no irregular changes occur in isopluvial spacing and where the stations are evenly distributed, thus being equally representative.

The Thiessen method can be used when the stations are not evenly distributed over the area. Moreover the method is rather rigid, excluding additional information on local meteorological conditions, its use is restricted to relatively flat areas.

When the rainfall is rather unevenly distributed over the area, for instance due to difference in orographic exposure, the isohyetal method may be applied to compute the area rainfall.

In this study the arithmatic mean method has been selected to calculate the area average of rainfall.

2.2.7 Estimation of Missing Data

If there are gaps in the observations of certain station, it will sometimes be possible to fill them by correlation with other nearby stations. In the procedure used by the U.S. Environmental Data Service[21/], precipitation amounts are estimated from observations at three stations as close to and as evenly spaced around the station with the missing record as possible. If the normal annual precipitation at each of the index station is within 10 percent of that for the station with the missing record, a single arithmetic average of the precitation at the index station provides the estimated amount. This method was adopted in this analysis.

2.2.8 Frequency Analysis of Rainfall

Since design and planning are concerned with future events whose time or magnitude cannot be forecast, we must base on probability or frequency with which a specified rate or volume will be equalled or exceeded. The frequency analysis can be conducted by several statistical methods. Since the pattern of rainfall in our country is variable, frequency analysis for moving totals of daily rainfall will be more appropriate for drainage design.

Works of several investigators on rainfall frequency analysis is cited here in order to select a method for the present analysis.

A Review on Comparison of Some Methods of Distribution

In 1959 Huff and Neil[14] compared five distributions for their ability to estimate the largest rainfall value in Illinois. The distribution included Gumbel (extreme-value distribution-I),Lognormal, Frechet, Log-skew and Jekinson method. Analysis were performed on both seasonal and annual maximum for storm period of one to ten days. Results of this study indicated that no marked superiority was obtained from any of these methods. In a paper, Hershfield and Kholar[12] appraising the predictive value of the Gumbel procedure from 60-minute rainfall data observed that this procedure was acceptable for practical purposes. Again Hershfield[13] made an extension to two other methods and additional duration to compare the three extreme value procedures of rainfall distribution. The extreme value procedures were Fisher-Tippet type-I distribution fitted by Gumbel and Lieblin method and lognormal method fitted by method of moments. He then concluded that type-I distribution fitted by Gumbel procedure was the best of three procedures for estimating the probability of extreme value data (Fig. 4). Chow[7] also applied this procedure to study the rainfall intensity frequency in Chicago, Illinois.

In a paper Narayana, Gupta and Tiwari[27] conducted frequency analysis of 25 years of daily rainfall data for the determination of runoff potential by four distribution methods. The methods were (a) Type-I extremal probability distribution,

(b) Pearson's Type-II logarithmic distribution (c) Log-normal distribution and (d) Gumbel distribution. The study region was Kernal, India. The results of the analysis of daily rainfall data (annual maximum series) by different methods indicated that in the range of 2-10 year return period which was important for agricultural purposes, the variation among the methods was only $\pm$ 4 percent (Table 1). As these values fitted the observed data well, any of these methods could be adopted depending upon the convenience. For their analysis, the 5-day rainfall values during June to September period were fitted by Gumbel distribution.

Recently Matin[25/] estimated the daily maximum rainfall magnitude for different return periods for 68 stations of the North-eastern region of Bangladesh by using the Gumbel distribution. The prediction equations for maximum daily rainfall for return periods of 2,5,10,20,50 and 100 year were developed. Typical plotting of the data in the probability paper for a station is shown in Fig. 5. For all the stations, the data fitted by Gumbel procedure presents good correlation. Hence the Gumbel method has been selected for the present analysis of rainfall data in the Northeastern region of Bangladesh.

Double Exponential Distribution Function

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

$$P = F(x) = \exp(-e^{-y}) \qquad 2.2.1$$

and $$y = \frac{X - U}{\beta} \qquad 2.2.2$$

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

Combining the above two equations, the distribution may be written as

$$F(x) = \exp\left[-\exp\left(\frac{1}{\beta}(x-U)\right)\right] \qquad 2.2.3$$

It was introduced for extreme values by R.A. Fisher and I.H. Tippet. This function is sometimes known in hydrology as Gumbel distribution because of Gumbel's various studies using this distribution in the flood frequency analysis.

Prediction equation for the double exponential distribution function:

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

$$U \doteq \bar{X}_N - \frac{\bar{y}_N}{\sigma_N} S_N \qquad 2.2.4$$

$$\beta = \frac{S_N}{\sigma_N} \qquad 2.2.5$$

where $\bar{y}_N$ and σ_N are the theoretical quantities which are function of sample size only. Gumbel provides a table of values (Table 2) for $\bar{y}_N$ and σ_N as function of sample size N. Therefore, the prediction equation for rainfall magnitude (X_T) may be expressed by the following function.

$$X_T = U - \beta \ln \left[\ln \left(\frac{T}{T-1} \right)\right] \qquad 2.2.6$$

where T = return period in year.

2.3 Tolerance of Crops to Submergence

2.3. Factors Effecting Tolerance

The depth of standing water under which a plant can survive without any economic damage or loss is the tolerance limit of the plant to submergence. Tolerance of crops due to standing water depends on the type of crop and its variety, the growth stage, the physiological behaviour of the plant, water depth, rate of rise of water, duration of submergence, rate of flow of drainage water, drought effect and turbidity of water. Tolerance limit of a crop effects drainage coefficient in many ways.

2.3.1 Type of Crop and Its Physiological Behaviour

In waterlogged soils, the availability of oxygen is redused considerably. This has a direct bearing on the respiratory activity of roots for most of the crops. As against thissa rice crop grows profusely under submerged conditions upto a certain extent, because of large intercelluar spaces in leave and stem which maintain continuity with roots. Thus in rice, oxygen transport throughout the plant is possible. Because of this physiological and anatomical behaviour rice can grow under flooded condition (upto a certain extent). But other crops which does not posses this special behaviour, cannot survice under submerged condition. Any water above field capacity will damage the crop. Hence excess water which will cause surface flooding should be removed in case of upland crops.

Tolerance to submergence changes with type of crop and also with its variety under similar agroclimatic conditions.

The physiological changes which occur to cope with the flooded condition is different for different types of rice.

Hence analysis will focus on different types of rice and upland crops separately.

RICE

Based on varietal type, rice culture can be classified into 4 types[8/]. These are:

1) Lowland rice, with plants of semidwarf to medium to tall (100 cm to 2m) height.

2) Upland rice, with plants of medium to tall (130-150 cm) height.

3) Deep water rice, with plants of medium to tall (120-150 cm tall without standing water, 2-3m with rising water level) height.

4) Floating rice, with tall (150 cm tall without standing water; 5-6 meter tall with rising flood water) plants.

Recently, Barker and Herdt (1979) classified rice lands of South and Southeast Asia, according to water depth[8/]. For lowland rainfed rice, they used shallow rainfed (5-15 cm) and medium deep rainfed (16-100 cm), with medium deep rainfed further classified into intermediate deep (15-50 cm) and semi-deep rainfed (51-100 cm). Where water depth exceeds 100 cm they classified rice lands as deep water. Further refinements has been made of the system suggested by Barker and Herdt (1979), with both deep-water and floating rice areas totally excluded from the rainfed lowland rice areas. The refinements of the classification are as follows:

Types of culture	Main method of planting	Maximum water depth in cm
Rainfed lowland rice	Transplanting	0-50
Shallow rainfed lowland rice	"	5-15
Medium-deep rainfed lowland rice	"	16-50
Deep water rice	Broadcast on to dry soil	51-100
Upland rice	Drilled into dry soil	No standing water

Rice is mainly a low land crop. In our country the different types of rice which usually grow are Aus, Aman and Boro. Aus and Aman rice can be either transplant or broadcast type. Boro rice is usually transplanted. Also there are many varities of local and HYV (high yielding variety) rice. Transplanted Aus (T. Aus), Transplanted Aman (T. Aman) and Boro of high yielding varieties (HYV) and broadcast Aman (B. Aman) were selected for the analysis of the present study.

Many upland crops (such as wheat, cotton, sugercane, vegetables etc.) grows in our country. Since the analysis mainly focusses on rice, other than rice only summer vegetables (cucerbit) which grows in the monsoon season has been considered for the present study.

2.3.2 Physiology of Different Types of Rice and Other Crops

Deepwater or Floating Rice

The most important feature of deep water rice is its ability to elongate with the rise of flood water or when it is suddenly submerged. Its ability to elongate depends on the age of the plant at the time of flooding, rate of water rise, duration of water rise and other factors. It is a varietal character. Most deep water rice attain the capacity to elongate at the age of 6 weeks (Vergara, 1974). The rate of elongation may vary from 20-28 cm a day. In Bangladesh the daily increase in plant height may be as much as 60-90 cm[8]. A typical variety of floating rice have been reported to elongate as much as 6 m[8]. Elongation of the plant occurs before the complete emergence of panicles. The plant makes a constant effort to keep its leaves above water by elongation as well as by increasing the number of internodes. A deep water rice variety produces 7-10 nodes and internodes under ordinary non-flooded condition but when flooded, it produces 16-22 nodes and internodes[3]. Increase and decrease in internode length is mostly associated with water level which varies from time to time during the monsoon. Each internode length ranges from a few to 50 centimeter. Flood resistance of a typical deep water rice variety is determined by the number of internodes the plant produces in response to the water rise. As time passes, the lower internodes get thin and weaken. Finally they become inactive while the upper internodes remain healthy and physiologically active. They usually tiller when water levels tend to remain constant and at the time of recedence. When water rises rapidly, the plants only elongate their internodes to survive without producing any nodal tillers and nodal roots.

Another feature of deep-water rice is the capacity to withstand uprooting. Deep-water rice is commonly known as floating rice because the plants upper culm or stem and leaves remain prostrate on the water surface and appear to float. If deep water rice is uprooted by water currents and winds, the nodal roots supplement the plant nutrient to survive and produce some grains.

The true floating varieties (which survive more than 3 m) can elongate internodes even just after germination if stress of flooding is present, but the culm will be thin like thread.

Because of the morphological behaviour of the deep water or floating rice, they can survive under flooded conditions. A flood resistant variety also needs a certain period of seedling growth to ensure flood resistance.

Non-floating Varieties of Rice

The gross morphology of deep water rice is not much different from that of other varieties of rice, except that some parts are modified to adapt to flooded condition. The degree of elongation (to keep pace with the rapid rise in water level) seems to be a critical difference between the floating and non-floating varieties rather than the ability to elongate. The non-floating varieties also elongate but to a lesser degree (this cannot keep pace with rise of water).

Physiology of Other Crops

Rice plants differ from others in that they can grow under waterlogged conditions because of their special anatomical and physiological characteristics (oxygen transport throughout the plant is possible).

Other crops (such as upland crops) can take oxygen only through the roots. If the rootzone of the soil get submerged there will be deficiency of oxygen. This deficiency causes reductions in root respiration. If the soil is allowed to remain water-logged, continued poor aeration results in death of a plant.

2.3.3 Rate of Flow of Drainage Water

If the rate of flow of water (rain water) is very high, the plants may be sweept away by the high speed of the flowing water. For this action, plant leaves may be submerged. If the leaves goes under water, very small area of the leaves will be exposed to sunlight. Hence the photosynthetic action of the plant will be reduced remarkably. This will reduce the tolerance limit of plants. If this type of flow lasts for 2-4 days, plants may wilt permanently.

2.3.4 Drought Effect

It will affect the tolerance of plants under submerged condition in different ways, (a) growth retarded and growth stages may be changed, (b) plants become weak.

If there is scarcity of available moisture, plant growth may be retarded, and plant becomes weak. Hence the expected height may not be achieved at expected time. Thus tolerance to submergence may be changed at different stages of growth. Hence the stage at which the crop is susceptible to a certain depth of water may be changed. The plant may be damaged even under a smaller depth of water than that specified at that stage of growth, because of the reduction in plant height.

2.3.5 Turbidity of Water

If the water (rain water or flood water) is turbid, it will affect the plant and hence tolerance limit in many ways. If the water is muddy it will form a layer around the plant, which may produce toxic substances harmful for the plant. Among the toxic substances which are known to accumulate in the rhizosphere are the metabolites (ethanol, aldehydes etc. and even some ethylene)[31]. Rice have been shown to have a strong alcohol dehydrogenase system which could effectively eliminate the accumulation of alcahol. Epinasty in leaves of the plants standing in water, could be due to the adverse effect of ethylene[31]. Since muddy water is denser than clear water, it can sweep the plant easily. Hence the tolerance limit is affected by the turbidity of water.

2.3.6 Growth Stage

Since tolerance is related to the plant physiology, it also varies with growth stages. Different physiological changes occur at different stages of growth. The growth stages are described here.

Rice

The entire life cycle of the rice plant may be divided into three main phases[8]. These are:

1. The vegetative phase, which runs from germination to panicle initiation.
2. The reproductive phase, which runs from panicle initiation to flowering.
3. The ripening phase, which runs from flowering to full maturity.

These main phases, however may be subdivided into physiologically distinct stages or periods. Fig. 6, shows the detailed divisions of the main phases of the rice crop with different durations. In short duration photo period-insensitive varieties (105-120 days variety) maximum tiller number, panicle initiation and internode elongation occur almost simultaneously. In long duration photoperiod sensitive varieties(150-270 days variety) there is a so-called lag vegetative period during which maximum tillering, stem elongation and panicle initiation occur in sucession. It is the vegetativephase which varies most in its duration depending upon the varieties. Seedling and maximum tillering constitue the basic vegetative (active) phase and from maximum tillering to panicle initiation it is called lag vegetative phase (grand growth). The duration of the basic vegetative phase varies among varieties generally between 25-65 days[31/]. The difference in the growth duration of rice varieties(long duration varieties) is mainly the result of variations in the duration of lag vegetative phase.

The reproductive phase begins with panicle initiation and lasts upto complete flowering. The flowering phase consists of panicle initiation, booting, heading, anthesis, pollination and fertilization stages. Panicle initiation begins from 70 to 75 days earlier to the approximate date of maturity regardless of variety[31/].

In the tropics, the ripening phase (from flowering to maturity) occupies a period of 25 to 35 days before maturity regardless of variety[8/]. In the temperature countries, such as Japan, Southern Australia and the United States, ripening takes 45-60 days[8/]. During this phase grain undergoes milk and dough stages.

The growth and development stages of the rice plant differ under different climatic and cultural conditions. Based on experience in Texas[8/], simplified time ranges for each development stage of the rice plant has been developed (Fig. 7). The time ranges presented are for the very early and early maturing photoperiod-insensitive varieties. Although the time ranges represent a warm or cool weather combination for the texas rice belt, the basic time ranges should be applicable in areas with a similar environmental regime.

Recently the consultants of MPO[19/] adopted the growth stages and number of days within each growth stage for rice growth in our country. Duration of the growth stages are as given in Table (i) (Next page):

Table (i) Duration of growth stages (short duration rice)

Crop	Growth stages	No. of days within growth stage
HYV Rice	Transplanting-Maximum tillering	45
	Maximum tillering-panicle initiation	5
	Panicle initiation-heading	30
	Heading - Milk	10
	Milk - Maturity	20
Local improved varieties of rice	Germination - maximum tillering	50
	Maximum tillering - heading	35
	Heading - milk	10
	Milk - maturity	20

On the basis of above specification, the duration of the different growth stage of HYV Aus, T. Aman & Boro has been selected as:

1. Vegetative phase - 50 days
2. Reproductive phase - 30 days
3. Ripening phase - 30 days

Total duration of Broad cast Aman in Bangladesh ranges between 180 to 270 days[3/]. The duration of growth stages of a variety of 220 days are shown in Table (ii) (Next page):

Table (ii) Duration of growth stages (Long duration rice)

Crop	Growth stage	No. of days within the growth stage
	Seeding to maximum tillering (active vegetative stage)	30
B. Aman	Maximum tillering to internode elongation and panicle initiation (lag veg. phase)	125
	Panicle initiation to flowering	35
	Flowering to maturity	30

The duration of different growth stages for B. Aman of 220 days has been selected as:

Vegetative stage : 155 days

Reproductive stage : 35 days

Ripening stage : 30 days

Even in case of deep-water or floating rice which is very much resistant to flood, the physiological changes such as elongation of leaves and internodes which is responsible for resistance against flood starts at certain stage of growth. Hence tolerance to submergence varies with growth stage.

Upland crops (vegetable crops) selected for the present analysis is susceptible to surface flooding during the entire growing period.

Several works have been conducted to determine the tolerance of rice. The works and their results are cited here.

2.3.7 A Review on the Tolerance Limit of Crops

Rice

Survival of a rice crop depends upon the rate at which water rise and the depth and duration of flooding as well as the morphological features as variety posses to cope with these conditions.

Deep Water or Floating Rice

Maurya conducted a study on flood resistance in rice at Rice Research station, Kanpur, India[2/]. During the monsoon, low-lying and shallow depressions of the area receive rain waters from surrounding areas. In that study water levels upto 1 m was designated as shallow stagnant conditions and levels above 1 m was considered as deep water. The experiment was conducted under field conditions with 200 flood resistant varities when plants were 20 days old, the field was inundated to about 60 cm. All the varities were completely submerged and flood levels in the field were maintained for more than 2 months. None of the plants survived under continuous submergence.

In another experiment different varities with different maturity and plant stature were exposed, at the age of 20 days, to water depths of 30 cm for 10 days. Most of the dwarf varieties survived (Table 3). In yet another experiment, when the same varieties were exposed to 15 cm of water most of the varieties including the dwarfs, survied.

Seventeen selected varieties were also put in different fields at the Agricultural Flood Research at Ghoraghat, UP, India[2/]. Results (Table 4) showed that varieties from 10 to 17 survived continuous stagnant flooding (3.7 m water depth). Under complete submerged condition their survival rate was poor to negligible. Under the third type of flooded conditions, their behaviour differed. Varieties 1 to 9 showed a distinctly better response under submerged conditions, but completely damaged under second set of conditions. They also performed poorly under the third set of conditions.

With these results he concluded that no rice variety could survive complete submergence for more than a month and some varieties die within a week. Their survival depends upon how rapidly they can elongate and their ability to withstand complete submergence temporarily at different stages of growth.

In another study Vergara and others stated that rice plants must be at least 4 to 6 weeks old by the time fields become flooded. If they are not, internodes will not elongate or will elongate insufficiently to allow plant survival to submergence. Internode elongation can occur in floating rice as early as 4 weeks after sowing but not at 2 weeks. Rice plants have to be at least 6 weeks old before they can resist rising water[3/].

In a different study Haque[2/] investigated the survival percentage of deep water rice of 2 to 10 week old seedling under depths of 15, 25 and 35 cm and of durations between 4 to 12 days. The results of which furnished useful information about their resistance capacity (Table 5 & 6). The following points are observed from Table 5.

1) The early pureline recorded a higher survival percentage than the late one for all depths of submergence proving the former grew faster;

2) Survival percentage becoming progressively lower with every increase in depth of submergence. Abrupt water rise was harmful to seedling specially those aged 2 and 4 weeks;

3) Seedling aged 6 weeks and above recorded a higher survival percentage than younger ones.

The following conclusions were drawn from Table 6.

1) Early prelines survived better under longer periods of submergence; (2) for both early and late-purlines, seedlings aged 6 weeks and above survived well under all periods of submergence; (3) early purlines were quick growing while the other late ones were slow.

Gomosta[3/] mentioned that problem for both deep water rice and low land rice were common in India, Bangladesh, Burma, Srilanka and Indonesia. Considering the frequency, depth and duration and time of occurence of flooding, it was broadly classified into three categories - namely prolonged, intermittent and stagnant intermittent flood types. The intermittent flood type was the flash flood where a transplanted crop might be suddenly submerged by 50 cm to 100 cm of water. The flood water completely drained off the field usually after about one to two weeks. The stagnant-intermittent flood behaved like intermittent flooding but flood water only partially remained inundated by about 30-70 cm deep water for a long time. Of all the factors, plant age was perhaps the most associated with submergence tolerance. Survival increased with seedling age. Zaman[3/] reported that until the seedling of deep water rice attained an age of about 4 weeks, survival of seedlings could not reach 80 percent (Table 7 & 8).

In case of prolonged flooding, when flood water increases rapidly, the basal tillers of deep water rice having slow elongation ability are partially or completely damaged due to sudden submergence. The extent of damage might vary from slight to extreme depending on variety. So far, most modern deep water rice breeding lines are slow elongation and hence, their tillers do not survive in rapidly rising water.

From the above results it can be concluded that deep water rice varieties can survive flooding upto 15 cm for periods upto 4 days, from 2 to 6 weeks age of seedling. Although 100% resistance to submergence starts at the age of 6 weeks with rapid internode elongation, survival of 80% (Table 7 & 8) can be attained at the age of about 4 weeks (since at this stage elongation of internodes starts but with a slow rate[3/].

Aus Rice

Aus rice in its early growing stage (in April) can survive flooding upto 300 mm (1 ft) in depth for periods upto 3 days with muddy water or 6 days with clear water[4/].

In its later growing stage (in late June) Aus rice can survive flooding upto 750 mm (2.5 ft). Damage to plants will begin at depths greater than 750 mm[4/].

Aus rice in its mature stage (in late July or early August) can survive flooding upto 6 days. If it is submerged under 900 mm (3 ft) for only 2 or 3 days, yield loss of 20 or 30% will occur. Submergence in still water for five days causes a crop loss of 40 to 50% [23/].

Aman Rice

Transplanted Aman in its early growing stage can survive upto 300 mm (1 ft) in depth for periods upto 3 days with muddy water or 6 days with clear water[4/].

The depth of flooding that causes submergence relative to the height of the crop during the growing season may be given as[22/]:

Submergence height	Period
300 mm (1 ft) (even less for seedlings)	July-August
450 mm (1.5 ft)	Aug-Sept
750-900 mm (2.5-3.0 ft)	Sept-Oct

After 5 days of submergence, damages are almost complete during any of these periods.

Boro Rice

Boro rice may be subjected to flooding in its mature stage during April or early May. Depths greater than 750 mm (2.5 ft) will cause damage[4/].

The survival percentage of rice (Aus, Aman & Boro) also varies with respect to grain yield. For a certain variety of rice, survival of 100% may be achieved at later stages of growth but grain yield may be reduced by more than 50%. In an experiment of IRRI[29/], the variation of yield under different levels of submergence was shown (Table 9) for a specific variety.

Upland Crops

Due to physiological cause upland crops have very low resistance to tolerance for submergence. Most of the upland crops, specially the vegetative crops cannot survive under waterlogged conditions (any depth which causes surface flooding) any time during its growing season. All surface water for these crops must be removed within 2 to 3 days[24/].

2.4 Crop Growing Season

Selection of the crop growing season or the crop calendar is very important in relation to drainage requirement. Crop calendar is different for different country and sometimes it varies region to region within a country. Moreover, particular crop may be very much susceptible to flooded condition upto certain stage of growth. But if the growing season of the crop is such that the timing of heavy rain does not coincide with the critical stage of growth, then there may not be a drainage problem to prevent crop damage. The resistance to submergence or the susceptibility to flooded condition at different stages of growth is same for T. Aus and T. Aman varieties. But the growing season of these two varieties in our country is such that critical condition to submergence for Aus may arise at the later stages of growth. While for T. Aman the critical stage or worst condition may arise both on vegetative and reproductive stages of growth because of heavy rainfall during these stages of growth. For Boro rice the critical condition arises only at the ripening stage of growth.

The growing season for T. Aman, T. Aus, Boro, B. Aman[4] and their median planting dates[19] are shown in the following Tables (iii) and (iv):

Table (iii) Growing season of rice

Crop	Planting	Harvesting
HYV T. Aus	March/April	July/August
HYV T. Aman	July/August	November/December
HYV Boro	December/January	April/May
B. Aman	March/April	November/December

Table (iv) Median Planting dates of rice

Crop	Median Planting Dates
HYV T. Aus	1st April
HYV T. Aman	15th July
HYV Boro	15th January
B. Aman	15th March

2.5 Evapotranspiration

In planning and designing irrigation and drainage projects and developing water management program the knowledge of evapotranspiration is essential. Since it is a direct source of water loss it is very important for the determination of drainage coefficient. Recently, Master Plan

Organization of Bangladesh[24] has reviewed the works done in Bangladesh for the determination of evapotranspiration.

Direct Measurements

Very few works have been done so far, for the direct measurement of evapotranspiration.

Tank and lysimeter studies have been conducted at Bangladesh Agricultural University[16] and Amla experimental station[6]. The results obtained at these stations are not reliable because of inappropriate experimental setup and other related problems.

Soil moisture depletion studies were conducted at various research stations of Bangladesh Agricultural Research Institute[17]. It was suggested that the values must be verified at other locations before using them in irrigation project planning.

Indirect Approaches

Several investigators and organizations estimated evapotranspiration by Pan evaporation method, Papadakis method and Penman combination equation modified by Doorenbos and Pruitt.

Manalo used Papadakis method to estimate evapotranspiration in different location of Bangladesh[23]. Those estimate were about 50% lower than values obtained by other methods during the period of high wind speed (April to August). During the periods of low wind speed and longer sunshine hours, this method slightly overestimated evapotranspiration.

Bangladesh Meteorological Department and Bangladesh Water Development Board collects evaporation data from about 42 locations in the country. The evaporation data are not very accurate because the pan is non-standard[1] and the pans are not located in cropped lands[24].

Compared to other methods, Penman combination equation is likely to provide the most satisfactory results[9]. Since the equation is based on physical laws and rational relationship, it will provide the best possible results.

Karim et. al. and Akhand[20] estimated evapotranspiration by Doorenbos and Pruitt for 19 locations which represent the various areas of the country.

Evapotranspiration estimates using this equation closely correlate with the values obtained by using lysimeter at Bangladesh Agricultural University and soil moisture studies at Bangladesh Agricultural Research Council[24].

Hence Penman combination equation modified by Doorenbos and Pruitt has been selected to estimate the evapotranspiration using long term weather data.

2.6 Seepage and Percolation

Water flows through the soil as seepage and percolation. Since it is a direct source of water removal, it is important for the determination of drainage coefficient. Relevant information is given here on seepage and percolation.

Seepage and percolation may form the major component of water loss for lowland rice. In principle, percolation refers to downward movement of water beyond the rootzone to the water table, while seepage is the lateral movement of subsurface water. The two are very difficult to separate and for practical purposes, they are considered together as a collective term. The rate of seepage and percolation is highly variable and is influenced by soil texture, density of drainage net work, topography and perimeter to area ratio. Management factors affecting seepage and percolation rate are puddling, soil compaction and insufficient water supply leading to dried and cracked conditions. Drying and cracking of the soil increased seepage and percolation rate by as much as ten times[20/]. Puddling of the soil effectively reduces the rate of seepage and percolation.

Wickham and Singh[30/] found seepage and percolation as the most elusive components in conducting water balance studies due to the difficulty in making accurate measurements. They found a wide variation of seepage and percolation among similar soil type. They also reported that seepage and percolation in dry season is higher than that in wet season. Field studies from 73 sites within central and southern Luzon, Phillipines in the dry season have shown mean percolation rates of 1.3 mm per day on alluvial and plastic soils with the water table between 0.5 and 2.0 mm and 2.6 mm per day whenwater table is deeper than 2 m. Sandy-clay loam and sandy loam had mean percolation losses of 2.9 mm/day, compared with 1.0, 1.6, and 1.2 mm/day for clay and silty-clay, silty clay loam and loam respectively.

Ghani[11] conducted field studies to measure seepage and percolation loss from four sites in Joydevpur, Bangladesh. He used water subsidence technique and found that weighted average seepage and percolation rate for clay loam soil 1.6 mm/day. Recently a diagnostic analysis[18] of five deep tubewell irrigation systems in the same area by Karim et. al indicated that the percolation rate for clay to silty clay varied from 1.5 to 2.0 mm/day.

In a study of EPC[10] Bangladesh, percolation loss rates of 5 mm/day, 3.8 mm/day and 2.5 mm/day were used for medium high land, high land and lowland respectively.

In the drainage coefficient determination by MPO[24] percolation rates of 1 mm/day were used for all paddy lands which can be puddled.

Percolation loss of 1.5 mm per day has been selected for this study.

2.7 Determination of Drainage Coefficient

Drains must be designed with proper drainage coefficient. Drainage coefficient is defined as the rate at which water must be removed per day.

Until recently, drainage has not been given the importance as it deserves in the design and implementation of water resources projects in Bangladesh.

Very recently MPO of Bangladesh have completed a brief report on crop drainage requirement due to on-site rainfall[24]. Drainage coefficient was calculated for rice and some upland crops.

For their study, they defined five drainage classes, Drainage class 1 was defined for B. Aman, Class 2 for T. Aman and Aus, Class 3 for HYV rice. Class 4 and 5 was defined for upland crops. The tolerance limit of the crops to submergence at different growth stages were also mentioned.

Drainage coefficient for class 2 and 3 was calculated using the following formulas:

$$Q = \frac{P(10 \text{ days}) - 10(ET_c + S) - B}{8} \qquad 2.7.1$$

where Q is the drainage rate, mm/day

P(10 day) = 10-yr frequency, 10 day duration depth of rainfall, mm

ET_c = the crop evapotranspiration, mm/day

S = the deep seepage in mm/day

B = an arbitrary constant

The above equation was used to obtain a first estimate of Q. The condition described by the following inequality should be met for each day of the storm period.

$$Pt + 50 - t(Q + ET_c + S) < 200 \text{ mm} \qquad 2.7.2$$

If this inequality is not met for more than three consecutive days for all values upto t = 10, then Q should be increased until it statifies the condition.

Drainage coefficient for class 4 and 5 was calculated using the following formulas:

$$Q = \left[P - 3(ET_c + S)\right] /3 \qquad 2.7.3$$

and $$Q = \left[P - 2(ET_c + S)\right] /2 \qquad 2.7.4$$

where Q is the drainage coeff. mm/day

P = 2 days 10 year frequency storm, mm.

The results of the study showing the value of Q for selected stations are presented in Fig. 8, 9 and 10.

For the above study rainfall analysis was done with total rainfall of some successive days. A more critical condition of drainage may arise if the analysis is done on the basis of running days. Basis for the selection of design storm duration of 10 days were not mentioned. Although it was mentioned that the drainage water for drainage class 2 and 3 must be removed within 2-4 days for yield to be unaffected. But here water balance was applied for the 10 days period. We cannot allow submergence for 10 days. Crop tolerance with submergence is an important factor in the selection of critical duration of rainfall. Also it was not justified why 8 is used in equation 2.7.1.

No result was given for drainage class 1 and it was not mentioned that whether it requires drainage at any stage of growth.

A joint study by BWDB and UNDP1/ was made to determine the drainage requirement for rice crop due to on-site rainfall. The design was based on 1 in 5 years maximum 2-6 day precipitation. The following assumptions were made to calculate the drainage rates:

a) Existing depth of water in the field	0.10 m
b) Allowable depth of water before drainage is required	0.20 m
c) Plant submergence maximum duration	6 days
d) Plants considered submerged when depth of water exceeds	0.30 m
e) Evapotranspiration and infiltration was considred to be small and ignored.	Negligible

Then Q, the drainage rate in mm/day was calculated from:

$$Q(t_2 - t_1 + 6) + 100 = 10^{b \log(t_2 + 6) + a} - 100$$

$$Q = \frac{10^{\left[b \log(t_2 + 6) + a\right]} - 200}{6 + t_2 - t_1}$$

where t_1 = time from commencement of rainfall until water depth is 0.20 m

t_2 = time from commencement of rainfall until water depth is 0.30 m

Using the results of the analysis a map was produced showing the isolines for different drainage rates (Fig. 11) to enable approximate drainage rates to be obtained for any particular area.

During analysis, crop evapotranspiration and infiltration were ignored which may cause overdesign of drainage rate. Also the actual season for which this analysis was conducted was not mentioned.

Narayana, Gupta and Tiwari conducted another study on rainfall and runoff analysis for rain water management in agriculture[27/]. The study region was Kernal in India. The range of climatic and catchment characteristics for the study region were presented in Table 10. Rainfall analysis was conducted for the period June to September. Using simple water balance equation total amount of expected runoff that was computed for paddy and maize are presented in Table 11.

In the above study evaporation and infiltration was decucted twice, which may cause under estimation of runoff. Also the rainfall analysis was not conducted on the basis of running days.

Hence studies involving a detailed quantitative evaluation will provide a reliable basis for drainage design. In a country like Bangladesh where the rainfall follows a skewed pattern, this type of study is of much importance. Not only the rainfall but also the topography and climatic characteristics influence the need for this study.

CHAPTER - 3

METHODOLOGY

3.1 Drainage Classification

Drainage classes are defined for different crops (mainly focussing on paddy), since susceptibility to water-logged condition varies with crop types. Each drainage class defines a critical level of drainage for a change in type of cropping. On the basis of crop variety, tolerence limit of the crops to submergence and crop growth status of five drainage classes are categorised. The classification is given below in tabular form (Table V).

3.2 Field Conditions for Drainage Class 2, 3 & 4

For the Drainage classes 2, 3 & 4, field conditions considered in the calculation of drainage coefficient are:

1. Antecedent moisture condition
2. Plant height
3. Allowable flooding on the paddy land
4. Paddy dike height

Antecedent Moisture

The amount of water which remains in the field before transplanting is the antecedent moisture. The antecedent moisture within a rice field can vary from zero water depth to the full depth of the paddy dikes. Initial depth of

Table V. Submergence tolerance of rice and summer vegetables

Drainage class	Crop Type	Tolerance of the crop to submergence in different stages of growth			
		Vegetative stage	Reproductive stage	Ripening stage	Remarks
1	B. Aman (Deep water or floating rice)	Flooding causes damage of seedling upto 2 weeks of age. From 2 to 4 weeks of age it can survive flooding upto 15 cm for 4 days(survival of 80% can be attained at the age of 4 weeks)[37]. At the age of 6 weeks survival of 100% can be attained with increasing water level[3]. Flood resistance is very high from 6 weeks of age upto panicle initation. It can grow under flooded condition with rapid internodes with rapid internode elongation with rising water. Average growth rate is 0.8 cm/day but may be 20-25 cm/day for short periods and 5 to 6 cm/day over extended periods during inundation[24]. Elongation of internodes with rising flood levels undergoes until panicles emerge (onset of flowering). The plant height may be 5-6 m[37]. The plant attains this height before complete emergence of the panicle	At this stage the internodes are matured and no longer elongate. The lower portion of the plant can still be submerged. Extended abrupt flooding at this stage could result in crop loss.	The plant can still survive with water in the lower portion of the plant. Some times crop harvesting is done with the help of a boat.	The most critical condition of drainage is upto 4 weeks age of seedling. But the growing season of the crop is such that rainfall during the critical period is insignificant. Hence no protection is required for this crop.

Table V (Contd.)

1	2	3	4	5	6
2	T. Aman	In the early stage of growth the plant can tolerate 30 cm of water in depth for periods upto 3 days[4]. The depth may be less for seedling. At later period of vegetative growth since the plant height increases it can tolerate flooding upto 45 cm to 50 cm in depth[22].	It can tolerate upto 70 cm of water in depth for periods upto 3 days[22].	Plant can survive flooding upto 90 cm for 3 days[22]	The most critical condition of drainage is just after transplanting. Design should be based on vegetative stage. Since HYV rice is much shorter than the local variaties, the tolerance limit is also lower than the local varities (as mentioned in different growth stage).
3	T. Aus (HYV)	"	"	"	The crop growing season is such that, flood hazard may arise at the reproductive and the ripening stage. Less protection will be required at these stage. Design should be based on the maximum requirement at the reproductive or ripening stage.

Table V: (Contd.)

1	2	3	4	5	6
4	Boro (HYV)	"	"	Plant can survive flooding upto 75 cm for 3 days.	Flooding may occur only at the mature stage i.e at the ripening stage of growth.
5	Summer vegetables (cucerbit)	Protection is required throughout the growing season. Since the crop cannot grow under submerged condition, all water which causes surface flooding should be removed within 3 days.			Drains should be designed for maximum protection.

water may vary from a minimum of 50 mm and maximum 200 mm. Hence 200 mm has been assumed as antecedent moisture.

Plant Height

The crop height at the time of transplanting will be approximately 300 mm plus an increase of 8 mm per day from the date of transplanting. This increase in height will occur mostly during the vegetative growth stage.

Allowable Flooding

All rice under class 1, 2, 3 and 4 is assumed to grow under flooded soil condition. The amount of water or the depth of water which can be allowed to remain on the paddy land beyond the critical period is the long term flooding. Water in excess of this should be removed to maintain the critical level of drainage (i.e. the maximum allowable depth of flooding).

The depth to which the plants can be submerged without damage is related to the height of the plant at that stage of growth. Submergence of the plant at different depths will influence the yield. Plants may tolerate that depth of water (as specified) but there may be a reduction in yield (Table 9). Information from BRRI (Bangladesh Rice Research Institute) indicated that submergence of 67% of plant height can be allowed without effecting yield[24/]. Hence the depth of water which can remain on the land i.e allowable flooding or long term flooding (F_{LT}) can be found by the equation:

$$F_{LT} = a(H_I + b \times T) \qquad 3.2.1$$

where H_I = initial height of the plant during transplanting, mm

a = decimal fraction of the plant which can be submerged on a long term

b = average rate of plant growth, mm/day

T = age of plant in days

F_{LT} = long term flooding in mm

The height of the seedling at the time of transplanting is 300 mm i.e. H_I = 300 mm. The plant will increase at an average rate, mostly in the vegetative growth stage. For the plant, the worst condition to flooding will be immediately after transplanting (since the plant can tolerate minimum depth of flooding at this critical condition of drainage, maximum protection is required at this stage of growth). Hence the maximum allowable flooding should be the depth that can be allowed at the critical condition of drainage. Hence F_{L2} i.e. allowable flooding 2 days after transplanting will be:

$$F_{L2} = 0.67\ (300 + 0 \times 2)^{*}$$

$$= 201.0 \text{ mm}$$

---

* Plant needs few days for stabilization and its height does not increase within 2 days.

From this calculation, maximum allowable depth on the paddy land has been fixed as 200 mm. A greater depth can be allowed at some later stages of growth. But for the design purpose, worst condition should be considered.

Paddy Dike Height

In rice lands some water can be allowed to stand on the land by bunded paddy fields. It appears to be as low as 100 mm in areas of low relief, but it may be as high as 300 mm in water short areas[24]. On irrigated lands dike height is about 200 to 250 mm[24]. The paddy dike height should be fixed in such a manner that allowable depth of flooding at the critical stage of growth or the critical level of drainage does not exceed. It was assumed that the critical stage of growth should be just after transplanting. Allowable flooding at that stage is 200 mm.

Hence 200 mm has been assumed to be the paddy dike height. 200 mm of water can be stored on the paddy land by either the functioning dike height or lack of slope.

The following conditions should be considered for calculation of the drainage coefficient for flood drainage protection classes 2,3 and 4:

1. Existing paddy water level or the initial depth of water at the time of transplanting may be 200 mm.

2. Allowable flooding in the critical growth stage (just after transplanting will be 200 mm (in consideration with crop growth status) and this depth can remain on land beyond the critical period. This is the maximum depth which can be allowed for the worst condition of drainage.

3. Paddy dike height will be 200 mm (since maximum allowable flooding at the critical growth stage is 200 mm) either from direct height or from effect of level terrain for all rice except deep water rice.

4. Paddy water level should be reduced to the long term flood depth within 2-4 days after start of drainage unless there is 100% possibility of clear water. With clear rainwater, drainage may be completed within 5-6 days.

   Since rain water is not clear drainage period is considered as 3 days without loss in yield (if some yield loss is allowed this time may be increased).

5. Deep seepage should be considered as 1.5 mm/day for all crops.

6. Crop evapotranspiration should be taken into consideration in the estimation of Q.

7. The 10-year frequency 3-day duration depth of rainfall should be used in the drainage coefficient (Q) calculation.

8. Design should be based on the critical or worst condition of drainage.

3.3 Calculation of Drainage Coefficient for Drainage Class 2, 3 & 4

The following procedure has been adopted for the calculation of drainage coefficient.

The volume of water to be removed from the watershed per day (Q) is the drainage coefficient.

The design discharge for an area may not be the peak discharge but may be one that will maintain a certain level of water in the agricultural lands not lasting longer than X days nor occurring with a frequency of more than Y years. Such values can be obtained by frequency analysis of rainfall data. Hence the drainage coefficient can be computed by the simple water balance equation:

$$P(T) + D(I) - T(Q + ET_c + S) = D(P) \qquad 3.3.1$$

where $P(T)$ = rainfall depth of a specified duration and frequency, mm

T = time in days

ET_c = crop evapotranspiration mm/day

S = deep percolation, mm/day

D(I) = initial or antecedent moisture on the paddy land, mm

D(P) = permissible or allowable depth of water on the paddy land, mm

Q = drainage coefficient, mm/day

For the present study, the following values of different parameters has been fixed:

T = 3 days

P(3) = 10-yr frequency 3-day duration depth of rainfall, mm

D(I) = 200 mm

D(P) = 200 mm (for drainage class 2)

The maximum permissible depth will be different for drainage class 3 and 4. The crop growing season is such that flooding occurs at the reproductive and ripening stage for drainage class 3 and for drainage class 4 flooding may occur only at the ripening stage. Hence protection required for these classes will be different from that of drainage class 2. For drainage class 3, critical condition will arrive at the reproductive stage of growth.

$$F_{LT} = 0.67\ (300 + 8 \times 50)$$
$$= 469 \text{ mm}$$

Hence D(P) = 450 mm for drainage class 3. For drainage class 4, D(P) = 700 mm.

The equation for the calculation of drainage coefficient for drainage class 2, 3 and 4 becomes:

For class 2: $P(3)+200-3(Q+ET_c+S) = 200$ mm 3.3.2

For class 3: $P(3)+200-3(Q+ET_c+S) = 450$ mm 3.3.3

For class 4: $P(3)+200-3(Q+ET_c+S) = 700$ mm 3.3.4

3.4 Calculation of Drainage Coefficient for Upland Crops

It was assumed for drainage class 5 (upland crops) that all water which causes surface flooding should be removed within 3 days and drainage should be adequate to remove all surface water within this period. This period would of necessity include any time during the design event in which rainfall intensity and duration had produced surface flooding. It was further assumed that throughout the growing season the maximum 3-day depth duration values for 10-yr frequency were considered to be most appropriate for design.

The drainage coefficient can be computed from the given equation:

$$Q = (P(3) - 3(ET_c+S))/3 \qquad 3.4.1$$

where Q is the drainage coefficient, mm/day

$P(3)$ = 10-yr frequency 3-day duration depth of rainfall, mm

ET_c = crop evapotranspiration, mm

S = deep percolation, mm

CHAPTER - 4

DATA COLLECTION

4.1 Source of Rainfall Data

Bangladesh Water Development Board is the main source of daily rainfall data. Daily rainfall records of a considerable period for a large number of stations are available in BWDB. At present BWDB preserves the daily rainfall data in the form of Data Index Card.

4.2 Study Region

On the basis of hydrological unit, Bangladesh may be divided into four regions (BWDB, 1982) (a) North-east, (b) North-west, (c) South-east and (d) South-west. North-east region comprises of the hydrological districts of Sylhet, Mymensingh, Jamalpur, Tangail, Dhaka and Comilla.

According to climatic classification (Fig. 12) by, Manalo[23], the type 2.2 (2 to 4 month dry, 7 to 9 months wet) covers the foothills of northern Sylhet, type 3.2 (5 to 6 months dry, 7 to 9 months wet) covers the Sylhet in a meandering pattern. Type 3.3 (5 to 6 month dry, 5 to 6 month wet) covers the biggest part of the North-east region including Dhaka, Mymensingh, Tangail and Comilla. The three climatic zones are shown in Fig. 13. Sylhet and Mymensingh have at least one month with greater than 500 mm rainfall. The Cherapunji (India) which is the rainest place in the world is located near the North-east of Sylhet. Rainfall lasts for about seven months of the year in average.

4.3 Selection of Raingauge Stations

All the stations within the study area were first verified for the entire gauge records. Stations to be used in this study were then selected. It was decided that the raingauge stations having at least 10 years (common to all) of records should be complete or nearly so. This exercise provided a network of 68 raingauge stations in the N-E region (Fig. 14).

4.4 Data Presentation

A list of selected stations showing their location and length of record for each station data are presented in Table 12 and 13.

The daily rainfall data from all the 68 stations were collected and compiled from BWDB Data Index Cards and then entered in the computer for analysis.

To facilitate the use of the collected data in various analysis all these data were stored in the data diskette.

CHAPTER 5

DATA ANALYSIS

5.1 Introduction

To select a method of distribution for frequency analysis of a group of long term records for application in the determination of drainage coefficient, it was already discussed in Chapter two that among the methods of distribution, Gumbel method would be more suitable for the North-eastern region of Bangladesh. Hydrologic design is usually governed by few critical conditions. Analysis should be conducted at those period where the design is governed by the most critical condition. Using the maximum probable values of rainfall and other related factors, water balance equation can be applied to determine the drainage coefficient for paddy and upland crops.

The analysis has been conducted separately for the three climatic zones comprising the North-eastern region of Bangladesh.

5.2 Rainfall Data Analysis

5.2.1 Selection of Base Period

For frequency analysis of rainfall, a common period of time for all the records is necessary to eliminate the effect of variability with time. This period, called the baseperiod, will be the longest period of continuous record common to the largest number of station available.

To optimize the use of existing data and to minimize estimates of missing data a base period of 10 year (1972-1982) was selected.

5.2.2 Estimation of Missing Data

The missing data within the base period of each station were estimated from the observations at three stations as close to and as evenly spaced around the station with the missing record by simple arithmetic average of the index stations.

5.2.3 Area Averages of Rainfall

The analysis of rainfall is understood here to be the area averages of rainfalls. Since analysis was conducted on areas of similar climate conditions, the hydrological boundary governs the area. The North-eastern region comprises of three climatic zones. The boundary of each zone and the location of the stations are shown in Fig. 14. The daily average precipitation representing each zone was computed for each year by arithmatic mean of all the available records in each zone.

5.2.4 Determination of Running Day Total of Rainfall

3-day moving totals or running totals were determined for each year using daily mean values of rainfall. This operation was conducted separately for the three climatic zones in the study region.

5.2.5 Frequency Analysis

Three day maximum probable rainfall for a return period of 10 year, were found for each of the 362 period for the three climatic zone separately by using the following equations:

$$X_T = U - \beta \ln \left[\ln \left(\frac{T}{T-1} \right) \right] \qquad 5.2.1$$

$$\text{where } U = \bar{X}_N - \frac{y_N}{\sigma_N} S_N \qquad 5.2.2$$

$$\text{and} \quad \beta = \frac{S_N}{\sigma_N} \qquad 5.2.3$$

Values of $\bar{y}_N$ and σ_N were extracted from Table 2. The mean ($\bar{X}_N$) and standard deviation (S_N) of rainfall sample for each of the station were computed by the conventional procedures as given by

$$\bar{X}_N = \frac{\Sigma x}{N} \qquad 5.2.4$$

$$S_N = \sqrt{\frac{\Sigma (X - X_N)^2}{N-1}} \qquad 5.2.5$$

where N is the sample size.

Typical plotting of the data in Gumbel's probability paper for some of the periods are shown in Fig. 15, 16 and 17.

The results of the frequency analysis for all the climatic zones is presented in Table 14.

A computer program based on Fortran IV coding was developed for the rainfall data analysis. A listing of the program is presented in Appendix-C.

5.2.6 Testing the Goodness of Fit of the Data to Gumbel's Distribution

Kolmogorov-Smirnov[28] test was adopted in this study for testing the goodness of fit of the data to Gumbel's distribution. The test was conducted as follows:

i) $P_x(x)$ was determined. It is the completely specified cumulative distribution function under the null hypothesis.

ii) Then $S_n(x)$ was determined. It is the sample cumulative histogram based on n observations.

iii) The maximum deviation D, was determined by

$$D = \max \left| P_x(x) - S_n(x) \right| \qquad 5.2.6$$

iv) The hypothesis will be rejected, if for the chosen significance level, the observed value of D is greater than or equal to the critical tabulated value (Table-15) of the Kolmogorov-Smirnov test. In this study, the test was conducted at 0.05 significance level and all the tests were accepted.

5.3 ET Estimation

The reference crop evapotranspiration (ET_o) was determined for different locations of Bangladesh by Penman equation modified by Doorenbos and Pruitt[9]. The equation is:

$$ET_o = c\left[W.R_n + (1-W).f(u).(e_a-e_d)\right] \qquad 5.3.1$$

where,

ET_o is the potential evapotranspiration or reference crop evapotranspiration, mm/day

W is the temperature related factor

R_n is net radiation, mm/day

$f(u)$ is wind related function

(e_a-e_d) is the difference between the saturation vapor pressure at mean air temperature and mean actual vapor pressure of the air, both in mbar

c is an adjustment factor to compensate for the effect of day and night weather conditions.

The values of monthly potential evapotranspiration for different locations of Bangladesh and average monthly potential evapotranspiration values for Bangladesh was calculated and presented in Table 16.

The evapotranspiration of a specific crop was obtained from reference crop evapotranspiration using appropriate crop coefficient i.e.

$$ET_c = K_c \times ET_o$$

In this study, values of crop coefficient obtained by MPO[24] were used for paddy. Crop coefficient for vegetable crops of Bangladesh are not available. A crop coefficient curve was developed (Fig. 18) for vegetable crops grown in the monsoon season using the FAO guidelines[9]. The following assumptions were made to develop the crop coefficient curve:

Date of planting	: 10th May
Average recurrence interval of significant rain	: 7 days
Total duration of crop	: 110 days
Date of harvesting	: 28th August

The curve shown in Fig. 18 was developed in a generalized form. Any vegetable crop that grows within this period (May-August) will follow this curve. The values of crop coefficient (K_c) for paddy and vegetables are shown in Table 17.

5.4 Determination of Drainage Coefficient

Analysis has not been conducted for drainage Class I. The growing season of the crop under drainage class I is such the critical time of crop does not coincide with considerable amount of rainfall.

Frequency analysis required to conduct for the different drainage classes are as shown below (Table vi)

Table vi Period of analysis for different drainage classes

Drainage class	Period for which frequency analysis has been conducted
2	15th July to end of August
3	20th May to 20th June
4	15th April to 15th May
5	10th May to 28th August

The analysis of rainfall was conducted for the whole year to facilitate future use.

The maximum value of the 3-day rainfall within the period specified for each class was considered in the frequency analysis. The sequence of 3-day periods are shown in Table 18.

Drainage coefficient (Q) was determined for different drainage classes by the following formulas for the three climatic zone separately:

For drainage class 2: $P(3) + 200 - 3(Q + ET_c + S) = 200$

" " " 3: $P(3) + 200 - 3(Q + ET_c + S) = 450$

" " " 4: $P(3) + 200 - 3(Q + ET_c + S) = 700$

" " " 5: $Q = P(3) - 3(ET_c + S) /3$

The results of the study are shown in Fig. 19, 20 and 21.

CHAPTER-6

RESULTS AND DISCUSSION

The investigation carried out in this study can be categorized under two headings; (a) determination of maximum probable 3-day rainfall on the basis of running days for the three climatic zones of the North-eastern region of Bangladesh (b) determination drainage coefficient for different crops to avoid crop damage from flooding caused by on-site rainfall.

3-day maximum probable rainfall on the basis of running days was determined by Gumbel's method for the critical period of all the drainage classes (Table 14, using extreme value of the period concerned) for a return period of 10 year.

Typical plottings of the data in the Gumbel's probability paper are shown in Figs. 15, 16 and 17 for climatic zones 1,2 and 3 respectively. The Kolmogorov-Smirnov test was applied for the goodness of fit of the Gumbel's distribution. Goodness of fit of observed data from the theoretical curve as tested by Kolmogorov-Smirnov statistics shows that deviation is within allowable range. Maximum deviation of 0.187 and minimum of 0.032 was found for drainage class 4 and 2 respectively for the climatic zone 3. All the deviations are far below the critical value of 0.409 at 0.05 significance level (Table 15).

Drainage coefficient was determined for 5 different drainage classes by using water balance equation. Each class defines a critical level of drainage for a particular crop (as defined earlier). Water balance equation was applied to that part of growing season which is most critical under submerged condition.

The only type of paddy which can grow with rising water in Broadcast Aman (drainage class 1). But, before attaining at the age of 6 weeks submergence tolerance of 100% cannot be achieved. Hence it was shown earlier that it requires drainage during this period. But the growing season of the crop is such that the time (15th March to 15th April) does not coincide with the rainy period i.e the condition of submergence does not take place due to defient rainfall during this period.

For drainage class 2 i.e. HYV Transplanted Aman, the worst condition of drainage may arise in the vegetative stage of growth. The most critical condition may even arise 2 days after transplanting. The calculated drainage coefficient for Transplanted Aman are 63.55 mm/day, 75.19 mm/day and 103.05 mm/day for climatic zone 1, 2 and 3 respectively as shown in Fig. 19. The highest value of drainage coefficient is 103.05 mm/day in the climatic zone 3.

The water balance equation was applied for the period 20th May to 20th June and 15th April to 15th May for HYV Aus and HYV Boro respectively. Drainage coefficient for Aus rice are 49.35 mm/day and 51.13 mm/day for the climatic zone 2 and 3 respectively (Fig. 20). Boro needs no drainage.

Drainage class 5 is for summer vegetable crops. Since these crops cannot survive under any depth of surface flooding, drainage is required throughout its growing season. The growing season was selected as 10th May to 28th August. Since crop coefficients of summer vegetable crops of Bangladesh are not available, a crop coefficient curve was developed in a generalized form on the basis of past studies as described earlier in Chapter 6. The maximum of the Q values throughout the growing season was taken as the design drainage coefficient. The calculated drainage coefficients for drainage class 5 is shown in Fig. 21. The results show highest drainage coefficient of 170.12 mm/day for climatic zone 3.

The above results indicate that Transplanted Aman needs drainage in the three climatic zones. Aus rice needs no drainage in climatic zone 1. In all the three climatic zones Boro rice can grow without any provision of drainage. On the other hand the requirement of drainage magnitude for upland crops (summer vegetables) is 1.5 times more than that of rice. This is because of the special physiological behavior of taking oxygen throughout the body of rice plant which is lacking for other crops. Hence rice can survive upto certain level of submergence (this level increases with age of plant) and other crops cannot tolerate any water above field capacity.

These are the causes due to which lower values of drainage coefficient are required for rice compared to the upland vegetables (cucerbit).

Estimated drainage coefficient by Master Plan Organization (Fig. 8) for HYV Transplanted Aman and HYV Aus crop is lower than the values obtained in the present study. The underestimation of drainage coefficient as estimated by MPO is probably not considering the running day totals of the rainfall of the area concerned.

In the present analysis, the drainage coefficients obtained for different crops may be used for the design of drainage structures. These drainage coefficient are applicable to the flood protection areas where the only source of water which creates drainage congestion is rainfall (Fig. 22). These drainage coefficient values will also be applicable to those areas where flood protection is under execution (Fig. 22). The cropping pattern to those areas can be improved if provision is mode for drainage.

Before designing a drainage system for agricultural purposes, drainage coefficient or the rate at which water is to be removed should be determined considering the crops for which protection is necessary. Drains should be designed with specified drainage coefficients. Lack of anticipated drainage may cause failure of the project.

CHAPTER - 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The following conclusions can be drawn from the results of the investigations:

The statistical analysis of 3-day running total of rainfall for the whole year from daily rainfall data for each climatic zone and the probable maximum 3-day rainfall estimated on the basis of running days for the critical period of different drainage classes will help in any water management development project in the North-eastern Region of Bangladesh. Particularly in the areas of crop water requirement and drought effect on crops.

Broadcast Aman can grow with the rising water level (due to on site rainfall) in the present study rainfall area.

Transplanted Aman (HYV) is the only type of paddy which needs drainage in all the areas of the region. Aus (HYV) rice needs drainage in the climatic zone 2 and 3. Maximum drainage is required in the hilly region of Sylhet (climatic zone 3) where rainfall lasts for about 7 to 9 months of the year. Provision of drainage with specified drainage coefficient, Q will allow cultivation of HYV Transplanted Aman and HYV Aus throughout the region without loss of crops. Hence area of HYV rice cultivation can be increased with provision of proper drainage.

The water balance study indicates that HYV Boro can be cultivated without any drainage hazard.

Successful cultivation of summer vegetables is possible with proper design and day out of drainage system. The value of the drainage coefficient for vegetables is 1.5 time more compared for the drainage coefficient of rice.

7.2 Recommendations

For future study the following topics can be taken up:

a) The study should be extended to other regions such as North-West, South-East and South-West.

b) Frequency analysis of rainfall data having longer base period should be incorporated to refine the present study.

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APPENDIX - A

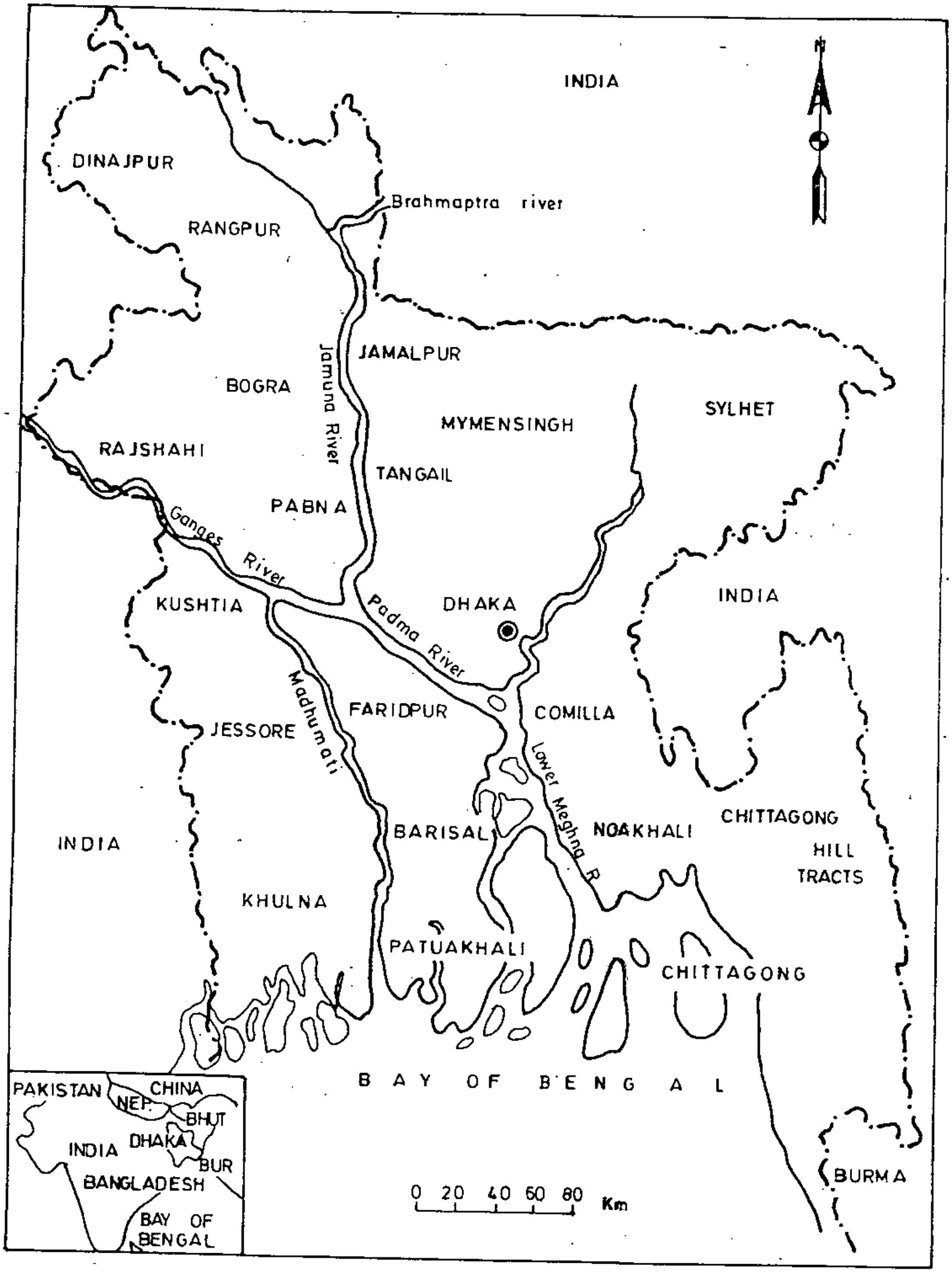


FIGURE. 1. MAJOR WATER SYSTEMS OF BANGLADESH [23]

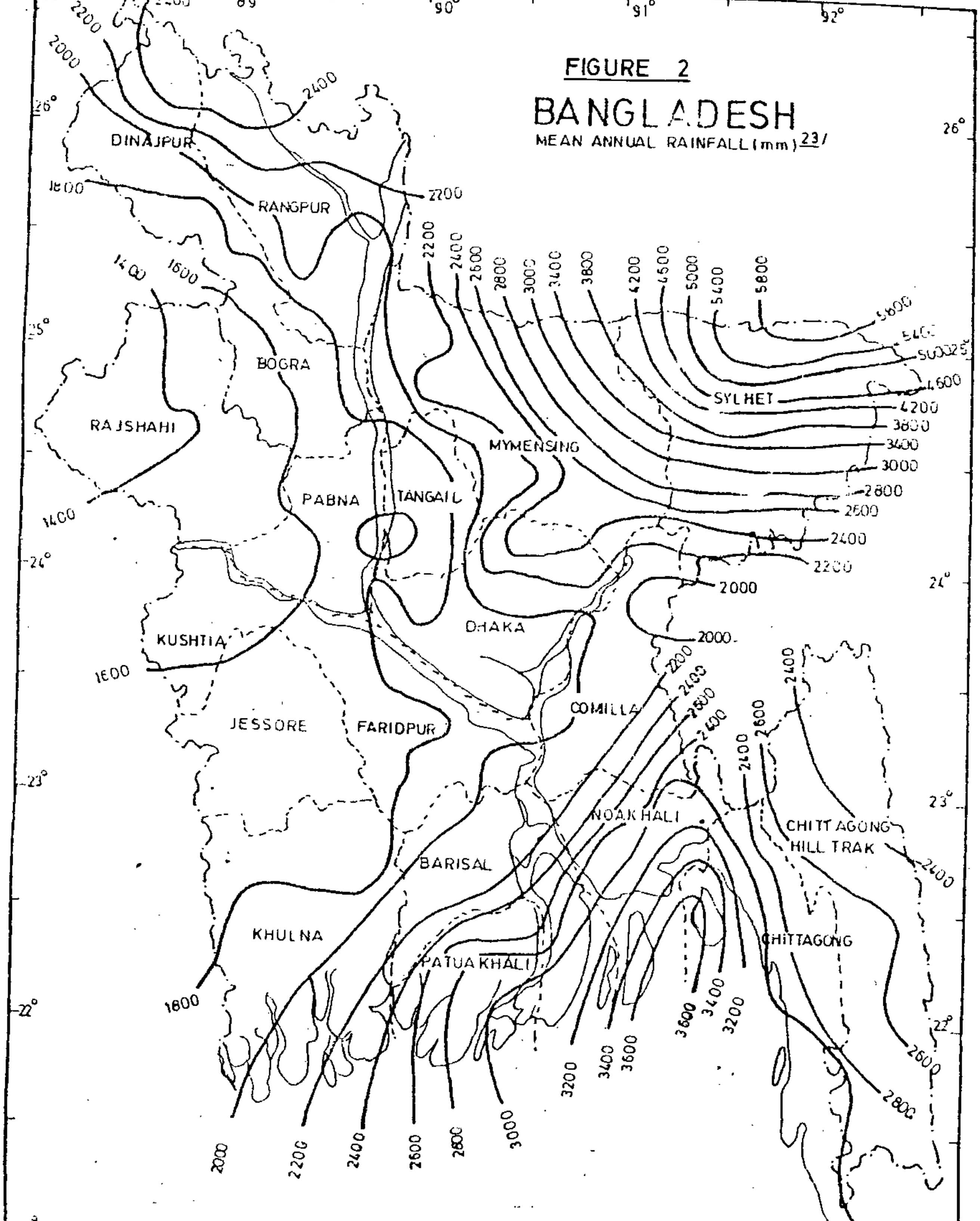


FIGURE 2

BANGLADESH

MEAN ANNUAL RAINFALL (mm) 23/

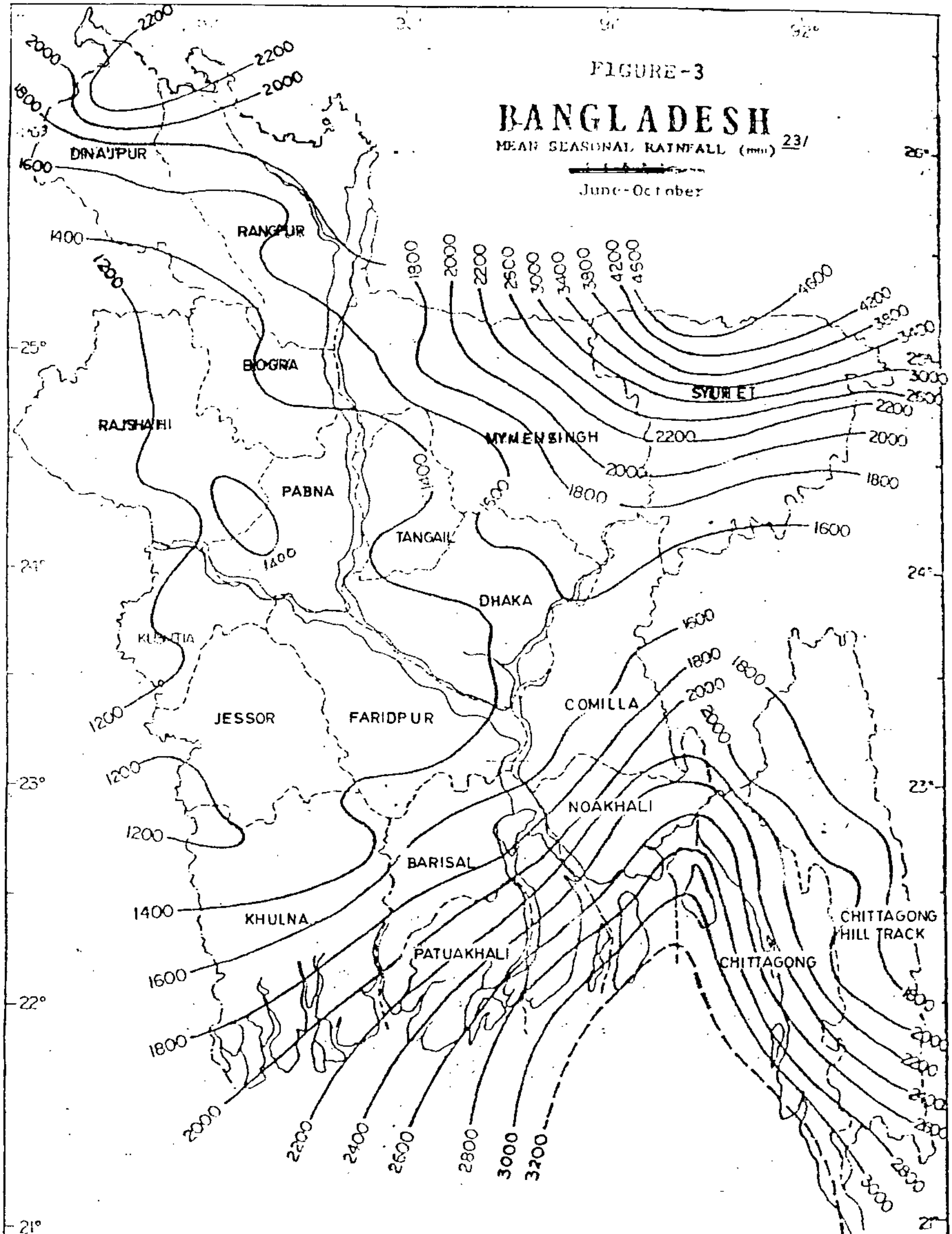


FIGURE-3
BANGLADESH
MEAN SEASONAL RAINFALL (mm) 23/
June-October
DINAJPUR
RANGPUR
BOGRA
RAJSHAHI
PABNA
TANGAIL
MYMENSINGH
SYLHET
DHAKA
KUSHTIA
JESSOR
FARIDPUR
COMILLA
NOAKHALI
BARISAL
KHULNA
PATUAKHALI
CHITTAGONG
CHITTAGONG HILL TRACK
26°
25°
24°
23°
22°
21°
89°
90°
91°
92°

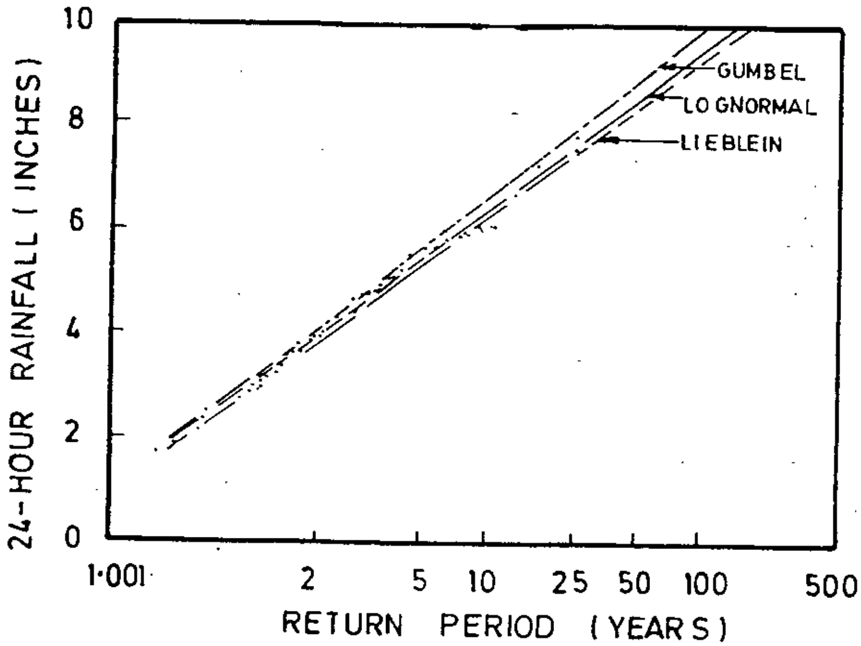


FIGURE. 4. A COMPARISON OF THE GUMBEL, LOG-NORMAL AND LIEBLEIN PROCEDURES FOR MONTOGOMARY, ALA [13]

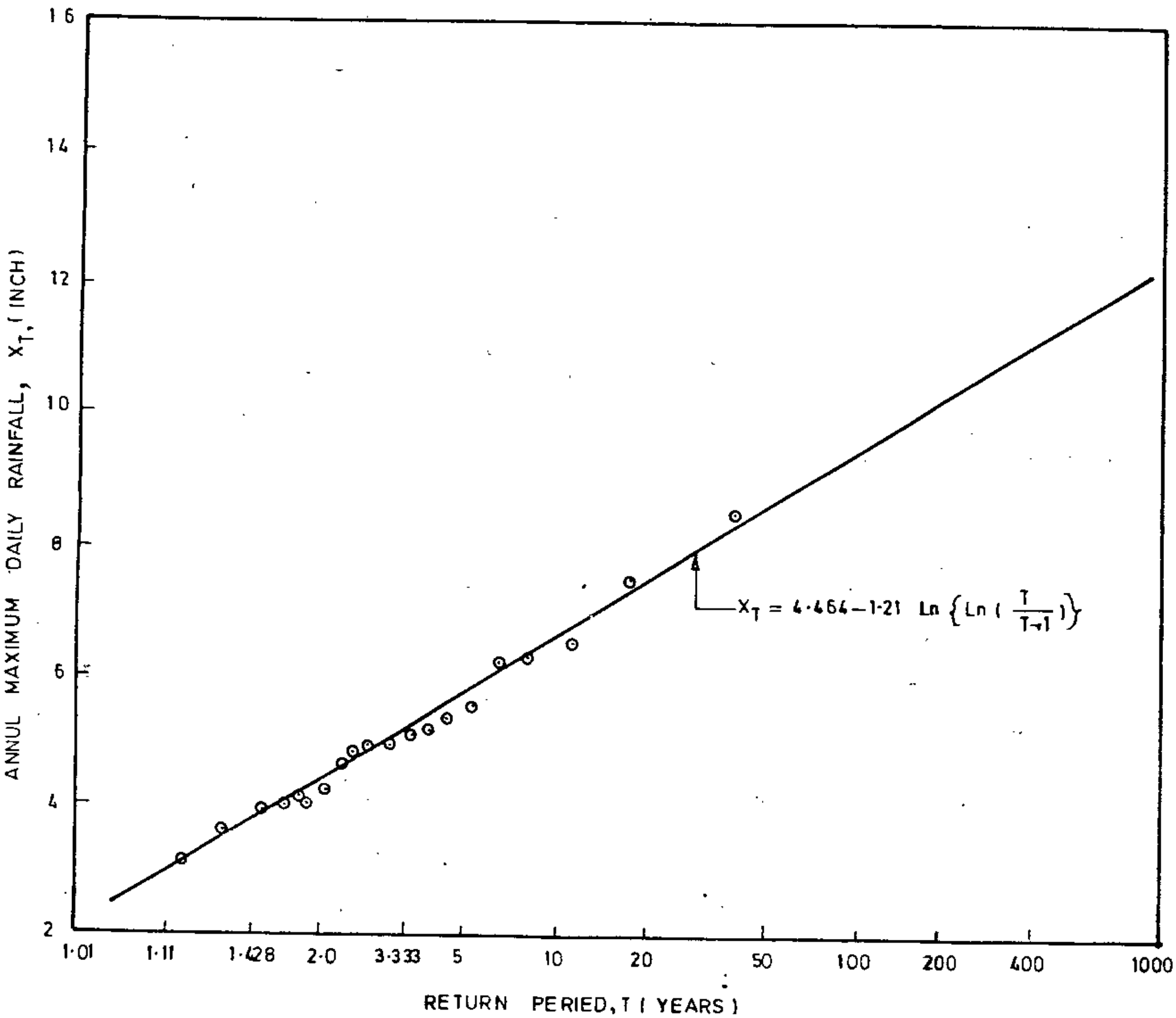
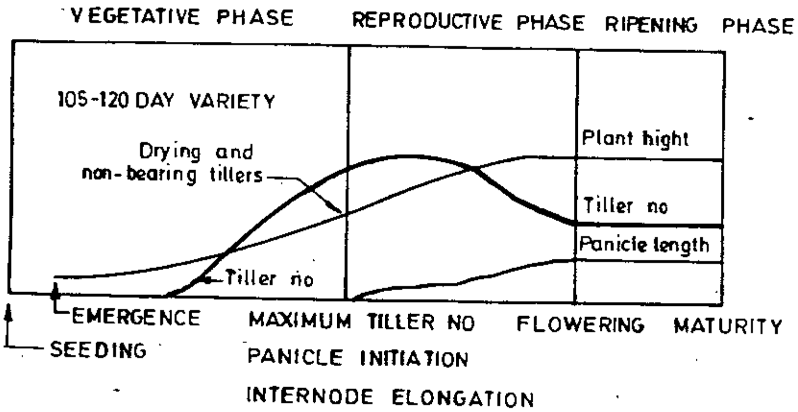
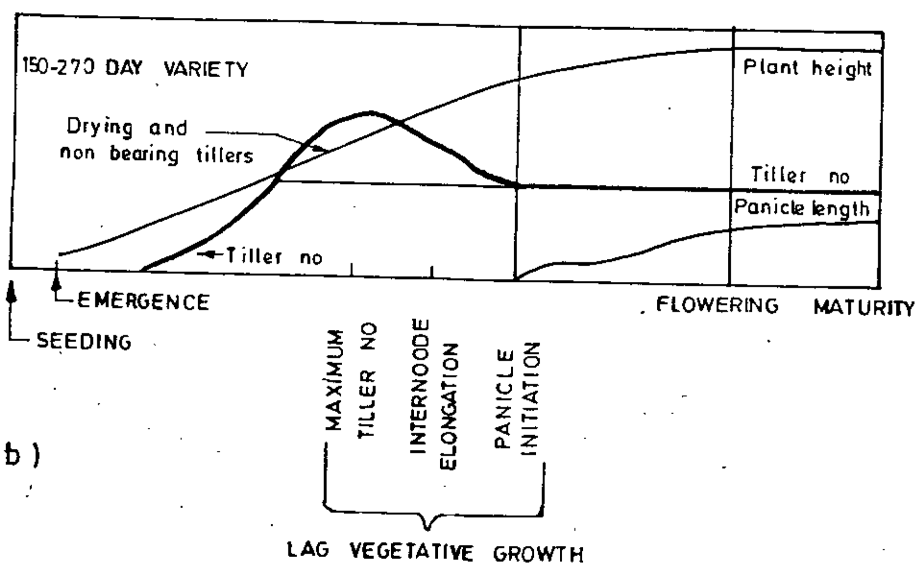


FIGURE. 5. DISTRIBUTION OF ANNUAL DAILY MAXIMUM RAINFALL FOR COMILLA STATION [25]



(a)



(b)

FIGURE. 6. DIFFERENT PHASES OF GROWTH FOR SHORT - DURATION (a) AND LONGDURATION (b) PADDY VARIETY [8]

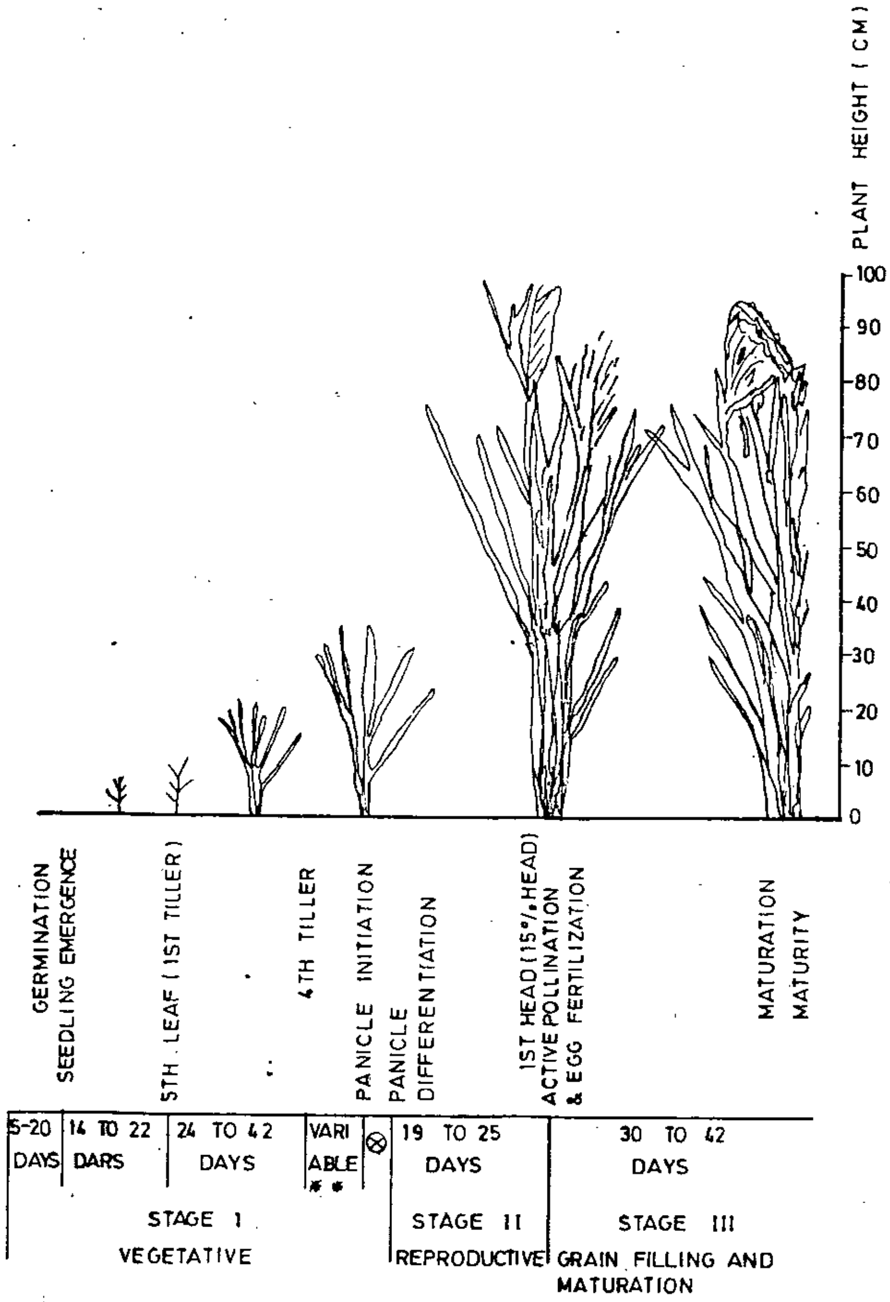


FIGURE. 7. DEVELOPMENT PHASES OF RICE PLANT

NOTE: UNDER WARM CONDITIONS USE THE LOWER NUMBER OF DAYS AND FOR COOL CONDITIONS USE THE LARGER NUMBER OF DAYS. (X) 3-5 DAYS ** VARIABLE TIME 0-25 DAYS (DEPENDENT UPON VARIETY) [8]

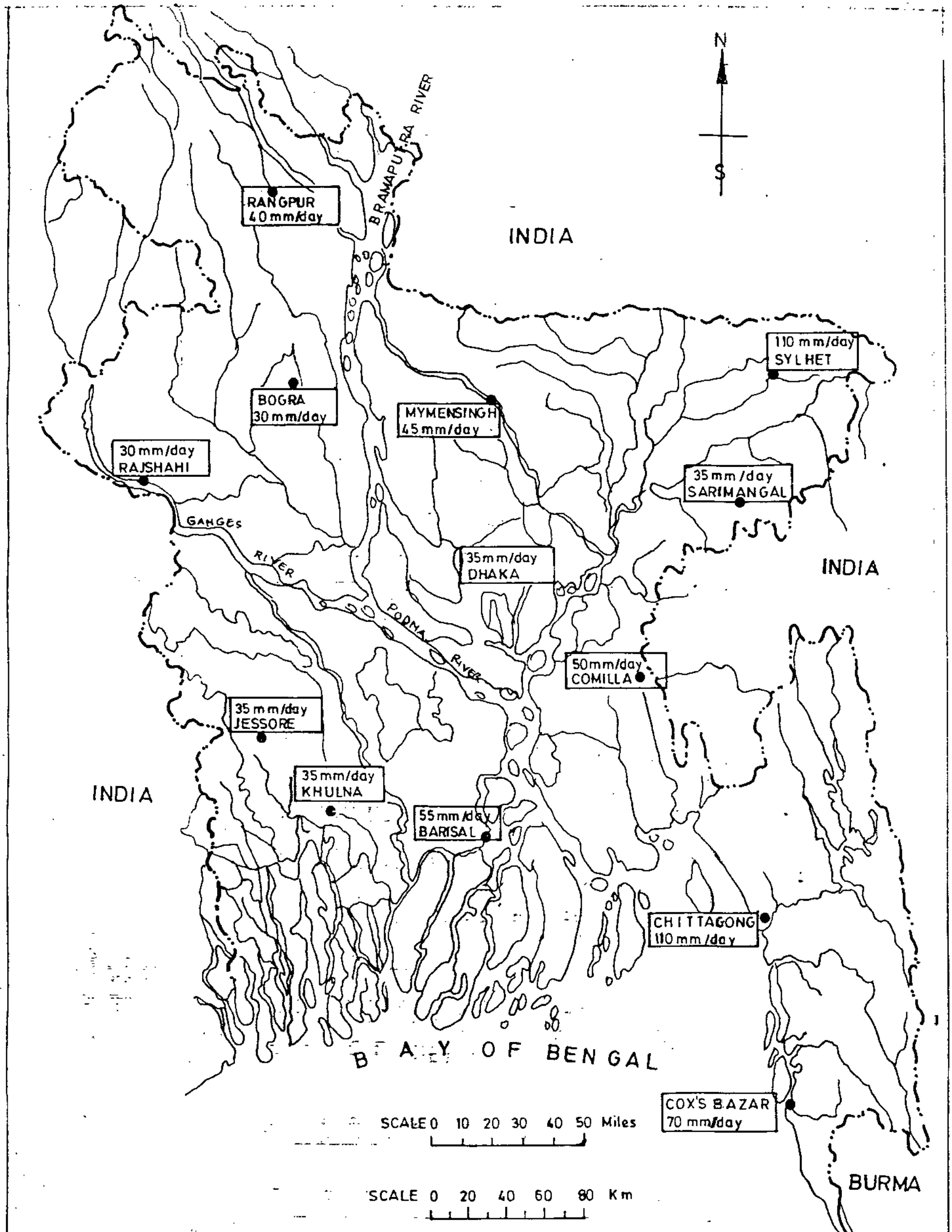


FIGURE. 8. DRAINAGE COEFFICIENT FOR DRAINAGE CLASS II & III FOR SELECTED STATIONS OF BANGLADESH BY MPO [24]

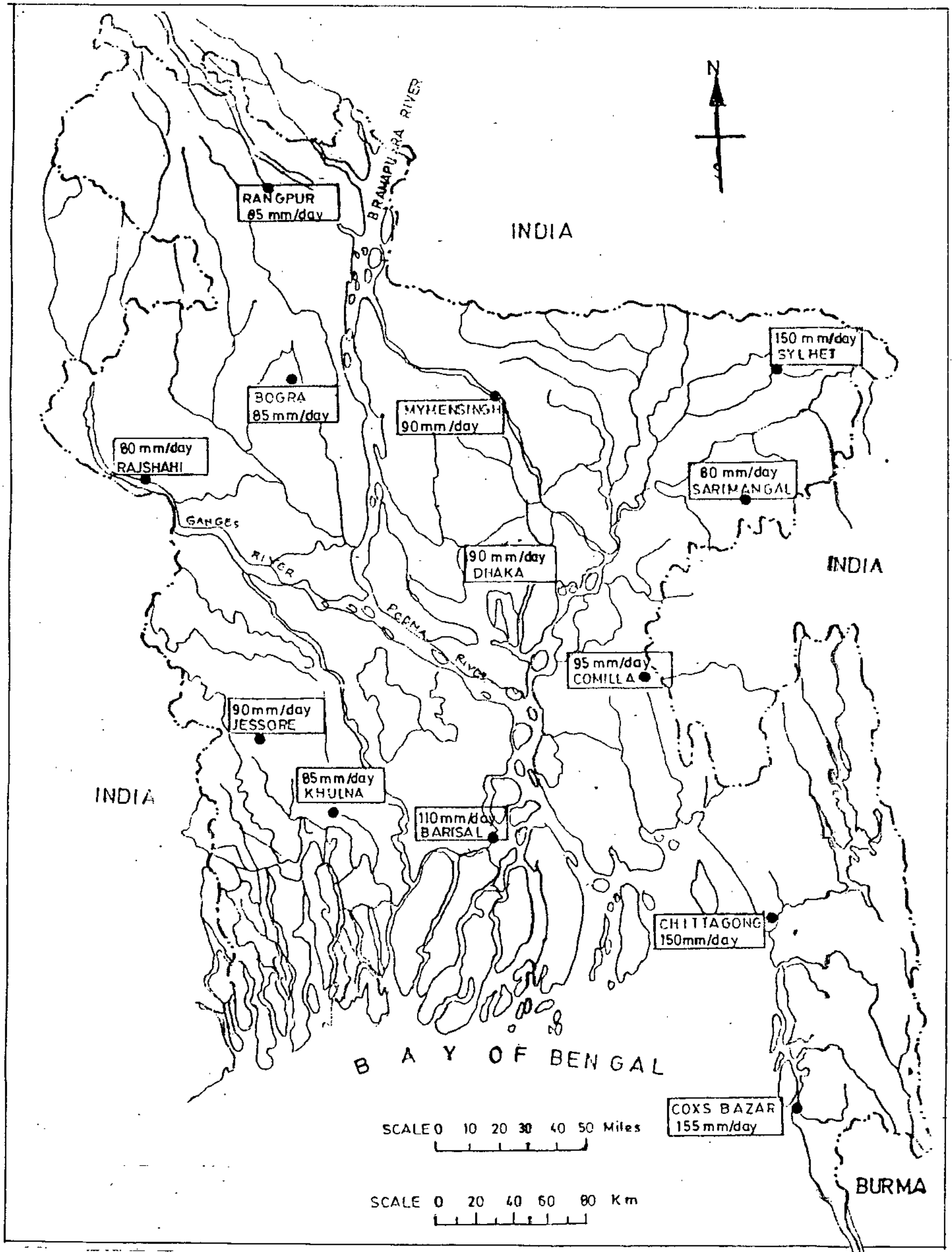


FIGURE. 9. DRAINAGE COEFFICIENT FOR DRAINAGE CLASS IV FOR SELECTED STATION OF BANGLADESH BY MPO[24]

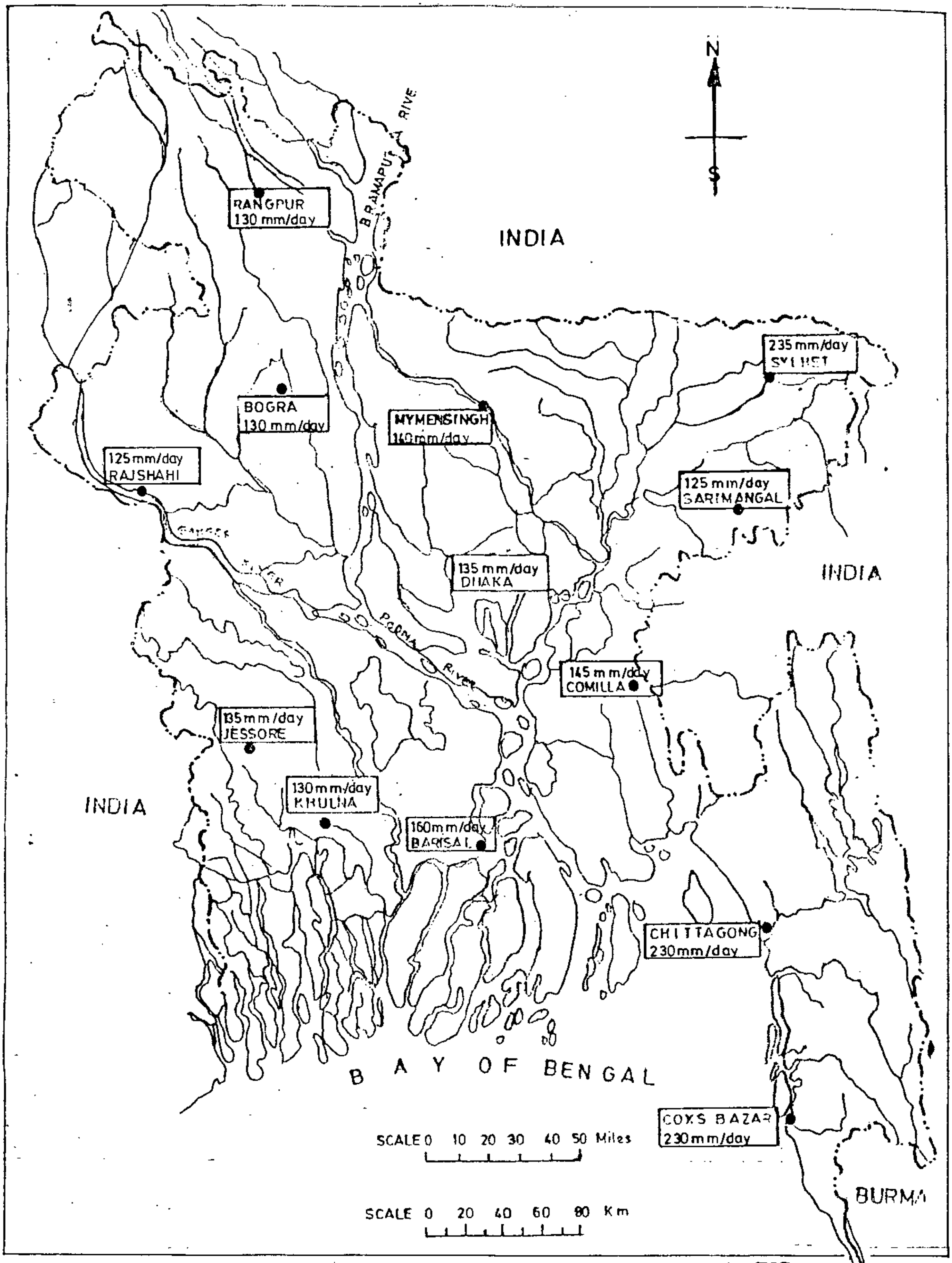


FIGURE. 10. DRAINAGE COEFFICIENT FOR DRAINAGE CLASS V FOR SELECTED STATIONS OF BANGLADESH BY MPO [24]

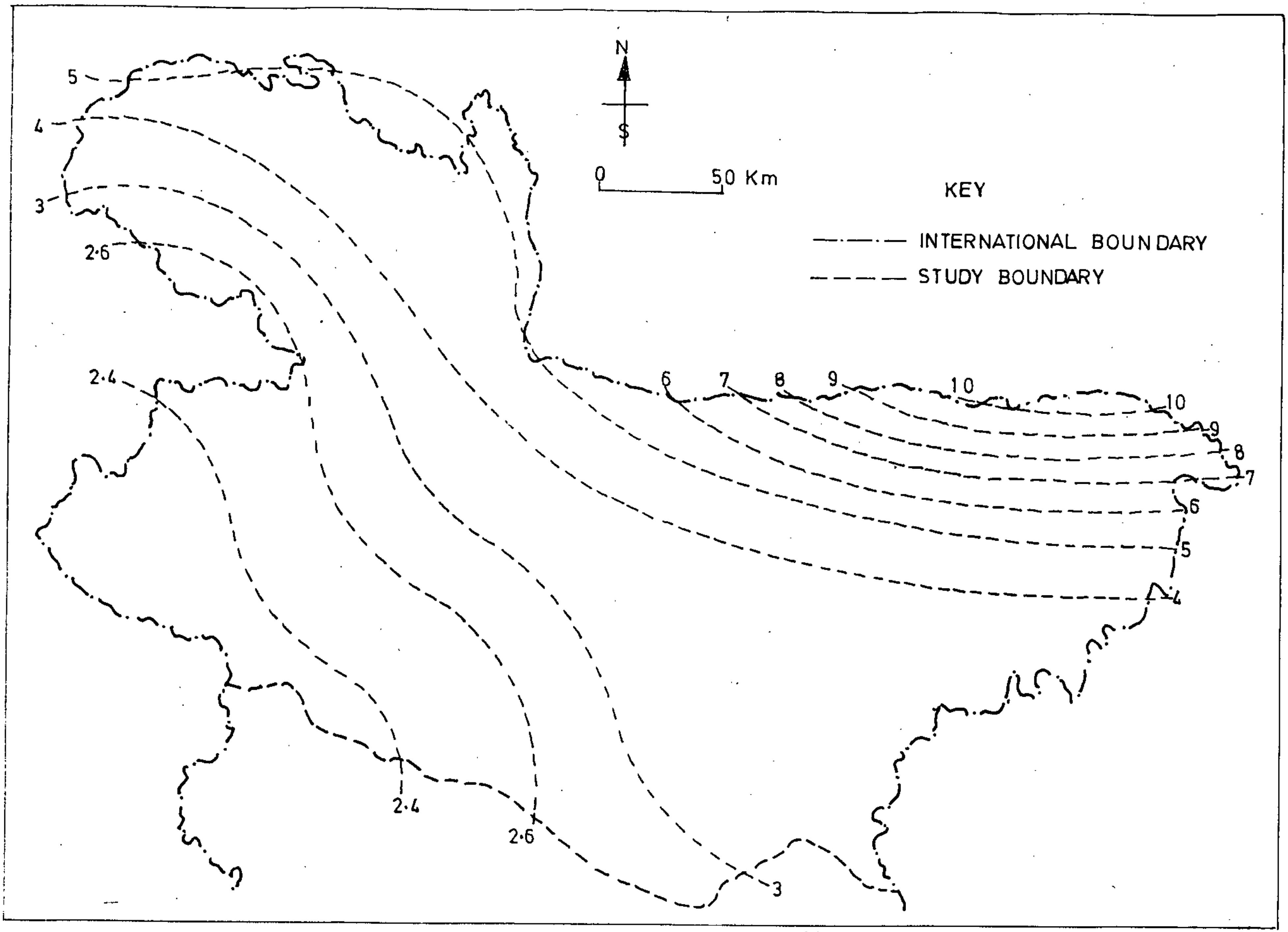


FIGURE. 11. 6 DAY AVERAGE DRAINAGE RATES VALUES OF THE ISOPLETHS IN L/S/HA [1/]

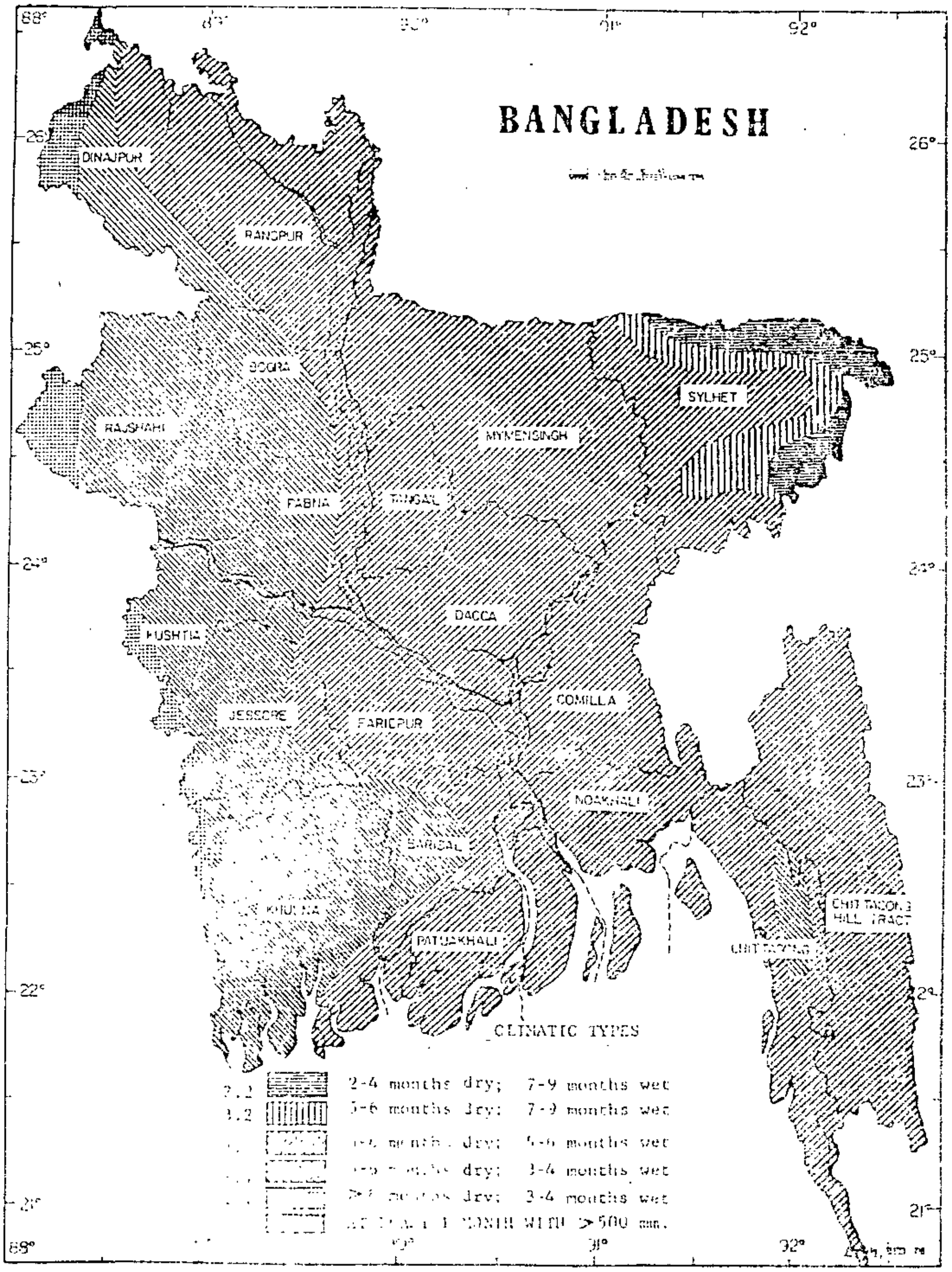


FIG. 12. Climatic Classification of Bangladesh[23]

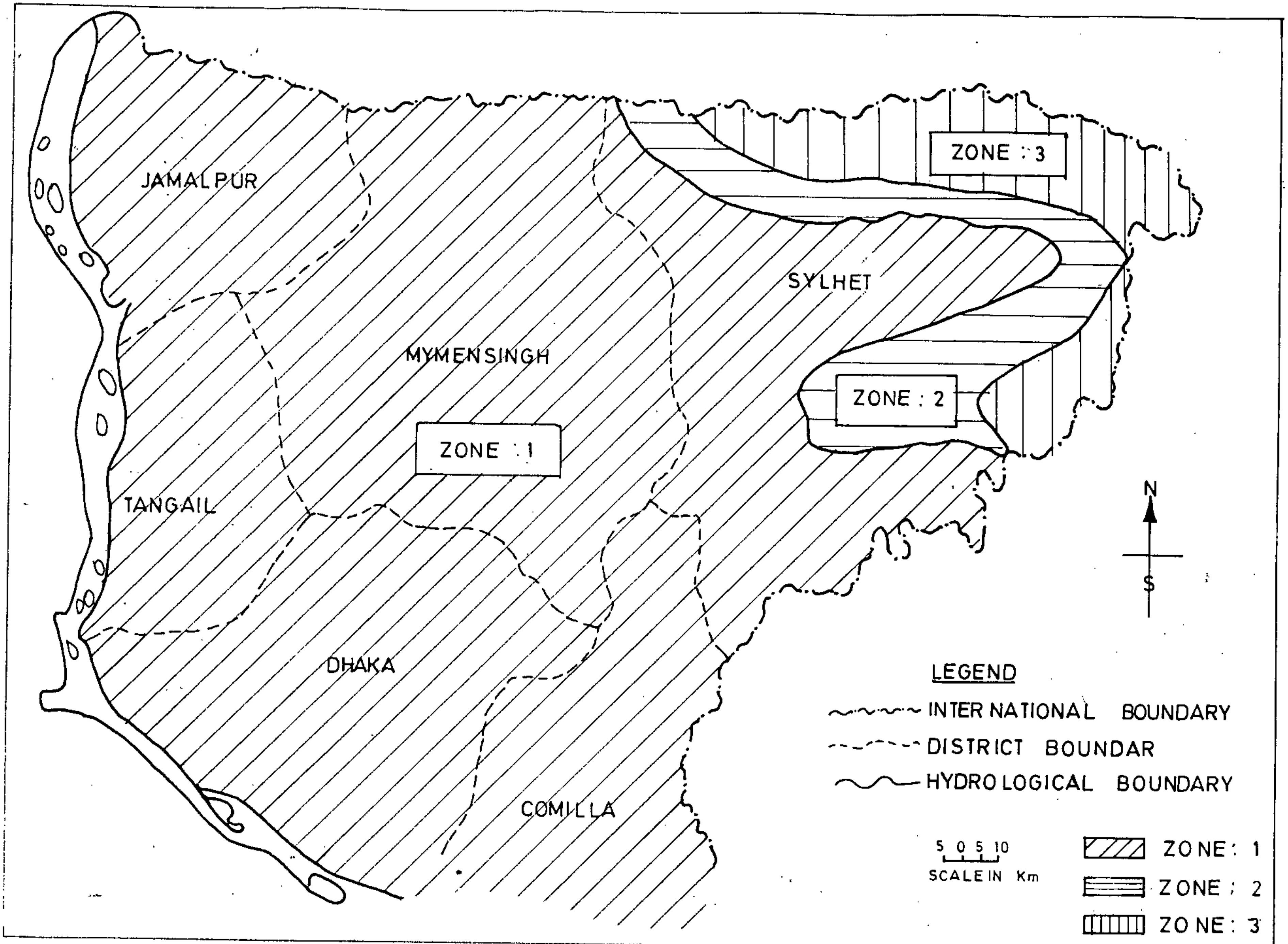


FIGURE. 13. THREE CLIMATIC ZONE IN THE NORTH-EASTERN REGION OF BANGLADESH

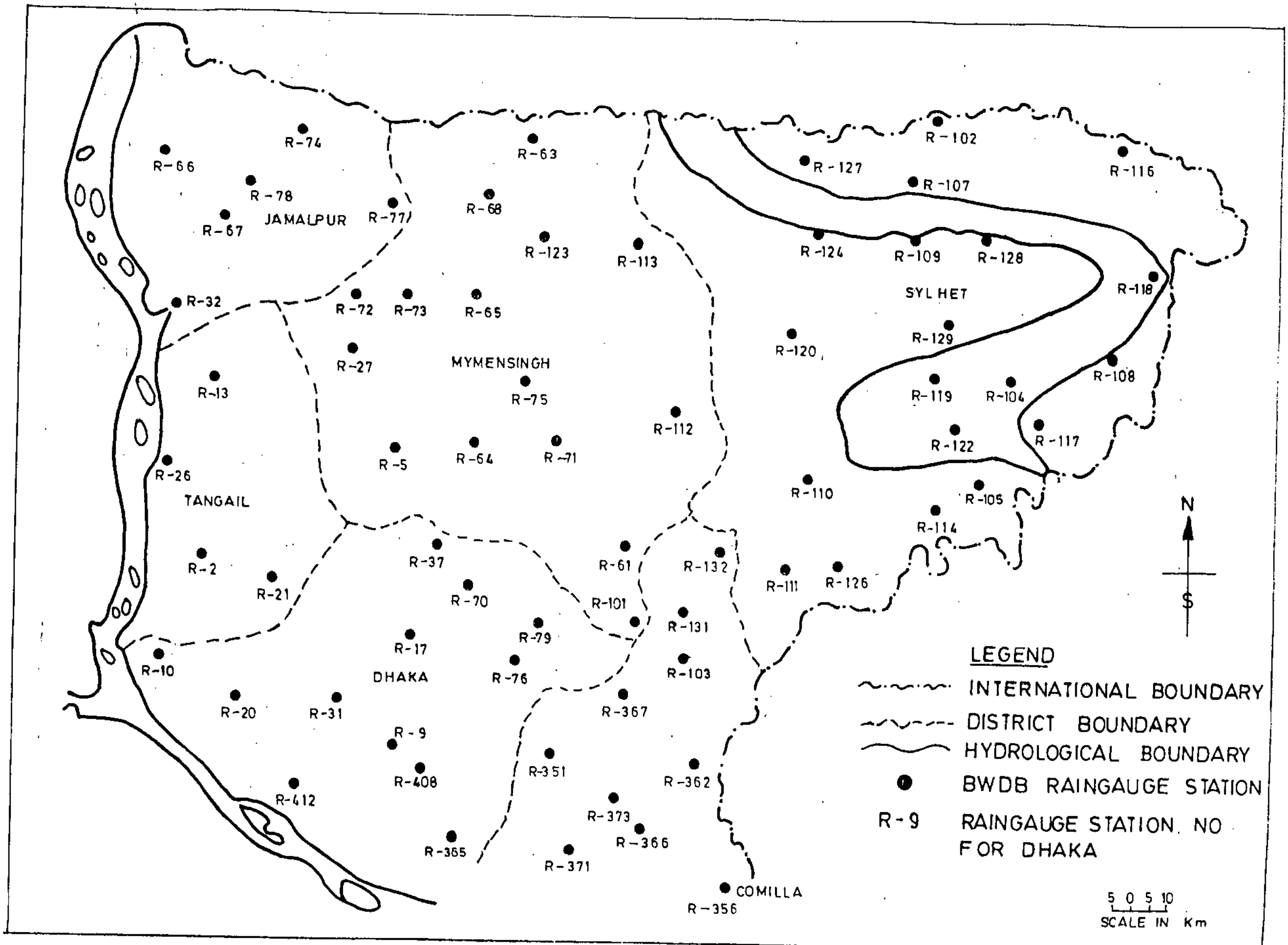


FIGURE. 14. SELECTED RAINGAUGE STATIONS IN THE THREE CLIMATIC ZONE OF THE NORTH-EASTERN REGION OF BANGLADESH

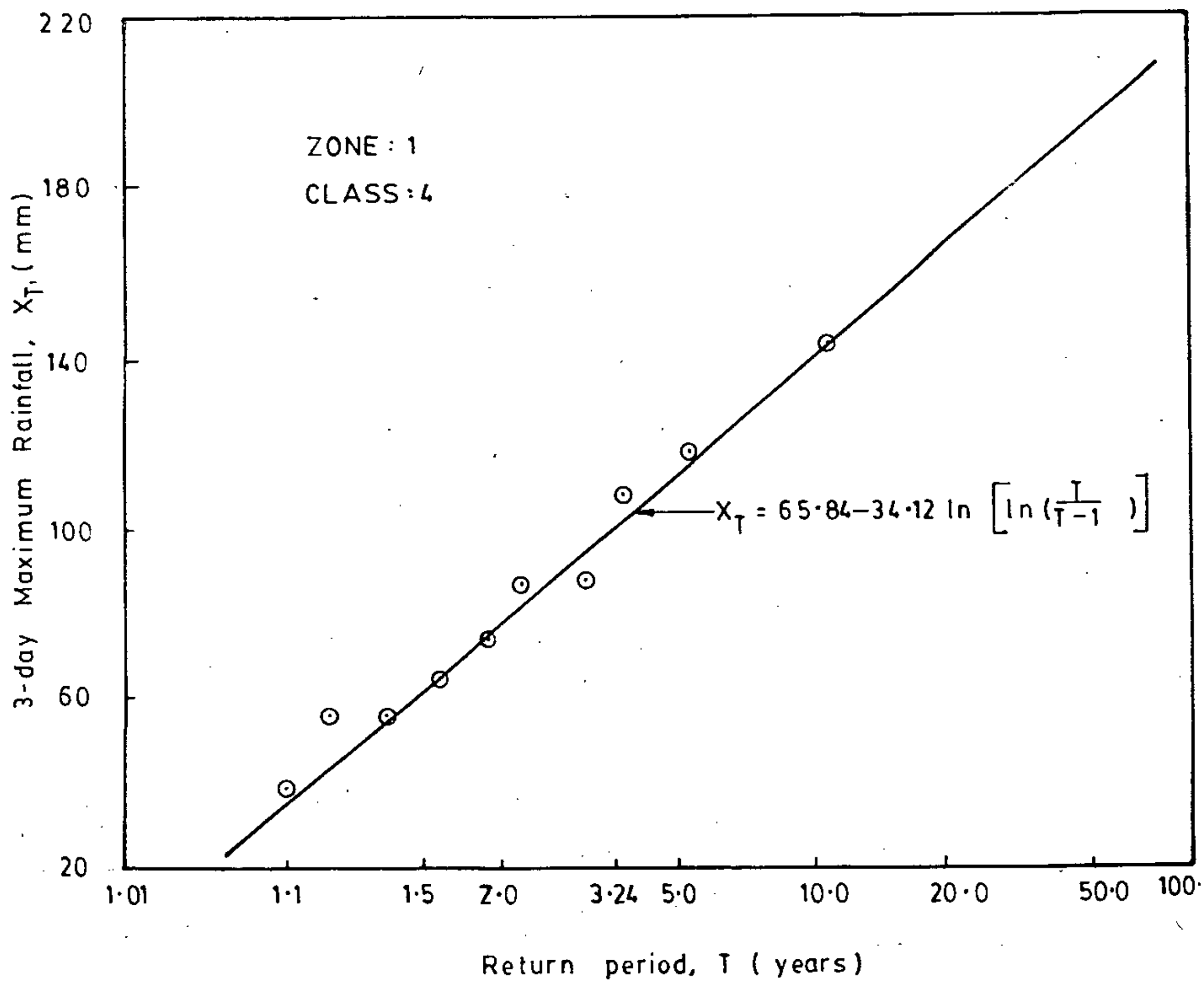


FIG. 15. TYPICAL PLOTING OF DATA ON GUMBEL PROBABILITY PAPER

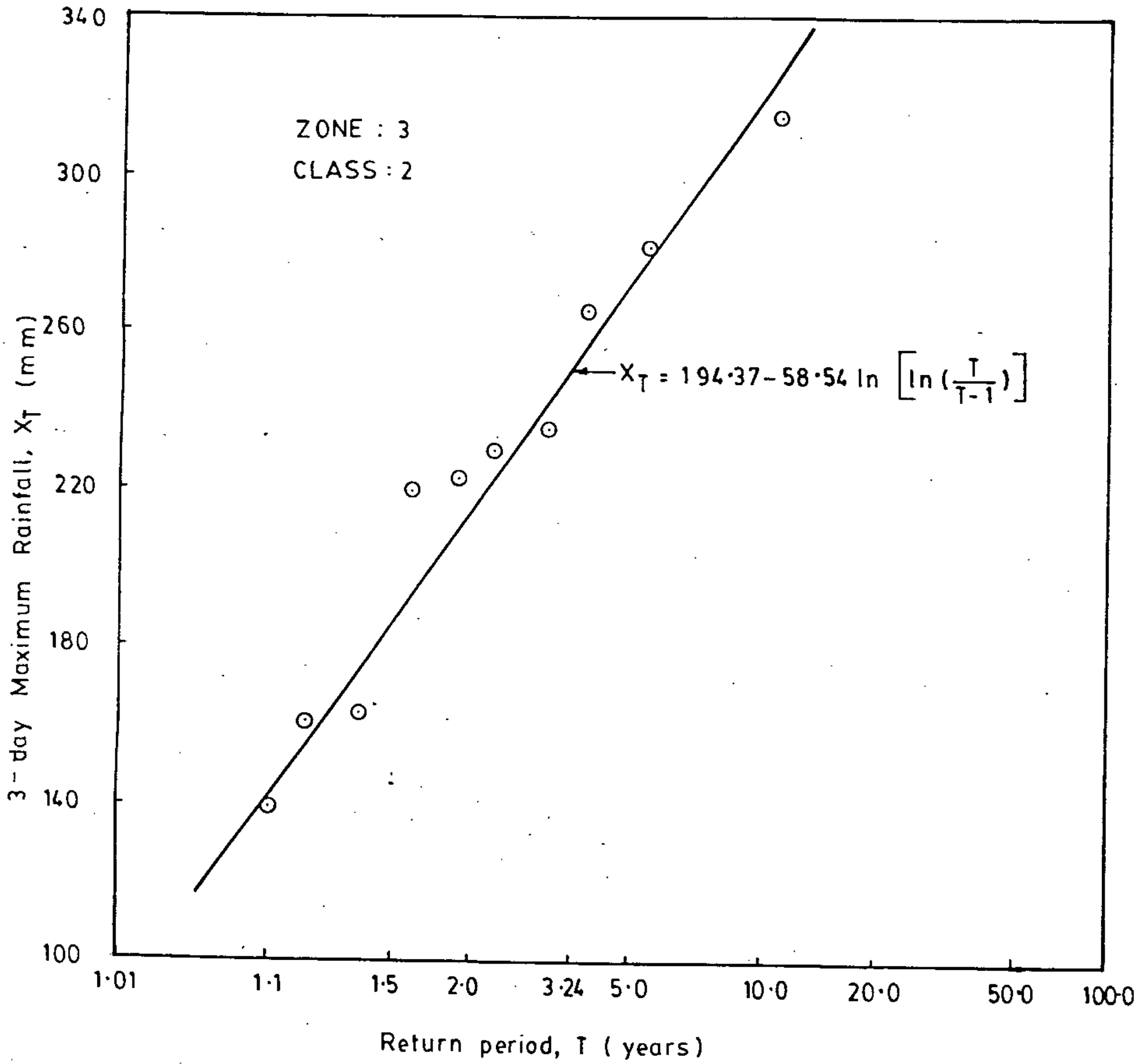


FIG. 16. TYPICAL PLOTING OF DATA ON GUMBLE PROBABILITY PAPER

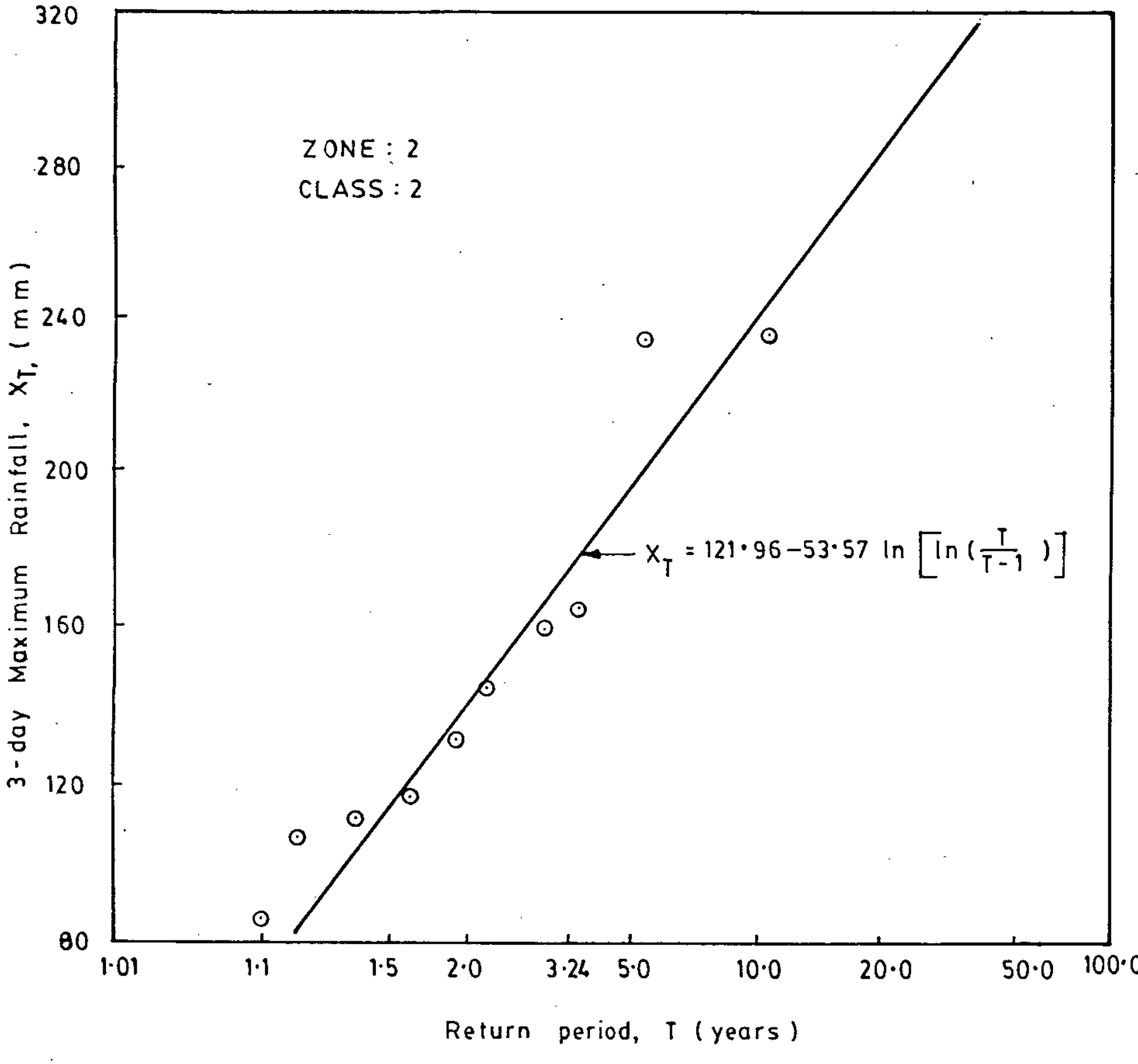


FIG. 17. TYPICAL PLOTING OF DATA ON GUMBLE PROBABILITY PAPER

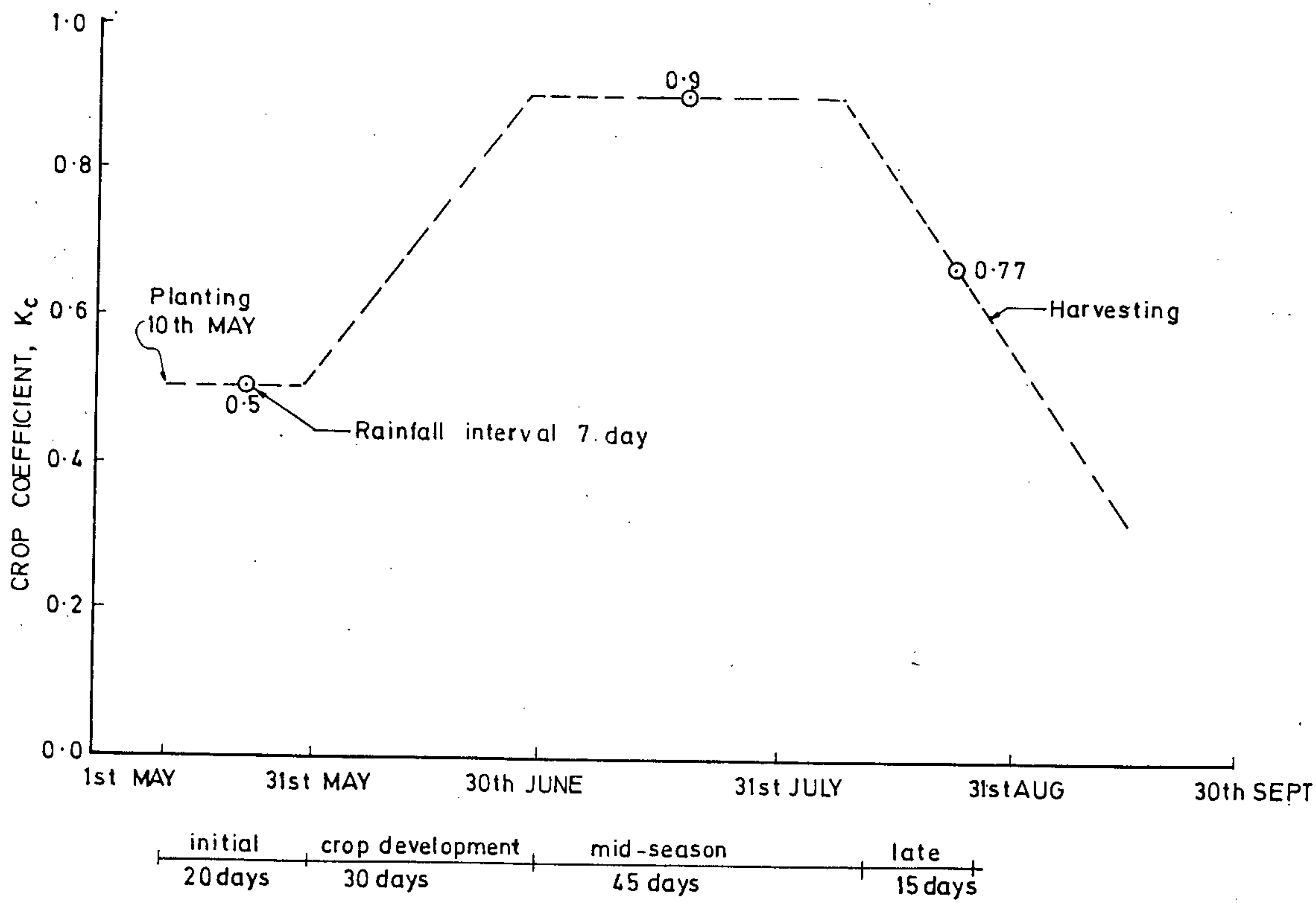


FIG. 18. CROP COEFFICIENT CURVE (VEGETABLES)

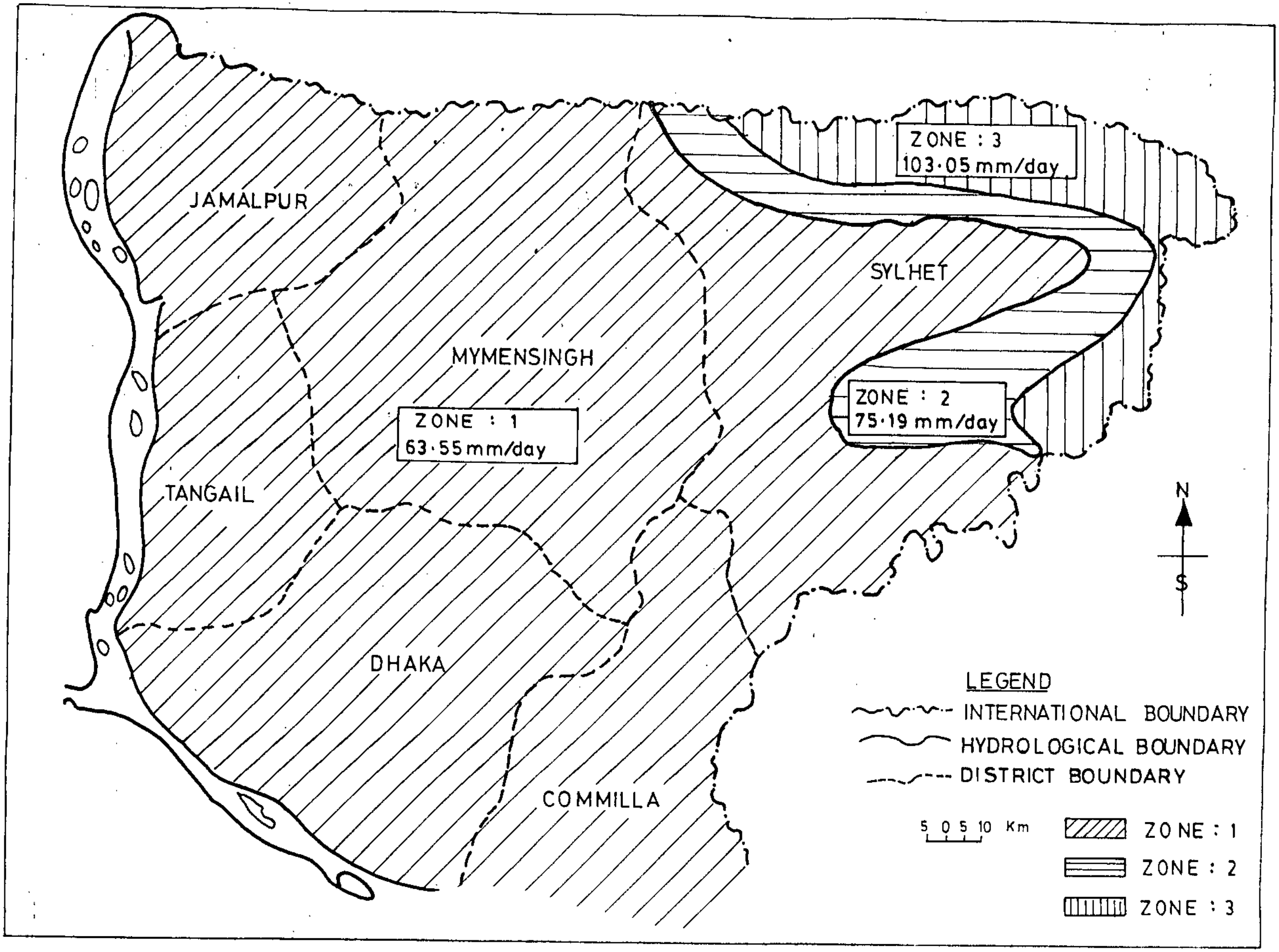


FIG. 19. DRAINAGE COEFFICIENT (Q) FOR DRAINAGE CLASS 2

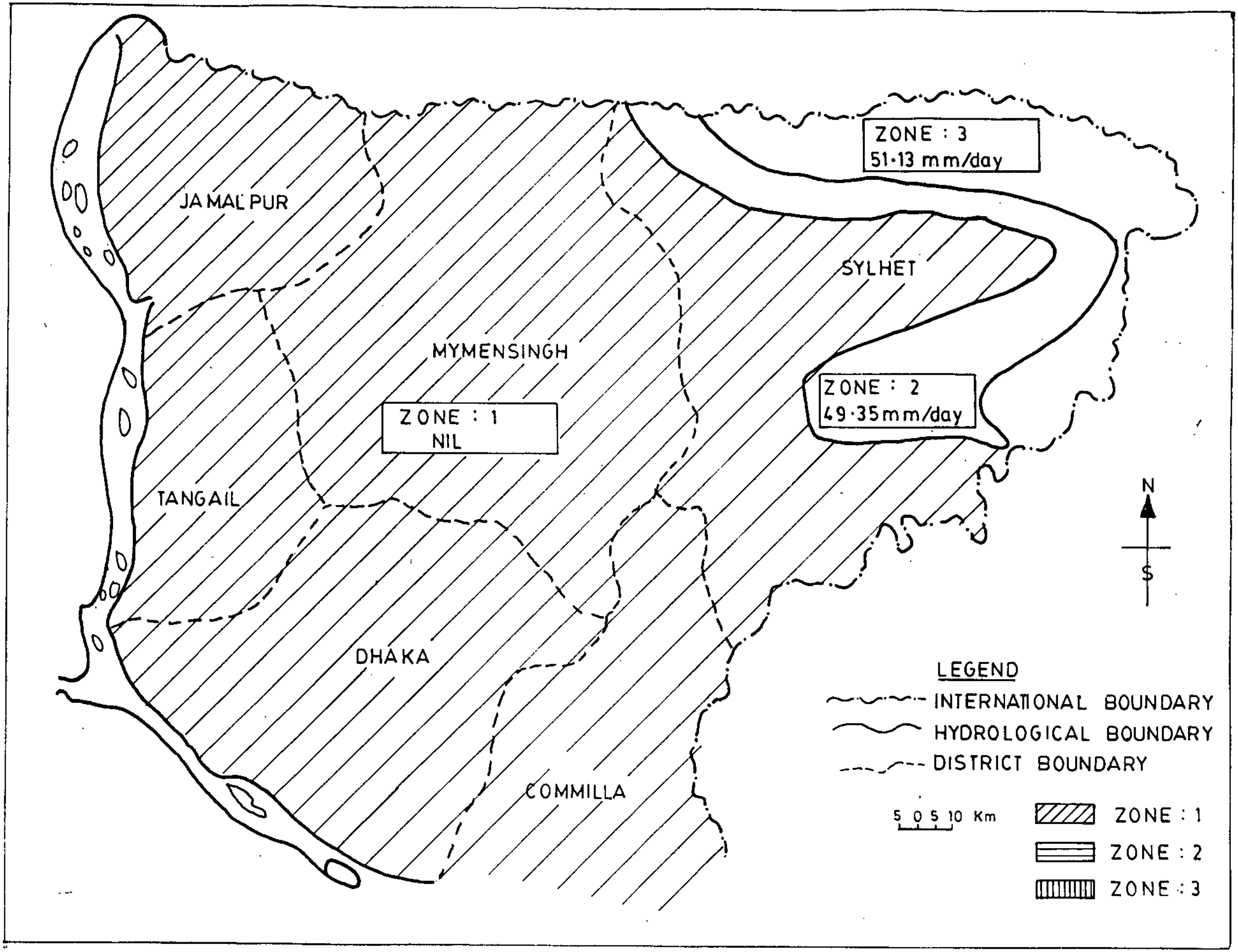


FIG. 20. DRAINAGE COEFFICIENT (Q) FOR DRAINAGE CLASS 3

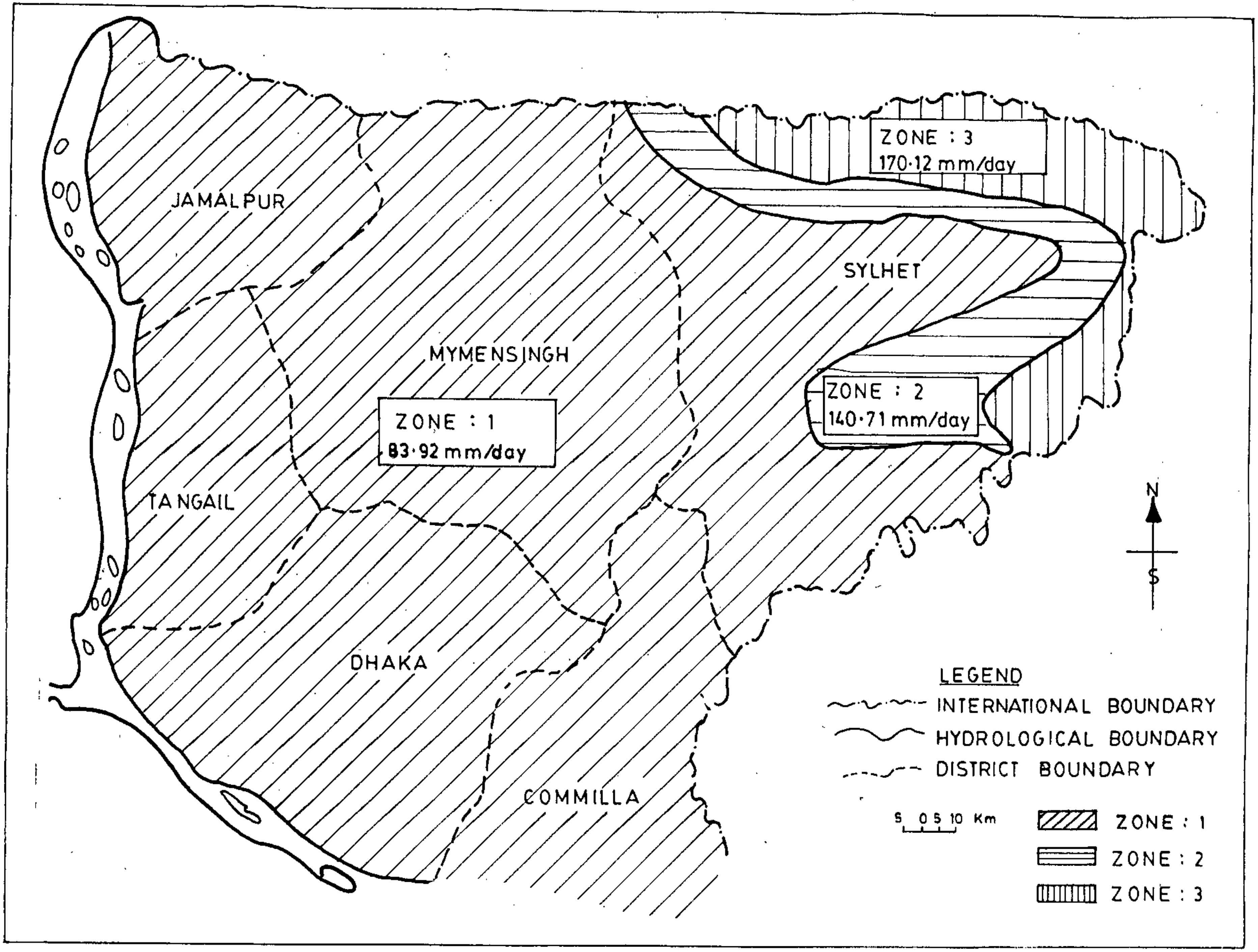


FIG. 21. DRAINAGE COEFFICIENT (Q) FOR DRAINAGE CLASS 5

APPENDIX - B

Table 1 Comparative values of rainfall for different return periods[27]

Procedure	Rainfall for different return periods (mm)				
	1.01	2	5	10	25
Type I Extremal	32.6	104.2	156.4	187.1	226.6
Log Pearson Type III	56.1	105.8	145.3	181.8	223.7
Log normal	36.9	105.1	153.9	184.7	221.3
Gumbel	38.8	108.7	150.5	178.2	212.0
Average	41.1	106.0	151.5	183.0	221.0

Table 2 Values of $\bar{y}_N$ and σ_N as a function of sample size N [a]

N	$\bar{y}_N$	σ_N	N	$\bar{y}_N$	σ_N
8	0.48430	0.90430	46	0.54680	1.15380
9	0.49020	0.92880	47	0.54730	1.15570
10	0.49520	0.94970	48	0.54770	1.15740
11	0.49960	0.96760	49	0.54810	1.15900
12	0.50350	0.98330	50	0.54854	1.16066
13	0.50700	0.99720	51	0.54890	1.16230
14	0.51000	1.00950	52	0.54930	1.16380
15	0.51280	1.02050	53	0.54970	1.16530
16	0.51570	1.03160	54	0.55010	1.16670
17	0.51810	1.04110	55	0.55040	1.16810
18	0.52020	1.04930	56	0.55080	1.16960
19	0.52200	1.05660	57	0.55110	1.17080
20	0.52355	1.06283	58	0.55150	1.17210
21	0.52520	1.06060	59	0.55180	1.17340
22	0.52680	1.07540	60	0.55208	1.17467
23	0.52830	1.08110	62	0.55270	1.17700
24	0.52960	1.08640	64	0.55330	1.17930
25	0.53086	1.09145	66	0.f5380	1.18140
26	0.53200	1.09610	68	0.55430	1.18340
27	0.53320	1.10040	70	0.55477	1.18536
28	0.53430	1.10470	72	0.55520	1.18730
29	0.53530	1.10860	74	0.55570	1.18900
30	0.53622	1.11238	76	0.55610	1.19060
31	0.53710	1.11590	78	0.55650	1.19230
32	0.53800	1.11930	80	0.55688	1.19382
33	0.53880	1.12260	82	0.55720	1.19530
34	0.53960	1.12550	84	0.55760	1.19670
35	0.54034	1.12847	86	0.55800	1.19800
36	0.54100	1.13130	88	0.55830	1.19940
37	0.54180	1.13390	90	0.55860	1.20073
38	0.54240	1.13630	92	0.55890	1.20200
39	0.54300	1.13880	94	0.55920	1.20320
40	0.54362	1.14132	96	0.55952	1.20440
41	0.54420	1.14360	98	0.55980	1.20550
42	0.54480	1.14580	100	0.56002	1.20649
43	0.54530	1.14800	150	0.56461	1.22534
44	0.54580	1.14990	200	0.56715	1.23598
45	0.54630	1.15185	250	0.56878	1.23292

[a] Raudkivi, A.J. 1976, Hydrology; Pergamon Press.

Table 3 Nature of survival of 20 day-old seedling subjected to 10 days submergence in 30 cm of water [2/]

Reaction to flood	Groups		
	TALL	Floating	Dwarf
Survived	Mansra W449 Cross 116, Bhai PTB 13, BR 3	Jaisuria Anjana SW 2	-
Partially survived	-	Jalmagn	-
Barely survived	MTU 16, T141 CR 70-79-9 Cross B2, Sundari	-	CR 1014
Died	MTU 22, Monoharshali, AC 3760, Jhona 349 Gauria Dhudlachi	-	FXC 4, IR 5, FXC 5, FXC 9 IR 8

Table 4 Showing differential response of varieties to different flooding 2/

Variety	% survial under inter-mittent flooding 12 days complete submergence	% survival under continuous flooding 3.7 m water depth	% survival under stagnant inter-mittent flooding 7 days submergence in 0.75 water depth
1	2	3	4
Cross 82	60.6	0	2
FR 61	64.4	0	5
FRG 2	69.0	0	5
FRG 10	52.0	0	7
Madhukar	68.0	0	15
FR 43 B	45.0	0	4
FR 13 A	40.2	0	13
Chakia 59	44.6	0	26
T 100	20.3	0	14
DW 6172 A	8.9	99.5	40
Dudhlach 7	19.8	98.8	32
DW 6258	19.9	97.9	29
DW 6258	15.0	99.0	25
Tarabao	6.7	98.2	2
SW 2	0.9	99.4	17
Jaisuria	0.8	96.7	2
Jalmagn	1.5	96.6	2

Table 5 Survial percentage of plants (early and late types) submerged under different depths of water[a/]

Depths of submergence (cm)	Variety	Seedling age in weeks					
		2	4	6	8	10	Average
15	a	72.6	98.5	100.0	100.0	100.0	95.0
	b	62.6	98.5	95.3	79.7	93.8	86.0
25	a	34.4	96.9	100.0	95.3	100.0	85.3
	b	32.9	65.9	90.6	66.7	93.8	74.0
35	a	34.4	69.7	100.0	100.0	100.0	80.8
	b	20.4	59.4	76.6	67.2	87.5	62.2
Average	a	48.5	88.4	100.0	98.4	100.0	87.0
	b	38.6	81.3	87.5	71.2	91.2	74.1

a - early pure-line - A, 54-19.

b - late pure-line - A, 192.

Table 6 Survival percentage of deep-water rice plant submerged under water for different durations 2/

Duration of submergence under 60 cm of water (days)	Variety	Age of seedlings in weeks					
		2	4	6	8	10	Average
5	a	64.7	93.3	95.3	100.0	100.0	90.9
	b	61.0	89.1	90.6	100.0	96.9	87.5
8	a	28.2	61.0	100.0	100.0	100.0	77.8
	b	23.5	86.0	86.6	92.2	75.0	72.5
12	a	0.0	25.0	98.5	100.0	100.0	64.7
	b	0.0	62.5	68.8	89.1	57.9	55.7
Average	a	33.8	60.4	97.9	100.0	100.0	77.8
	b	28.2	79.2	81.9	93.8	76.6	71.9

a - early pure-line - A, 54-19.

b - late pure-line - A, 192.

Table 7 Survival percentage of deep water rice seedling as affected by duration of submergence and age of seedling [3/]

	Duration of submergence (days)	Survival (%)				
		Seedling age (weeks)				
		2	4	6	8	10
A. 54-19	4	64.1	95.3	95.3	100.0	100.0
Early type	10	28.2	61.0	100.0	100.0	100.0
	14	0.0	25.0	98.9	100.0	100.0
	Mean	30.8	60.4	97.9	100.0	100.0
A. 192	4	61.0	89.1	90.6	100.0	96.9
Late type	8	23.5	86.0	86.6	92.2	75.0
	14	0.0	62.5	68.6	89.1	57.9
	Mean	28.2	79.2	81.9	93.8	76.8

Table 8 Survival percentage of deep water rice seedling as affected by depth of submergence and age of seedling[3/]

Variety	Depth of submergence (cm)	Survival (%)					
		Seedling age (weeks)					
		2	4	6	8	10	Mean
A 54-19	15	76.5	98.5	100.0	100.0	100.0	95.0
Early type	25	34.4	26.9	100.0	95.3	100.0	95.3
MD	35	34.4	9.7	100.0	100.0	100.0	80.3
MD	Mean	48.5	88.4	100.0	98.4	100.0	-
A. 92	15	62.5	98.5	95.3	79.7	93.8	86.0
	25	32.6	6.6	90.6	6.7	93.8	52.3
Late type	35	20.4	59.4	76.6	67.2	87.5	62.2
	Mean	38.6	81.3	87.5	71.2	91.2	-

Table 9 Yield of variety Jaya under three levels of submergence (25, 50, 75% of crop height) at each of the three growth phases during Aman (July-Nov) and Boro (Jan - Apr) [29]

Plant growth stage	Ht. of plant submerged	Relative grain yield (%) 1973 (Aman)	1974 (Boro)
Control (continuous submergence) 5 ± 2 cm		100	100
Seedling establishment to maximum tillering	25%	82	75
	50%	75	62
	75%	68	58
Maximum tillering to flowering	25%	81	74
	50%	71	64
	75%	72	56
Flowering to maturity	25%	79	71
	50%	76	66
	75%	70	50

Table 10 Range of climatic and catchment characteristics [27]

Sl. No.	Characteristics	Range	Specific values for Kernal
1.	Storm rainfall	5-25 cm	20 cm
2.	Storm duration	1-2 days	2 days
3.	Daily infiltration rate in the catchment	0.5-5 cm	0.5 cm
4.	Depth of permissible detention in the catchment	0-15 cm	10 cm
5.	Daily evaporation during the storm	0.2-0.4 cm	0.2 cm

Table 11 Computed runoff for paddy during the growing season[27]/

Period	Return period	Average storm magnitude	Run-off expected (Normal land with paddy)
July			
1-5	1x25	115.6	0
6-10	2x25	119.6	0
11-15	1x25	231.2	71
16-20	0	-	-
21-25	1x25	127.0	0
26-31	0*	-	-
August			
1-5	1x25	99.1	0
6-10	0*	-	-
11-15	3x25	132.3	0
16-20	0*	-	-
21-25	2x25	138.3	52
26-31	0*	-	-

* The event has not occurred in the 25 years of record.

Table 12 Index of rainfall stations

Sl. No.	Station names	BWDB Nr	Location N deg	N min	E deg	E min
1.	Atia (Tangail)	R 2	24	22	89	55
2.	Bancharampur	R 351	23	44.5	90	49
3.	Bajitpur	R 61	24	13.5	90	57.5
4.	Bhairab Bazar	R 101	24	02.7	90	59.3
5.	Bhaluka	R 5	24	25	90	24
6.	Bholaganj	R 102	25	86	91	45.1
7.	Brahmanbaria	R 103	23	58.7	91	07
8.	Chandbagh (Sylhet)	R 104	24	34.8	91	55.2
9.	Chanpurbagan (")	R 105	24	09.3	91	29
10.	Chhatak	R 107	25	01.4	91	38
11.	Comilla	R 356	23	27.5	91	11
12.	Dhaka	R 9	23	45.2	90	22.5
13.	Dakshinbagh	R 108	24	38	92	22.5
14.	Daulatpur	R 10	23	56	89	50.4
15.	Durgapur (Mymensingh)	R 63	25	07.5	90	41
16.	Fatullah	R 408	23	40	90	31.6
17.	Gaffargaon	R 64	24	24	90	35
18.	Gobindaganj	R 109	24	55.7	91	41.7
19.	Gopalpur	R 13	24	32	89	58
20.	Gouripur	R 65	24	45	90	35
21.	Habiganj	R 110	24	22	91	25.5
22.	Islampur	R 66	25	03.8	89	49

Table 12 (Contd..)

Sl. No.	Station names	BWDB Nr	Location N deg	N min	E deg	E min
23.	Itakhola	R 111	24	09	91	22
24.	Intna	R 112	24	30	91	07
25.	Jamalpur	R 67	24	54	89	57
26.	Jaria-Jhanjail	R 68	25	00	90	39.3
27.	Joydebpur	R 17	24	00	90	25
28.	Kaliajuri	R 113	24	41.5	91	09
29.	Kamalganj (Sylhet)	R 114	24	21	91	51.5
30.	Kapasia	R 70	24	07	90	36
31.	Kasbah	R 362	23	43	91	08.5
32.	Kishoreganj	R 71	24	26	90	47.5
33.	Lallakhal (Sylhet)	R 116	25	05.7	92	11.7
34.	Langla	R 117	24	29.5	91	98
35.	Latu	R 118	24	49	92	15.5
36.	Manikganj	R 20	23	51	90	03
37.	Manumukh	R 119	24	35	91	43
38.	Markuli	R 120	24	41	91	43
39.	Mirzapur	R 21	24	05	90	10
40.	Moulvi Bazar	R 122	24	28.5	91	46.8
41.	Muktagacha	R 72	24	45	90	16
42.	Munshiganj	R 365	23	33.1	90	32.2
43.	Muradnagar	R 366	23	38.3	90	57
44.	Mymensingh	R 73	24	46	90	24
45.	Nabinagar	R 367	23	53.5	90	58.5

Table 12 (Contd..)

Sl. No.	Station names	BWDB Nr	Location			
			N		E	
			deg	min	deg	min
46.	Nalitabari (Taraganj)	R 74	25	04.8	90	10.7
47.	Nandail	R 75-	24	33.8	99	40.3
48.	Narsinghdi	R 76	23	57.3	900	42
49.	Nasirnagar	R 132	24	11.8	91	12
50.	Nawabganj (Dhaka)	R 412	23	38	90	09
51.	Netrokona	R 123	24	53	90	43
52.	Pagla	R 124	24	54.5	91	27.1
53.	Phulbaria	R 27	24	37.5	90	16
54.	Phulpur	R 77	24	57.3	90	22
55.	Pingna	R 28	24	35	89	50
56.	Raipur	R 371	23	31	90	53
57.	Ramchandrapur	R 373	23	43	90	53.3
58.	Sarail	R 131	24	02	91	07
59.	Savar	R 31	23	49	90	18
60.	Sharishabari	R 32	23	44	89	49
61.	Sherpur (Mymensingh)	R 78	25	00	90	00.8
62.	Shibpur	R 79	24	01.5	90	46
63.	Shreepur	R 37	24	11.7	90	29
64.	Srimangal	R 126	24	18.2	91	44
65.	Sunamganj	R 127	25	04.5	91	25
66.	Sylhet	R 128	24	53.4	91	52
67.	Tajpur	R 129	24	42.5	91	44
68	Zakiganj	R 130	24	56	92	19

TABLE : 13

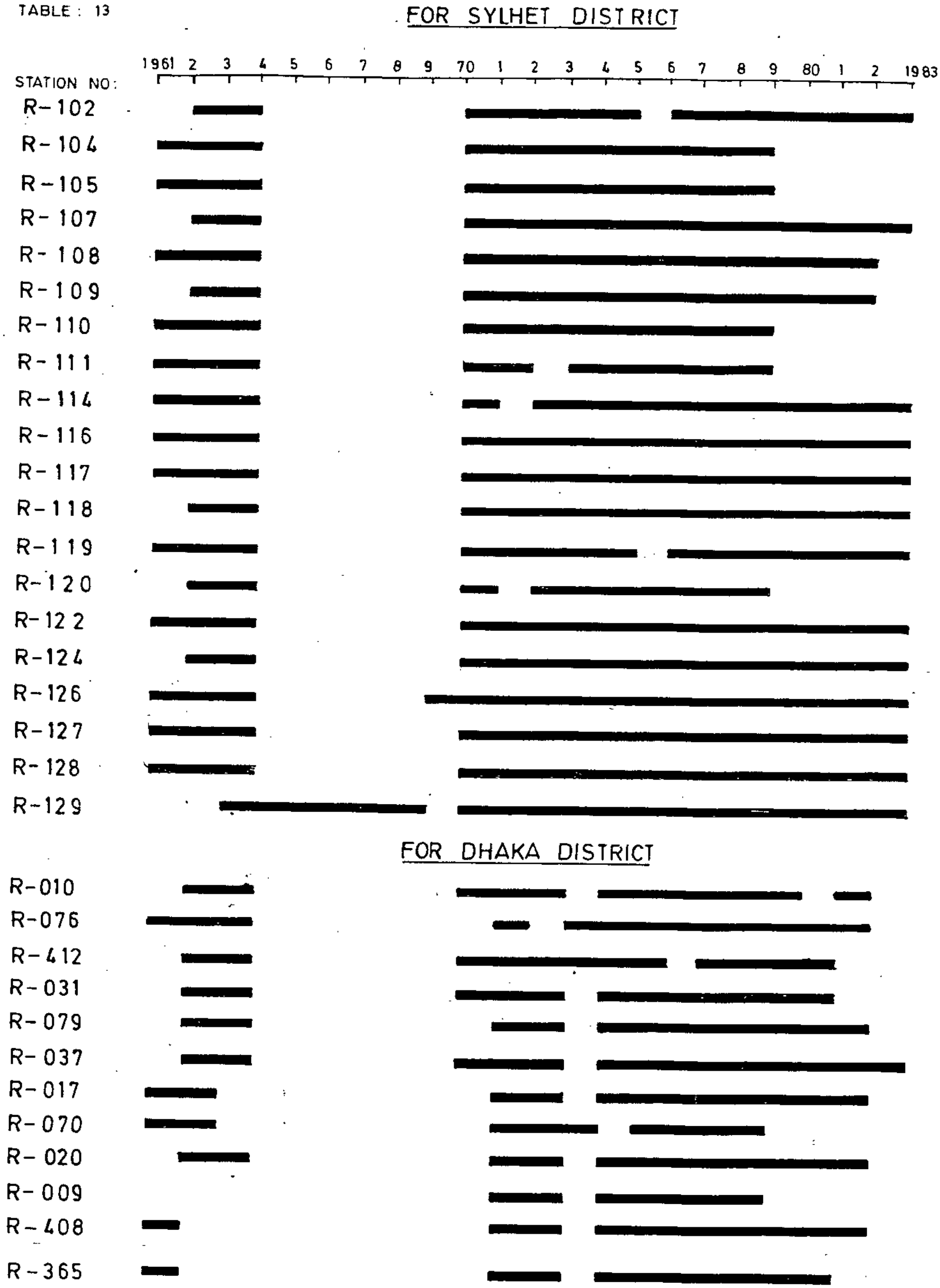

FOR SYLHET DISTRICT
1961 2 3 4 5 6 7 8 9 70 1 2 3 4 5 6 7 8 9 80 1 2 1983
STATION NO:
R-102
R-104
R-105
R-107
R-108
R-109
R-110
R-111
R-114
R-116
R-117
R-118
R-119
R-120
R-122
R-124
R-126
R-127
R-128
R-129
FOR DHAKA DISTRICT
R-010
R-076
R-412
R-031
R-079
R-037
R-017
R-070
R-020
R-009
R-408
R-365

TABLE : 13 (Contd.)

FOR MYMENSINGH DISTRICT

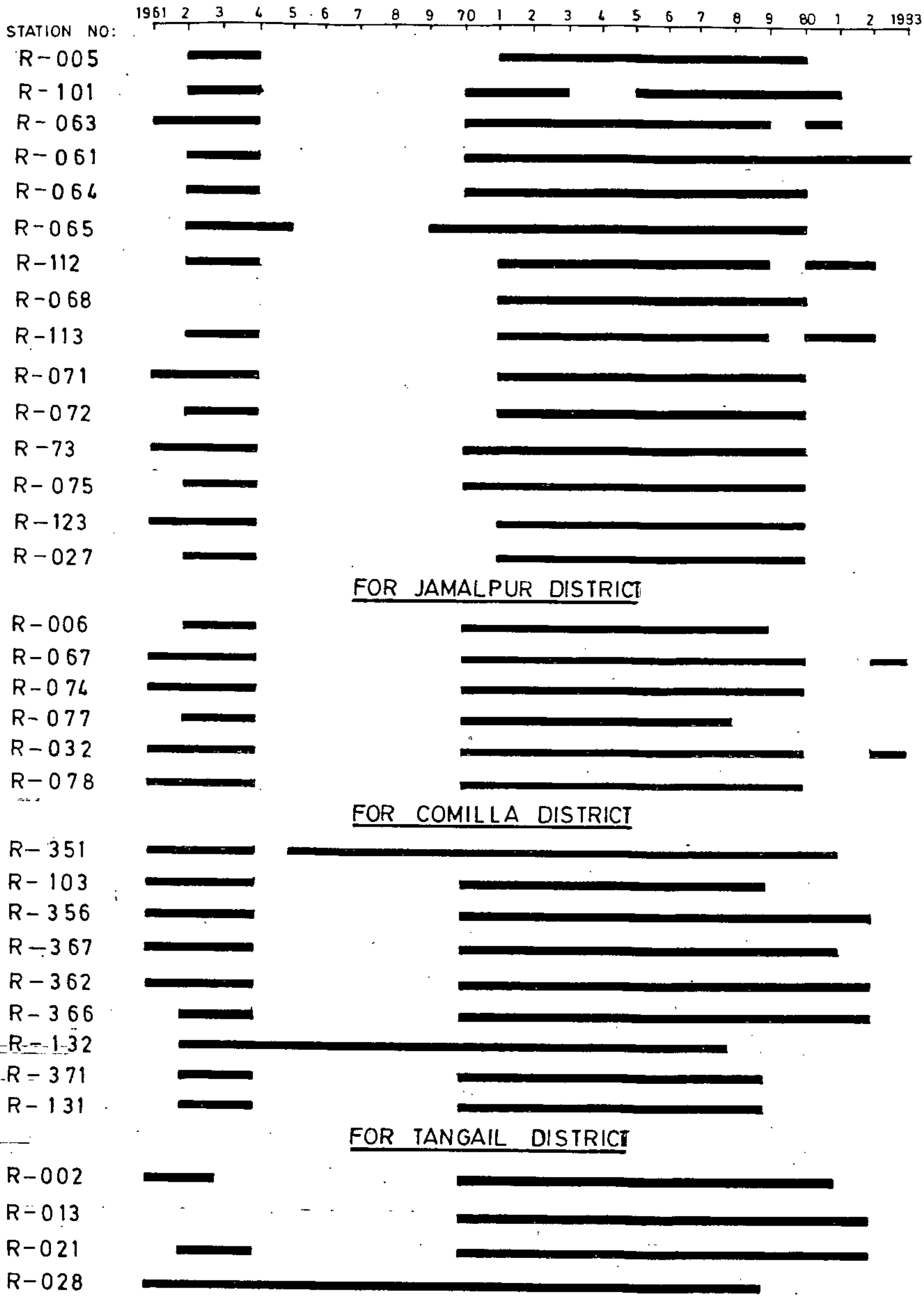


Table 14 Probable maximum 3-day rainfall

Drainage Class	Critical period	Probable maximum 3-day rainfall, mm		
		Zone 1	Zone 2	Zone 3
2	15th July to end of August	207.56	242.49	326.08
3	20th May to 20th June	262.38	417.62	422.95
4	15th April to 15th May	142.61	252.37	258.64
5	10th May to 28th August	261.22	431.44	519.66

Table 15 Critical values for the Kolmogorov-Smirnov Test Statistic[27/]

Sample Size(n)	Significance level .20	.15	.10	.05	.01
1	.900	.925	.950	.975	.995
2	.684	.726	.776	.842	.929
3	.565	.597	.642	.708	.829
4	.494	.524	.564	.624	.734
5	.440	.474	.510	.563	.669
6	.410	.436	.470	.521	.618
7	.381	.405	.438	.486	.577
8	.358	.381	.411	.457	.543
9	.339	.360	.388	.432	.514
10	.322	.420	.388	.409	.486
11	.307	.326	.352	.391	.468
12	.295	.313	.338	.375	.450
13	.284	.302	.325	.361	.433
14	.274	.292	.314	.349	.418
15	.266	.283	.304	.338	.404
16	.258	.274	.295	.328	.391
17	.250	.266	.288	.318	.380
18	.244	.259	.278	.309	.370
19	.237	.252	.272	.301	.361
20	.231	.246	.264	.294	.352
25	.210	.220	.240	.264	.320
30	.190	.200	.220	.242	.290
35	.180	.190	.190	.230	.270
40				.210	.250
50				.190	.230
60				.170	.210
70				.160	.190
80				.150	.180
90				.140	
100				.140	
Asymptotic Formula:	$\frac{1.07}{\sqrt{n}}$	$\frac{1.14}{\sqrt{n}}$	$\frac{1.22}{\sqrt{n}}$	$\frac{1.36}{\sqrt{n}}$	$\frac{1.63}{\sqrt{n}}$

TABLE. 16. AVERAGE MONTHLY POTENTIAL EVAPOTRANSPIRATION FOR DIFFERENT LOCATIONS OF BANGLADESH (mm/day)

STATION	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
BARISAL	2.59	3.54	4.48	5.30	5.33	3.82	3.71	3.50	3.74	3.72	3.13	2.46
BOGRA	2.51	3.02	4.91	6.22	5.78	4.35	4.18	3.96	3.97	3.37	2.97	2.37
COMILLA	2.46	3.48	4.51	5.00	4.61	4.08	3.62	3.56	3.51	2.99	2.59	2.08
CHITTAGONG	3.19	4.38	5.79	6.39	5.96	4.20	4.66	4.41	4.28	3.88	3.52	2.73
COX'S BAZAR	2.64	2.64	3.80	5.19	6.22	5.98	4.37	4.47	4.36	4.12	3.79	3.20
DHAKA	2.64	3.30	5.19	6.22	5.98	4.37	4.47	4.36	4.12	3.74	3.18	2.48
DINAJPUR	2.15	3.17	4.58	5.34	4.70	3.91	3.44	3.12	3.02	2.75	2.35	1.86
FARIDPUR	2.26	7.25	4.77	5.53	4.97	3.95	3.51	3.33	3.24	2.99	2.54	2.13
ISHURDI	2.30	3.53	5.11	6.37	4.40	4.47	3.74	3.25	3.37	2.91	2.52	2.11
JESSORE	2.71	3.86	5.23	6.48	6.83	4.61	4.40	4.31	4.10	3.99	3.16	2.49
KHULNA	2.40	3.37	4.54	5.08	4.87	3.93	3.42	3.26	3.13	2.90	2.65	2.16
MYMENSINGH	2.15	3.07	4.21	4.83	4.41	3.70	3.45	3.31	3.16	2.72	2.40	1.97
NOAKHALI	2.35	3.14	4.04	4.50	4.15	3.58	3.34	3.21	3.02	2.84	2.43	2.05
NARAYANGANJ	2.53	3.61	5.50	4.02	4.71	3.93	3.67	3.52	3.35	3.26	2.73	2.36
RANGPUR	2.08	3.17	4.52	5.49	4.90	4.28	3.92	3.54	3.36	2.96	2.44	1.94
RANGAMATI	2.86	4.02	5.27	5.67	5.45	4.36	4.27	3.96	3.85	3.32	2.87	2.32
SATKHIRA	2.47	3.26	4.72	5.29	5.27	4.22	3.47	3.40	3.27	2.88	2.86	2.20
SYLHET	2.71	4.16	5.18	5.18	4.84	3.59	3.87	3.72	3.73	3.69	3.30	2.78
$\bar{X}$	2.56	3.81	4.89	5.56	5.19	4.10	3.86	3.66	3.58	3.29	2.87	2.32
σ_{N-1}	0.41	0.98	0.48	0.61	0.72	0.32	0.42	0.42	0.43	0.48	0.45	0.34
C.V.	0.16	0.26	0.10	0.11	0.14	0.08	0.11	0.11	0.12	0.14	0.16	0.15

Table 17 Crop coefficients (K_c) for different varities of rice and vegetables of Bangladesh by 10-day period [24]

Crop	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
B.Aman	0.45	0.57	0.74	0.94	1.07	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.05	0.96	0.85
HYV Aman	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.05	0.95	0.85									
HYV Aus	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.05	0.95	0.85										
HYV Boro	1.10	1.10	1.10	1.10	1.11	1.15	1.22	1.29	1.29	1.22	1.10	0.85								
Monsoon vegeta-bles	0.05	0.05	0.59	0.74	0.86	0.09	0.09	0.09	0.09	0.09	0.83	0.68								

Table 18 Sequence of 3-day running periods

Date	Period	Date	Period
April 1-3	1	May 1-3	31
" 2-4	2	" 2-4	32
" 3-5	3	" 3-5	33
" 4-6	4	" 4-6	34
" 5-7	5	" 5-7	35
" 6-8	6	" 6-8	36
" 7-9	7	" 7-9	32
" 8-10	8	" 8-10	38
" 9-11	9	" 11-13	41
" 10-12	10	" 12-14	42
" 11-13	11	" 13-15	43
" 12-14	12	" 14-16	44
" 13-15	13	" 16-18	46
" 14-16	14	" 17-19	47
" 15-17	15	" 18-20	48
" 16-18	16	" 19-21	49
" 17-19	17	" 20-22	50
" 18-20	18	" 21-23	51
" 19-21	19	" 22-24	52
" 20-22	20	" 23-25	53
" 21-23	21	" 25-27	55
" 22-24	22	" 26-28	56
" 23-25	23	" 27-29	57
" 24-26	24	" 28-30	58
" 25-27	25	" 29-31	59
" 26-28	26	" 30-1st June	60
" 27-29	27	" 31-2nd June	61
" 28-30	28	June 1-3	62
" 29-1st May	29	" 2-4	63
" 30-2nd May	30	" 3-5	64
		" 4-6	65

Table 18 (Contd..)

Date	Period	Date	Period
June 5-7	66	June 16-18	77
" 6-8	67	" 17-18	78
" 7-9	68	" 18-20	79
" 8-10	69	" 19-21	80
" 9-11	70	" 20-22	81
" 11-12	71	" 21-23	82
" 11-13	72	" 22-24	83
" 12-14	73	" 23-25	84
" 13-15	74	" 24-26	85
" 14-16	75	" 25-27	86
" 15-17	76	" 26-28	87
....	...	....	...
....	...	....	...
....	...	....	...
March 29-31	362		

APPENDIX - C

```
C----------------------------------------------------------------------------
C----------------------------------------------------------------------------
C       DAILY RAIN FALL      : DATA(STATION,DAY)
C       3 DAYS GROUPS        : G3(YEAR,DAY)
C       SD OF G3             : SD(DAY)
C       HEADINGS             : HEAD,HD1
C       OBJECT TIME FORMAT:  FMT
C       STATION HEADER       : FF
C       DAY OF MONTH         : MMD(MONTH)
C       CUM. DAY OF MONTH :  MD(MONTH)
C----------------------------------------------------------------------------
C----------------------------------------------------------------------------
C
C----------------------------------------------------------------------------
C       DECLARATIVES:
C----------------------------------------------------------------------------
        REAL DATA(56,365),G3(10,363),XT(362),MEAN(365),MAX(365)
       ,                             ,SD(362),   S(362)  ,XTT(362)
        INTEGER D,S,S4,Y,Q,FF(20),FMT(20),HEAD(40),HD1(40),MD(12),MMD(12)
C----------------------------------------------------------------------------
C       DATA INITIALIZATION AND FORMAT READING
C----------------------------------------------------------------------------
        DATA MMD,Q/30,31,30,31,31,30,31,30,31,31,28,31,'****'/
        READ(1,55) FMT,FF,HD1,HEAD
        DATA G3/3630*0./
C----------------------------------------------------------------------------
C       SUM OF DAYS FROM BEGINNING OF THE YEAR IN A MONTH.
C----------------------------------------------------------------------------
        MD(1)=MMD(1)
        DO 999 M=2,12
999     MD(M)=MMD(M)+MD(M-1)
C----------------------------------------------------------------------------
C       DATA READING: HEIRARCHICAL LEVEL ARE YEAR,STATION.MONTH.DAY;
C                     **** IS DELIMETER OF YEAR LEVEL;
C                     STATIONS HAVE HEADER CARD;
C                     FOR EACH MONTH TWO CARDS HAVE BEEN USED;
C                     THE EXCESS FIELDS ARE IGNORED.
C----------------------------------------------------------------------------
        DO 31 Y = 1,10
        DO 11 S = 1,57
        M = 1
        READ(1,55,END=987)   FF
55      FORMAT( 20A4 )
        IF(FF(1).EQ.Q) GO TO 42
        WRITE(3,55) FF
        DO 12 J = 1,12
        L = MMD(J)+M-1
        READ(1,20,END=42)  (DATA(S,D),D=M,L)
        WRITE(3,20)        (DATA(S,D),D=M,L)
12      M = L+1
11      WRITE(3,28 )
28      FORMAT(////)
        GO    TO    42
C----------------------------------------------------------------------------
C       WRITE YEAR NAME AT STARTING FROM 5TH COLUMN
C----------------------------------------------------------------------------
42      IN1 = FF(2)
        IN2 = FF(3)
14      K    =  
        MM   = S-1
C----------------------------------------------------------------------------
C       CUMULATION FOR COMPUTING MEAN
C----------------------------------------------------------------------------
        DO 21 D = 1,365
        K = K+1
        X = 0.0
        Z = 0.0
        DO 23 S = 1,MM
        DAD = DATA(S,D)
        IF(Z.LT.DAD) Z=DAD
23      X      = X+DAD
        MAX(D) = Z
```

```
21    MEAN(D)= X/MM
C-----------------------------------------------------------------------
C     3 DAY GROUPS
C-----------------------------------------------------------------------
      X = MEAN(1)+MEAN(2)
      L = 365-3
20    FORMAT(16F5.1)
      DO 33 D=1,L
      VV = X+MEAN(D+2)
      G3(Y,D) = VV
C-----------------------------------------------------------------------
C     ROUNDING TO AVOID UNDERFLOW PROBLEMS.
C-----------------------------------------------------------------------
      IF(ABS(VV).LT.0.00001)  VV = 0.
      X = VV - MEAN(D)
      IF(X.LT.0.0) X = 0.0
33    CONTINUE
C-----------------------------------------------------------------------
C     WRITING YEAR CODE
C-----------------------------------------------------------------------
      WRITE(3,799) IW1,IW2
799   FORMAT(1X,2A4)
C-----------------------------------------------------------------------
C     PRINTING OF HEADING AND COMPUTED VALUES.
C     FOR FIRST 6 MONTHS
C-----------------------------------------------------------------------
      WRITE(3,HD1)
      WRITE(3,FMT)(I,MEAN(I),         MAX(I),
     +        (   MEAN(I+MD(J)),MAX(I+MD(J)),J=1,5),I=1,30)
      M = 31
      WRITE(3,77) M,MEAN(31+MD(1)),MAX(31+MD(1)),
     .              MEAN(31+MD(3)),MAX(31+MD(3)),
     .              MEAN(31+MD(4)),MAX(31+MD(4))
77   .FORMAT(I4,24X,2F7.1,24X,2F7.1,3X,2F7.1)
C-----------------------------------------------------------------------
C     HEADING AND MEAN, MAX. PRINTING
C     FOR THE LAST 6 MONTH
C-----------------------------------------------------------------------
      WRITE(3,HD2)
      DO 31 I=1,3
      IF(I.LE.2.)GO TO 32
      WRITE(3,333) I,(MEAN(I+MD(J)  ), MAX(I+MD(J)),J=5,9),
     .              MEAN(I+MD(11)), MAX(I+MD(11))
     .GO TO 31
32    WRITE(3,FMT) I,(MEAN(I+MD(J)  ), MAX(I+MD(J)),J=5,11)
333   FORMAT(I4,4(F12.1,F7.1),19X,F12.1,F7.1)
31    CONTINUE
      WRITE(3,78) M,MEAN(M+MD(6)  ), MAX(M+MD(6)),
     ,              MEAN(M+MD(8)  ), MAX(M+MD(8)),
     ,              MEAN(M+MD(9)  ), MAX(M+MD(9)),
     ,              MEAN(M+MD(11)), MAX(M+MD(11))
78   .FORMAT(I4,5X,2F7.1,19X, 2(F12.1,F7.1), 24X,2F7.1)
C-----------------------------------------------------------------------
C     3 DAYS GROUP PRINTING
C-----------------------------------------------------------------------
      WRITE(3,437)  (J,G3(Y,J),J=1,362)
437   FORMAT(1H1/' 3DAYS GROUP'///(I4,F8.1,I9,F8.1,I9,F8.1,I9,F8.1))
31    CONTINUE
C-----------------------------------------------------------------------
C     CALCULATIONS OF INVARIENTS FOR  XTT
C-----------------------------------------------------------------------
937   CONTINUE
      DATA SIGMA,CON,T/0.9497,.4952,10./
      SI = ALOG(T / (T-1.))
      SI = ALOG( SI )
C-----------------------------------------------------------------------
C     XT = MEAN OF 10 YEARS  FOR EACH G3 ;
C     SD =  SD OF 10 YEARS  FOR EACH G3  ;
C     XTT=PROBABLE MAX. G3.
C-----------------------------------------------------------------------
      DO 501 J=1,362
      [illegible]
```

```
      DO 601 Y=1,10
601   Z = Z+G3(Y,J)
501   XT(J) = Z/10.
      DO 801 J=1,362
      Z = 0
      DO 901 Y=1,10
      P = G3(Y,J)-XT(J)
      IF(ABS(P).LT.0.000001) GO TO 901
      Z = Z+P*P
901   CONTINUE
      SD(J) = SQRT(Z/9.)
      B(J) = SD(J)/SIGMA
      U = XT(J)-CON * B(J)
      XTT(J) = U-B(J)*SI
801   CONTINUE
C-----------------------------------------------------------------------
C     PRINTING XTT
C-----------------------------------------------------------------------
      WRITE(3,69)FF(2),FF(3),(J,XTT(J),J=1,362)
69    FORMAT(1H1/' XTT VALUE',2A4/(I4,F10.1,I9,F10.1,I9,F10.1,I9,F10.1
     +))
      STOP
      END
```

```
*****************************************
*   FORMAT READ FROM DATA CARDS*
*****************************************
```

```
(I4,F11.1,F .1,F11.1,F9.1,F11.1,F9.1,F12.1,F9.1,     F13.1,F3.1, F10.1,F3.1
(2A4//' ',5 (' ')//)
('1',13X,' APRIL '12X,'  MAY '13X,'JUNE '1 X,'JULY'14X,'AUGUST'1 X,'SEPTEMB
1X,6(10X,1 ('-'))//' DAY'7X,6('MEAN'5X,'MAX'7X)//)
('1'13X,'OCTOBR'12X,'NOVEMBER',13X,'DECEMBER',13X,'JANUARY',13X,'FEBRUARY'13
 'MARCH'///1X,6(1 X,1 ('-'))//' DAY'7X,6('MEAN',5X,'MAX'7X)//)
```