STOCHASTIC ANALYSIS OF DEFICIENCY OF CROP WATER REQUIREMENT UNDER RAINFED CONDITION IN BOGRA AND RANGPUR AREAS

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ABSTRACT

The study involves with finding out crop water requirement (CWR) and characterization of stochastic behavior of surplus and deficiency of crop water requirements. Crop water requirement is calculated by CROPWAT, a computer software released in 1991 by agriculture division of FAO. Availability of crop water requirement (ACWR) is obtained by subtracting CWR from rainfall. Deficit or negative values are termed as deficiency of crop water requirement (DCWR) and positive values are simply termed as surplus. Deficiency of crop water requirement is related to drought, the main concern of this study. Study has also been logically focussed on surplus of crop water requirement. On the basis of theory of runs and direct enumeration technique a general method is presented herein to interpret the surplus and deficiency of crop water requirements characteristics in periodic stochastic process. The methodology developed has been applied to some hypothetical and observed (actual) ACWR sequences at north-western zone of Bangladesh.

Monthly climatic data (temperature, wind speed, humidity, bright sunshine hour) and rainfall record of two stations (Rangpur and Bogra) in the north west region of Bangladesh are used here. The analysis has been performed for 32 years. A number of functional truncation levels (normal, median, 40^{th} and 60^{th} percentile of five-day availability of crop water requirement) have been assumed here to form positive and negative deviations. The periodic stochastic process with enumeration technique has shown good relationship between observed and simulated expected deficit durations for truncation level at median values, while no good relation for any of truncation levels has been found for surplus duration. Assuming ACWR spells are persistent or independent in nature, Markov (order 1) and random process respectively, under the theory of runs are modeled by using Poisson probability density function of the occurrence of spells, coupled with geometric distribution for the length of spells, and the Weibul, normal, lognormal, Gumble and exponential distributions for the deficit and surplus sums of respective ACWR spells. It is found that, longest period of deficit is better predicted by

Markov model while longest surplus period with random model gives better performance. Random model appears comparatively good for surplus-sum and surplus spell because of its less persistence nature than deficit. For truncation level at normal values, deficit-sum and surplus-sum can best be obtained by Markov-Weibul model and random-Weibul model respectively. No good relationship has been found between observed and simulated ACWR spells and their respective spell-sums for truncation level at median values. Under the above application of the periodic stochastic models, it has been found that the two stations from northwest Bangladesh have very similar surplus and deficit (drought) spells characteristics.

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LIST OF ABBREVIATION

ACWR	Availability of Crop Water Requirement
BARC	Bangladesh Agricultural Research Council
BMD	Bangladesh Meteorological Department
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
CWR	Crop Water Requirement
DCWR	Deficiency of Crop Water Requirement
FAO	Food and Agricultural Organization
ILRI	International Institute for Land Reclamation and Infrastructure
NW	North West
NE	North East
PDF	Probability Distribution Function
RH	Relative Humidity
SC	South Central
SD	Stress Day
SDI	Stress Day Index
SE	South East
SI	Stress Index
SW	South West
USDA	United States Department of Agriculture

LIST OF SYMBOLS

R_s	incoming solar radiation in W/m^2, can be measured directly
R_{nl}	outgoing long-wave radiation in W/m^2,
R_a	extra-terrestrial radiation or 'Angot value'
R_{sc}	a solar constant, $R_{sc} = 435\ W/m^2$
δ	declination of the sun
ω_s	sun-set hour angle
φ	latitude in degree
d_r	relative distance between the earth and the sun
E_{aero}	aerodynamic evaporation equivalent to $kg/m^2.s$
α	'albedo', the reflection coefficient, $\alpha = 0.23$ for the reference crop,
Δ	slope of the vapor pressure curve in kPa/°C,
γ	psychometric constant in kPa/°C, and is given as
n	duration of bright sunshine hour
N	day length
u	wind speed measured at 2 m above the ground surface in m/s.
σ	Stefan-Boltzmann Constant,
E_{aero}	aerodynamic evaporation equivalent in $kg/m^2.s$,
p_a	atmospheric pressure in kPa,
ε	ratio of molecular masses of water vapor over dry air, $\varepsilon = 0.622$,
ρ_a	density of moist air in kg/m^3,
s	second
m	meter
t	average temperature in °C,
e_a	actual vapor pressure in kPa,
e_s	saturated vapor pressure at temperature t in kPa,
r_a	aerodynamic diffusion resistance in s/m.
t_F	air temperature in ^0C
K_c	crop coefficient

p_1	probability of any interval being a surplus
q_1	probability of any interval being a deficit
p_2	probability of surplus interval followed by surplus interval
q_2	probability of deficit interval followed by deficit interval
L_s	length of surplus
L_d	length of deficit
L_{sm}	duration of longest surplus
L_{dm}	duration of longest deficit
μ	mean

Chapter 1

INTRODUCTION

1.1 General

Bangladesh predominantly is an agriculture based country. Annual rainfall ranges from 1400 mm in northwest to over 5000 mm in the northeast while the mean is about 2300 mm. But 90 percent of this rainfall occurs during the six months from May to October. Rice, the most important crop in Bangladesh, is grown in three seasons: Kharif I (April-July, Aus), Kharif II (July-December. Aman) and Rabi (November-March, Boro).

The agro-economy, generating about 32.8 percent of the gross domestic product (GDP) (Bangladesh Bureau of Statistics, 1996). Natural calamities like flood, cyclone, tornado, tidal-bore, drought etc. have masked the actual production capability. Water, the most important input for crop production, occurs abundantly in Bangladesh. But the distribution it holds is extremely skewed in time. As a nature of consequence, water availability may become super and/or sub-normal with respect to its requirement at many places. It is generally accepted that floods and droughts are the two extremes in the fluctuation of hydrologic phenomena. They represent some of the most dangerous natural disasters. The unprecedented increase in population, industry and living standard give rise to significant water shortage. A certain quantity of water is needed from meteorological requirement for maximum yielding of a particular crop. This requirement is termed as Crop Water Requirement (CWR). Rainfall is the main source of natural irrigation. Sometime there is a shortage of water to crop for maximum yield. This shortage or deficit of water may be defined as the Deficiency of Crop Water Requirement (DCWR), while excess of water may be defined as surplus. The calculation of the above items is based on meteorological data which uses some methods for it, particularly Penman-Monteith method, the most common one that is in extensive use now a days. Prediction of deficiency of crop water requirement is needed for supplementary irrigation project planning and design.

In general, drought is related to deficit or shortage of some kind. For instance, in water resources system design and operation the relative positions of demand pattern and available water play an important role in drought definition. The definition adopted here has been suggested by Yevjevich (1967) and is based on theory of runs. A good aspect of such an approach is that the definition of run-length, run-sums and run-intensities are clear and they can be examined analytically.

Regardless of whether the process is independent or Markovian, a deficit or surplus of water availability due to natural processes may extend to a long period. In hydrology it is a well-known fact that if the time series is considered to be dependent, then high values tend to follow high values and low values tend to follow low values. At times the level of persistence may be negligible and such processes are termed independent. This can be interpret in different ways by saying that in the case of dependent series, the periods of surplus or deficit tend to be greater than in the case of independent series. Such a property has been termed "persistence" in hydrology. The total water over a deficit spell is designated as deficit-sum. The total deficit of water requirement over a deficit spell is of importance in designing reservoir for irrigation system. In probability theory these spells are termed as "runs" and the sum over a surplus or deficit spell as "run-sum" in general. In classical terms a run is defined as a sequence of observations of the same kind preceded and succeeded by one or more observations of a different kind. The "negative run-length" represents the duration of a drought.

The runs of the continuous sequence of a stochastic variable, or a combination of stochastic and deterministic components making a composite sequence, may be defined according to Yevjevich (1972) in various ways. Figure 1.1 represents a continuous time series of a variable x(t). By selecting an arbitrary value x_o the series is intersected at many places and the relation of the constant value x_o to all other values of x(t) serves as the basis for various definition of runs. Some of them are as follows: τ_1 - distance between upcrosses, τ_2 - distance between downcrosses, τ_3 - distance between successive peak, τ_4 - distance between successive troughs, τ_5 - distance between consecutive upcross and downcross, τ_6 - distance between downcross and upcross, S - integral of positive deviations between the consecutive downcross, D - integral of negative

deviations between the consecutive upcross, I_1- maximum positive deviation for any given τ_5, I_2 - minimum negative deviation for any given τ_6, s - average positive deviation (S/τ_5), d - average negative deviation (S/τ_6), etc. The truncation level may be taken as a time dependent functional value $x_o(t)$. For convenience a continuous time series, x(t) as available water sequence and a functional demand level, $x_o(t)$ are shown in Fig.1.2. The truncation of the time series at the $x_o(t)$ level forms positive and negative deviations. Hence, the sequence of consecutive negative deviations preceded and succeeded by positive deviations is called a negative run, which is an objective representative of drought duration. Negative run-length and drought duration is interchangeably used in this thesis. Depending on the circumstances it may be important that the truncation level is either a constant or a deterministic or stochastic variable (Sen, 1980c). Generally the available water sequence is of stochastic nature with stationary or non-stationary properties (Sen, 1980c). Drought investigations of periodic stochastic processes are essential in finding fluctuations of water deficit within a year, especially for growing seasons. In the periodic stochastic processes, the time position becomes one of the important factors in evaluating drought characteristics.

Once the analytical expressions for drought characteristics of periodic stochastic processes are derived, they can be easily reduced to the case of stationary and/or independent processes. Among the several droughts the critical one, i.e. the maximum, is of special interest since it will create the most severe conditions under which the system will operate (Sen, 1980c).

Drought must be related to the particular crops or animals in the agrarian system. The lack of precipitation during both the growing and non-growing seasons can have many adverse ramifications on present and future agricultural activities. But most of the criteria used in the literature to identify drought have been arbitrary because a drought is a "non-event" as opposed to a distinct event such as a flood. As such drought has no distinct on-set and is recognizable only after a period of time. In addition, the period is variable because the time required for a drought to occur depends on many interacting variables.

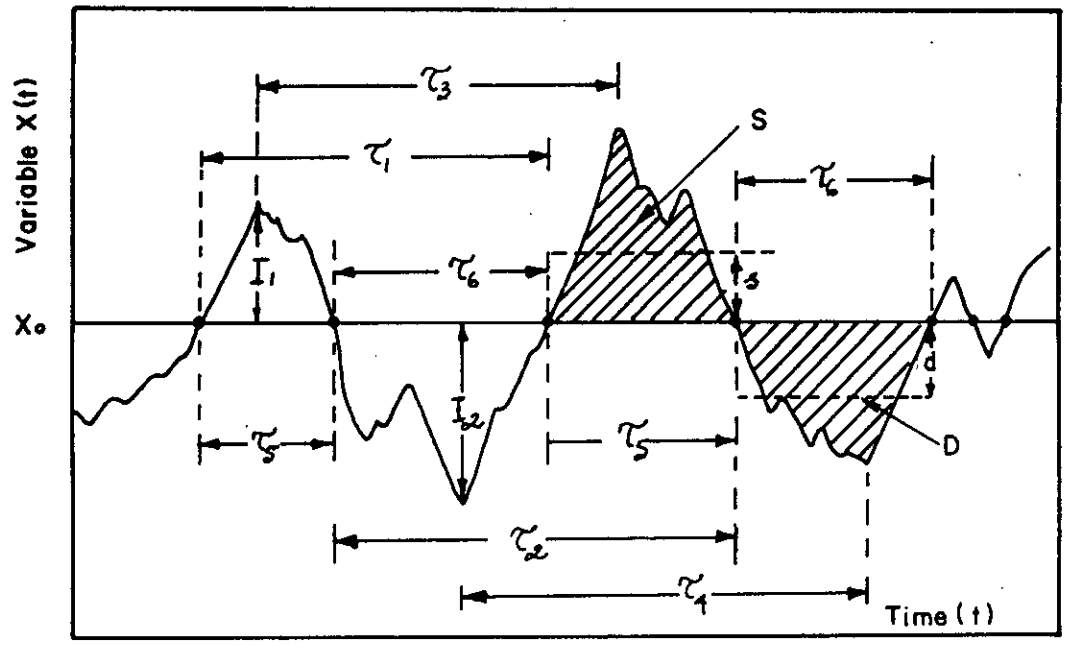


Fig. 1·1 : Various Definitions of Runs for a Given Constant Crossing Level x_o

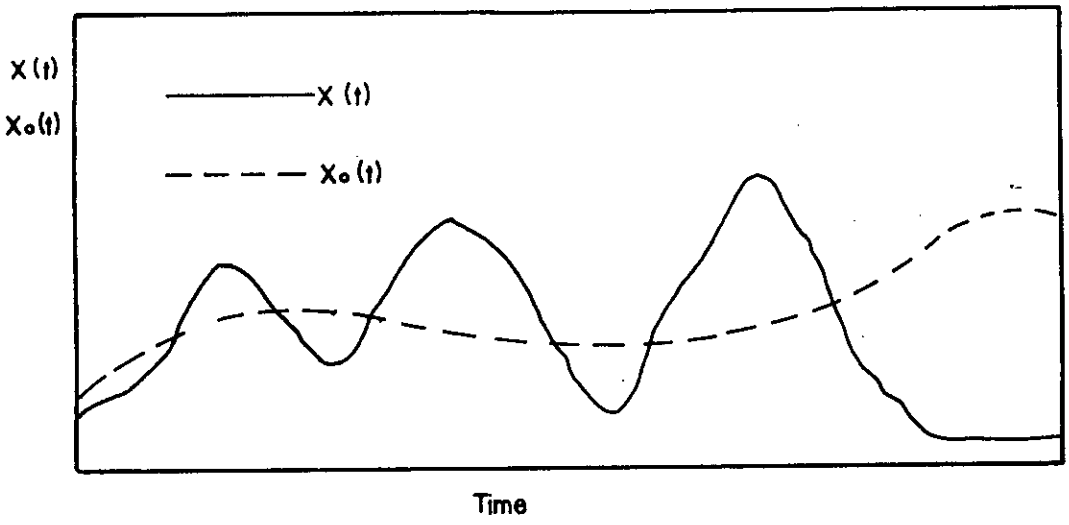


Fig. 1·2 : Deficiency of Crop Water Requirement and Functional Truncation Level, $x_o(t)$

1.2 Stochastic Process

Stochastic processes treat sequences that are governed by laws of chance. A stochastic process is the mathematical abstraction of an empirical process, with its development governed by probabilities of laws. Nearly all hydrologic processes can be characterized as stochastic processes, or as a combination of deterministic and stochastic processes (Yevjevich, 1972). A stochastic process is called discrete if its behavior is studied at distinct points in space or time. If the process is defined for all points of a time interval or for all points of a region in space, it is called continuous (Shahin et al., 1993).

Stochastic processes are further subdivided into stationary and non-stationary processes. If properties of time series do not change with the absolute time they are called stationary (time-invariant, non-evolutive). If properties of sequences along lines do not change with the position on the line, the series are called homogeneous (line-invariant, non-evolutive). In the contrary, non-stationary stochastic processes are time-variant, evolutive and line-variant or non-homogeneous (Yevjevich, 1972). The stationary processes in turn, are subdivided in ergodic and non-ergodic processes. Ergodicity is the property by which each realization of the process is a complete and independent representative of all possible realizations of the process. Ergodicity thus allows the investigator to determine the statistical properties of a process from a single realization. A realization of a process can be seen as the outcome of an experiment in which the process is observed. In time series analysis usually only one realization is available. In practice stationary time series are commonly assumed to be ergodic (Shahin et al., 1980).

1.3 Periodic and Dependent Bernoulli Trials

The exact probability distribution function (PDF) of the longest drought duration in periodic stochastic processes can best be obtained through dependent Bernoulli trials and direct enumeration technique (Sen, 1980c). In the following text this PDF is found exactly for the case in which the result of each trial is dependent only on the outcome of the previous trial.

If the processes are periodic then the dependent Bernoulli trials will also be periodic, constituting a non-homogeneous Markov chain with two states whose transition probabilities, P_i, between any two consecutive time instants $(i-1)$ and i can be written in a matrix form as:

$$P_i = \begin{bmatrix} P_i(+|+) & P_i(-|+) \\ P_i(+|-) & P_i(-|-) \end{bmatrix} \tag{1.1}$$

In Eq. 1.1 the two states are denoted by - and + corresponding to deficit (failure) and surplus (success) to crop water requirements, respectively. The elements in the transition matrix are the conditional probabilities of passing from one state to the following state. The sum of probabilities in each row is equal to one, therefore:

$$P_i(+|+) + P_i(-|+) = 1 \quad \text{and} \quad P_i(+|-) + P_i(-|-) = 1 \tag{1.2}$$

1.4 Bernoulli's Experiments

It considers an experiment with two possible outcomes. The outcomes are labeled as success (s) and failure (f). Thus the sample space of the experiment is the set {s, f}. Such an experiment is called a Bernoulli trial. Suppose the probability of success equals p and define a random variable x as follows

x = 1 if the experiment results in a success,

x = 0 if the experiment results in a failure.

Then the random variable x has a so-called Bernoulli distribution. It's probability mass function reads

$$f(x) = p^x (1-p)^{1-x} \qquad x = 0, 1 \qquad (0 < p < 1) \tag{1.3}$$

The expected value and variance can be given as

$$E(x) = p \tag{1.4}$$

$$Var(x) = p(1-p) \tag{1.5}$$

A Bernoulli trial can be used to model several phenomena in engineering practice. For instance, in a certain year the total amount of precipitation may or may not exceed 120 mm. If the precipitation exceeds 120 mm, we record a success. Otherwise a failure is recorded. Viewed in this way a year can be modeled as a Bernoulli trial.

1.5 Objective of the Study

All meteorological events are natural phenomena and therefore random in its occurrences. Their occurrences can not be predicted with certainty. Crop water requirements (CWR) that are subtracted from rainfall data may result into surpluses or deficits based on meteorological events, which are thus random in character. To characterize these surpluses and deficits for a particular crop (here paddy), statistical analysis will be performed. All the analysis will be on five-day summation CWR based. Therefore, the present study can be divided into two major objectives:

Crop Water Requirement

CROPWAT (version 5.7, 1991), a software released by FAO publication No. 46, is used to determine crop water requirements using meteorological data of the Bogra and Rangpur stations; subsequently these crop water requirements will be subtracted from rainfall time series to obtain availability of crop water requirement (ACWR). If this ACWR is negative, a shortage of water that is termed as deficiency of crop water requirement (DCWR), and if positive that is termed simply as surplus is obtained.

Stochastic Behavior

Characterization of the stochastic behavior of ACWR which includes:

- finding the expected value of longest surplus and deficit crop water requirement durations;
- stochastic behavior of longest surplus and deficit crop water requirements; and
- stochastic behavior of deficit and surplus sums over availability of crop water requirements.

By applying the theory of runs and direct enumeration technique, variability of deficit and surplus over a year will be found out. Longest negative run length will provide duration of deficiency of water demand. A major application of longest duration of DCWR is for planning an irrigation project. Total water deficit over a deficit spell provides information for designing a reservoir. Also the study will provide some idea about drought characteristics of region concerned. It is worthy to mention here that more emphasis has been put for DCWR (deficit water) to characterize drought of the region concerned. Analysis based on surplus comes as a by-product when applied under the theory of runs.

1.6 Organization of the Thesis

The report contains six chapters in total. In chapter 1, a general description of the periodic stochastic process has been presented. Various definitions relating to the theory of runs and Bernoulli's trial are discussed in this chapter. The objectives of the study are also given in this chapter.

Chapter 2 contains literature review on drought study related to hydrological, meteorological and agricultural analyses. It also includes the methods available for crop water requirement determinations.

Chapter 3 contains description of the study area and data sources. Climatic, environmental, agricultural, and geographical conditions of the study area are discussed here.

Chapter 4 contains methodology used in this study. A brief description of the procedure of the current study is given in this chapter.

Chapter 5 is on the results and discussions based on the study. Here the results obtained from the analysis have been described.

Chapter 6 is on conclusions and recommendations for further study.

Chapter 2

LITERATURE REVIEW

2.1 General

Availability of crop water requirement (ACWR) is defined as the rainfall minus amount of crop water requirement and is termed as deficiency of crop water requirement (DCWR) when it is negative, and simply as surplus when it is positive. Longest duration of DCWR (deficit duration) is the representation of longest drought duration. The deficiency of crop water requirement is a periodic and stochastic process (related to meteorological events). The exact probability distribution function of the longest drought duration in periodic stochastic processes can best be obtained through dependent Bernoulli trials and direct enumeration technique under the theory of runs (Sen 1980c). Crop water requirement (CWR) for paddy is calculated based on Penman-Monteith method for the reference crop evapotranspiration (ET_o).

The explanations of droughts are based on physical relationships and interactions of the drought affecting factors, while the descriptions of droughts are based on statistical and analytical methods. Precipitation is one of the inputs and streamflow is one of the outputs from a watershed system. Dracup et al. (1980) notes that if one is interested in determining the cause of drought events, attention should be focused on precipitation drought; if one is interested in determining the effects and impacts of drought events, attention should be focused on streamflow drought and agricultural drought. Agricultural drought is directly related to crop water deficiency for a particular crop in a particular region. Therefore the study on the deficiency of crop water requirement is the main concern of this thesis. In this regard the study has been divided into two main parts: one is the determination of crop water requirements and subsequently DCWR from rainfall consideration; another one is the use of these DCWR to the statistical analysis to characterize the longest drought period along with volume of water deficit.

2.2 Evapotranspiration and Crop Water Requirement

The determination of reference crop evapotranspiration by different methods, that has been

discussed by Ankum (1996) are Pan method, Temperature methods, Radiation methods, Penman formula, FAO modified Penman formula and Penman-Monteith formula. According to FAO the suggested method for the calculation of the reference evapotranspiration is the Penman-Monteith formula. The Penman-Monteith formula is the basis of the FAO computer program CROPWAT (Smith, 1992, 1993) and the ILRI computer program RIWAR (Bos, 1996).

Pan method: The open water evaporation in a standardized pan can be measured directly, and can be transferred into the reference evapotranspiration after multiplication with an adjustment factor. The pan method may involve a possible error of 15 percent (Doorenbos, 1977).

Temperature methods: Thornthwaite method (1948) that used for humid climate and the Blaney-Criddle method (1950) that used for western USA are the examples of temperature methods. They are empirical methods depending on the mean daily temperature, the humidity and the day length. Possible errors up to 25 percent has been noted (Doorenbos, 1977).

Radiation method: The Makking formula (1980) in the Netherlands has been developed for a specific climate falls under the radiation method. Radiation methods relate the reference evapotranspiration to the radiation and the temperature, but not to the humidity and the wind. The possible error may reach in extreme conditions up to 20 percent in summer (Doorenbos, 1977). The Makking formula (1980) is not recommended for use outside the Netherlands.

Penman formula: The Penman method (1948) considers evaporation as a physical process of heat exchange and transport. It is the basis for other methods. This formula is the basis for other methods. The original Penman method in its initial state is not recommended by FAO.

FAO modified Penman formula: FAO has made the original Penman formula operational for practical use in the FAO publication 24 (Doorenbos, 1977). This method has been a standard in many irrigation projects, but is not recommended by FAO. It is found (Allen, 1994[a]) that the FAO modified Penman formula frequently over estimates the evapotranspiration ET_o, and the use of adjustment factor is not very practical.

Penman-Monteith formula: FAO has revised the methodologies of FAO Penman modified formula to determine the reference evapotranspiration by adopting the Penman-Monteith formula. Monteith (1965) introduced a 'canopy resistance' to provide for the obstruction of vapor transport in the leaf stoma. Furthermore, the actual vapor pressure (e_a) is determined in a more accurate manner, the reference crop is better standardized ('albedo' α = 0.23), and the wind function has been improved. The Penman-Monteith formula is recommended by FAO as the only approach for the determination of the reference evapotranspiration.

To explain evapotranspiration the following terms are needed to define.

- Evaporation (E_o): It is a process by which water is changed into water vapor through transfer of heat energy from liquid state.
- Transpiration: It is the evaporation of water absorbed by the crop. It does not include soil evaporation.
- Evapotranspiration (ET): It is the water loss through transpiration from the vegetation (transpiration) and soil evaporation.
- Reference Evapotranspiration (ET_o): It is the evapotranspiration from a reference crop, i.e. standardized grass, under optimal soil and water conditions. The reference crop is defined as "an hypothetical crop with an assumed height of 0.12 m, a fixed canopy resistance of r_c = 70 s/m, and an albedo of α = 0.23, which would closely resemble the evaporation from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground, and not short of water" (Smith, 1990).
- Crop Evapotranspiration (ET_{crop}): It is the evapotranspiration of the crop under optimal soil water conditions. It is also called 'potential evapotranspiration'.
- Actual Evapotranspiration (ET_a): It is the evapotranspiration equal to or smaller than the predicted crop evapotranspiration as effected by the available soil water, salinity or other causes.

The reference evapotranspiration (ET_o) can be determined by different methods. The methods that are in common are Pan method, Temperature methods, Radiation methods, Penman formula, FAO modified Penman formula, Penman-Monteith formula etc. The Penman-Monteith formula

is the basis of the FAO computer program CROPWAT. Crop evapotranspiration (potential evapotranspiration) is then found by multiplying crop coefficient (K_c) to the reference evapotranspiration.

Recently, Molla (1995) has studied the relationship between observed and estimated evapotranspiration of paddy where evapotranspiration of BR-3 (boro) variety of rice was calculated by five different methods, namely, the modified Penman, the Hargreaves, the Thornthwaite, the pan evaporation and the Blaney-Criddle. In the study three years climatic data from the Amla farm, Kustia are used and compared with the observed evapotranspiration. He has shown that the modified Penman method and the Hargreaves method provided the better estimate of the evapotranspiration of BR-3 (boro) rice for the climatic condition considered. The consumptive use is the highest for BR-3 variety of rice in the month of April when the crop is in the reproductive phase, the most vulnerable period.

According to Uddin (1988) crop diversification was found to give highest service area and net return for each level of deficit water availability. Staggering of planting date based on optimum land preparation progress rate was found to increase the paddy area by about 10 to 15 percent. For deficit water supply, deficit irrigation and water delivery according to crop sensitivity to water stress gave higher acreage as well as more net return than that of full irrigation of paddy.

Karim (undated) studied on drought stress estimate in Bangladesh where it has been shown that transplanted aman paddy is generally cultivated from August to December, broadcasted aus paddy from April to July and wheat between November and February. He developed a methodology to quantify the effect of moisture stress on the yield of a crop that can be used for planning irrigation project. He calculated stress day (SD), stress day index (SDI), stress index (SI) and drought yield (YDi) of crops. He has been shown how crop yield decreases with water stress in a region.

2.3 Methods of Drought Analysis

Two of the most extreme fluctuations of hydrologic phenomena are drought and flood, which are directly related to socio-economic condition of a region. Various investigations have been performed to establish drought property previously but none succeeded to give a universal definition for drought since there exist widely diverse views about the interpretation of drought among the scientist of different disciplines. However, in common, drought is basically regarded as a deficit of water in time. In this context, a drought is the deficiency in water supply over a significant time (Sen, 1980b). The hydrologist is concerned with drought in the context of a period below normal streamflow and depleted reservoir storage. The meteorologist is concerned with drought in respect of a period during which rainfall or snowfall is bellow normal level. Agricultural drought is said to exist when soil moisture is depleted so that yield of plants is reduced considerably. The economist is concerned with drought in respect to a period of low water supply, which affects society's productive and consumptive activities (Dracup et al., 1980).

On the other hand, in a slightly different note, Thomas (1965) defines meteorological drought as a prolonged and abnormal moisture deficiency. Agricultural drought is described in terms of crop production without any reference to streamflow. Both meteorological and agricultural droughts are terminated by rainfall, or in the case of agricultural drought by the end of cropping season. Hydrologist thoughts the period during which the actual water supply is less than the minimum water supply necessary for normal operation of the particular region.

Practically, indicators such as precipitation, groundwater and streamflow measurements can also define drought. Based on climatological data the Palmer drought index was developed (Palmer, 1965), defined as an interval of time, generally of the order of months or years in duration during which the actual moisture supply at a given place rather consistently falls short of the climatically expected or climatically appropriate moisture supply. Further the severity of drought considered as being a function of both the duration and magnitude of moisture deficiency. Lowing (1987) defined climatic drought as the difference between potential evapotranspiration and precipitation.

Yevjevich (1967) gave a definition of drought on the basis of theory of runs and stationary time series. Here drought is defined as the deficiency in the water supply over significant time to meet water demand for various human activities. Chang et al. (1984) developed the strategy of application of run length distribution for daily precipitation modeling where dry run related to the drought by using a three-step stochastic model called Binary-DARMA (Direct Auto Regressive-Moving Average).

Salazar (1988) described several potential techniques for drought analysis of periodic stochastic process. The first alternative in treating the drought of periodic stochastic series is to remove trends and periodicity in parameters, using either the parametric or nonparametric method of their removal. The second alternative is to use the supply less than demand series. The third alternative used for analysis is the "drought magnitude and drought duration criteria". A fourth alternative is based on a simultaneous generation of annual and monthly series by jointly preserving their parameters such as the variance, and serial correlation coefficients among others.

Theory of runs is an important method of examining the behavior of annual stream-flow sequences. Millan and Yevjevich (1971) and Salazar and Yevjevich (1975) established a truncation level of streamflow objectively where they examined all the positive and negative deviations from this truncation level.

Thus various methods of analysis of drought relevant to specific water uses or to specific disciplines have been divided here. Analysis based on hydrological, agricultural, and meteorological domains developed in the past for identification of drought problem are presented in the following for better understanding of the drought characteristics. In this regard, broad-based statistical tools are applied for the hydrological and meteorological drought analyses. Agricultural droughts are viewed as the effect arising from the hydrological and meteorological droughts.

2.3.1 Hydrological Analysis

One of the fundamental issues in any water-resources-system design and operation is to identify droughts that are likely to occur during the projected life of that system. Many works have been done with streamflow in connection with hydrologic drought. Considering droughts for the purpose of water resources system analysis, Sen (1980[b]) modified Palmer (1965) drought definition as: "the several of time generally of the order of several days, months or years in duration during which the actual water supply at a given location rather consistently falls short of demand". Linsley et al. (1975) defined the hydrological drought as a period during which streamflows could not supply established uses under a given water management plan. In this context a drought is the deficiency in water supply over a significant time to meet demand necessary for various human activities. The deficiencies are determined with respect to annual flows.

Sen (1976) derived a method to provide simple analytical solutions to various problems concerning probabilistic and statistical properties of wet and dry periods of streamflow sequences. Droughts are representative of dry periods in a streamflow sequence during which successive flow values remain less than a given reference value, x_o. Later, Sen (1980[a]) developed a drought-generating mechanism from an observed streamflow time series and formulated simple analytical solutions of the probabilistic behavior of extreme droughts by using Markov process.

Chang (1989) defined drought events as period of flow below specified truncation level. Chang (1990) studied the effect of drought on streamflow characteristics. He defined drought events as a period of flow below specified truncation levels. For a truncation level there may be one, several or no drought events. Different truncation levels can be used to reflect different levels of drought severity. The drought intensity function was developed to investigate drought severity in the basin.

2.3.2 Meteorological Analysis

Herbst et al. (1966) described a technique for the evaluation of drought based on monthly rainfall data. In this method it is possible to determine the duration and intensity of droughts. A drought index is calculated which enables to ascertain the intensity of drought of a station. This method can be programmed for an electronic computer to facilitate the investigation of data from a large number of rainfall stations. A modification to Herbst et al. (1966) method is suggested by Datta (1997) using fortnightly rainfall data of northwestern region of Bangladesh.

Lowing (1987) defined climatic drought as the difference between potential evapotranspiration and precipitation. This type of drought analysis is more relevant for supplementary irrigation project design. He also studied low flows by taking a discharge value of x as an arbitrary reference level. He used three parameters to describe low flow x, which are: (i) duration, (ii) minimum value, and (iii) overall deficit. Alam (1994) adopted Lowing's (1987) defined drought for his study. He calculated ten-day basis drought maximum in a year in the study for five rainfall stations in the Teesta Barrage Project area.

Sharma (1996) developed a model using a Markov (order 1) process. This model describes the behavior of dry and wet spells using theory of runs, in combination with Poisson, geometric and Weibul distributions for occurrences of spells, run lengths of spells, and total rain-sum of a wet spell, respectively. In this regard the longest period of dry and wet spells and the corresponding largest rain-sum value for different exceedence probabilities can be deduced by applying the theory of the extremes of random number of a random variable (Todorovic and Woolhiser, 1975).

Sajjan (1998) studied drought characteristics of northwestern region of Bangladesh. The analysis involves in determining the different sequential property with a view to apply simple analytical solutions to various problems relating to stochastic behavior of wet and dry spells of rainfall sequences. The study shows that Markov model of order-one is superior to random model. Various aspects of theory of runs have been applied for monsoon rainfall. The method failed to model the seasons other than monsoon.

2.3.3 Agricultural Analysis

Bidwell (1972) studied about the methodology for analyzing agricultural drought. In his study he introduced techniques of constructing and analyzing models to simulate the relationship between hydrologic drought to crop yields.

Karim et al. (1990) developed a methodology by using the agroecological database at BARC to characterize drought situations and estimate loss of different crop yields due to drought. To avoid crop loss and to increase cropping intensities in the drought prone area, an irrigation schedule for different crops have been worked out.

Karim (undated) developed a methodology to quantify the effect of moisture stress on the yield of a crop, which can be used for the planning of an irrigation project. He calculated stress day index (SDI), stress index (SI) and drought yield of crops. He showed how crop yield decreases with water stress.

Hershfield et al. (1972) studied about some measures of agricultural drought. The frequency of dry day sequences for both precipitation and streamflow is used as a drought discriminate or as an indicator of precipitation input to the agricultural system in time. The analysis is based on the premises that sequence lengths as statistical properties of time series, provide useful parameters in drought investigation.

Saleh (1981) has shown that the Aus crop requires supplementary irrigation in one out of four years and in case of Aman crop the supplementary irrigation is required in three out of four years. He has also shown that supplementary irrigation increases the yield varying from 8 percent to 71 percent over rainfed condition.

Victor and Sastry (1994) made an evaluation of agricultural drought using probability distribution of soil moisture index (SMI) for kharif crop.

Narayana et al. (1984) performed a statistical study on incidence of drought in relation to agricultural production. Here they showed how yield declined with increase of probability of drought.

Chapter 3

STUDY AREA AND DATA SOURCE

3.1 General

Depending on the availability of meteorological data and closeness to the study area, stations for analysis should be selected. Calculation of evapotranspiration and crop water requirement for each day is a time consuming process. Thus only two stations are selected for the present study. On the basis of hydrological characteristics, Bangladesh may be divided into five regions: (a) Northwest (NW), (b) Northeast (NE), (c) Southwest (SW), (d) South-Central (SC) and (e) Southeast (SE). The present study area is in the Northwest (NW) region. On the basis of the availability of data, Bogra and Rangpur stations for analysis have been selected. Figure 3.1 shows the location of the study area.

3.2 Sources of Data

Meteorological data are available from a number of organizations like, Bangladesh Meteorological Department (BMD), Bangladesh Water Development Board (BWDB), Bangladesh Agricultural Research Council (BARC) etc. For the present study rainfall, humidity, temperature, wind speed and daily sunshine hour data from BMD along with latitude, longitude and altitude of the climatic stations concerned are obtained. BMD is responsible for the collection, compilation and storage of the above mentioned data in Bangladesh. Daily rainfall records are available in BMD for a considerable period for a number of stations. Daily maximum, minimum and average humidity and temperature, daily average wind speed, daily bright sunshine hours are also available for those stations. All of the above data records are supplied by BMD on daily basis. There are some missing climatic data. Climatic data of other stations has been used to fill the missing data. The missing bright sunshine hour (BSSH) data for Rangpur station has been filled by the data of Bogra station. BWDB rainfall data are also needed for filling the missing BMD rainfall data. Types of data, number of years available and name of stations for data collection are given in Table 3.1. Geographical data for the climatic stations are

shown in Table 3.2. Considering the uninterrupted data available in the climatic time series of Rangpur and Bogra stations, a total of 32 years from 1963-94 for Bogra and from 1962-93 for Rangpur are identified for the present analysis.

Table 3.1 Types of Data, Number of Years and Name of Stations Available from BMD for the Northwest of Bangladesh

	Number of Years of Collected Data				
Name of Stations	Temperature	Humidity	Wind Speed	Daily Bright Sun Shine Hours	Rainfall
Bogra	1948-95	1948-95	1948-94	1961-96	1948-95
Rangpur	1957-95	1954-95	1954-94	1979-96	1954-95
Stations Used to Fill the Missing Temperature, Wind speed, Bright Sunshine Hour and Humidity Data					
Dinajpur	1948-95	1948-95	1948-95	1989-96	1948-95
Rajshahi	1964-95	1965-95	1964-95	1979-96	1964-95
Ishurdi	1961-95	1961-95	1961-95	1985-96	1961-95

Table 3.2 Geographical Data for Selected Climatic Stations

Climatic Station	Altitude (meters)	Latitude (° N)	Longitude (° E)	No. of Years Data Used
Bogra	14.5	24.85	89.85	32 (1963-94)
Rangpur	30.5	25.733	89.233	32 (1962-93)*

* The bright sun shine data from 1961 to 1978 have been filled from Bogra station data by multiplying a correlation coefficient.

3.3 The North West Region

The North West Region of Bangladesh has a total area of 34,600 sq. km. Its principal features and characteristics are described in the following sub-sections.

3.3.1 Topography and soils

The region slopes from the north towards the southeast, with an altitude range of 90 m to less than 10 m above sea level. There is considerable physical diversity and micro-relief, which has a

major impact on agriculture and the incidence of flooding. The most basic division is that between the Barind and Alluvial tracts; the later comprises three main geomorphologic units, the Himalayan Piedmont Plains and the Alluvial Lowlands along the Jamuna and Ganges. Slopes in the Barind tract, which has non-alluvial soils, are generally steeper and flooding is much less than in most parts of the alluvial zone. Most of the region's soils are capable of high level of productivity.

3.3.2 Agriculture

Cropping intensity, the percentage of the cultivated area actually cropped each year, are about 158 percent, as shown in Table 3.3. Of these rice takes up 119 percent. The kinds planted are either broadcast or transplanted; either local or HYV. The Main crops in this region are Aus, Aman, and Boro for rice. Other crops in descending order of importance are wheat, jute, oilseeds (mainly brassicas and sesamum), sugarcane, pulses, vegetables and spices. Minor crops take up only 8 percent. The cropping pattern is largely dictated by flooding, soil drainage and soil moisture storage capacity, although irrigation facilities and markets are among other factors, which affect choices of cropping. Irrigated dry season paddy (boro) is increasingly popular, as it is more reliable and productive than the wet season crops.

Table 3.3 Agriculture in the North West Region of Bangladesh

Name of Crops		% of NCA	Name of Crops	% of NCA
Paddy			Other Crops	
HYV			Wheat	8
	Boro	26	Jute	7
	Aus	6	Oilseeds	6
	Aman	28	Sugarcane	5
Local			Pulses	3
	Boro	1	Vegetables	2
	Aus	20	Minor Crops	8
	T. Aman	28		
Aus/Aman		5		
B. Aman		5		
Sub Total		119	Sub Total	39
Total		158		

Source: The North West Regional Study (FAP-2)

3.3.3 Climate

The north west region of Bangladesh lies just outside the tropics between latitudes 23°50' and 26°40' N. The region has a typical monsoon climate. Figure 3.2a displays the climatic norms for Bogra, which is centrally located in the region. The climatic norms for Rangpur are also shown in Fig.3.2b. There are two main seasons, separated by transition seasons. The monsoon season lasts from May/June until September and shows the typical monsoon characteristics of heavy rain and very high humidity. The dry season from November to February is sunny and relatively cool, with only occasional scattered showers. The transition from monsoon to dry seasons in October-November is fairly smooth, with declining temperature, humidity and storm frequency. The start of the transition period at the end of the dry season is also smooth, but the pre-monsoon period in April and May have somewhat unstable conditions. This period is very hot and is characterized by thunderstorms and squalls, known as Nor'westers. This is also the peak season for cyclones in the Bay of Bengal which sometimes have catastrophic consequences in the coastal regions of the country.

As a result of its sub-tropical location, temperature variations are more pronounced than in typical tropical regions: diurnal variation is a low 5°C during monsoon but around 15°C in February. Maximum temperature ranges from around 35°C in April/May to about 25°C in January, while minimum peak at about 26°C in August and drop to 10-11°C in January. The monthly temperature pattern for Bogra is shown in Fig. 3.2a, a typical of the whole region: seasonal pattern and absolute values show relatively little variation with location. The occurrence of peak temperatures is closely connected with the passage of the monsoon: daily maximum occurs just before the arrival of the monsoon, while the highest night time minimum occurs at the peak of the monsoon season.

Humidity levels are consistently very high during the monsoon season, and only drop significantly for a relatively short period at the end of the dry period. Sunshine levels are of course low during the monsoon, but from November to May are consistently high. Wind speeds are at a maximum in the early part of the monsoon, but drop substantially by the beginning of the dry season.

Evapotranspiration reaches a maximum in April when temperature, sunshine and wind are all at or close to their maximum for the year, while humidity is at little below its peak. Evapotranspiration drops substantially thereafter as the humidity reaches very high levels and the other significant parameters all are also become less favorable for evapotranspiration. Evapotranspiration is exceeded by average rainfall from May to October, while for the remaining months it is substantially higher than rainfall.

3.3.4 Rainfall

The region has an average annual rainfall of little over 1900 mm. The driest area is in the south west of the region where the annual rainfall of around 1400 mm is the lowest in the country. The highest rainfall is in the far north of the region, where annual rainfall averages around 3000 mm; however, this is much lower than in the parts of the north east region of Bangladesh where annual average reaches nearly 6000 mm. Figure 3.3 shows the isohyets of annual mean rainfall of the region. The average monthly rainfall pattern is shown in Fig.3.4; the absolute monthly rainfalls vary considerably but this average pattern remains approximately the same across the region.

3.3.5 The River System

The region is bounded, and effectively defined, by the Jamuna to the east and the Ganges to the south (Fig. 3.5). These two rivers, into which the entire area drains, meet up at the southeast corner of the region and play a dominant role in constraining its drainage. Before the construction of the embankment, the Ganges and Jamuna rivers were major contributors to flooding in the region. The major internal rivers are shown in Fig. 3.5.

Three large tributaries of the Jamuna, the Teesta, Dharala and Dudhkumar, pass through the north east corner of the region, and the Mohananda, a tributary of the Ganges, pass through the south west corner. All other rivers in the region are connected to the Atrai-Karatoya-Bangali system, which drains to the Jamuna through the Hurasagar at the southeast corner of the region.

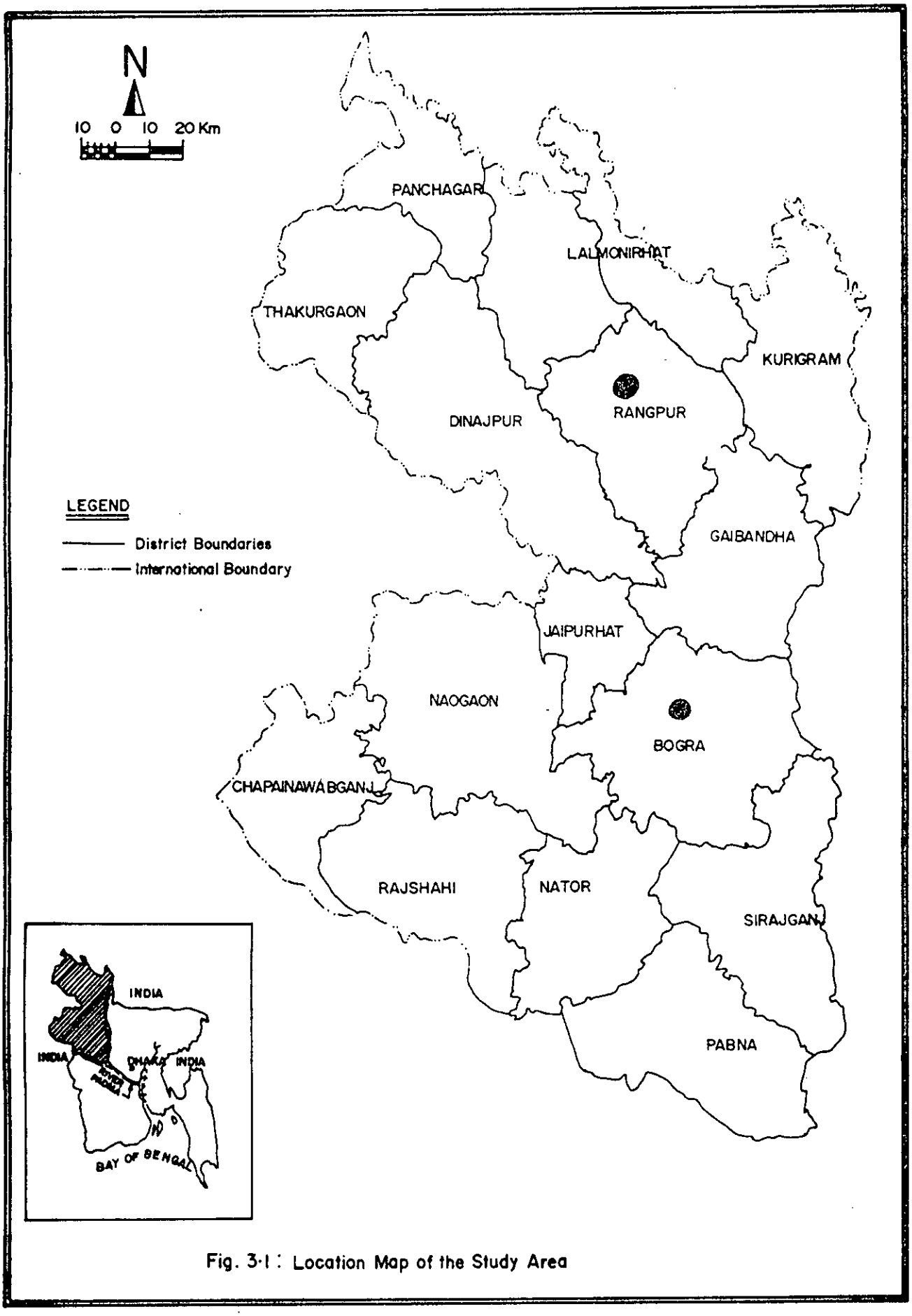
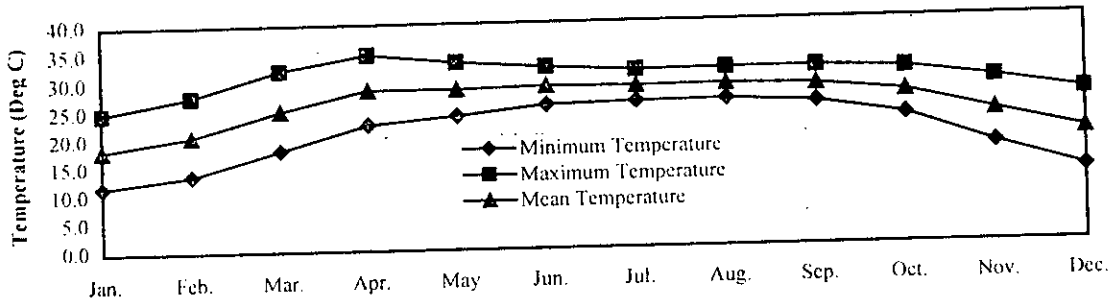


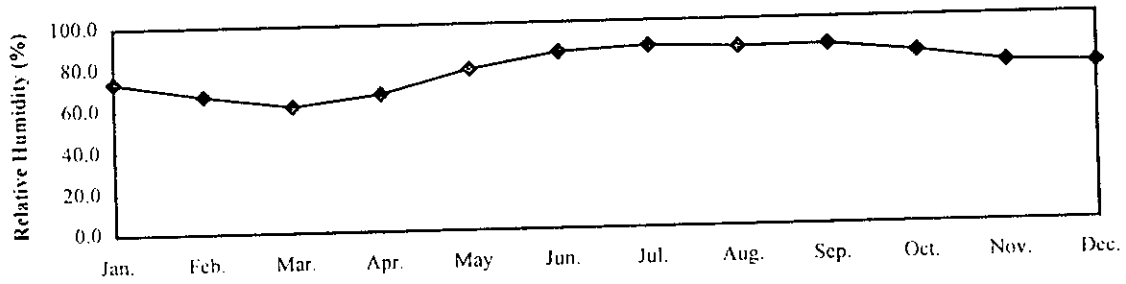
Fig. 3·1 : Location Map of the Study Area

Figure: 3.2a Climatic Norms for Bogra Based on BMD Data from 1963-94

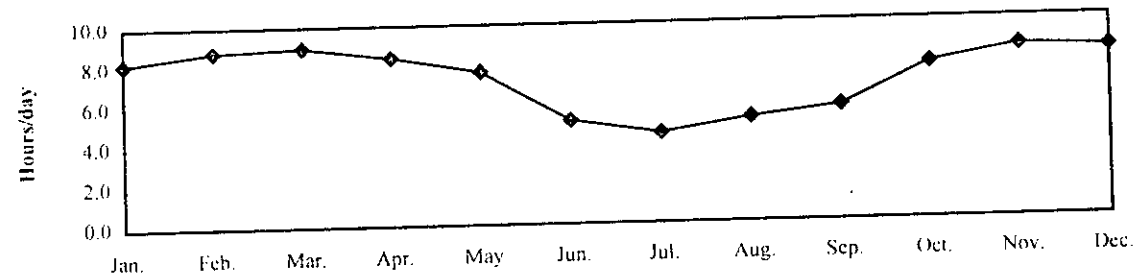
Temperature



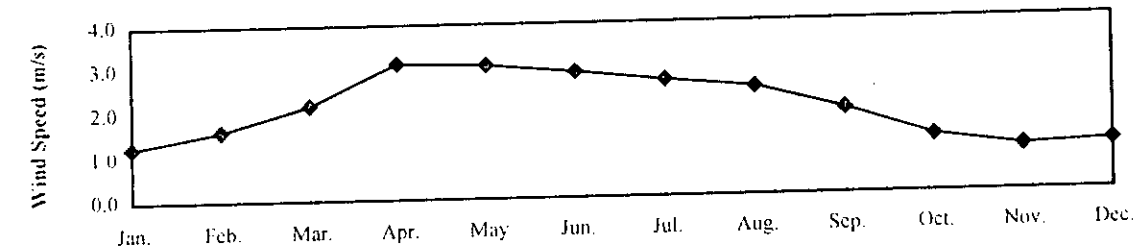
Realative Humidity



Sunshine



Wind Speed



Rainfall and Evaporation

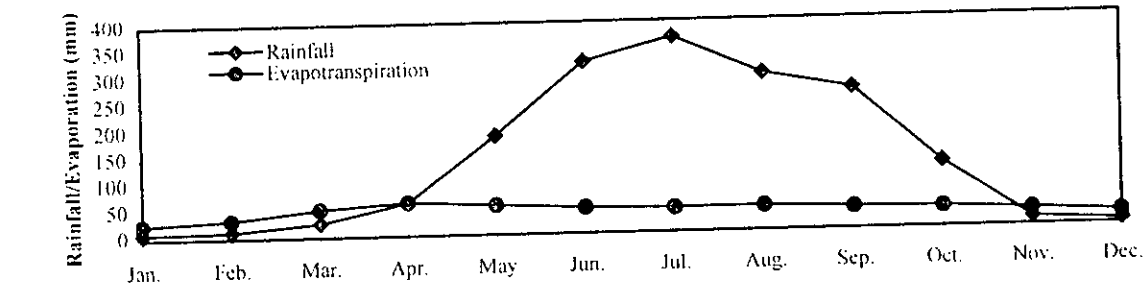
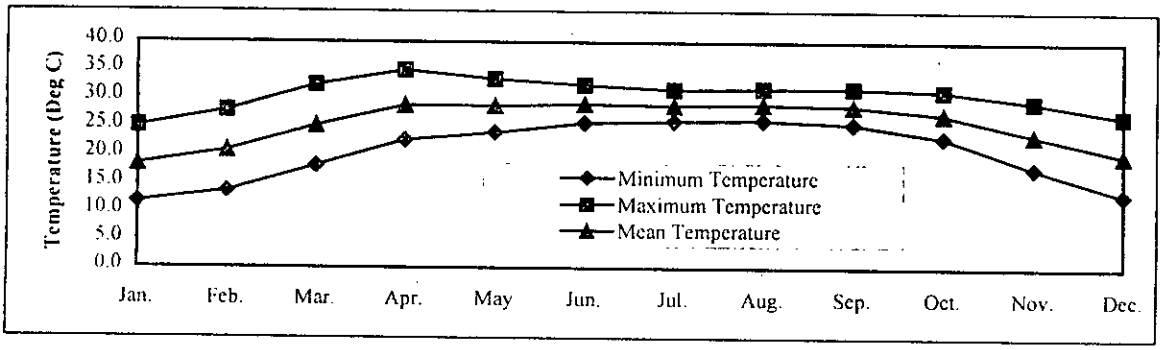
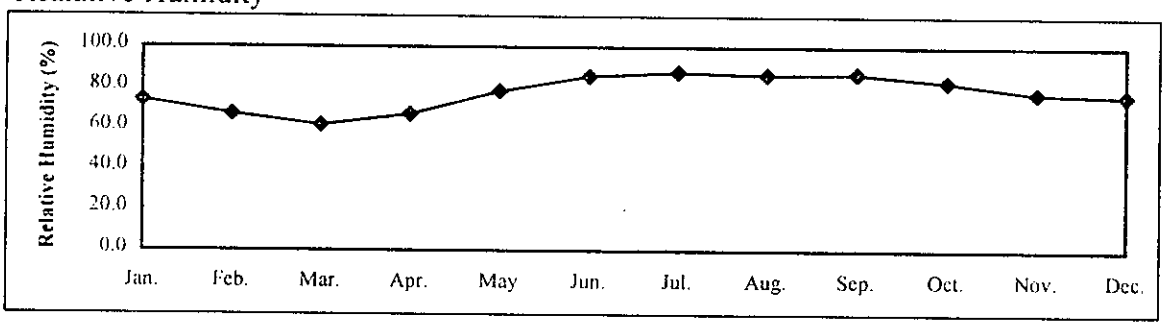


Figure: 3.2b Climatic Norms for Rangpur Based on BMD Data from 1963-94

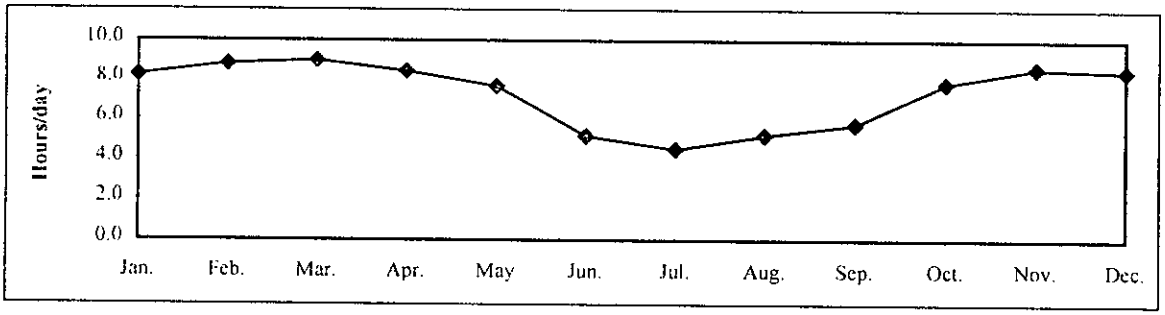
Temperature



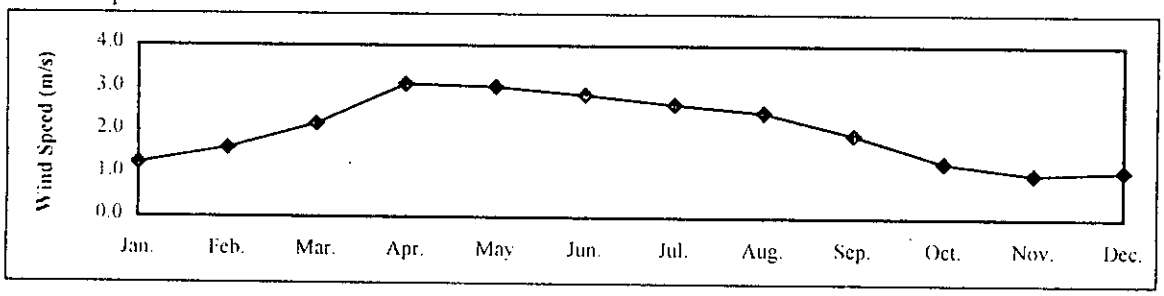
Realative Humidity



Sunshine



Wind Speed



Rainfall and Evaporation

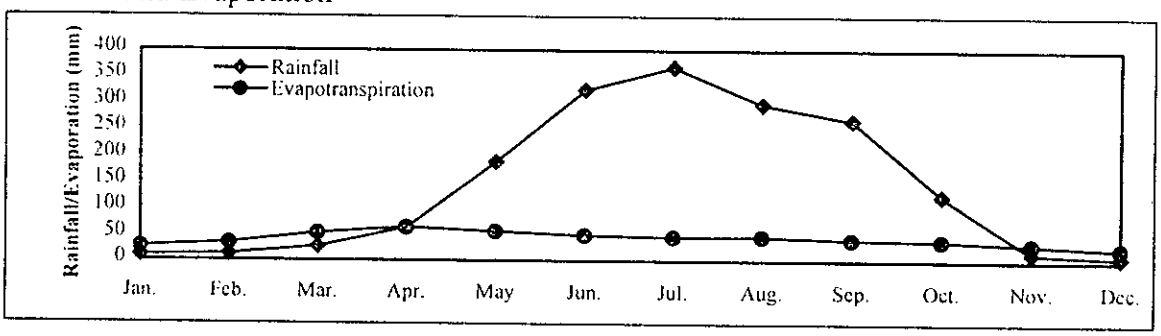


Fig. 3-3 : Isohyet of Mean Annual Rainfall

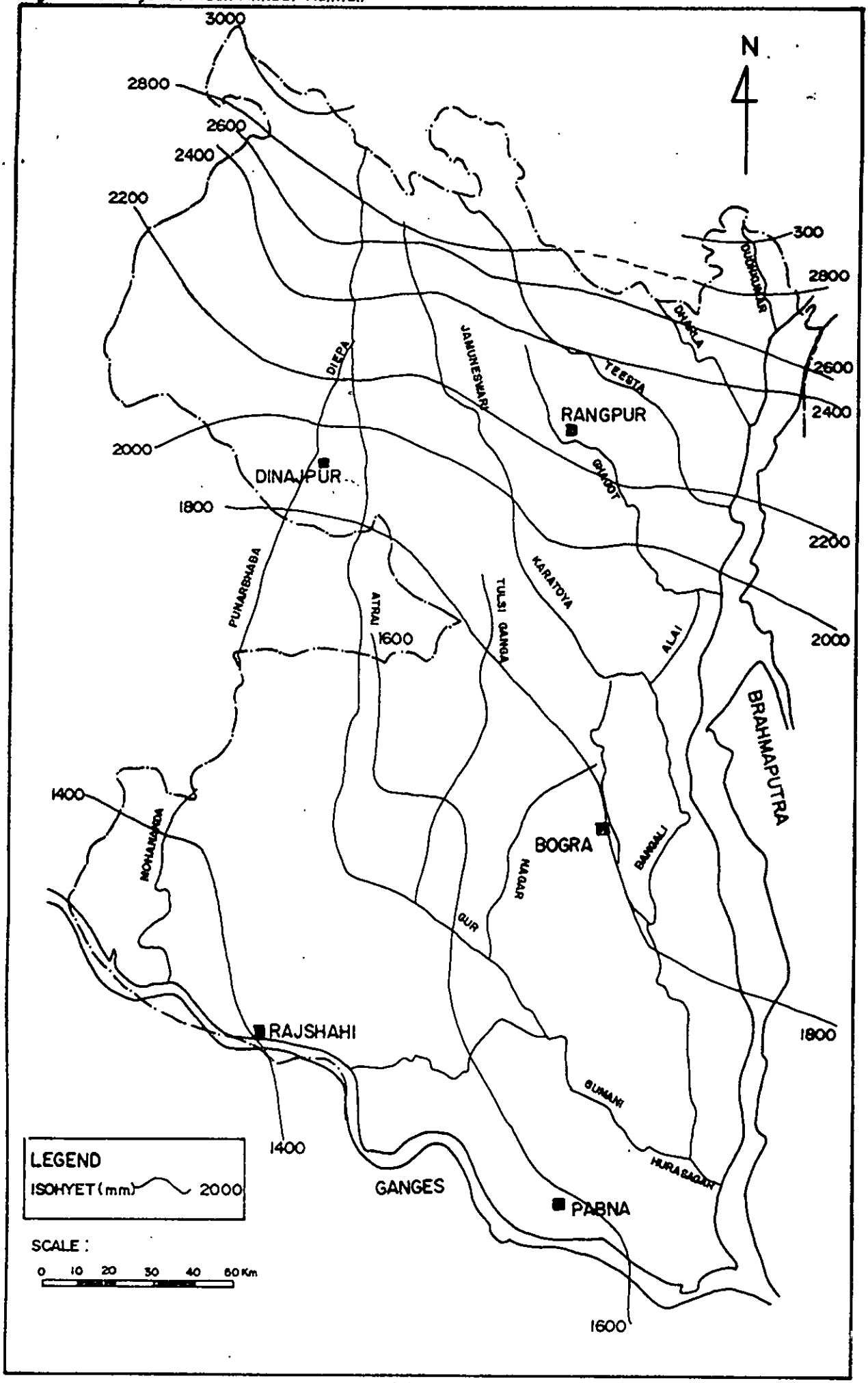


Fig. 3·4 : Monthly Rainfall and Runoff Patterns in the North West Region

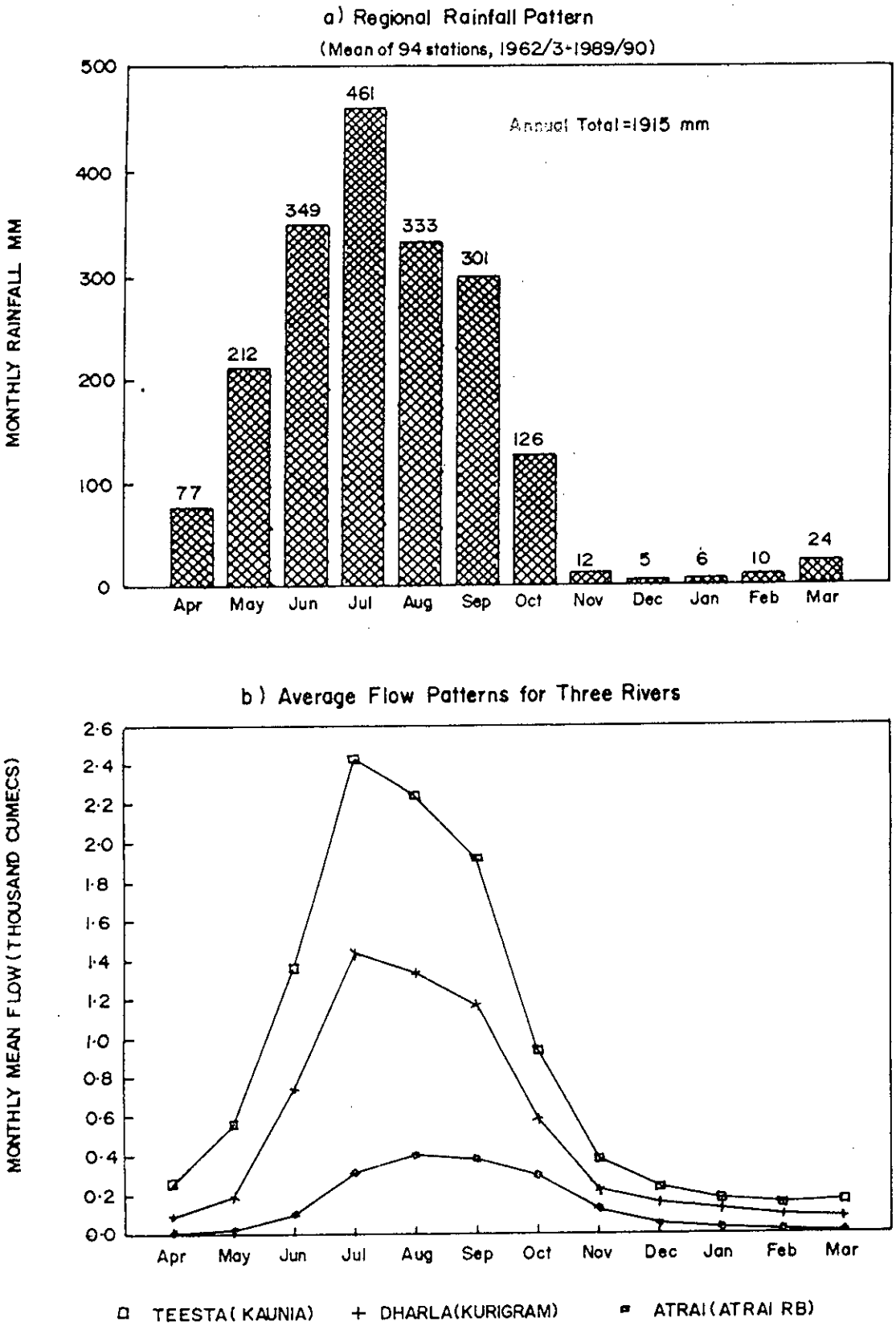
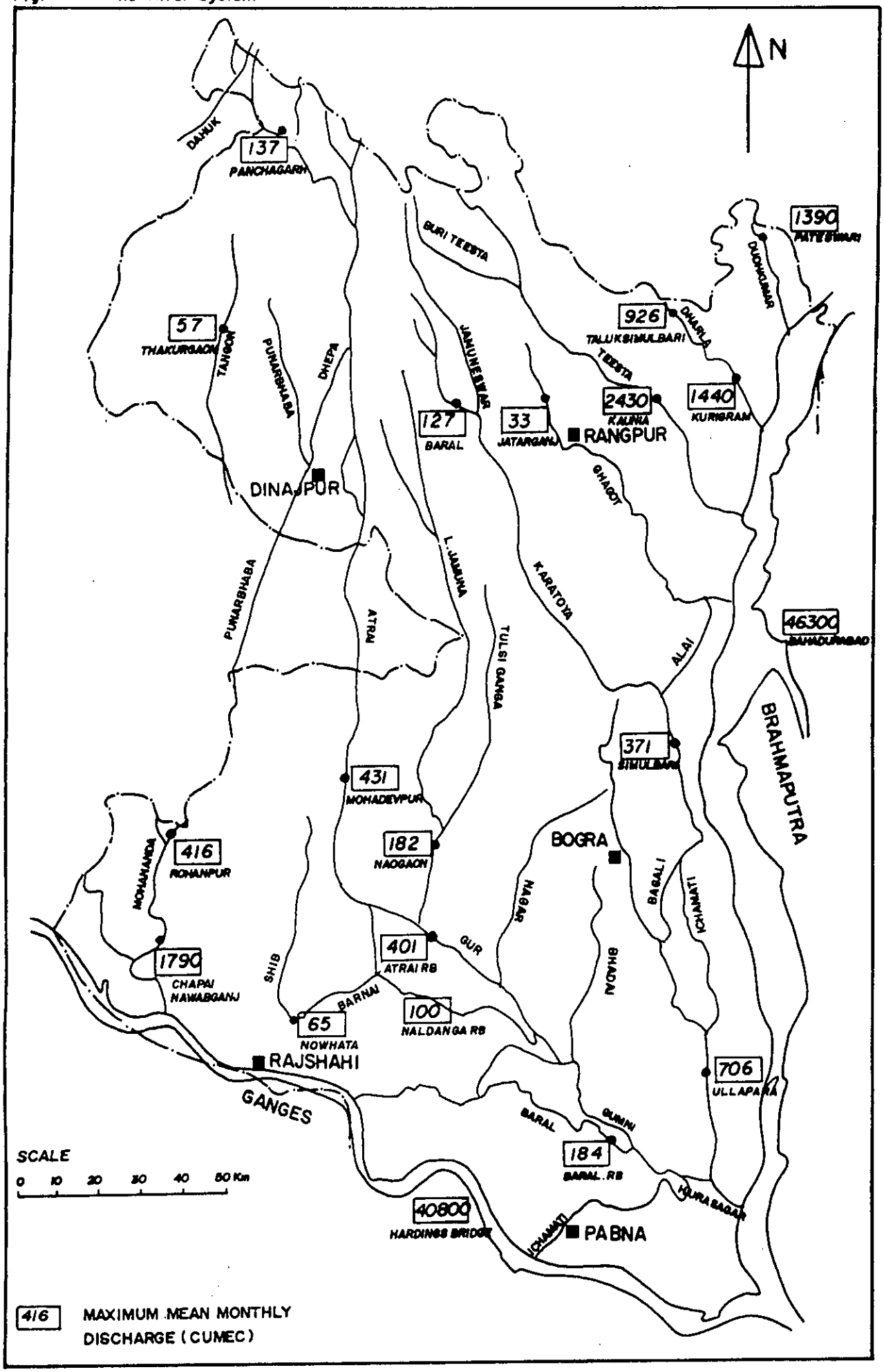


Fig. 3·5 : The River System



Chapter 4
METHODOLOGY

4.1 General

The study mainly focuses on the statistical behavior of surplus and DCWR (longest drought duration) based on the theory of runs and direct enumeration technique. The methodology applied to calculate the DCWR uses available meteorological data from Bangladesh Meteorological Department (BMD). It contains monthly and daily data, which have been analyzed under two categories:

(i) determination of deficiency of crop water requirement (DCWR), and

(ii) analyses of stochastic behavior of the DCWR.

4.2 Crop Water Requirements by CROPWAT

Crop water requirements have been computed from reference evapotranspiration. All of these computations have been performed by CROPWAT. The equations used in the CROPWAT are shown in Appendix-C. The CROPWAT (version 5.7, 1991, FAO publication 46) have the options:

- to calculate :
  - reference evapotranspiration
  - crop water requirement
  - irrigation requirement
  - scheme water supply
- to develop:
  - irrigation schedules under various management conditions,
- to estimate :
  - rained production and drought effects.

4.2.1 Data Input in CROPWAT

Climatic data, information related to location of the climatic station, and specific crop related information is needed for the calculation of CWR and subsequently ACWR from the prevailing rainfall of the station concerned.

4.2.1.1 Information Related to Climatic Stations

The following information is needed

- Country name (Bangladesh)
- Climatic station (station name such as Rangpur, Bogra)
- Altitude (meters)
- Latitude (°N)
- Longitude (°E)

The above information is given in Table 3.2.

4.2.1.2 Climatic Data

Climatic data input in CROPWAT for the calculation of CWR are temperature, air humidity, wind speed, and daily sunshine hours.

Temperature

Temperature data are provided in degree Celsius either as average temperature or as maximum and minimum temperature data from which average is calculated.

Air Humidity

Air humidity can be given as:

- relative humidity expressed in percent (10-100); or as
- vapor pressure in kPa (1-9).

The program automatically distinguishes between vapor pressure value (<10 kPa) and relative humidity (10-100).

Daily Sunshine

The daily sunshine can be given as:

- percentage (20-100) of the ratio sunshine length/day length;
- fraction (0-1) sunshine/day length: or as
- hours sunshine (1-20);

- values > 20 are interpreted as daily sunshine in percent.
- values < 1 as daily sunshine as fraction.
- values > 1 and <20 as sunshine in hours

Wind Speed

Wind speed can be given in km/day (10-500) or m/s (0-10);

- values > 10 are interpreted as wind speed in km/day.
- values < 10 are interpreted as wind speed in m/sec.

4.2.1.3 Rainfall Data

In the present analysis, rainfall data to CROPWAT is not used as input. Crop water requirements (CWR) based on the climatic data are calculated by CROPWAT. Deficiency of crop water requirement (DCWR) is then found by subtracting CWR from rainfall. For the calculation of irrigation requirements from CROPWAT an input of monthly rainfall data is required. Although in the present analysis, irrigation requirements are not calculated, the rainfall data that can be used in CROPWAT be as:

- average rainfall data,
- actual or historical rainfall data, and
- dependable rainfall.

Given the above rainfall data, effective rainfall is obtained from CROPWAT to account for losses due to surface runoff and deep percolation in the region concerned. Four different options that are in use to determine the effective rainfall are:

- fixed percentage of rainfall,
- dependable rainfall,
- empirical formula, and
- USDA Soil Conservation Service Method.

4.2.1.4 Crop Data

CROPWAT needs the input of crop information for CWR. Crop data for paddy are shown in Table 4.1. The required crop information is described below:

Length of Crop Stages

Normally upland crops have four growth stages. In wetland paddy, this is extended to six stages to include nursery and land preparation periods. The lengths of the different stages are defined as below.

- Length of nursery period: number of nursery days starting from land preparation of nursery area to transplanting.
- Length of land preparation: number of days required to carry out land preparation and inundation prior to transplantation for given irrigation unit; normally land preparation fall within the nursery period.
- Initial stage (A)
- Development stage (B)
- Mid-season (C)
- Late season (D)

Crop Factors (K_c)

Crop factors, K_c for initial stage, mid season stages and harvest stages are to be defined shown in Table 4.1 (CROPWAT, 1992); K_c values for development stage are interpolated. The same values of K_c are assumed for the two regions.

Planting Date

The date of planting is a separate crop data input, normally to be determined from climatic conditions (for instance, rainy season) and local agricultural practices. August 5, April 5, and November 25 are the date of transplanting of T. Aman, sowing of B. Aus and wheat, respectly (Karim, undated). In this study three transplanting dates (April 10 for Aus, August 10 for Aman and December 10 for Boro) are assumed for the ease of analysis.

Table 4.1 Crop Information that Used in CROPWAT
Crop : Paddy

Growth Stages	Length of Stages	Crop Coefficient (K_C)
Nursery	30 days	1.20
Land preparation	20 days	Interpolated*
Initial stage (A)	20 days	1.10
Development stage (B)	30 days	Interpolated*
Mid-season (C)	40 days	1.05
Late-season (D)	30 days	0.80
Total	140 days (excluding nursery)	
Nursery area	10 %	
Water requirement for land cultivation	180 mm	
Percolation rate	1.50 mm/day	

* Interpolation has been performed by the CROPWAT automatically.

4.2.2 Calculation of ACWR

The calculation of CWR is carried out as per every ten-day interval (decade). CROPWAT gives the CWR results in the form of mm/day and mm/decade. Reference evapotranspiration (ET_0) that obtained is converted into average daily crop evapotranspiration (ET_{crop}) by using respective crop coefficient (K_c) as follows:

$$ET_{crop} = K_c . ET_o \tag{4.1}$$

Crop water requirements (for paddy) include the combined effect of evapotranspiration and percolation and the requirements for land preparation and nursery before transplantation. Evapotranspiration and percolation occur as soon as the fields are inundated. During the nursery period ET_o and percolation are accounted for only over that area covered by nursery. During the land preparation this area increases daily with more land being inundated until the area is fully covered by transplantation.

$$CWR = ET_{crop} + \text{Percolation} + \text{Land Preparation} \tag{4.2}$$

This CWR is found on the basis of mm/day from CROPWAT, converted into 5-day basis for further statistical analysis. A sample result from CROPWAT is shown in Table 4.2.

Availability of crop water requirement (ACWR) are determined by:

$$ACWR = P - CWR \tag{4.3}$$

where, P is the 5-day rainfall (mm/5 days). The computed CWR are shown in Appendix B-1 and B-2 for Bogra and Rangpur stations, respectively. The ACWR values are also shown in Appendix B-3 and B-4 for the respective stations. In the present analysis the ACWR values obtained are either positive or negative indicating surplus or deficit water, respectively for the

crop in the field. Here negative values are termed as deficiency of crop water requirements (DCWR) and positive value as simple surplus.

Table 4.2 A Sample Result from CROPWAT

Rice Evapotranspiration and Irrigation Requirements

Climate : Bog-90 Station: Bogra
Crop : Paddy Date of Transplant: 10 April
Effective Rainfall: 80%

Month	Dcade	Stage	Area %	Coef	ETcrop mm/day	Perc mm/day	LPrep mm/day	RiceReq mm/day	EffRain mm/day	IRReq mm/day	IRReq mm/dec
Mar	2	NUR	0.10	1.20	0.46	0.2	1.8	24	0.6	2.35	23.5
Mar	3	LP	0.33	1.18	1.60	0.5	8.1	10.2	2.6	9.93	99.3
Apr	1	LP	0.78	1.13	3.99	1.2	8.1	13.3	3.2	12.94	129.4
Apr	2	A	1.00	1.10	5.43	1.5	0.0	6.9	2.9	6.64	66.4
Apr	3	A	1.00	1.09	5.01	1.5	0.0	6.5	27.9	3.97	39.7
May	1	B	1.00	1.09	5.01	1.5	0.0	6.5	57.6	0.75	7.5
May	2	B	1.00	1.07	4.79	1.5	0.0	6.3	84.9	0.00	0.0
May	3	B	1.00	1.06	4.49	1.5	0.0	6.0	90.2	0.00	0.0
Jun	1	C	1.00	1.05	4.22	1.5	0.0	5.7	94.2	0.00	0.0
Jun	2	C	1.00	1.05	3.99	1.5	0.0	5.5	98.8	0.00	0.0
Jun	3	C	1.00	1.05	3.90	1.5	0.0	5.4	110.2	0.00	0.0
Jul	1	C	1.00	1.05	3.81	1.5	0.0	5.3	130.3	0.00	0.0
Jul	2	D	1.00	1.01	3.58	1.3	0.0	4.8	146.1	0.00	0.0
Jul	3	D	1.00	0.92	3.41	0.9	0.0	4.3	120.9	0.00	0.0
Aug	1	D	1.00	0.84	3.22	0.4	0.0	3.7	87.8	0.00	0.0

4.3 Periodic Stochastic Analysis.

The stochastic behavior of the longest duration of DCWR can be predicted by using theory of runs and direct enumeration technique. A continuous time series x(t) as ACWR and a functional truncation level $x_o(t)$ are shown in Fig.1.2. The truncation of the time series at the $x_o(t)$ level forms positive and negative deviations. The consecutive negative deviation preceded and succeeded by positive deviation is called negative run which is an objective representative of the drought duration. The functional truncation levels $x_o(t)$ are taken as the five-day normal, 40th percentile, 50th percentile (median) and 60th percentile of ACWR values from a period of 1962-95. The truncation level values are given in Table 4.3 for the Bogra and Rangpur stations.

Table 4.3 Five-day Truncation Level Values

Station : Rangpur

Date	Mean	40th Percentile	Median	60th Percentile
Apr-1	-58.7	-64.5	-64.5	-64.0
2	-59.7	-64.5	-64.5	-64.0
3	-18.6	-31.8	-30.5	-28.3
4	-14.9	-28.5	-24.3	-19.6
5	-12.9	-31.0	-29.3	-19.6
6	-14.1	-26.1	-22.8	-16.2
May-1	6.5	-19.0	-9.4	6.6
2	0.0	-24.7	-19.6	-15.7
3	6.1	-9.0	-4.6	-0.6
4	-1.0	-16.7	-5.3	-0.6
5	18.2	-3.3	6.7	11.4
6	18.2	-17.4	-1.2	15.0
Jun-1	12.6	-6.8	0.7	14.5
2	34.9	-9.6	8.9	30.4
3	26.7	-2.2	25.0	44.1
4	48.2	-0.2	19.2	37.8
5	33.9	3.4	7.3	16.2
6	25.2	-2.8	2.3	13.5
July-1	41.7	-6.8	8.0	50.8
2	54.9	18.7	41.7	56.5
3	34.1	9.6	30.9	42.3
4	44.5	12.2	24.5	45.1
5	19.7	-8.0	-3.2	16.3
6	45.1	8.0	30.7	55.8
Aug-1	-8.0	-35.7	-23.8	-5.3
2	-22.1	-39.2	-31.0	-23.9
3	7.2	-10.7	-1.8	3.2
4	19.9	-12.5	-4.5	13.7
5	30.6	10.3	14.6	22.3
6	22.8	0.2	15.0	28.0
Sep-1	4.8	-25.8	-15.5	-7.4
2	6.2	-14.1	-0.1	4.1
3	14.0	-4.6	1.2	16.8
4	17.4	-1.1	7.0	19.6
5	13.2	-16.6	-10.8	3.3
6	14.1	-13.4	6.8	24.8
Oct-1	19.3	-11.7	-1.1	9.5
2	11.9	-24.2	-16.5	-9.6
3	-2.4	-24.5	-23.5	-18.1
4	-10.8	-24.3	-23.5	-23.2
5	-3.0	-23.3	-22.3	-21.3
6	-17.6	-23.5	-23.0	-22.7
Nov-1	-20.3	-22.5	-22.5	-22.0
2	-20.7	-22.5	-22.3	-22.0
3	-17.7	-19.5	-19.5	-19.0
4	-19.5	-19.5	-19.5	-19.0
5	-46.5	-47.5	-47.5	-47.5
6	-44.3	-47.5	-47.5	-47.5
Dec-1	-54.8	-56.0	-56.0	-55.5
2	-53.8	-56.0	-55.8	-55.5
3	-14.8	-18.5	-18.0	-18.0
4	-18.4	-18.5	-18.3	-18.0
5	-18.2	-18.5	-18.0	-18.0
6	-16.7	-18.3	-18.0	-18.0
Jan-1	-16.3	-18.0	-18.0	-17.5
2	-11.9	-18.0	-18.0	-17.5
3	-16.2	-17.5	-17.3	-17.0
4	-16.3	-17.5	-17.5	-17.2
5	-17.8	-18.5	-18.5	-18.5
6	-17.8	-18.5	-18.5	-18.5
Feb-1	-17.6	-19.5	-19.5	-19.5
2	-18.1	-19.8	-19.5	-19.5
3	-20.4	-21.0	-20.8	-20.5
4	-19.4	-21.0	-20.5	-20.5
5	-20.3	-23.0	-22.7	-22.5
6	-20.3	-23.0	-22.8	-22.5
Mar-1	-24.6	-25.0	-25.0	-24.5
2	-23.2	-25.0	-24.5	-24.5
3	-19.0	-24.8	-24.5	-24.2
4	-22.3	-25.0	-24.5	-24.5
5	-43.7	-50.5	-50.5	-50.0
6	-47.9	-50.5	-50.5	-50.0

Station : Bogra

Mean	40th Percentile	Median	60th Percentile
-57.4	-66.5	-66.0	-65.5
-59.7	-67.0	-66.3	-66.0
-20.6	-34.5	-33.8	-29.9
-15.3	-30.7	-25.4	-23.7
-18.9	-32.8	-31.5	-20.7
-17.2	-30.1	-25.3	-17.9
3.7	-27.8	-11.2	4.1
-2.0	-28.1	-21.5	-18.3
6.7	-9.1	-5.0	-0.3
-0.9	-17.1	-6.5	-3.5
16.8	-10.8	3.6	17.6
16.5	-19.2	-3.7	11.7
10.3	-11.2	-2.0	13.0
31.8	-13.7	3.6	23.2
25.0	-2.4	23.8	41.8
45.1	-0.3	9.3	34.1
34.7	3.4	6.8	16.3
25.6	-2.8	2.8	17.7
38.6	-7.5	10.3	34.1
53.3	17.3	30.5	53.4
33.4	9.3	31.1	44.0
36.7	7.3	14.6	30.8
20.4	-8.2	-3.2	22.9
43.4	7.1	13.6	45.4
-9.1	-43.2	-26.6	-5.4
-24.2	-44.7	-34.3	-26.5
7.1	-11.8	-2.3	2.5
11.0	-19.4	-12.6	-4.8
21.8	7.1	9.7	14.4
14.7	-8.2	2.6	15.8
4.0	-26.8	-15.2	-8.1
4.5	-17.8	-2.4	3.8
8.9	-6.5	-3.6	2.1
16.1	-1.6	6.0	18.7
7.5	-19.7	-14.2	-10.0
10.4	-16.6	-2.1	13.0
16.3	-15.0	-7.5	0.4
15.2	-25.5	-17.2	-11.1
-3.5	-25.5	-24.3	-19.1
-12.0	-25.3	-24.8	-24.0
-3.9	-24.3	-23.0	-22.5
-20.7	-24.5	-24.0	-23.5
-21.0	-23.5	-23.0	-23.0
-21.4	-23.5	-23.0	-23.0
-19.8	-20.5	-20.0	-20.0
-21.0	-20.5	-20.0	-20.0
-46.8	-48.0	-48.0	-48.0
-44.6	-48.0	-48.0	-48.0
-55.7	-57.0	-57.0	-56.5
-55.5	-57.0	-57.0	-56.5
-18.0	-20.0	-20.0	-19.5
-19.8	-20.0	-20.0	-19.7
-19.5	-19.5	-19.5	-19.5
-18.0	-19.8	-19.5	-19.5
-17.6	-19.0	-19.0	-19.0
-12.7	-19.0	-19.0	-19.0
-17.5	-18.5	-18.5	-18.5
-17.7	-18.8	-18.5	-18.5
-19.2	-20.0	-19.8	-19.5
-19.2	-20.0	-19.8	-19.5
-19.3	-21.0	-21.0	-21.0
-19.8	-21.8	-21.0	-21.0
-22.3	-23.0	-22.5	-22.0
-21.1	-23.0	-22.5	-22.0
-22.0	-25.2	-24.5	-24.0
-22.3	-24.8	-24.5	-24.2
-26.1	-27.0	-26.5	-26.2
-24.7	-26.5	-26.0	-25.7
-20.6	-27.0	-26.5	-25.7
-23.7	-27.0	-27.0	-26.2
-44.5	-51.0	-51.0	-51.0
-48.2	-51.5	-51.0	-51.0

The application of direct enumeration technique requires mainly four conditional probabilities, one surplus probability and one deficit probability which are respectively $P_i(+|+)$, $P_i(-|-)$, $P_i(+|-)$, $P_i(-|+)$, $P_i(-)$ and $P_i(+)$ as are determined by the above mentioned truncation level values.

where,

$P_i(+|+)$ implies the actual conditional probability of surplus followed by surplus.

$P_i(-|-)$ implies the actual conditional probability of deficit followed by deficit.

$P_i(+|-)$ implies the actual conditional probability of surplus followed by deficit.

$P_i(-|+)$ implies the actual conditional probability of deficit followed by surplus.

$P_i(-)$ implies the actual probability of deficit.

$P_i(+)$ implies the actual probability of surplus.

4.3.1 Estimation of Probabilities

The estimations of the probabilities $P_i(+|+)$, $P_i(-|-)$, $P_i(+|-)$, $P_i(-|+)$, $P_i(-)$ and $P_i(+)$ can be obtained through the following steps:

1. The five-day sum ACWR values at (i+1) and i^{th} intervals (i.e., 5-day intervals) in each year are truncated at given respective demand levels.
2. The number $(n_{ss})_i$ of joint surplus occurrences and the number $(n_{dd})_i$ of joint deficit occurrences are counted throughout the observation period. In addition the number $(n_s)_i$ of surpluses and the number $(n_d)_i$ of deficits in the ith interval is determined.
3. Finally the estimation can be calculated as:

$$P_i(+,+) = (n_{ss})_i / n \quad \text{and} \quad P_i(+) = (n_s)_i / n \qquad P_i(+|+) = P_i(+,+) / P_i(+)$$

$$P_i(-,-) = (n_{dd})_i / n \quad \text{and} \quad P_i(-) = (n_d)_i / n \qquad P_i(-|-) = P_i(-,-) / P_i(-)$$

$$P_i(+|+) + P_i(-|+) = 1 \quad \text{so that} \quad P_i(-|+) = 1 - P_i(+|+)$$

$$P_i(-|-)+P_i(+|-)=1 \quad \text{so that} \quad P_i(+|-)=1-P_i(-|-) \tag{4.4}$$

where, n is the record length in years (in the present analysis n = 32 years).

4.3.2 Longest DCWR and Surplus Durations

Longest drought duration means longest duration of DCWR. The methodology presented herein bases on a direct application of the enumeration technique with the considerations of:

1) that in each sequence there exists one longest positive and one longest negative run lengths;
2) the longest positive or negative run length probability in sample size say, i can be related to the similar probability in the sample size $(i-1)$ leading to a recurrence type of relationship; and
3) in transition from one sample of $((i-1)$dependent Bernoulli trials to the following sample only the two state probabilities of the final stage in the previous sample are necessary in addition to the four conditional probabilities of $P_i(+|+)$, $P_i(-|-)$, $P_i(+|-)$, and $P_i(-|+)$

The probability of the longest positive run length, L, to be equal to an integer j-value in a sample size of i with + state at the final stage will be denoted by $P_i^+\{L=j\}$. At the initial state there exists no transition. The state probabilities of the initial stage will be denoted by $P_i(+)$ and $P_i(-)$ for the + and - states, respectively. It is obvious that $P_i(+)+P_i(-)=1$. After all of these definitions the enumeration technique can be applied step by step as follows. For sample size $i=1$, it is straightforward to write:

$$P_1^-\{L=0\}=P_1(-) \qquad \text{and} \qquad P_1^+\{L=1\}=P_1(+) \tag{4.5}$$

In the case of i=2 there are 2^2 combinations of surpluses and deficits which can be written by transition from i=1 to i=2. For the purpose of finding maximum run length this transition according to Sen (1980c) can be decomposed into the following probabilities.

$$P_2^-\{L=0\} = P_1^-\{L=0\}.P_2(-|-) \tag{4.6}$$

$$P_2^+\{L=1\} = P_1^-\{L=0\}.P_2(+|-) \tag{4.7}$$

$$P_2^-\{L=1\} = P_1^+\{L=1\}.P_2(-|+) \tag{4.8}$$

$$P_2^+\{L=2\} = P_1^+\{L=1\}.P_2(+|+) \tag{4.9}$$

In the same way the transition from i = 2 to i = 3 leads to:

$$P_3^-\{L=0\} = P_2^-\{L=0\}.P_3(-|-) \tag{4.10}$$

$$P_3^+\{L=1\} = P_2^-\{L=0\}.P_3(+|-) + P_2^-\{L=1\}.P_3(+|-) \tag{4.11}$$

$$P_3^-\{L=1\} = P_2^+\{L=1\}.P_3(-|+) + P_2^-\{L=1\}.P_3(-|-) \tag{4.12}$$

$$P_3^+\{L=2\} = P_2^+\{L=1\}.P_3(+|+) \tag{4.13}$$

$$P_3^-\{L=2\} = P_2^+\{L=2\}.P_3(-|+) \tag{4.14}$$

$$P_3^+\{L=3\} = P_2^+\{L=2\}.P_3(+|+) \tag{4.15}$$

and finally for i = 4 similar type of relationships can be obtained as:

$$P_4^-\{L=0\} = P_3^-\{L=0\}.P_4(-|-) \tag{4.16}$$

$$P_4^+\{L=1\} = P_3^-\{L=0\}.P_4(+|-) + P_3^-\{L=1\}.P_4(+|-) \tag{4.17}$$

$$P_4^-\{L=1\} = P_3^+\{L=1\}.P_4(-|+) + P_3^-\{L=1\}.P_4(-|-) \tag{4.18}$$

$$P_4^+\{L=2\} = P_3^+\{L=1\}.P_4(+|+) + P_3^-\{L=2\}.P_4(+|-) \tag{4.19}$$

$$P_4^-\{L=2\} = P_3^+\{L=2\}.P_4(-|+) + P_3^-\{L=2\}.P_4(-|-) \tag{4.20}$$

$$P_4^+\{L=3\} = P_3^+\{L=2\}.P_4(+|+) \tag{4.21}$$

$$P_4^-\{L=3\} = P_3^+\{L=3\}.P_4(-|+) \tag{4.22}$$

$$P_4^+\{L=4\} = P_3^+\{L=3\}.P_4(+|+) \tag{4.23}$$

If desired it is possible to continue the enumeration, but for the sake of brevity it has been avoided herein. However, a close inspection through Eqs.(4.5) to (4.23) reveals some features of the general pattern of equations. For instance, the probability of no run-length in a sample of size n can be easily detected from the first expressions in Eqs.(4.5) to (4.23). Hence, in general:

$$P_n^-\{L=0\} = P_{n-1}^-\{L=0\}P_n(-|-) \tag{4.24}$$

By inspection the probability of the full run-length can be obtained from the final expressions in Eqs. (4.5) to (4.23) as:

$$P_n^+\{L=n\} = P_{n-1}^+\{L=n-1\}P_n(+|+) \tag{4.25}$$

All other probabilities in the interval $1 \le j \le n-1$ have two components, one for + state and one for the - state. In fact:

$$P_n\{L=j\} = P_n^+\{L=j\} + P_n^-\{L=j\} \tag{4.26}$$

with the explicit expressions of components as,

$$\begin{aligned} P_n^+\{L=j\} &= \sum_{m=0}^{k_1} P_{n-1}^-\{L=m\}P_{n-j+1}(+|-)\prod_{k=1}^{j-1} P_{n-j+k+1}(+|+) \\ &+ \sum_{m=1}^{k_2} P_{n-m}^-\{L=j\}P_{n-m+1}(+|-)\prod_{k=1}^{m-1} P_{n-m+k+1}(+|+) \end{aligned} \tag{4.27}$$

and

$$P_n^-\{L=j\} = P_{n-1}^+\{L=j\}P_n(-|+) + P_{n-1}^-\{L=j\}P_n(-|-), \tag{4.28}$$

$$\text{if } n-1=j \text{ then} \qquad P_n(-/-)=0$$

where

$$k_1 = \min(n-j-1, j) \text{ and } \quad k_2 = \min(n-j-1, j-1)$$

Hence Eqs. (4.24) to (4.28) give the full description of the longest positive run-length in n dependent Bernoulli trials. For the longest negative run-length, N, probability with the aforementioned sign interchanges one obtains:

$$P_n^+\{N=0\} = P_{n-1}^+\{N=0\}P_n(+|+) \tag{4.29}$$

$$P_n^-\{N=j\} = \sum_{m=0}^{k_1} P_{n-j}^+\{N=m\}P_{n-j+1}(-|+)\prod_{k=1}^{j-1} P_{n-j+k+1}(-|-) + \sum_{m=1}^{k_2} P_{n-m}^+\{N=j\}P_{n-m+1}(-|+)\prod_{k=1}^{m-1} P_{n-m+k+1}(-|-) \tag{4.30}$$

$$P_n^+\{N=j\} = P_{n-1}^-\{N=j\}P_n(+|-) + P_{n-1}^+\{N=j\}P_n(+|+) \tag{4.31}$$

if $n-1=j$ then $P_n(+|+)=0$

$$P_n^-\{N=n\} = P_{n-1}^-\{N=n-1\}P_n(-|-) \tag{4.32}$$

Eqs. (4.29) to (4.32) are exact probabilities for nonhomogeneous two-state Markov chains.

The expected value of the longest drought duration, E(N) can be calculated numerically by:

$$E(N) = \sum_{i=1}^{n} iP_n\{N=i\} \tag{4.33}$$

Changing N by L, Eq. (4.33) can be used for the expected value of the longest surplus duration, E(L).

4.4 ACWR Analysis by Stochastic Model

Sequences characterized by statistical properties are called stochastic process. A stochastic process is the mathematical abstraction of an empirical process, with its development governed by probability laws. Nearly all hydrologic processes can be characterized as stochastic process, or as a combination of deterministic and stochastic processes (Yevjevich, 1972).

The stochastic behavior of the longest dry (deficit) and wet (surplus) spells can be predicted using theory of runs, where Poisson probability density function for the occurrence of spells, geometric distribution for the length of spells and Weibul, normal, lognormal, Gumble and exponential distributions for the total water deficit or surplus over a spell (designated as deficit-sum or surplus-sum) are coupled. Availability of crop water requirement (plus or minus) more than a given reference constant value x_o {or a functional value $x_o(t)$}designated as surplus interval and one with less than x_o designated as deficit interval. The functional truncation level $x_o(t)$ may be taken as the normal and median or any percentile of five-day ACWR values. Here normal value is defined as the mean of i^{th} interval (i.e, May 1 is the 7^{th} interval) for the period of last 32 years. In a year of N intervals (5-day) there will occur runs of surplus and deficit intervals. The numbers of these spells are designated as N_s (surplus) and N_d (deficit). A surplus or deficit spell lasts for L_s or L_d intervals and the duration of a spell is known as the length of run or spell. L_s or L_d intervals take on values 1,2,3,...j. Longest L_s and L_d designated as L_{sm} and L_{dm} respectively. For water harvesting and design of water storage system, interest lies in the deficit-sum designated as S_d. On the other hand, for the design of drainage system, the surplus-sum designated as S_s is used. This analysis can be carried by using only five parameters namely p_1, q_1, p_2, q_2, μ and σ^2, where p_1 is the probability of any interval being a surplus interval, p_2 is the probability of a surplus interval followed by the previous surplus interval, q_1 is the probability of any interval being a deficit interval, q_2 is the probability of a deficit interval followed by the previous deficit interval, μ is the mean and σ^2 is the variance of five-day deficiency of CWR.

The phenomena of surplus and deficit spells are random. At times the level of persistence may be negligible and such processes are independent. If level of persistence is high, such process are termed as dependent. One powerful model to describe level of persistence is that of Markov process of order-one, in which today's state is dependent only up to one day behind. The degree of persistence is quantified through conditional probability of lag-1 serial correlation coefficient. So, two models are described, one is Markov process and other one is under random independent process (Random model).

4.4.1 Markov Model

Lag-one Markov model is employed to represent the DCWR and surplus data. Various important probabilistic and statistical properties of the lag-one Markov process run lengths have been previously derived either by Monte Carlo techniques on digital computers or by approximate analytical expressions.

4.4.1.1 Probability Density Function of the Occurrences

The distribution of the occurrences of the surplus or deficit spells can be regarded as following the well-known Poisson distribution (Gupta and Duckstein, 1975; Sen, 1980[a]). Probability density functions for this process with an average rate of occurrences equal to $np_1(1-p_2)$ under Markovian dependence can be written as (Sen, 1980[a]);

$$P(N_s = i) = \frac{\exp[-Np_1(1-p_2)][Np_1(1-p_2)]^i}{i!} \tag{4.34}$$

where $P(N_s = i)$ is the probability of number of surplus spell equal to i; N is the sample size in a particular year or season.

4.4.1.2 Distribution of Length of Runs

Likewise the distribution of length of runs can be modeled using geometric distribution (Sen, 1980[a]; Bogardi et al., 1988). The probability of positive run length to be equal or greater than j (Feller, 1957) is

$$P(L_s > j) = p_2^{\,j-1} \tag{4.35}$$

The longest period of surplus and deficit spells can be deduced by applying the theorem of extremes of random numbers of a random variable (Todorovic and Woolhiser, 1975). The probabilistic relationship for a sample size n to find out the longest period of surplus spell can be written as (Sen, 1980[a]):

$$P(L_{sm} \le j) = \exp[-Np_1(1-p_2)P(L_s > j)] \tag{4.36}$$

and mean, variance, and skewness of L_s are (Sen, 1976)

$$E(L_s) = \frac{1}{1-p_2} \tag{4.37}$$

$$V(L_s) = \frac{p_2}{(1-p_2)^2} \tag{4.38}$$

$$\gamma_{L_s} = \frac{p_2(1-p_2)}{p_2^{3/2}} \tag{4.39}$$

Similar relationship can be written for deficit intervals but q_1 and q_2, will be used instead of p_1 and p_2.

4.4.1.3 Distribution of Run-Sums

The amount of water over a deficit or surplus period is known as run-sum, is important in water resources system design. One of the problems in water resources system design is to predict the total amount of water available (or deficit) over an operational period of the project considered. For instance, in reservoir design, if the total amount of water is in excess of the demand, the excess water will be stored, where as during a deficit period the extraction of water is necessary. Therefore to find out the run-sum, cdf's of largest run-sum are evaluated and compared to their observed counterpart using both Markov and random models in conjunction with Weibul, normal, lognormal, Gumble and exponential PDF's.

Weibul Distribution

The extreme value type III distribution for minimum value is known as the Weibul distribution. This distribution has found its greatest use in hydrology as the distribution of low streamflows. Naturally low flows are bounded by zero on the left.

In the present analysis Weibul probability law (Benjamin and Cornell, 1970) has been used for the theorem of extremes of random numbers to model the run-sum (S_s for surplus, S_d for deficit) sequences. Hann (1977) has derived the following relationship

$$P(S_s > S) = \exp\left[-\left(\frac{S}{b}\right)^a\right] \tag{4.40}$$

where $P(S_s > S)$ is the probability of surplus-sum greater than a particular value S; and a and b are parameters of Weibul distribution and can be estimated using method of moments. The relationship for deficit-sum can also be written similarly as:

$$P(S_d > D) = \exp\left[-\left(\frac{D}{b}\right)^a\right] \tag{4.41}$$

The mean and variance of the distribution are

$$E(S_s) = b\Gamma(1+\frac{1}{a}) \tag{4.42}$$

$$V(S_s) = b^2[\Gamma(1+\frac{2}{a}) - \Gamma^2(1+\frac{1}{a})] \tag{4.43}$$

The sequence of S_s are based on surplus intervals over wet spells and therefore $E(S_s)$ and $V(S_s)$ can be estimated using statistics E(x) and V(x) of the five-day surplus sequence as follows (Sen, 1978, 1980; Llamas, 1987):

$$E(S_s) = \frac{\omega E(x)}{p_1} \tag{4.44}$$

$$V(S_s) = \left[\frac{p_1 V(x) + q_1 E^2(x)}{p_1^2}\right]\left[\omega + 2\rho\frac{\omega(1-\rho) - (1-\rho^\omega)}{(1-\rho)^2}\right] \tag{4.45}$$

where ρ is the lag-1 serial correlation coefficient between five-day ACWR.

$$\rho = \sin \pi (p_2 - 0.5) \tag{4.46}$$

and

$$\omega = \frac{1}{1 - p_2} \tag{4.47}$$

Applying the theorem of the extremes of random numbers of a random variable (Todorovic and Woolhiser, 1975), the probabilistic relationship for sample size n to find out the largest surplus sum value can be written as (Sen, 1980[a]):

$$P(S_{sm} \leq S) = \exp[-Np_1(1 - p_2)P(S_s > S)] \tag{4.48}$$

The probabilistic relationship for deficit sum can be written by interchanging p_1 and p_2 with q_1 and q_2 respectively, as.

$$P(S_{dm} \leq D) = \exp[-Nq_1(1 - q_2)P(S_d > D)] \tag{4.49}$$

In the above cdf, Weibul distribution has been used to derive the analytical solution of the problem.

Normal Distribution

The most widely used and most important continuous probability distribution is the Gaussian or normal distribution. In a strict theoretical sense, most hydrologic variables cannot be normally distributed because the range on any random variable that is normally distributed is the entire real line ($-\infty$ to $+\infty$). Thus non-negative variables such as rainfall, streamflow, reservoir storage, etc., cannot be strictly normally distributed. Since run-sum is the sum of different individual values, the sum may be assumed as normally distributed. The cdf can be written as:

$$P(S_d \le D) = \frac{1}{\sqrt{2\pi}\sigma_d} \int_0^{D} \exp\left\{-\frac{1}{2}\left(\frac{S_d - \mu_d}{\sigma_d}\right)^2\right\} dS_d \qquad (4.50)$$

in which μ_d and σ_d are parameters of the distribution and equal to mean $E(S_d)$ and standard deviation $\sqrt{V(S_d)}$ of the deficit sum sequence, S_d. Values of above integration are calculated by using normal distribution table of the text book. The same integration can also be performed for surplus sum, S_y.

Lognormal Distribution

The lognormal distribution has the advantage over the normal distribution that it is bounded for x>0 and the log transformation tends to reduce the positive skewness commonly found in hydrologic data, because taking logarithm reduces large numbers proportionality more than it does small numbers. The edf can be written as:

$$P(S_d \le D) = \frac{1}{\sqrt{2\pi}\sigma_y} \int_0^{y_D} \exp\left\{-\frac{1}{2}\left(\frac{y - \mu_y}{\sigma_y}\right)^2\right\} dy \qquad (4.51)$$

in which $y = \ln S_d$ and $y_D = \ln D$, μ_y and σ_y are the parameters of the distribution and can be evaluated by the following relationships:

$$\sigma_y^2 = \ln\left[\frac{V(S)}{E(S)^2} + 1\right] \qquad (4.52)$$

$$\mu_y = \ln\left(E(S) - \frac{\sigma_y^2}{2}\right). \qquad (4.53)$$

Gumble Distribution

The type I extreme value has been referred to as Gumble's extreme value distribution. The type I extreme value distribution has been used for rainfall-duration-frequency studies (Hershfield,

1961) and as the distribution of the yearly maximum of daily river flows. The cdf can be written as:

$$P(S_d \le D) = \exp(-\exp(-\alpha(x-\beta))) \tag{4.54}$$

in which α and β are the parameters of this distribution and can be evaluated from the following equations:

$$E(S_d) = \beta + \frac{0.5772}{\alpha} \tag{4.55}$$

$$V(S_d) = \frac{1.645}{\alpha^2} \tag{4.56}$$

Exponential Distribution

The exponential distribution arises as the probability distribution of the time between occurrences of events of a Poisson process (Hann, 1977). The cdf of this distribution can be given as:

$$P(S_d \le D) = 1 - e^{-\lambda x} \tag{4.57}$$

where λ is the parameter of the distribution and can be given as:

$$\lambda = \frac{1}{E(S_d)} \tag{4.58}$$

4.4.2 Random Model

If the level of persistence is negligible, such process is known as random. For random process in the above equations, p_1 and q_1 will be used instead of p_2 and q_2, respectively, and $\rho = 0$ has to be inserted to make the process random.

Probability Density Function of the Occurrences

$$P(Ns = i) = \frac{\exp[-Np_1(1-p_1)][Np_1(1-p_1)]^i}{i!} \tag{4.59}$$

Distribution of Length of Runs

$$P(L_s > j) = p_1^{j-1} \tag{4.60}$$

The longest period of surplus spell can be written as:

$$P(L_{sm} \le j) = \exp[-Np_1(1-p_1)P(L_s > j)] \tag{4.61}$$

and mean, variance, and skewness of L_s are

$$E(L_s) = \frac{1}{1-p_1} \tag{4.62}$$

$$V(L_s) = \frac{p_1}{(1-p_1)^2} \tag{4.63}$$

$$\gamma_{L_s} = \frac{p_1(1-p_1)}{p_1^{3/2}} \tag{4.64}$$

Distribution of Run-sums

For surplus-sum under Weibul distribution, the analytical solution can be given as

$$P(S_{sm} \le S) = \exp[-Np_1(1-p_1)P(S_s > S)] \tag{4.65}$$

and for deficit-sum

$$P(S_{dm} \le D) = \exp[-Nq_1(1-q_1)P(S_d > D)] \tag{4.66}$$

For the application of other distributions under random model, it will follow the same equations as shown in Eqs. (4.50) to (4.58).

Chapter 5
RESULTS AND DISCUSSIONS

5.1 General

The present analysis has been divided into two major categories. In the first category, crop water requirement (CWR) and availability of crop water requirement (ACWR) are found out. In the second category, stochastic analysis has been performed on those ACWR data obtained. Analysis has been performed with ACWR data to establish its nature that follows periodic stochastic process in general. Some stochastic models have also been applied in the analysis to obtain its surplus and deficit characteristics objectively for Rangpur and Bogra stations of the north-western Bangladesh. Analyses for the second category are discussed in the following sections.

5.2 Periodic Stochastic Process

The application of exact formulas derived in Eqs. (4.24) to (4.33) in the previous chapter can be achieved provided that 2N+1 probability values are given or estimated from an available sequence, where N is the number of time units over which periodicity of the process concerned. Among these probabilities there are one initial state probability $P_1(+)$ or $P_1(-)$ and any of the non-complementary transition probabilities out of the total 4N transition probabilities. Given 2N transition probabilities the rest can be evaluated from Eq. (1.2). In the present case where 5-day summation of ACWR are obtained necessitate the requirement of 144 transition probabilities in a year in addition to initial state probability.

On the other hand, the transition probabilities are directly related to the persistence and/or periodic properties of the underlying process concerned. It is well known that in persistent processes surpluses follow surpluses and deficits are followed by deficits as a result of which the conditional probabilities $P_i(+|+)$ and $P_i(-|-)$ are expected to be relatively higher than the crossing probabilities $P_i(-|+)$ and $P_i(+|-)$. A similar statement is valid also for periodic but independent process. Solution of the Eqs. (4.27) to (4.33) has been performed by programming with FORTRAN 77 language (Appendix-A).

Two sets of applications are considered herein. In the first set four hypothetical cases similar to Sen (1980[c]) are considered where initial and conditional probabilities taken that are periodic but independent to evaluate the mean longest deficit and surplus durations for the situations concerned. The second set of applications is on the actual ACWR from Bogra and Rangpur stations.

Hypothetical Cases

The conditional probabilities in hypothetical cases are shown Appendix B-5. In all these cases the truncation levels are assumed to be at the median value which means that initial probabilities are equal to 0.5. Hence by considering the process, x_t, to have either +1 or -1 deviations from the truncation level, it has been shown that the mean, variance and first order autocorrelation coefficient are $E(x_t) = 0$, $V(x_t) = 1$, and:

$$\rho = \sum_{i=1}^{144} [P_i(+|+)P_i(+) - P_i(-|+)P_i(+) - P_i(+|-)P_i(-) + P_i(-|-)P_i(-)] \qquad (5.1)$$

respectively. Applying Eq. (5.1) to the four hypothetical cases it is sufficient to prove that the processes considered are independent as the autocorrelation coefficient in all these cases are equal to zero. Due to the differences in transition probabilities within a basic cycle the processes are only periodic.

In the first hypothetical case (Case 1) the transition probabilities $P_i(+|+)$ (given in Appendix B-5) increase steadily from a value of 0.03 to 0.93 and then decrease at the same rate to 0.05 where as $P_i(-|-)$ have just the opposite pattern. The interpretation of these patterns in terms of periodicity is that within the cycle of seventy-two of 5-day ACWR summations, surplus-to-surplus transitions between two successive intervals increase and then decrease to the same value. Practically speaking, within a year there is a steady transition from water-poor to water-rich intervals again to water-poor intervals. The mean longest duration of DCWR of this situation has been evaluated by using Eq. (4.56) and plotted against the sample length as shown in Fig. 5.1. It is evident that the periodic structure in the conditional probabilities is reflected in

the expected value of the longest DCWR duration. As the sample size increases the periodicity that started with accentuated structure damps out and approaches to an asymptotic value.

A different periodic pattern of transitions has been considered in Case 2 where this time the transition probabilities from a deficit-to-deficit increase followed by decrease and an opposite pattern for surplus-to-surplus transitions. On the other hand, the average of seventy-two deficit-to-deficit transition probabilities in Case 2 is less than those in Case 1 as a result of which one expects more severe longest DCWR duration in this case than those of Case 1 as is obvious from Fig. 5.1.

Case 3 includes alternate surplus-to-surplus and deficit-to-deficit transition probabilities without any distinction between surplus and deficit patterns. Both deviations are given the same weight. In fact Case 3 in Fig. 5.1 reflects a stationary process DCWR property appearance with no periodicity at all.

Finally in Case 4 a jump is considered in the middle of the water year. The effect of such a jump in the expectation of the longest DCWR duration in Fig. 5.1 is also periodic almost with the same cycle as in the original transition probabilities. The transition probabilities in this case can be viewed as coming from an alternate truncation level with epoch length equal to thirty-six time units. Therefore, the comparison of Cases 3 and 4 leads to the conclusion that in an alternate truncation level, epoch length is important and periodic longest DCWR are to be expected when this length increases.

Actual Cases

The actual records are truncated at periodic levels of the normal, 40^{th} percentile, 50^{th} percentile (median), and 60^{th} percentile of 5-day ACWRs. The necessary parameter estimates for the application of Eqs. (4.24) to (4.32) are given in Appendix B-6 to B-9 for Bogra and Rangpur stations. Employment of these parameters in Eqs. (4.24) to (4.32) and Eq. (4.33) lead to the expected longest surplus and deficit durations which are shown in Figs. 5.2 to 5.5 for Rangpur and Bogra stations for various truncation levels. Since these actual records are periodic the

curves in Figs. 5.2 to 5.5 do reflect their joint effects. The longest surplus and DCWR durations are all periodic and the periodicity diminishes with increase in sample length.

A summery table (Table 5.1) has been prepared from the Figs. 5.2 to 5.5 for showing the closeness between the observed and calculated expected longest deficit and surplus lengths. In Table 5.1, closeness is indicated by the numbers 1, 2, 3, and 4, where 1, 2, 3, and 4 imply closest, 2nd closer, 3rd closer and 4th closer respectively. A closest relationship has been found between observed and simulated expected deficit duration for truncation level equal to median, but not for truncation levels equal to normal, 40th and 60th percentiles. The same analysis that has been performed for expected longest surplus length as shown in Figs. 5.4 and 5.5, it is found that the method of direct enumeration technique does not give good result for surplus (positive) length.

Table 5.1 Fitting of the Actual Expected Longest Deficit and Surplus Lengths with the Calculated Expected Lengths of the Periodic Stochastic Process under the Enumeration Technique

Deficit / Surplus	Station	Normal	Median	40th Percentile	60th Percentile	Comment
Deficit	Rangpur	4	1	3	2	Truncation level at median gives good result.
		Fig. 5.2	Fig. 5.2	Fig. 5.2	Fig. 5.2	
	Bogra	-	2	3	4	
		Fig. 5.3	Fig. 5.3	Fig. 5.3	Fig. 5.3	
Surplus	Rangpur	4	3	NA	NA	No good relationship has been found.
		Fig. 5.4	Fig. 5.4	NA	NA	
	Bogra	-	4	NA	NA	
		Fig. 5.5	Fig. 5.5	NA	NA	

*NA = Not Applied

5.3 ACWR Analysis by Stochastic Models

The analysis requires the estimation of p_1, p_2, q_1, q_2, E(x) and V(x) for the truncation levels at normal and median values. Probabilities p_1, p_2, q_1, and q_2 are approximated by estimates of relative frequencies from data of each year. A number of tables are generated to calculate the values, which are given in Appendix B-10 to B-13. The values in those tables are found out by

using a program developed under FORTRAN77 language (Appendix-A). Median values of p_1, p_2, q_1, and q_2 are used for this analysis. Values of E(x) and V(x) are estimated using N years of five-day ACWR including zero values. In case of deficit analysis, positive (surplus) values have been omitted while in case of surplus analysis, negative (deficit) values have been omitted. $P(S_{dm} \leq D)$ are computed by assigning D equal to 0-1000 mm with a step of 50 mm for truncation level $x_o(t)$ = normal, and D equal to 0-600 mm with a step of 25 mm for truncation level $x_o(t)$ = median. Similarly $P(S_{sm} \leq S)$ are computed by assigning S equal to 0-600 mm with a step of 50 mm for truncation level $x_o(t)$ = normal, and S equal to 0-700 with a step of 50 mm for truncation level $x_o(t)$ = median. The cumulative distribution function (cdf) of the longest surplus and DCWR durations are predicted using Eqs. (4.36) and (4.61) for Markov and random models respectively. The parameters for deriving the cdf's are shown in Table 5.2.

Sharma (1996) has shown for Kenyan rainfall that the chi-square criterion for identifying the dependence structure of runs is not as powerful as the graphical plot of cdf of the longest deficit and surplus spells. As such, for our purpose, graphical plots in Figs. 5.6 to 5.17 are used to show the simulated and observed cdf's. The summary of these figures is tabulated in Tables 5.3 and 5.4. From Table 5.3 (summary taken from Figs. 5.14 to 5.17), the close relationship between observed and predicted cdfs suggest that the analysis with Markov model can be used as a powerful model for longest deficit lengths. On the other hand, random model shows better performance than Markov for predicting the longest surplus lengths. These close relations are obtained under the truncation level at normal values.

The plots in Figs. 5.6 to 5.13 (summary given in Table 5.4) show the best performance of Markov model with Weibul distribution in predicting the largest deficit sum for functional truncation level at normal values. For functional truncation level at normal values, random model with exponential distribution shows the second better performance in predicting deficit sum. Degrees of closeness for each of the distributions applied have been shown in Table 5.4. In predicting surplus-sum, random-Weibul model shows the best performance for normal truncation level. It has been found that there is little persistency ($p_2 < 0.5$) in the surpluses for truncation level at normal values, Makov model could not be applied here. It has also been revealed in

Table 5.2, where a and b values for surplus remain blank due to non-applicability of Markov model.

Table 5.2 Parameters for Surplus and Deficit Spells and Surplus and Deficit Sums

Truncation Levels	Probabilities			Deficit						Surplus					
	P_1	p_2	q_2	E(x), mm	V(x), mm^2	a (Mm)*	b (Mm)	a (Rm)*	b (Rm)	E(x), mm	V(x), mm^2	a (Mm)	b (Mm)	a (Rm)	b (Rm)
Rangpur															
$x_o(t)$ = Normal	0.28	0.41	0.75	11.20	295.10	0.87	57.99	0.20	0.46	11.2	1073.10	-	-	0.71	44.4
$x_o(t)$ = Median	0.57	0.72	0.63	5.36	136.17	0.82	136.17	0.83	19.84	14.98	140.3.41	.65	68.8	.81	54.5
Bogra															
$x_o(t)$ = Normal	0.31	0.44	0.74	11.3	291.00	0.88	58.82	1.45	69.32	11.3	1088.20	-	-	0.75	47.1
$x_o(t)$ = Median	0.57	.74	0.63	5.11	116.14	0.84	29.31	0.84	19.03	15.31	1456.46	.65	75.6	.81	55.7

*Mm = Markov model
*Rm = Random model

Table 5.3 Fitting of the Observed Longest Deficit and Surplus Lengths under Markov and Random Models

Deficit or Surplus	Station	Normal		Median		Comment
		Markov	Random	Markov	Random	
Deficit	Rangpur	1	-	2	-	Markov model is good for predicting deficit length and Random model is good for predicting surplus length under normal truncation level
		Fig. 5.14(a)	Fig. 5.14(a)	Fig. 5.14(b)	Fig. 5.14(b)	
	Bogra	1	-	3	-	
		Fig. 5.16(a)	Fig. 5.16(a)	Fig. 5.16(b)	Fig. 5.16(b)	
Surplus	Rangpur	-	1	4	-	
		Fig. 5.15(a)	Fig. 5.15(a)	Fig. 5.15(b)	Fig. 5.15(b)	
	Bogra	-	1	4	-	
		Fig. 5.17(a)	Fig. 5.17(a)	Fig. 5.17(b)	Fig. 5.17(b)	

The median, mean and variance values of the longest surplus and deficit spells and largest deficit and surplus sums are shown in Table 5.5. As it has been observed that the truncation at normal values have better performance over median values, truncation level equal to median values is omitted subsequently. It has been observed in Table 5.5 that on average (mean) the longest DCWR durations (deficit lengths) both for Rangpur and Bogra are 65 days for functional

truncation level is at normal values. On average the length of longest surplus spells are 20 days for Rangpur and 22.5 days for Bogra. For truncation level at normal values, the lengths of deficit and surplus at 80 percent non-exceedance probability are 77 days and 28 days respectively for Rangpur, and 72 days and 23 days respectively for Bogra. At 50 percent non-exceedance probability, the lengths of deficit and surplus spells are 57 days and 17 days respectively for Rangpur whereas 53 days and 18 days respectively for Bogra. Percent of deviations from observed to calculated longest lengths of deficit and surplus are 14 and 17.6 respectively for Rangpur whereas 8.5 and 11.1 for Bogra.

The Markov-Weibul model for largest deficit-sum can be used to derive the statistics for the design of reservoir systems. For example one may chose water deficit values of 290 mm for Rangpur, and 288 mm for Bogra at an 80 percent level of non-exceedance probability (for truncation level at normal value). If a system is to be designed for 50 percent level of non-exceedance probability, the design water deficits are 200 mm and 190 mm respectively for Rangpur and Bogra. Percent of deviations from observed to calculated largest deficit-sums are -1.55 and 1.0 respectively, for Rangpur and Bogra.

The random-Weibul model for largest surplus-sum can be used to derive the statistics for the design of runoff draining and rain harvesting systems. For example one may choose values of 320 mm for Rangpur, and 325 mm for Bogra at an 80 percent level of non-exceedance probability (for truncation level at normal value). If a system is to be designed for 50 percent level of non-exceedance probability, the design parameters are 220 mm and 215 mm respectively for Rangpur and Bogra. Percent of deviations from observed to calculated largest surplus-sums are -10.45 and 22.04 respectively, for Rangpur and Bogra.

It can be mentioned here that for the design of the above systems, joint probability distribution of the longest surplus and deficit lengths and largest deficit and surplus sums would provide optimum value.

Table 5.4 Fitting of the Observed Surplus and Deficit Sums with Different Distributions under Markov and Random Models

Deficit or Surplus	Stations	$x_o(t)$ = Normal										$x_o(t)$ = Median										Comment
		Markov					Random					Markov					Random					
		W	G	N	LN	Exp	W	G	N	LN	Exp	W	G	N	LN	Exp	W	G	N	LN	Exp	
Deficit	Rangpur	1	-	-	-	-	-	-	-	-	2	-	-	-	-	3	4	-	-	-	-	Markov-Weibul model under normal truncation level is the best in predicting deficit-sum.
		Fig. 5.6 (a)					Fig. 5.6 (b)					Fig. 5.7 (a)					Fig. 5.7 (b)					
	Bogra	1	-	-	-	-	-	-	-	-	2	3	-	-	-	-	-	-	-	-	-	
		Fig. 5.8 (a)					Fig. 5.8 (b)					Fig. 5.9 (a)					Fig. 5.9 (b)					
Surplus	Rangpur	NA	NA	NA	NA	NA	1	-	-	-	-	-	-	-	-	2	3	-	-	-	-	Random-Weibul under normal truncation level is suitable for surplus-sum.
		-					Fig. 5.10					Fig. 5.12 (a)					Fig. 5.12 (b)					
	Bogra	NA	NA	NA	NA	NA	1	-	-	-	-	-	-	-	-	2	4	-	-	-	-	
		-					Fig. 5.11					Fig. 5.13 (a)					Fig. 5.13 (b)					

Note: W = Weibul; G = Gumble; N = Normal; LN = Log-normal; Exp = Exponential

Table 5.5 Statistics for Longest Spell Lengths and Largest Surplus and Deficit Sums

	Median				Mean				Variance			
	L_{dm}, days	L_{sm}, days	S_{dm}, Mm	S_{sm}, mm	L_{dm}, days	L_{sm}, days	S_{dm}, mm	S_{sm}, mm	L_{dm}, days	L_{sm}, days	S_{dm}, mm	S_{sm}, mm
Rangpur												
Observed ($x_o(t)$ = Normal)	65.0	20.0	196.9	243.0	65.0	20.0	236.0	253.0	135.0	10.0	25385	14985
50% Non-excedance Prob	57.0	17.0	200.0	220.0								
80% Non-exceedance Prob	77.0	28.0	290.0	320.0								
% of Deviation	14.0	17.6	-1.55	10.45								
Bogra												
Observed ($x_o(t)$ = Normal)	57.5	20.0	191.9	262.4	65.0	22.5	262.9	271.1	32.4	21.0	45893	12450
50% Non-excedance Prob	53.0	18.0	190.0	215.0								
80% Non-exceedance Prob	72.0	23.0	288.0	325.0								
% of Deviation	8.5	11.1	1.0	22.04								

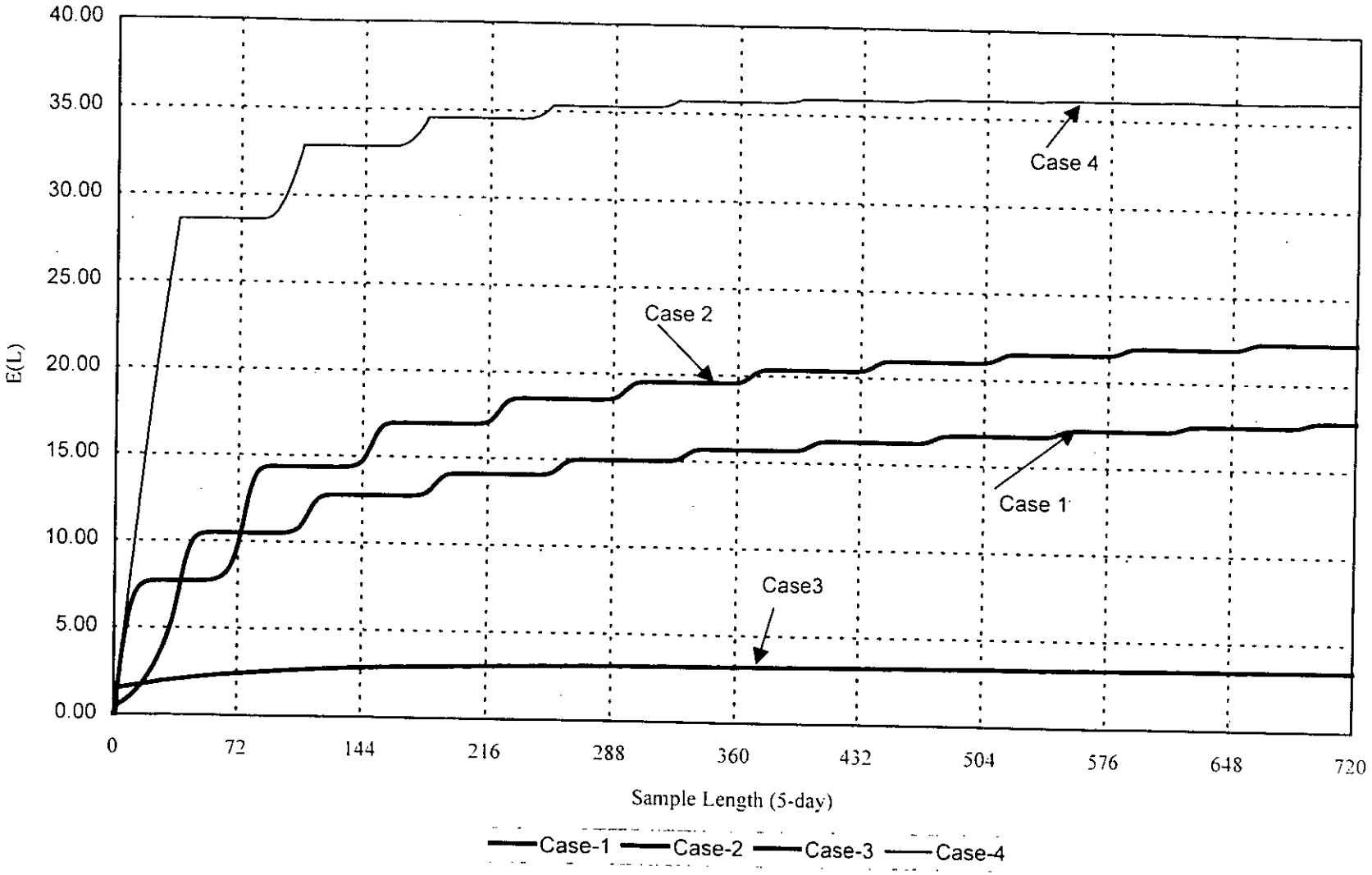


Fig. 5.1 Hypothetical Expected Longest DCWR Duration vs. Sample Length.

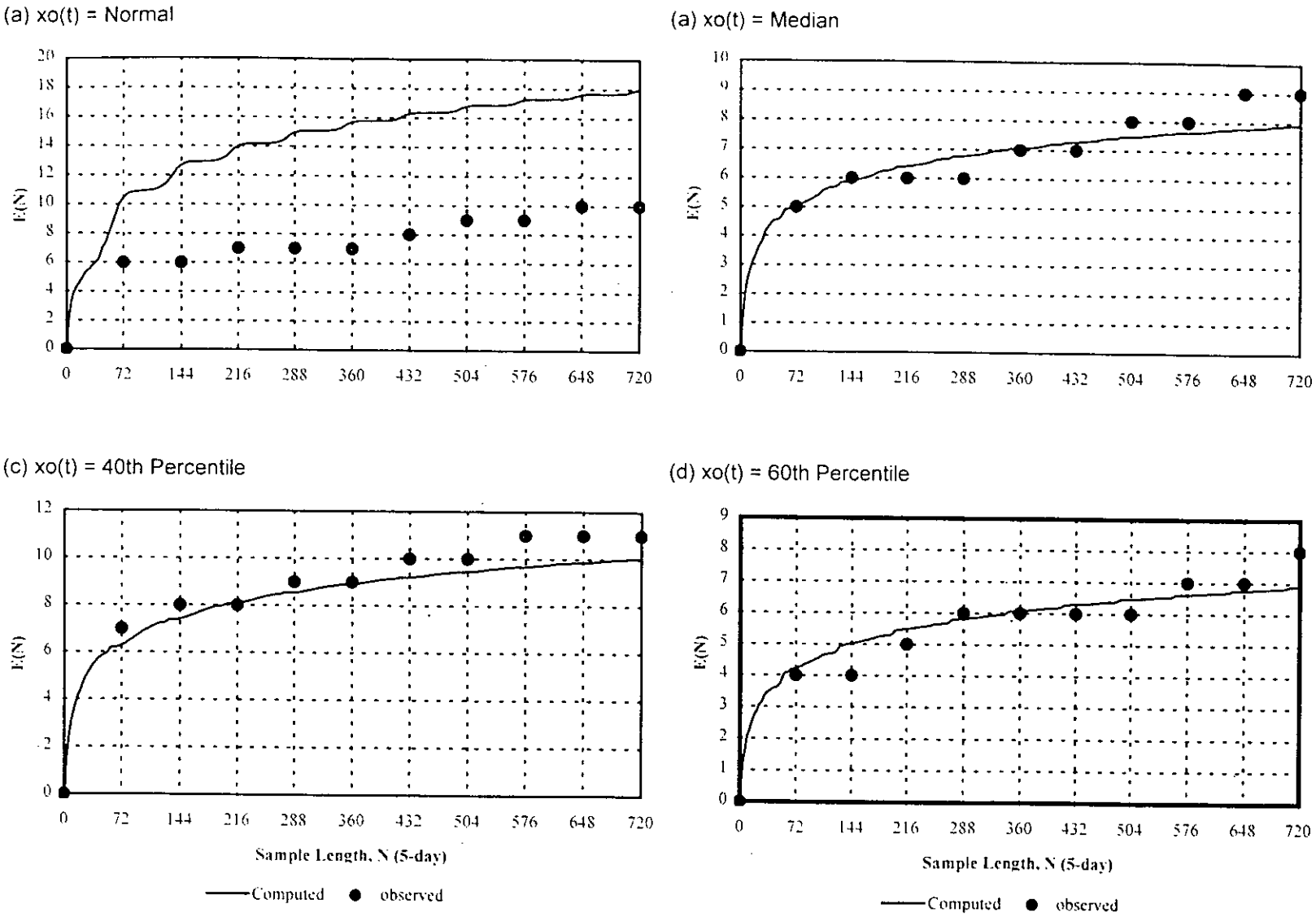
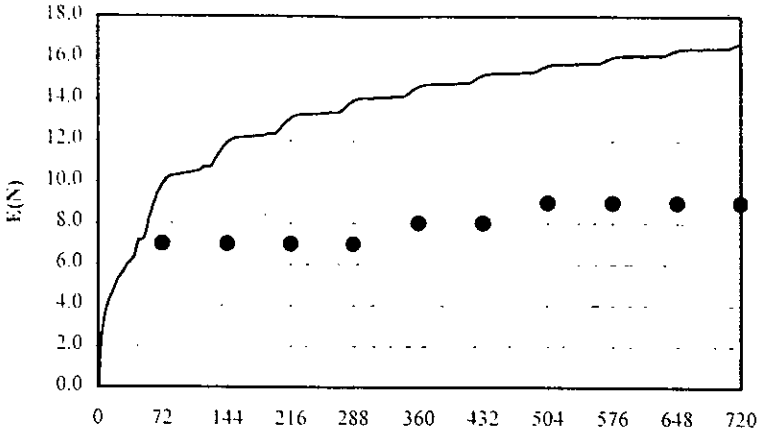
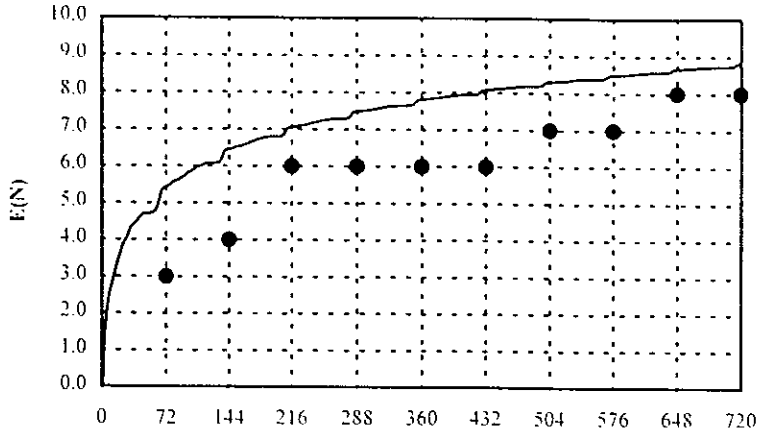


Fig.5.2 Actual Expected Longest DCWR Duration for Rangpur at Truncation Levels (a) xo(t) = Normal (b) xo(t) = Median (c) xo(t) = 40th Percentile and (d) xo(t) = 60th Percentile

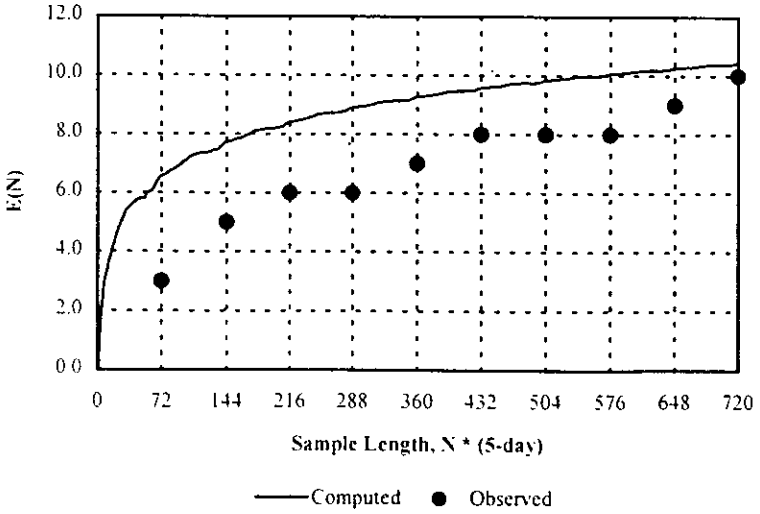
(a) xo(t) = Normal



(b) xo(t) = Median



(c) xo(t) = 40th Percentile



(c) xo(t) = 60th Percentile

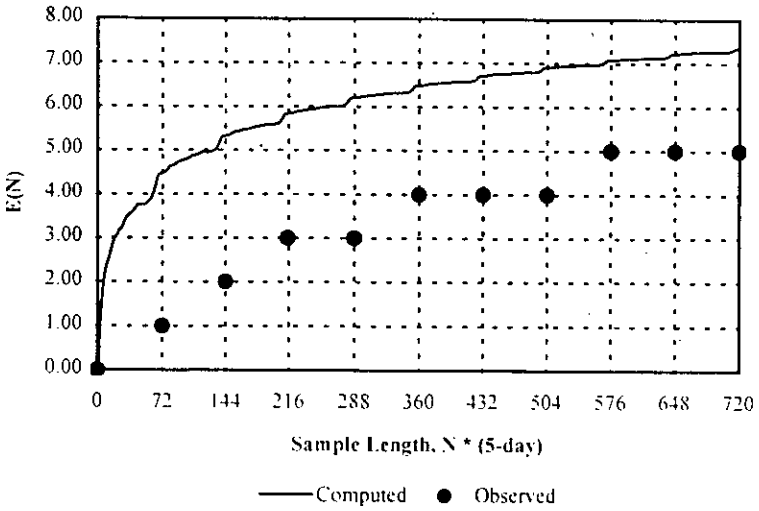
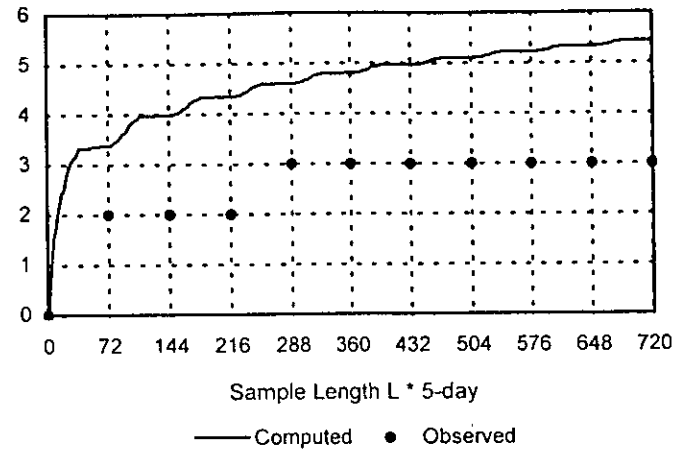


Fig. 5.3 Actual Expected Longest DCWR duration For Bogra at Truncation Levels (a) xo(t) = Normal (b) xo(t) = Median (c) xo(t) = 40th Percentile and (d) xo(t) = 60th Percentile

(a) xo(t) = Normal



(b) xo(t) = Median

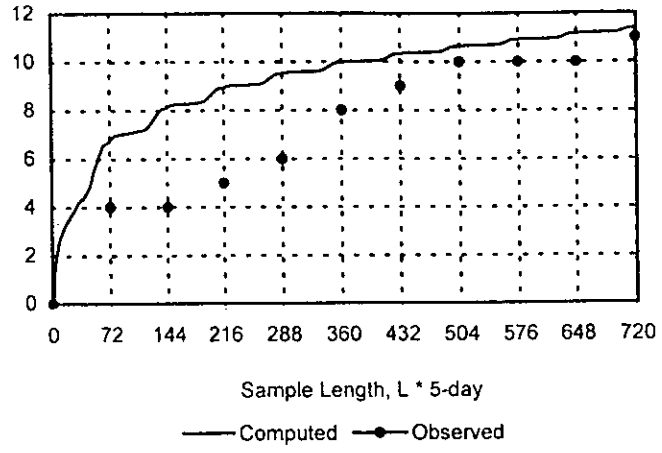
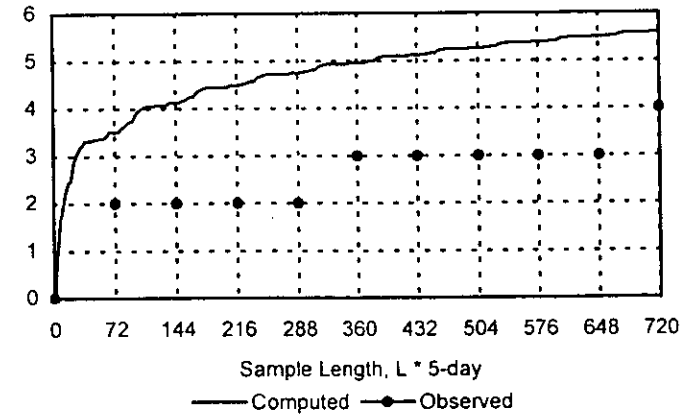


Fig. 5.4 Actual Expected Longest Surplus Length for Rangpur Station at Truncaton Level (a) Normal and (b) Median

(a) xo(t) = Normal



(b) xo(t) = Median

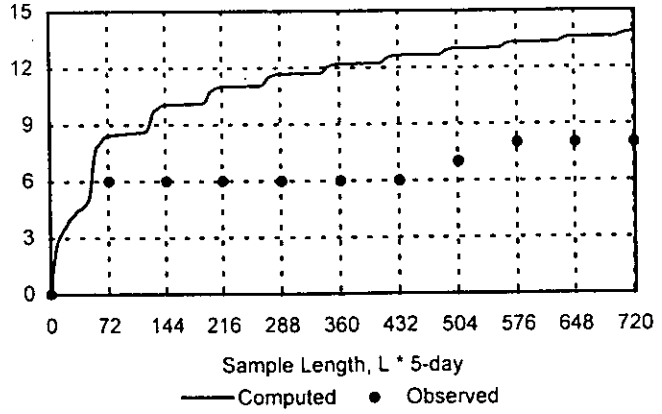
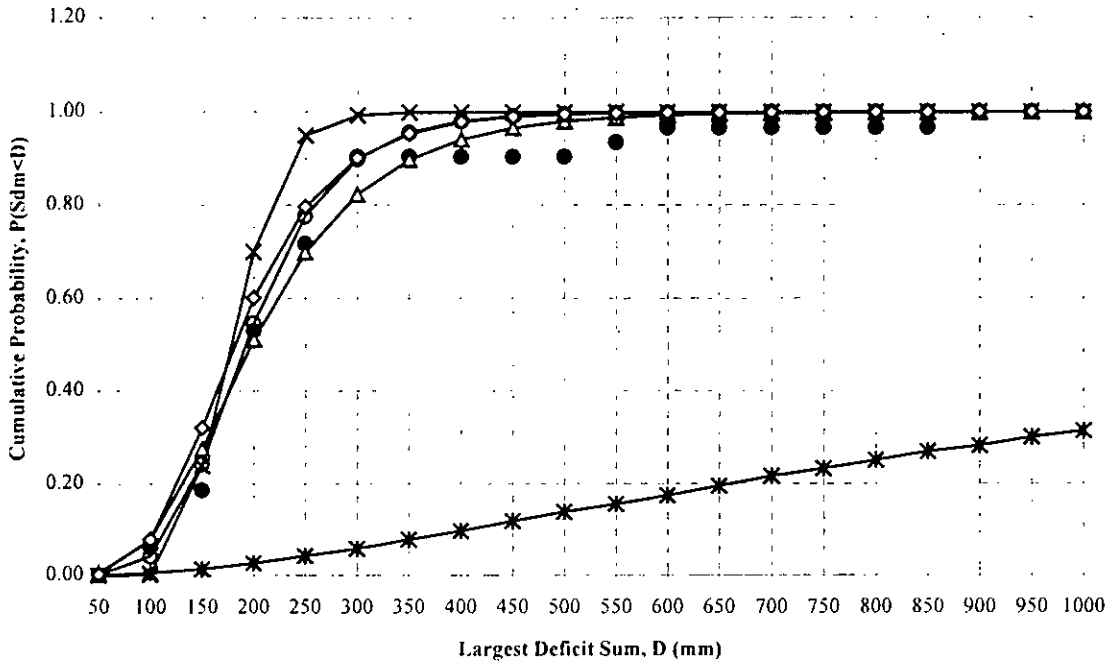


Fig. 5.5 Actual Expected Longest Surplus Length for Bogra Station at Truncaton Level (a) Normal and (b) Median

(a) Markov



(b) Random

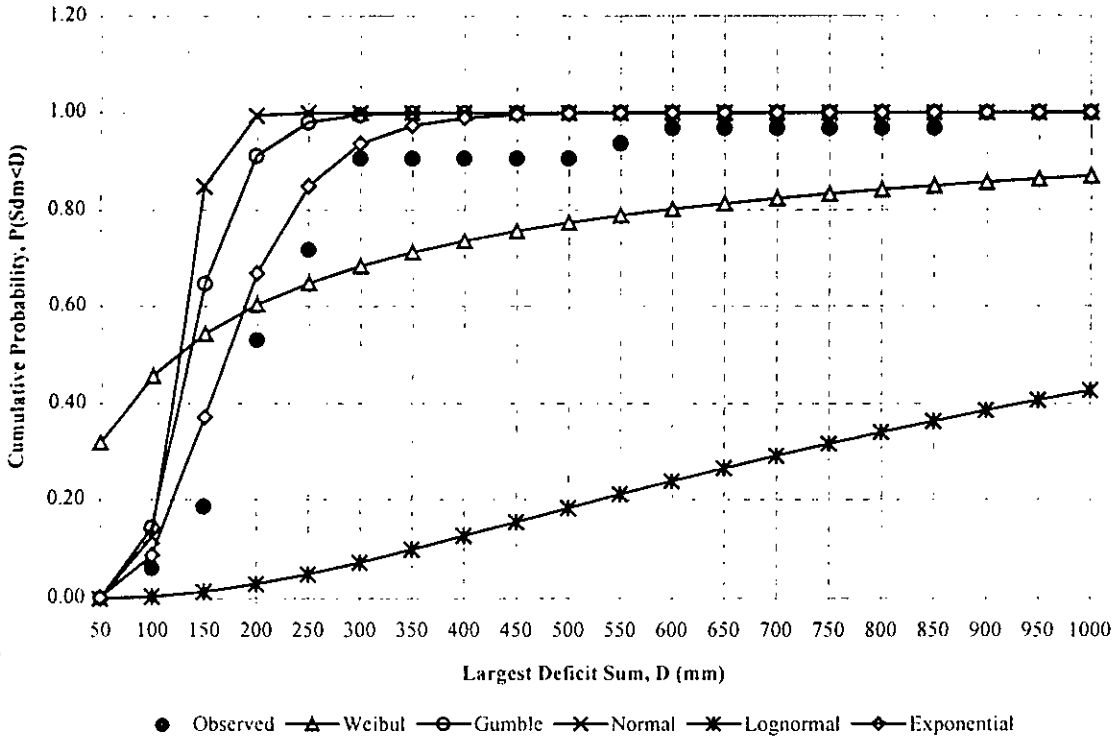
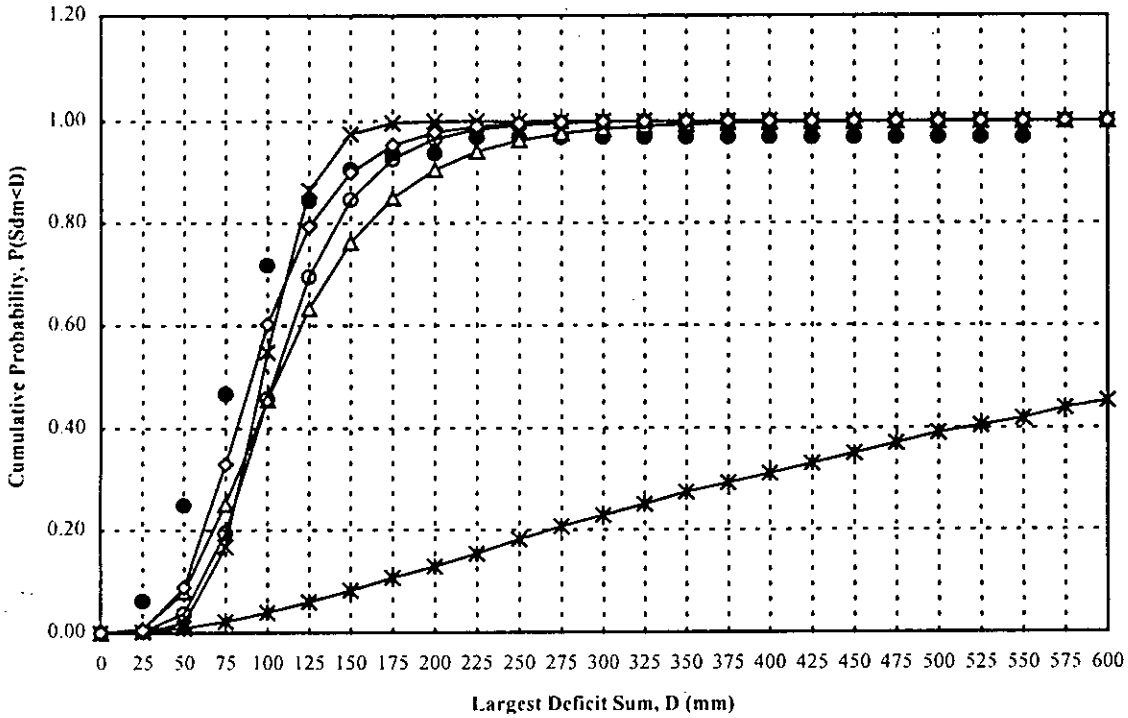


Fig. 5.6 Cdf of Largest Deficit Sum (Sdm) for Rangpur at Truncation Level, Xo(t) = Mean for (a) Markov (b) Random Model

(a) Markov



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(b) Random

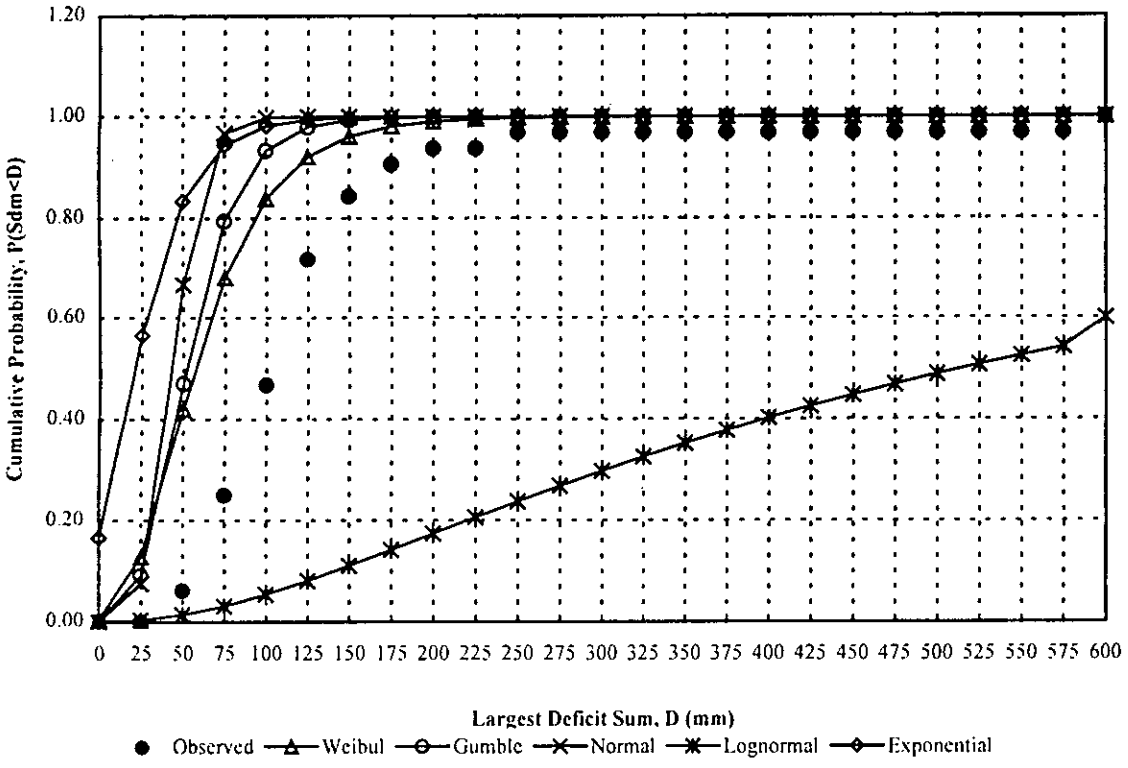
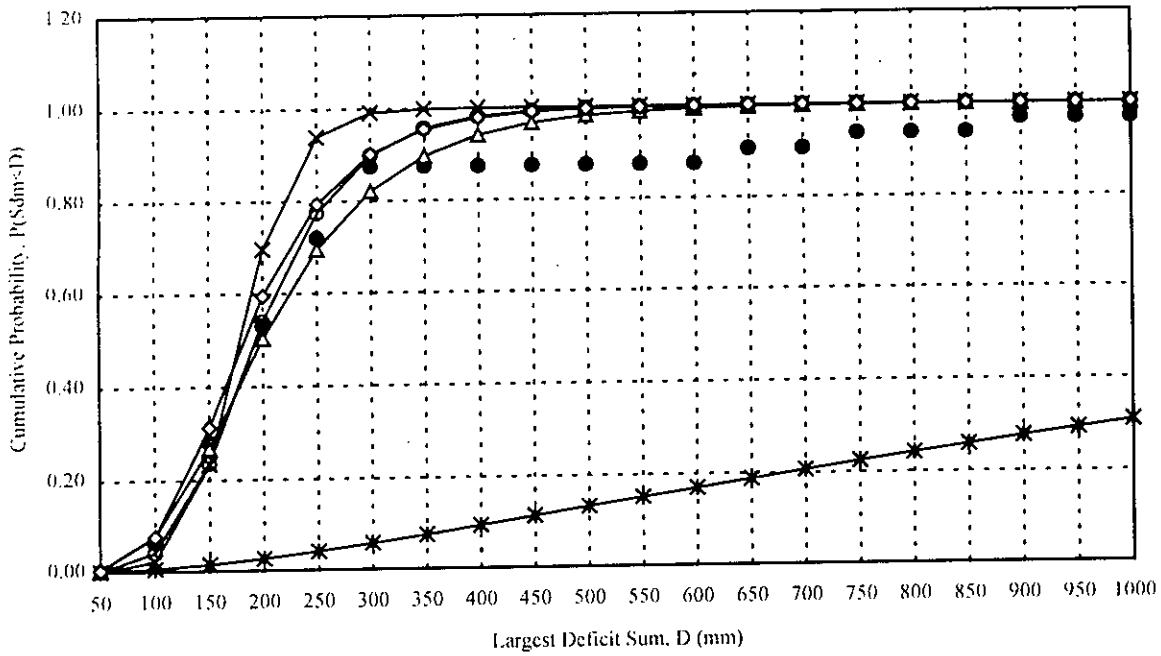


Fig. 5.7 Cdf of Largest Deficit Sum (Sdm) for Rangpur at Truncation Level, xo(t) = Median for (a) Markov and (b) Random Model

(a) Markov



(b) Random

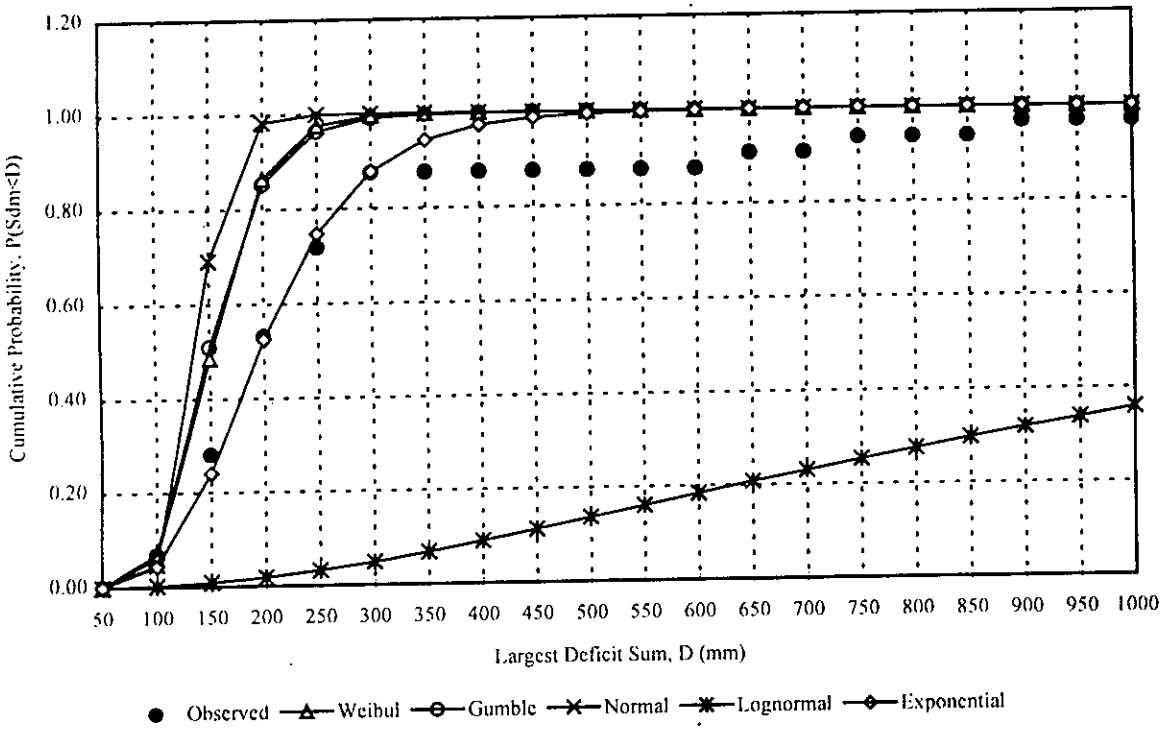
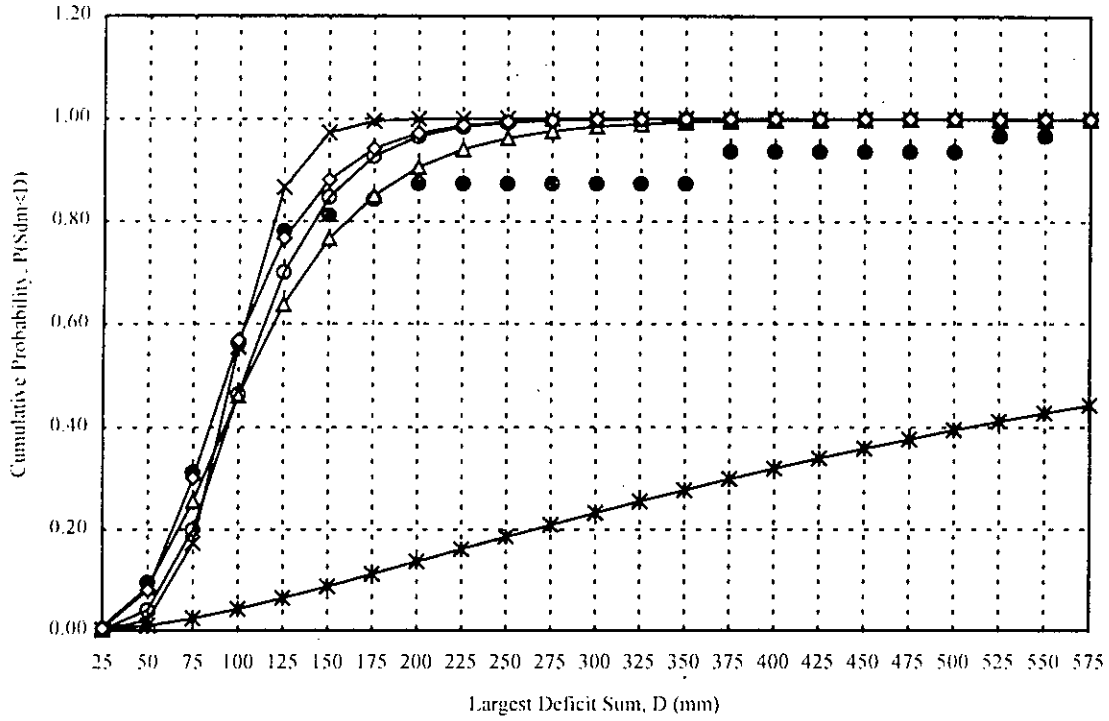


Fig. 5.8 Cdf of Largest Deficit Sum (Sdm) for Bogra at Truncation Level, xo(t) = Normal for (a) Markov model and (b) Random Model

(a) Markov



(b) Random

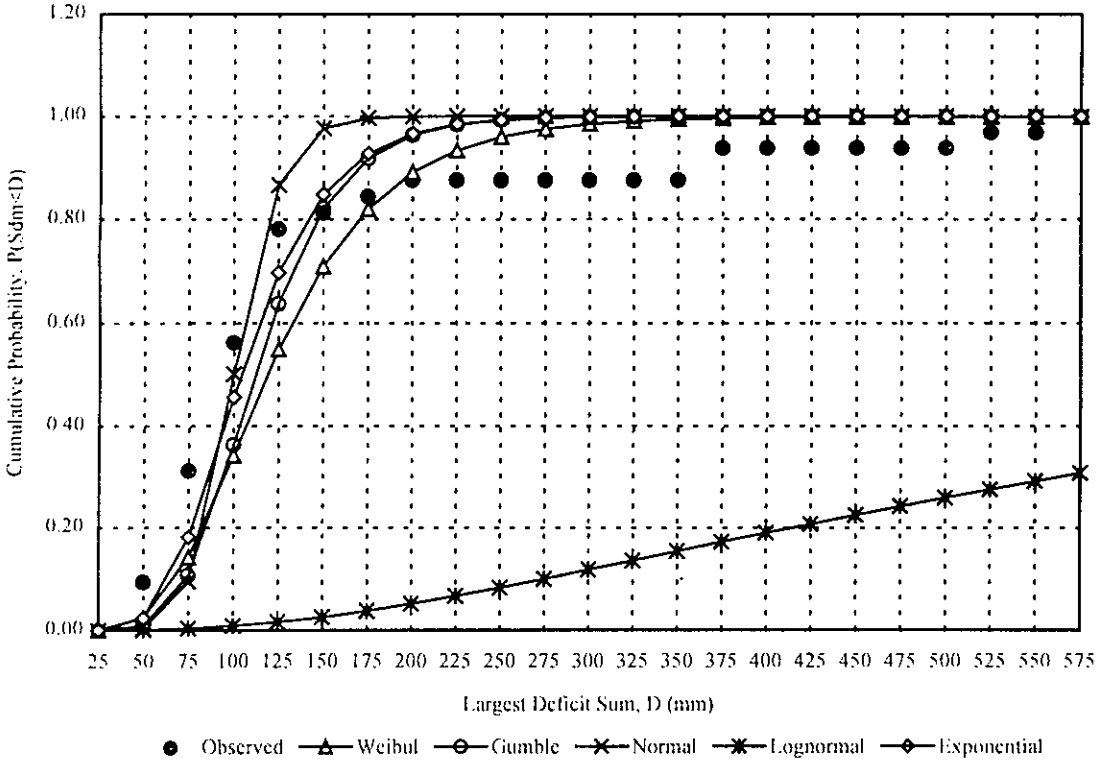


Fig. 5.9 Cdf of Largest Deficit Sum (Sdm) for Bogra at Truncation Level, Xo(t) = Median for (a) Markov model and (b) Random Model

Random

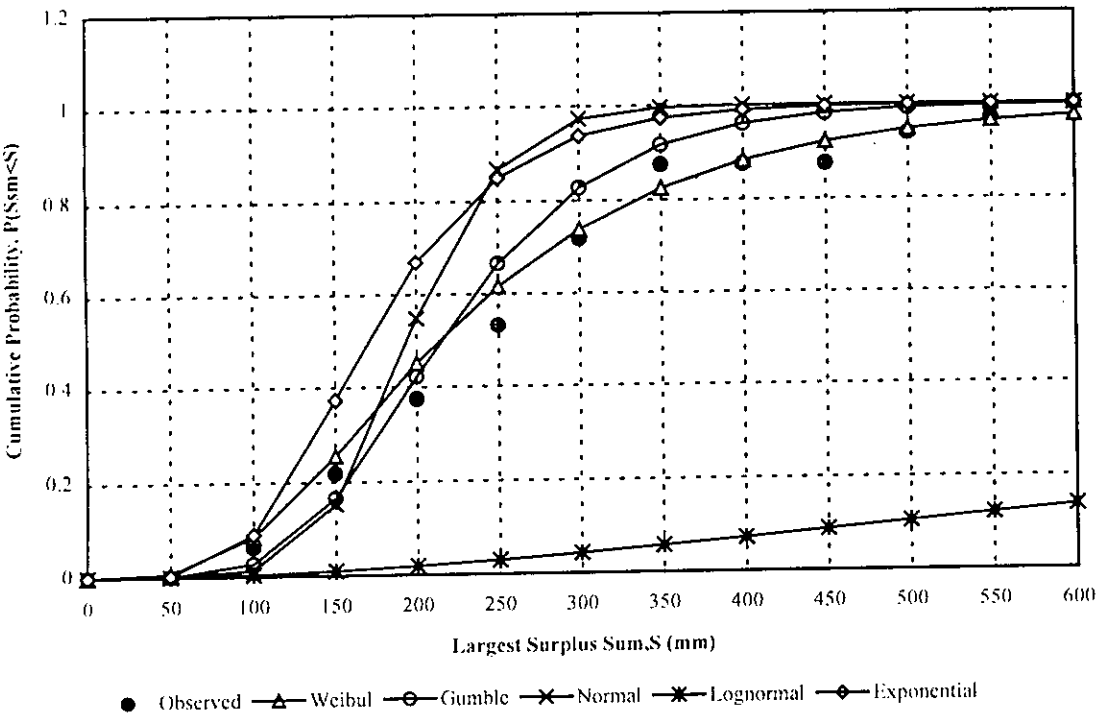


Fig. 5.10 Cdf of Largest Surplus Sum (Ssm) for Rangpur at Truncation Level, xo(t) = Normal for Random Model (Markov Not Applicable)

Random

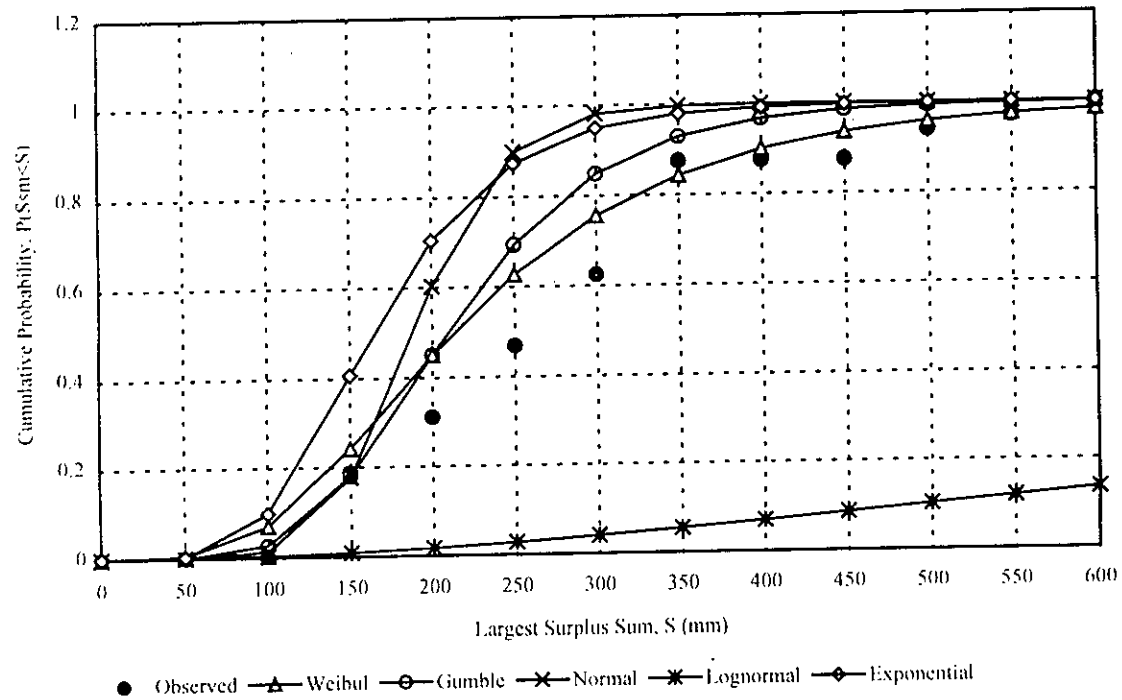
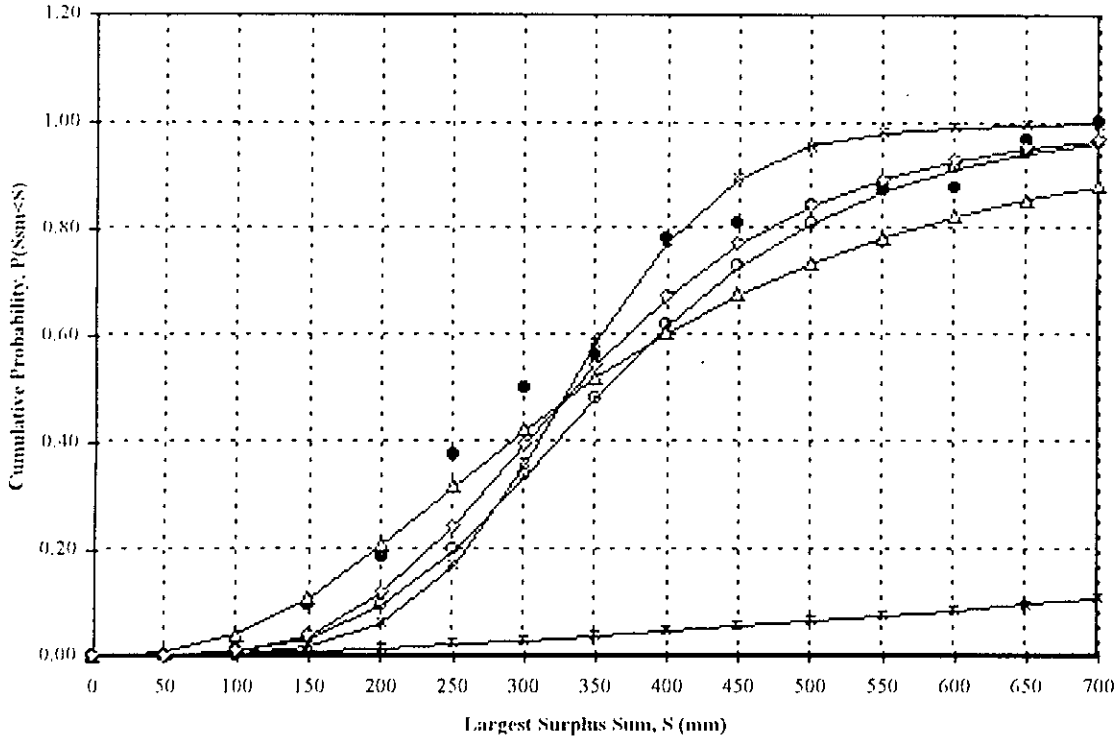


Fig. 5.11 Cdf of Largest Surplus Sum (Ssm) for Bogra at Truncation Level, xo(t) = Normal for Random Model (Markov Not Applivable)

(a) Markov



(b) Random

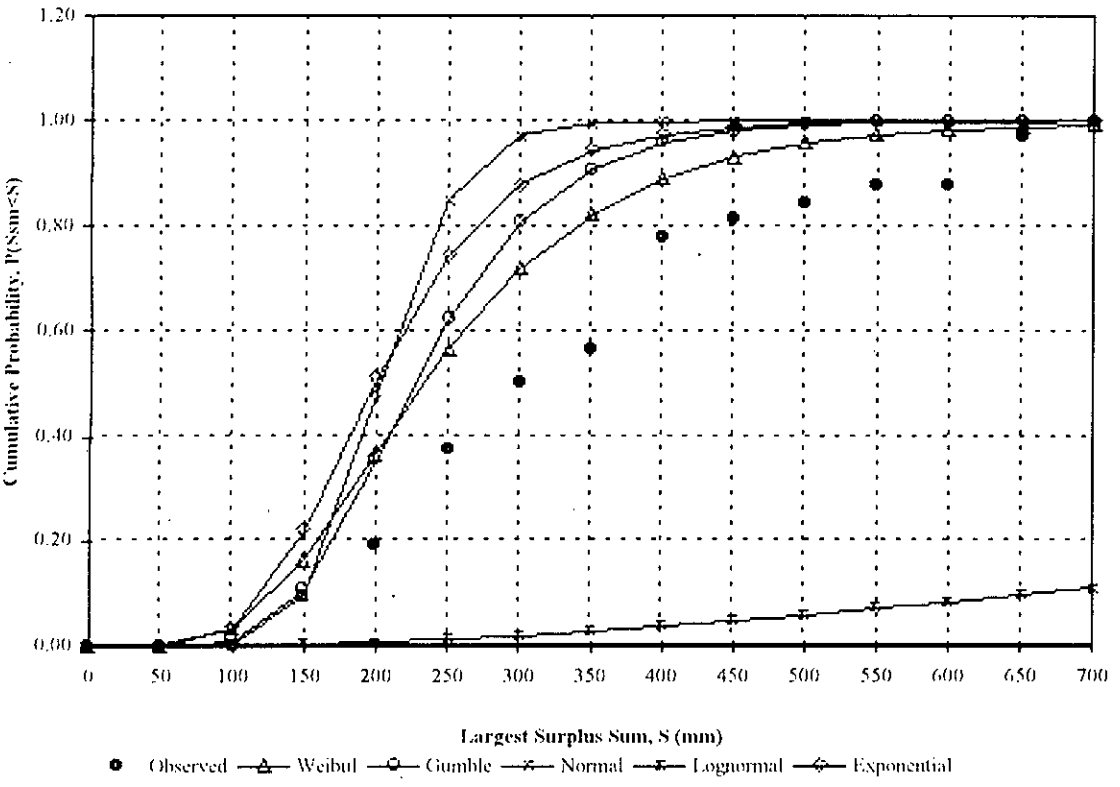
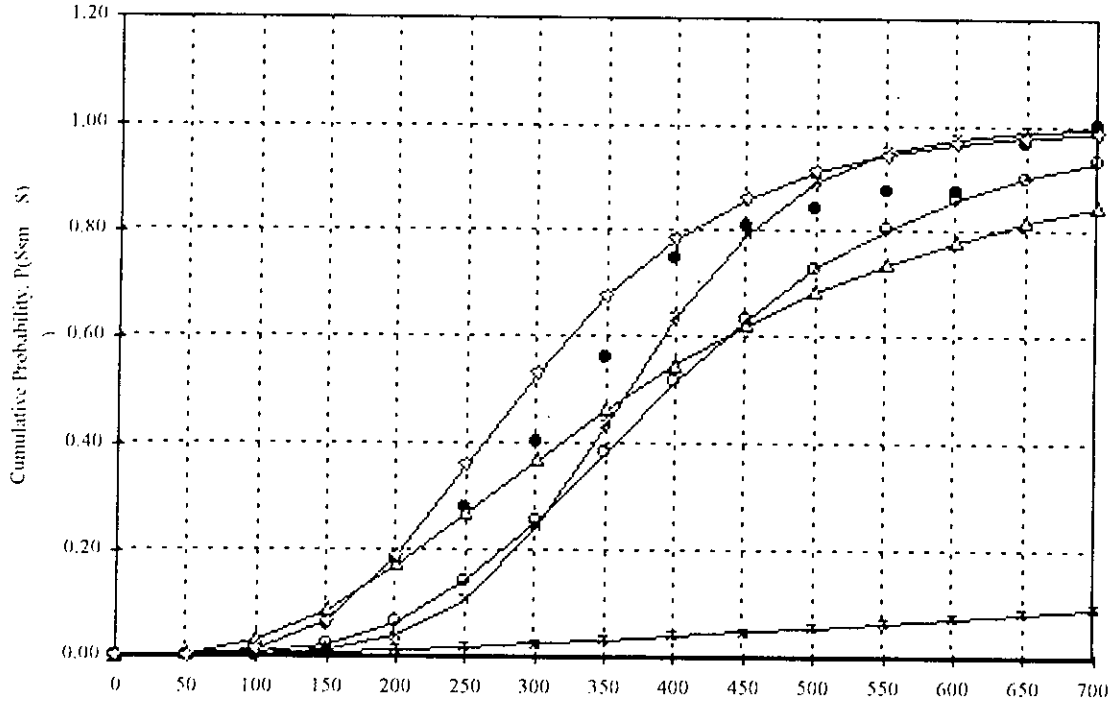


Fig. 5.12 Cdf of Largest Surplus Sum (Ssm) for Rangpur at Truncation Level, xo(t) = Median for (a) Markov (b) Random Model

(a) Markov



(b) Random

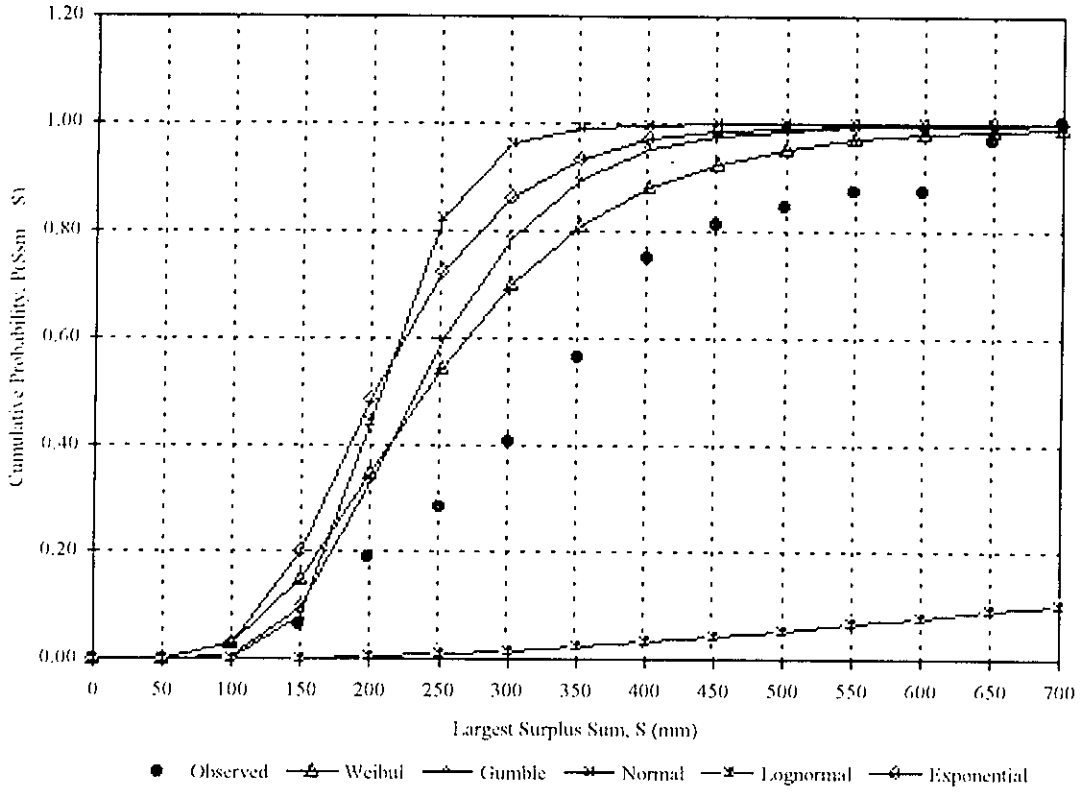
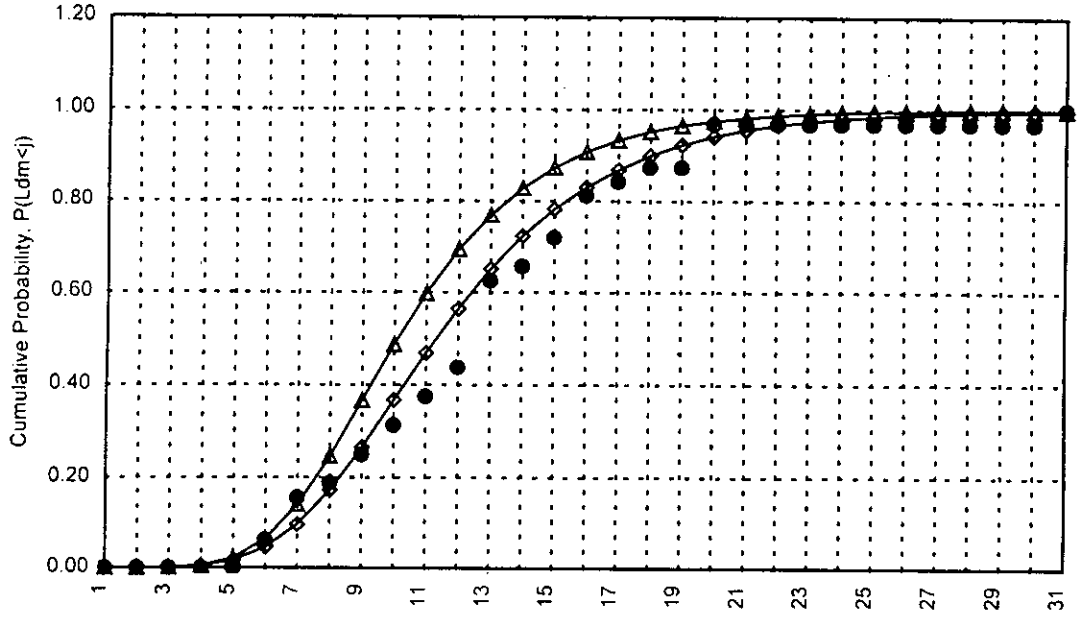


Fig.5.13 Cdf of Largest Surplus Sum (Ssm) for Bogra at Truncation Level, xo(t) = Median for (a) Markov model and (b) Random Model

(a) xo(t) = Normal



(b) xo(t) = Median

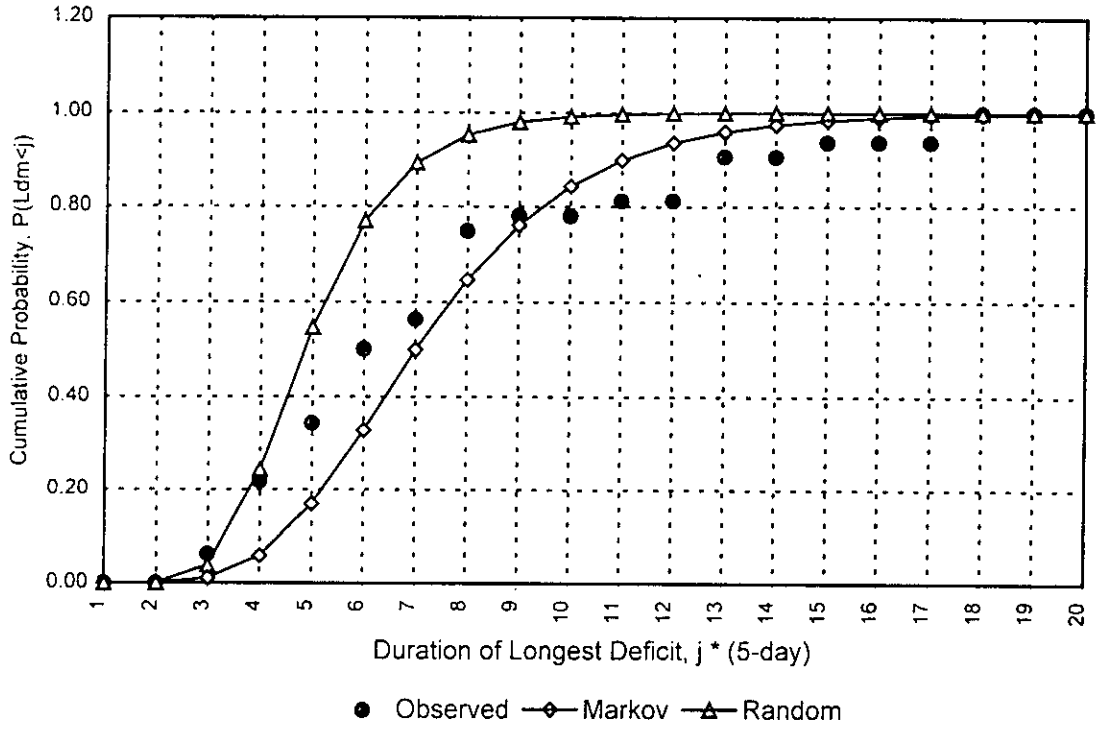
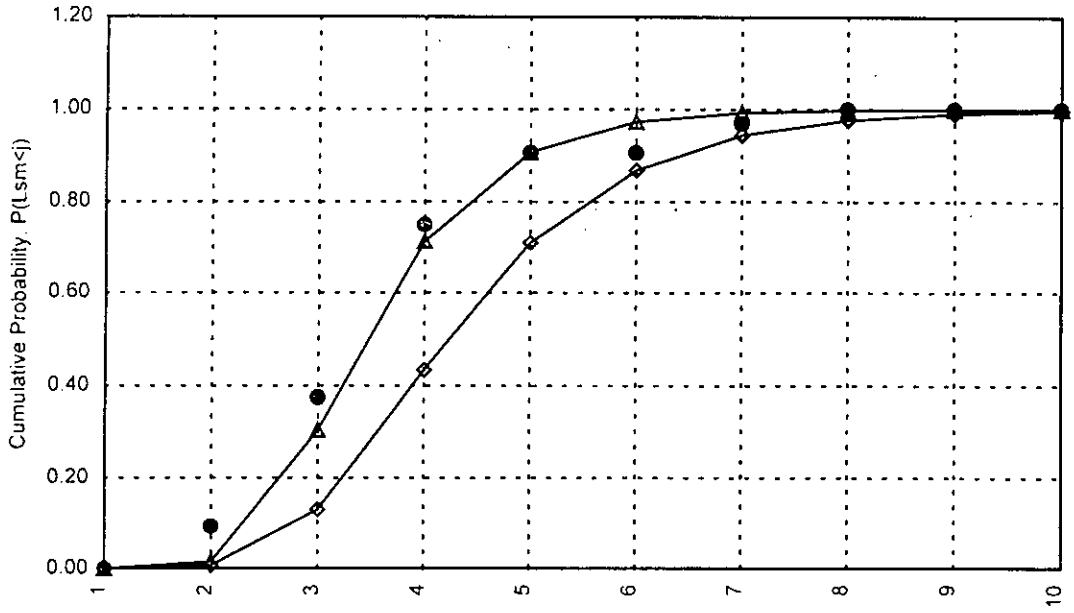


Fig. 5.14 Cumulative Probability of Duration of Longest Deficit (Ldm) for Rangpur at Truncation Level (a) xo(t) = Normal and (b) xo(t) = Median

(a) xo(t) = Normal



(b) Xo(t) = Median

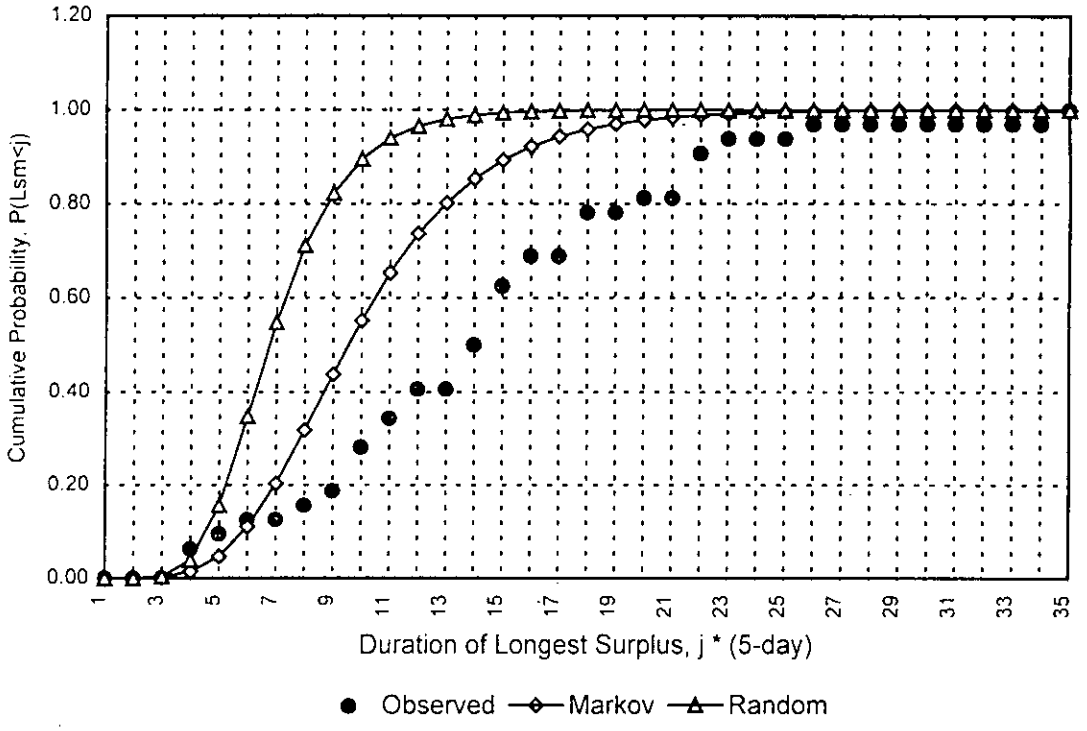
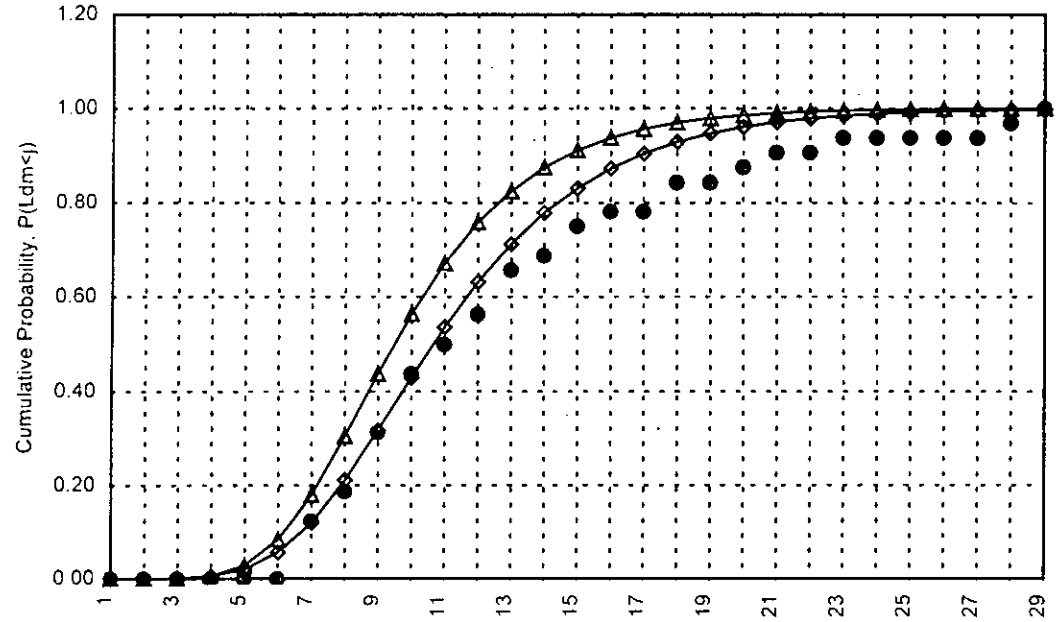


Fig. 5.15 Cumulative Probability of Duration of Longest Surplus (Lsm) for Rangpur at Truncation Level (a) xo(t) = Normal and (b) xo(t) = Median

(a) xo(t) = Normal



(b) Xo(t) = Median

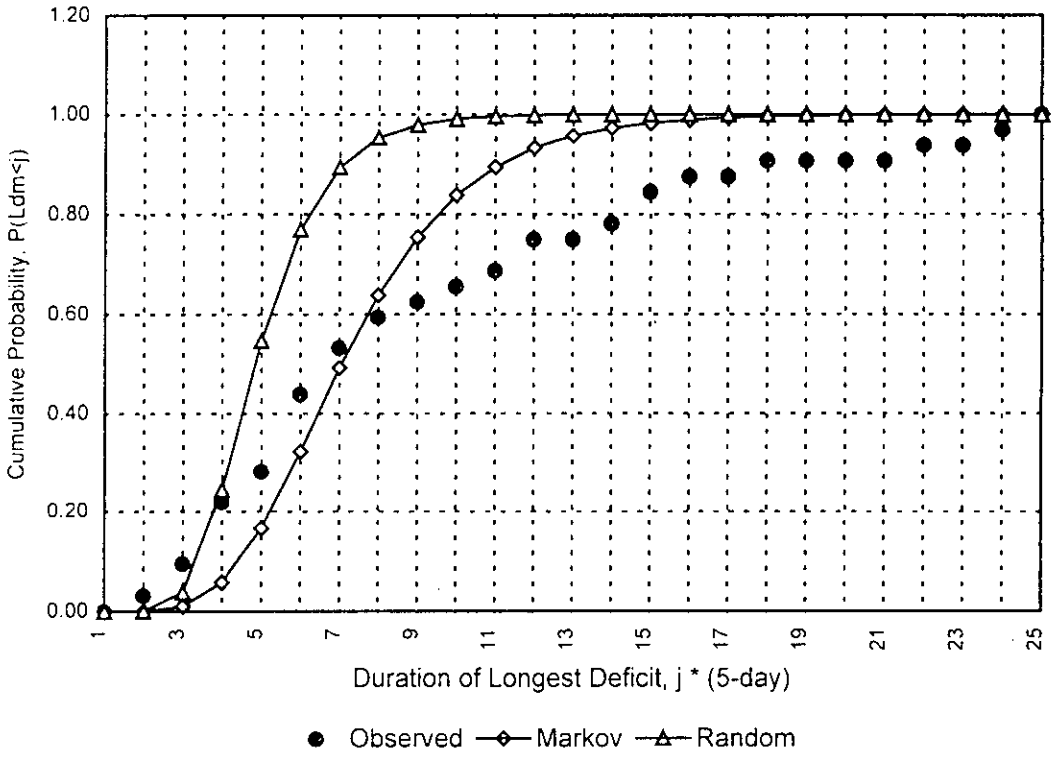
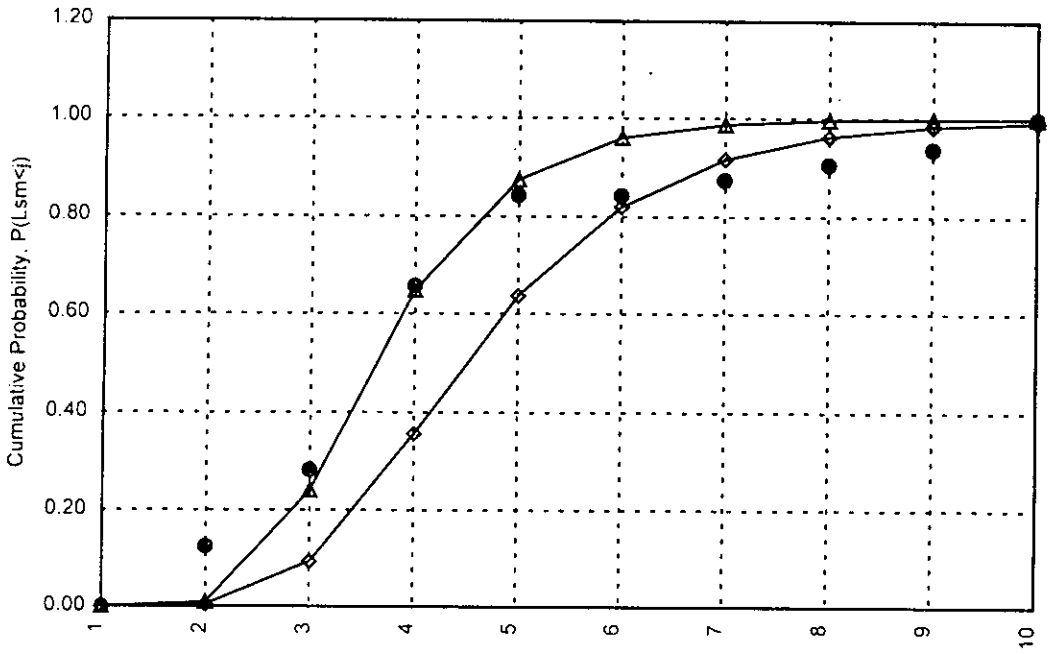


Fig. 5.16 Cumulative Probability of Duration of Longest Deficit (Ldm) for Bogra at Truncation Level (a) xo(t) = Normal and (b) xo(t) = Median

(a) xo(t) = Normal



(b) xo(t) = Median

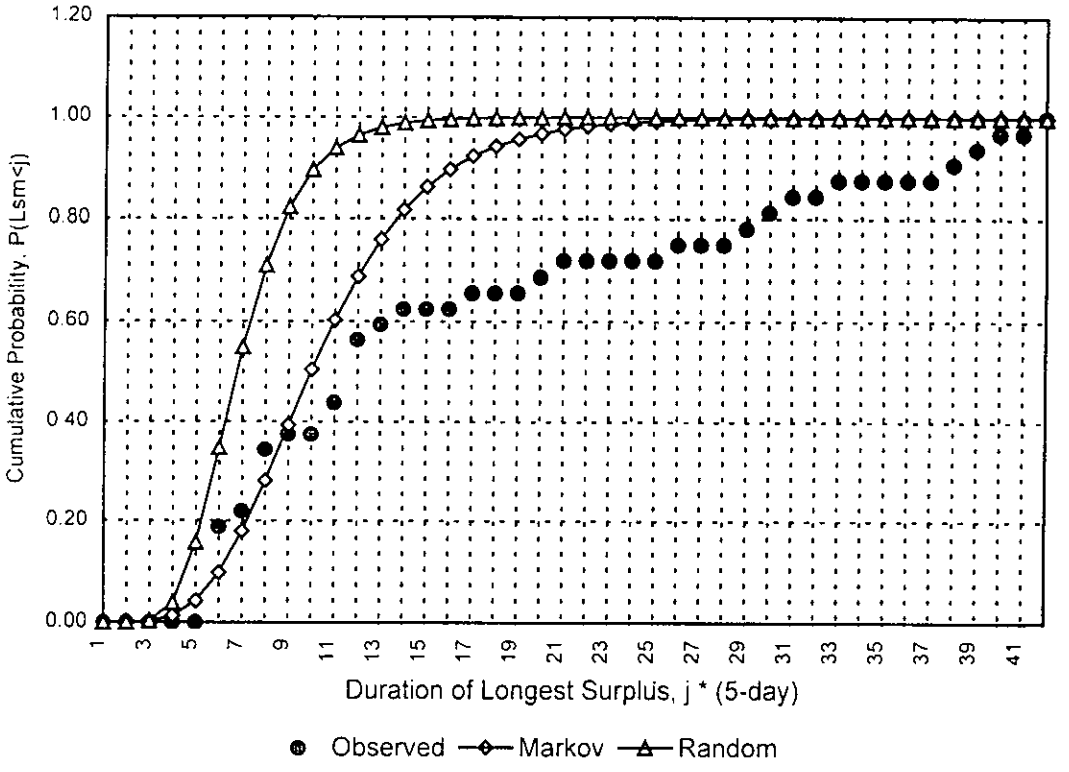


Fig. 5.17 Cumulative Probability of Duration of Longest Surplus (Lsm) Bogra at Truncation Level (a) xo(t) = Normal and (b) xo(t) = Median

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The longest surplus and deficit lengths are of crucial importance in planning agricultural activities and managing the associate water supply systems. The present study is mainly divided into two parts: these are (*i*) to find out the crop water requirements and availability of crop water requirements from climatic data, and (*ii*) perform statistical analysis on those availability of crop water requirements. The second part includes in finding out (a) the expected values of surplus and deficit lengths by direct enumeration technique and (b) the stochastic behavior of longest surplus and deficit lengths and the total surplus and deficit sums over them.

The PDFs of the longest surplus and deficit durations in periodic stochastic processes has been derived and applied to some hypothetical periodic independent cases and then to actual deficit and surplus sequences for Rangpur and Bogra stations. The following general conclusions can be drawn from the study:

Conclusions from the hypothetical cases of direct enumeration technique:

1. If the transition probabilities include a periodic pattern so does the expectation of the longest deficit and surplus periods.
2. The effect of periodicity in the longest surplus and deficit durations decreases with increasing sample size.
3. The order of transition probabilities is much more important than their values.
4. The parameters such as the expectations of the longest surplus and deficit (drought) durations in periodic stochastic process are also periodic.

Conclusions from the actual cases of direct enumeration technique:

5. Truncation level at median values gives the close relationship between the observed and computed expected duration of deficit lengths in periodic stochastic process by direct enumeration technique.

6. No relationship has been found between observed and computed expected values of surplus lengths in periodic stochastic process by direct enumeration technique.

Conclusions from the ACWR analysis by stochastic models:

7. Truncation level plays an important role in predicting surplus and deficit lengths as well as surplus and deficit sums. Truncation level at normal values has shown good performance in predicting deficit and surplus lengths as well as deficit and surplus sums.
8. Present stochastic method under the theory of runs, as applied to determine an independent (random) or lag-one Markov process is capable of simulating the longest run-lengths and the largest run-sums of spells in a region of north-west of Bangladesh. The random model appears to be good simulator of the surplus lengths and surplus sums, while in general, the Markov model is inferred as a promising one for the deficit spells. In particular, the Markov-Weibūl model shows good performance in predicting the deficit-sum, on the other hand random-Weibul shows a better performance for surplus-sum.
9. It can assume that Rangpur and Bogra have very similar and close characteristics of surplus and deficit (drought) spells. Although deviations between the observed and the calculated longest lengths of deficits and surpluses are less in Bogra than in Rangpur. Also better result has been found in Bogra station than in Rangpur in predicting deficit sum but not surplus sum.

6.2 Recommendations for Further Studies

Following recommendations may be made for further studies:

1. The study is carried out only for two stations in north west region of Bangladesh. To understand clearly the spatial variation other stations in north west region may be studied.
2. The study may be carried out on daily basis for better application in the stochastic model developed here.
3. The application of periodic stochastic process with enumeration technique specified here for the current study, can be applied to river flow drought analysis for Bangladeshi rivers.

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APPENDIX-A

```
******PROGRAM FOR DIRECT ENUMERATION TECHNIQUE*******

*********************************************************
*ppp = probability of surplus followed by surplus      *
*pmm = probability of deficit followed by deficit       *
*ppm = probability of surplus followed by deficit       *
*pmp = probability of deficit followed by surplus       *
*pmin = P(-)                                           *
*pplus = P(+)                                          *
*********************************************************
      real ppp(720),pmm(720),ppm(720),pmp(720)
      real pmin(1:720,0:720),pplu(1:720,0:720)
      real p(1:720,0:720),s1,s2,p1,p2,exp(720),sum(720)
      integer i,j,k,m,k1,k2
      open(1,file='c:\shyamal\Temp\BogPd50S.txt')
      open(2,file='c:\shyamal\Temp\Bogex50S.out')
c     Reading input file
      n=10*72
        do i =1,n
      read(1,*)ppp(i),pmm(i),ppm(i),pmp(i)
      enddo
c     input complete*******************

c     Determination of Pmin-n{L=0}******
      pmin(1,0)=0.4375
       pplu(1,1)=0.5625
      do i=2,n
      pmin(i,0)=pmin(i-1,0)*pmm(i)

c     ***** Determination of k1***************
          do j =1,i-1
         if((i-j-1).gt.j)then
          k1=j
         else
          k1=i-j-1
         endif
c     *****Determination of k2 *****************
         if((i-j-1).gt.(j-1))then
          k2=j-1
         else
          k2=i-j-1
         endif
c     s1** First term of the equation*************
```

```
      s1=0.0
      do m=0,k1
      p1=1.0
          do k=1,j-1
             p1=p1*ppp(i-j+k+1)
          enddo
          s1=s1+pmin(i-j,m)*ppm(i-j+1)*p1
      enddo
c     s2***Second term of the equation*************
          s2=0.0
          do m=1,k2
             p2=1.0
              do k=1,m-1
                 p2=p2*ppp(i-m+k+1)
              enddo
          s2=s2+pmin(i-m,j)*ppm(i-m+1)*p2
          enddo
c     ************************************************
      pplu(i,j)=s1+s2
c     ************************************************
          if((i-1).eq.j) pmm(i)=0
          pmin(i,j)=pplu(i-1,j)*pmp(i)+pmin(i-1,j)*pmm(i)
          p(i,j)=pplu(i,j)+pmin(i,j)
          enddo
      pplu(i,i)=pplu(i-1,i-1)*ppp(i)
      pmin(i,i)=0.0
      p(i,i)=pplu(i,i)+pmin(i,i)
      pplu(i,0)=0
      p(i,0)=pplu(i,0)+pmin(i,0)
      enddo
      exp(0)=0.0
      do i=1,n
          do j=1,i
      exp(j)=j*p(i,j)+exp(j-1)
      sum(i)=exp(j)
          enddo
      enddo
        do i=1,n
      write(2,50)i,sum(i)
 50   format(1x,I3,2x,F5.2,)
      enddo
      stop
      end
```

```
      ***PROGRAM FOR COUNTING THE PROBABILITY PARAMETERS****

      ******************************************
      *RFL    = Rainfall or Availability of CWR  *
      *np      = Np1                             *
      *nq      = Nq1                             *
      *npp     = Np2                             *
      *nqq     = Nq2                             *
      ******************************************
      real RFL(72,32)
      integer np(72),nq(72),npp(72),nqq(72)
      integer i,j

      OPEN(11,FILE='C:\Shyamal\TEMP\RangDcM.txt')
      OPEN(2,FILE='C:\Shyamal\TEMP\RangMpp.out')
      do 5 i=1,72
        READ(11,*)(RFL(i,j),j=1,32)
!       WRITE(*,*)(RFL(i,j),j=1,32)
5     continue
      PAUSE
!     PRINT*,'Input Complete'
!      print*,'val8=',rfl(1,8)

      do i=1,72
        np(i)=0
        npp(i)=0
        nqq(i)=0
      enddo

      p=0.0

      do 10 i=1,72
        do j=1,32
          if(rfl(i,j) .gt. p)then
            np(i)=np(i)+1
          else
          endif
        enddo
10    continue
!      print*,'np=',np(33)
!     PAUSE

      do 20 i=1,72
```

```
        do j=1,31
          if(rfl(i,j) .gt. p .and. rfl(i,j+1) .gt. p)then
            npp(i)=npp(i)+1
          else
          endif
        enddo
  20  continue

!      print*,'np=',np(33)
      do i=1,72
        nq(i)=32-np(i)
      enddo
!      print*,'np=',np(33)

      do 30 i=1,72
        do j=1,31
          if(rfl(i,j) .le. p .and. rfl(i,j+1) .le. p)then
          nqq(i)=nqq(i)+1
          else
          endif
        enddo
  30  continue
!      write(*,40)33,np(33),nq(33),npp(33),nqq(33)
!     pause
      do i=1,72
        write(2,40)i,np(i),nq(i),npp(i),nqq(i)
  40    format(1x,i2,2x,i2,2x,i2,2x,i2,2x,i2)
      enddo

      STOP
      END
```

APPENDIX-B

Table B-1 Crop Water Requirement, CWR from CROPWAT (mm/5day)

Station : Rangpur

Interval St.	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Apr-1	67.0	64.0	63.5	64.5	66.0	63.5	63.0	64.5	64.5	64.5	63.5	65.5	64.0	65.0	64.5	64.0
2	67.0	64.0	63.5	64.5	66.0	63.5	63.0	64.5	64.5	64.5	63.5	65.5	64.0	65.0	64.5	64.0
3	36.5	31.5	30.0	32.5	34.0	31.0	30.0	32.5	32.0	32.0	31.0	33.5	31.5	32.5	31.5	31.0
4	36.5	31.5	30.0	32.5	34.0	31.0	30.0	32.5	32.0	32.0	31.0	33.5	31.5	32.5	31.5	31.0
5	34.5	31.5	30.5	32.5	34.0	32.0	31.0	32.5	33.0	32.0	31.0	32.5	31.5	33.0	32.0	31.0
6	34.5	31.5	30.5	32.5	34.0	32.0	31.0	32.5	33.0	32.0	31.0	32.5	31.5	33.0	32.0	31.0
May-1	32.5	31.5	32.0	33.5	34.5	32.5	32.5	33.5	35.0	32.5	31.0	31.5	31.0	32.5	33.0	31.5
2	32.5	31.5	32.0	33.5	34.5	32.5	32.5	33.5	35.0	32.5	31.0	31.5	31.0	32.5	33.0	31.5
3	31.0	31.0	32.5	33.5	34.5	32.5	33.0	33.5	35.5	32.5	31.0	30.5	31.0	32.5	33.5	31.5
4	31.0	31.0	32.5	33.5	34.5	32.5	33.0	33.5	35.5	32.5	31.0	30.5	31.0	32.5	33.5	31.5
5	29.0	29.5	29.5	30.5	32.0	32.0	31.0	30.5	32.0	31.0	29.5	28.5	30.0	32.0	31.5	29.0
6	29.0	29.5	29.5	30.5	32.0	32.0	31.0	30.5	32.0	31.0	29.5	28.5	30.0	32.0	31.5	29.0
Jun-1	27.0	28.0	26.0	27.5	30.0	32.0	29.5	27.5	28.5	30.0	28.0	26.5	29.0	31.5	29.0	26.5
2	27.0	28.0	26.0	27.5	30.0	32.0	29.5	27.5	28.5	30.0	28.0	26.5	29.0	31.5	29.0	26.5
3	25.5	27.0	23.5	25.0	28.5	32.0	28.0	25.0	25.5	29.0	27.0	25.0	28.0	31.0	27.0	24.5
4	25.5	27.0	23.5	25.0	28.5	32.0	28.0	25.0	25.5	29.0	27.0	25.0	28.0	31.0	27.0	24.5
5	27.0	27.0	24.0	25.5	28.5	30.5	28.0	25.5	25.5	28.5	27.0	26.5	26.5	30.5	27.5	25.5
6	27.0	27.0	24.0	25.5	28.5	30.5	28.0	25.5	25.5	28.5	27.0	26.5	26.5	30.5	27.5	25.5
July-1	29.0	27.5	24.5	26.0	28.0	29.0	27.5	26.0	25.5	27.5	26.5	28.5	24.5	29.5	28.5	26.5
2	29.0	27.5	24.5	26.0	28.0	29.0	27.5	26.0	25.5	27.5	26.5	28.5	24.5	29.5	28.5	26.5
3	28.0	25.5	23.0	24.0	26.0	25.5	25.0	24.0	23.5	24.5	24.5	27.5	21.0	27.0	26.5	25.0
4	28.0	25.5	23.0	24.0	26.0	25.5	25.0	24.0	23.5	24.5	24.5	27.5	21.0	27.0	26.5	25.0
5	50.5	50.0	49.5	49.5	50.0	50.5	50.0	49.5	49.5	49.5	50.0	51.0	49.0	51.0	50.5	50.5
6	50.5	50.0	49.5	49.5	50.0	50.5	50.0	49.5	49.5	49.5	50.0	51.0	49.0	51.0	50.5	50.5
Aug-1	62.0	62.5	63.0	61.0	61.0	64.0	61.5	61.0	62.0	61.5	62.0	63.5	60.5	64.5	63.0	63.5
2	62.0	62.5	63.0	61.0	61.0	64.0	61.5	61.0	62.0	61.5	62.0	63.5	60.5	64.5	63.0	63.5
3	26.0	28.0	30.0	25.5	24.5	30.5	26.0	25.5	28.0	26.0	27.5	29.0	26.5	31.0	28.5	29.5
4	26.0	28.0	30.0	25.5	24.5	30.5	26.0	25.5	28.0	26.0	27.5	29.0	26.5	31.0	28.5	29.5
5	26.5	28.0	29.0	26.5	25.5	29.0	26.5	26.5	27.0	26.5	27.5	28.5	26.5	29.0	28.5	29.0
6	26.5	28.0	29.0	26.5	25.5	29.0	26.5	26.5	27.0	26.5	27.5	28.5	26.5	29.0	28.5	29.0
Sep-1	27.5	28.0	27.5	27.0	27.0	28.0	27.0	27.0	26.5	26.5	27.5	27.5	26.0	26.5	28.5	29.0
2	27.5	28.0	27.5	27.0	27.0	28.0	27.0	27.0	26.5	26.5	27.5	27.5	26.0	26.5	28.5	29.0
3	27.5	28.0	26.5	27.5	27.5	26.5	27.0	27.5	25.5	27.0	27.0	27.0	25.5	24.5	28.5	28.5
4	27.5	28.0	26.5	27.5	27.5	26.5	27.0	27.5	25.5	27.0	27.0	27.0	25.5	24.5	28.5	28.5
5	26.5	26.5	25.0	26.0	26.5	26.5	26.5	26.0	25.0	26.0	26.5	26.0	25.5	25.0	27.5	27.0
6	26.5	26.5	25.0	26.0	26.5	26.5	26.5	26.0	25.0	26.0	26.5	26.0	25.5	25.0	27.5	27.0
Oct-1	25.5	25.5	24.5	24.5	25.0	26.5	26.0	24.5	24.5	25.0	27.0	25.5	25.0	26.5	26.5	25.5
2	25.5	25.5	24.5	24.5	25.0	26.5	26.0	24.5	24.5	25.0	27.0	25.5	25.0	26.5	26.5	25.5
3	25.0	24.5	23.5	23.5	24.5	27.0	26.0	23.5	24.0	24.5	27.5	25.0	25.0	27.0	26.0	24.5
4	25.0	24.5	23.5	23.5	24.5	27.0	26.0	23.5	24.0	24.5	27.5	25.0	25.0	27.0	26.0	24.5
5	23.5	23.5	23.0	22.5	23.0	25.5	24.0	22.5	23.5	24.0	25.5	23.5	24.0	25.5	24.5	23.0
6	23.5	23.5	23.0	22.5	23.0	25.5	24.0	22.5	23.5	24.0	25.5	23.5	24.0	25.5	24.5	23.0
Nov-1	22.5	22.5	22.5	21.5	21.5	23.5	22.5	21.5	22.5	23.0	24.0	22.5	23.5	23.5	23.0	22.0
2	22.5	22.5	22.5	21.5	21.5	23.5	22.5	21.5	22.5	23.0	24.0	22.5	23.5	23.5	23.0	22.0
3	19.0	19.5	20.0	18.5	18.0	20.0	19.0	18.5	20.0	20.5	20.5	19.5	20.5	20.0	19.5	19.0
4	19.0	19.5	20.0	18.5	18.0	20.0	19.0	18.5	20.0	20.5	20.5	19.5	20.5	20.0	19.5	19.0
5	47.5	47.5	47.5	47.5	47.0	47.5	47.5	47.5	48.0	48.0	48.0	47.5	48.0	47.5	47.5	47.5
6	47.5	47.5	47.5	47.5	47.0	47.5	47.5	47.5	48.0	48.0	48.0	47.5	48.0	47.5	47.5	47.5
Dec-1	55.5	56.0	56.0	55.5	55.5	56.0	56.0	55.5	56.5	57.0	57.0	56.0	56.5	56.5	56.5	56.0
2	55.5	56.0	56.0	55.5	55.5	56.0	56.0	55.5	56.5	57.0	57.0	56.0	56.5	56.5	56.5	56.0
3	18.0	18.5	18.5	18.0	18.0	19.0	18.5	18.0	19.0	20.0	19.5	19.0	19.5	19.0	19.0	18.5
4	18.0	18.5	18.5	18.0	18.0	19.0	18.5	18.0	19.0	20.0	19.5	19.0	19.5	19.0	19.0	18.5
5	18.0	18.5	18.0	18.0	18.0	18.5	18.0	18.0	18.5	19.5	19.0	19.0	19.0	19.0	19.0	18.5
6	18.0	18.5	18.0	18.0	18.0	18.5	18.0	18.0	18.5	19.5	19.0	19.0	19.0	19.0	19.0	18.5
Jan-1	18.0	18.0	18.0	18.0	17.5	18.5	18.0	18.0	18.0	18.0	18.5	18.5	18.5	18.5	18.5	18.0
2	18.0	18.0	18.0	18.0	17.5	18.5	18.0	18.0	18.0	18.0	18.5	18.5	18.5	18.5	18.5	18.0
3	17.5	17.5	17.5	18.0	17.0	18.0	17.5	18.0	17.0	17.0	18.0	18.0	17.5	18.5	18.0	18.0
4	17.5	17.5	17.5	18.0	17.0	18.0	17.5	18.0	17.0	17.0	18.0	18.0	17.5	18.5	18.0	18.0
5	18.5	19.0	18.5	19.0	18.5	19.0	18.5	19.0	18.5	18.5	18.5	19.0	19.0	19.5	19.5	18.5
6	18.5	19.0	18.5	19.0	18.5	19.0	18.5	19.0	18.5	18.5	18.5	19.0	19.0	19.5	19.5	18.5
Feb-1	20.0	20.0	19.5	20.0	20.0	20.0	19.5	20.0	20.0	19.5	19.5	20.5	20.5	20.5	20.5	19.5
2	20.0	20.0	19.5	20.0	20.0	20.0	19.5	20.0	20.0	19.5	19.5	20.5	20.5	20.5	20.5	19.5
3	21.5	21.5	20.5	21.0	21.5	21.5	20.5	21.0	21.5	21.0	20.5	21.5	22.0	21.5	21.5	20.5
4	21.5	21.5	20.5	21.0	21.5	21.5	20.5	21.0	21.5	21.0	20.5	21.5	22.0	21.5	21.5	20.5
5	23.5	23.0	22.5	22.5	24.0	22.5	22.0	22.5	23.0	23.0	22.0	23.5	23.5	23.5	24.0	22.5
6	23.5	23.0	22.5	22.5	24.0	22.5	22.0	22.5	23.0	23.0	22.0	23.5	23.5	23.5	24.0	22.5
Mar-1	25.5	25.0	25.0	24.0	26.0	23.5	23.0	24.0	24.5	25.0	24.0	25.5	25.0	25.0	26.0	24.5
2	25.5	25.0	25.0	24.0	26.0	23.5	23.0	24.0	24.5	25.0	24.0	25.5	25.0	25.0	26.0	24.5
3	25.5	24.5	25.0	23.5	26.0	23.0	22.5	23.5	24.0	24.5	23.5	25.0	24.5	25.0	26.0	24.5
4	25.5	24.5	25.0	23.5	26.0	23.0	22.5	23.5	24.0	24.5	23.5	25.0	24.5	25.0	26.0	24.5
5	51.0	50.5	49.5	50.0	50.0	50.0	49.5	50.0	49.5	50.5	50.0	50.5	50.5	50.5	50.5	50.5
6	51.0	50.5	49.5	50.0	50.0	50.0	49.5	50.0	49.5	50.5	50.0	50.5	50.5	50.5	50.5	50.5

Table B-1 Crop Water Requirement, CWR from CROPWAT (mm/5day)

Station : Rangpur

Interval Sl.	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Apr-1	68 0	65.0	66.0	64.0	64 0	64.5	67.0	67.0	65.0	61.0	65.0	66.5	62 5	65.5	67.5	64.5
2	68.0	65.0	66.0	64.0	64.0	64 5	67.0	67.0	65.0	61 0	65.0	66.5	62 5	65.5	67.5	64.5
3	35.5	31.5	34.0	31.0	31.0	32.0	36.5	35.5	31.0	32.0	33.0	35.5	28.5	33 0	36.0	32.0
4	35 5	31.5	34.0	31.0	31.0	32 0	36.5	35.5	31.0	32.0	33.0	35.5	28.5	33.0	36.0	32.0
5	33.5	33.5	33.0	31.0	32.5	31.0	33 5	34.5	31.5	32.5	31.5	34.5	29 5	30.5	34.5	30.5
6	33 5	33.5	33.0	31.0	32.5	31.0	33.5	34.5	31.5	32.5	31.5	34.5	29 5	30.5	34.5	30.5
May-1	31.0	35.5	31.5	31.0	34.0	30.5	29.5	33 0	32.0	34.0	30.0	33 0	30 0	26 5	33 0	29.0
2	31.0	35.5	31.5	31.0	34.0	30.5	29.5	33.0	32.0	34.0	30.0	33.0	30 0	26 5	33 0	29 0
3	28.5	37.5	30.5	30.5	35.5	29.5	26.5	31.5	32.0	34.5	28.5	32 0	30.0	23 5	31 5	28 0
4	28.5	37.5	30.5	30 5	35.5	29.5	26.5	31.5	32.0	34.5	28.5	32.0	30 0	23 5	31.5	28 0
5	29 0	35.0	30.0	30.0	32.5	29.5	26.5	30.0	30.5	31.5	28.0	31.0	29 0	24 0	30 5	27.5
6	29.0	35.0	30.0	30.0	32.5	29.5	26.5	30.0	30.5	31.5	28.0	31.0	29 0	24 0	30.5	27 5
Jun-1	30.5	32.5	29.5	29.5	29.5	29.0	26.5	29.0	29.5	28.5	27.5	30.5	28.5	24.5	30.0	27.5
2	30 5	32.5	29.5	29.5	29.5	29.0	26 5	29.0	29.5	28.5	27.5	30.5	28 5	24 5	30 0	27.5
3	31.5	31.0	29.0	29.0	27.5	29.5	26.0	27.5	29.0	26.5	27.5	30.0	27.5	25.0	29.5	27.0
4	31.5	31.0	29.0	29.0	27.5	29.5	26.0	27.5	29.0	26.5	27.5	30 0	27.5	25.0	29.5	27.0
5	30.0	29.0	28.5	27.5	27.0	28.5	26.0	26.5	28.0	25.5	27.0	28.5	27.0	26 0	28.5	27.5
6	30 0	29.0	28.5	27.5	27.0	28.5	26.0	26.5	28.0	25.5	27.0	28.5	27.0	26.0	28.5	27.5
July-1	28.5	26.5	28.0	25.5	26.5	28.0	26.0	25.0	27.0	24.0	26.5	26.5	26.5	26.5	27 0	28.0
2	28.5	26.5	28.0	25.5	26.5	28.0	26.0	25.0	27.0	24.0	26.5	26.5	26.5	26 5	27 0	28.0
3	25.0	22.5	25.5	22.0	23.5	25.0	23.5	22.0	24.0	21.0	24.0	22.5	24 5	25.0	23.5	26.5
4	25.0	22.5	25.5	22.0	23.5	25.0	23.5	22.0	24.0	21.0	24.0	22.5	24.5	25.0	23.5	26.5
5	50.5	49.5	50.0	49.5	50.0	50.0	50.0	49 5	50.0	49.0	49.5	50.0	50.0	50.0	50.0	50.5
6	50.5	49.5	50.0	49.5	50.0	50.0	50.0	49.5	50.0	49.0	49.5	50.0	50 0	50.0	50.0	50.5
Aug-1	64.0	62.5	62.0	62.5	63.0	62.5	62.5	62.5	63.0	60.5	60.5	64.0	63.5	63 0	64.0	62.5
2	64.0	62.5	62.0	62.5	63.0	62.5	62.5	62.5	63.0	60.5	60.5	64.0	63 5	63.0	64.0	62.5
3	30.5	29.0	27.0	29.5	29.5	28.0	28.5	29.0	29.0	26.0	24.5	32.0	30.5	29.0	31.0	27.0
4	30.5	29.0	27.0	29.5	29.5	28.0	28.5	29.0	29.0	26.0	24.5	32.0	30.5	29.0	31.0	27.0
5	29.5	29.0	27.0	28.0	29.0	27.0	28.0	28.0	27.5	25.5	25.0	29.5	29.0	27.0	30.0	27.0
6	29.5	29.0	27.0	28.0	29.0	27.0	28.0	28.0	27.5	25.5	25.0	29.5	29.0	27.0	30 0	27.0
Sep-1	27.5	28.5	27.5	26.5	28.0	25.5	26.5	26.5	25.5	24.5	25.5	26.0	27.5	24.5	29.0	26.5
2	27.5	28.5	27.5	26.5	28.0	25.5	26.5	26.5	25.5	24.5	25.5	26.0	27.5	24.5	29.0	26.5
3	26.5	28.0	27.5	25.0	27.0	24.5	25.5	25.5	23.5	24.0	26.0	23.0	26.5	22.0	28.0	26.0
4	26.5	28.0	27.5	25.0	27.0	24.5	25.5	25.5	23.5	24.0	26.0	23.0	26.5	22.0	28.0	26.0
5	26.0	27.0	26.5	25.5	26.0	23.5	25.0	25.0	23.0	24.0	26.0	23.5	25.0	22.5	26.5	25.5
6	26 0	27.0	26.5	25.5	26.0	23.5	25.0	25 0	23.0	24.0	26.0	23.5	25.0	22.5	26.5	25.5
Oct-1	25.5	26.0	25.5	25.5	25.5	23 0	24.0	24.5	23.0	24.5	25.5	25.0	23.5	23.5	25.5	25.0
2	25.5	26.0	25.5	25.5	25.5	23.0	24.0	24.5	23.0	24.5	25.5	25.0	23.5	23.5	25.5	25.0
3	25.0	25.5	24.5	26.0	24.5	23.0	23.5	24.5	22.5	25.0	25.5	25.5	22.5	23.5	24.5	25.0
4	25.0	25.5	24.5	26.0	24.5	23.0	23.5	24.5	22.5	25.0	25.5	25.5	22.5	23.5	24 5	25.0
5	23.5	23.5	23.5	26.5	23.0	22.5	23.0	23.5	22.0	23.5	24.5	24.0	22 0	23.0	23.5	23.5
6	23.5	23.5	23.5	26.5	23.0	22.5	23.0	23.5	22.0	23.5	24.5	24.0	22 0	23.0	23.5	23.5
Nov-1	22.0	22.0	22.5	27.5	21.5	22.0	22.5	22.0	21.0	21.5	23.0	22.5	22.0	22.0	22.5	22.5
2	22.0	22.0	22.5	27.5	21.5	22.0	22.5	22.0	21.0	21.5	23.0	22.5	22.0	22.0	22.5	22.5
3	18.5	18.5	19.5	26.0	18.0	19.5	20.0	19.0	18.5	18.5	20.0	19.5	20.0	19.0	20.0	19.5
4	18.5	18.5	19.5	26.0	18.0	19.5	20.0	19.0	18.5	18.5	20.0	19.5	20.0	19.0	20.0	19.5
5	47.5	47.0	47.5	49.0	47.0	47.5	47.5	47.5	47.5	47.5	47.5	47.5	47 5	47.5	47.5	47.5
6	47.5	47.0	47.5	49.0	47 0	47.5	47.5	47.5	47.5	47.5	47.5	47.5	47 5	47.5	47.5	47.5
Dec-1	55.5	55.5	55.5	57.0	54.5	55.5	56.0	55.5	55.5	55.5	56.0	55.5	56.5	55.5	56.0	56.0
2	55.5	55.5	55.5	57.0	54.5	55.5	56.0	55.5	55.5	55.5	56.0	55 5	56 5	55.5	56.0	56.0
3	18.0	18.0	18.0	17.0	17.0	17.5	18.0	18.0	18.0	18.5	18.5	18.0	19.0	18.0	18.0	19.0
4	18.0	18.0	18.0	17.0	17.0	17.5	18.0	18.0	18.0	18.5	18.5	18.0	19 0	18 0	18.0	19.0
5	18.5	18.0	18.0	17 0	17.5	17.5	17.5	18.0	18.0	18.5	18.5	18.0	18.5	17.5	18.0	18.0
6	18.5	18.0	18.0	17.0	17.5	17.5	17.5	18.0	18.0	18.5	18.5	18.0	18 5	17.5	18.0	18.0
Jan-1	18.5	18.0	17.5	17.5	17.5	17.5	17.5	17.5	17.5	18.0	18.0	17.5	17.5	17.5	17.5	16.5
2	18.5	18.0	17.5	17.5	17.5	17.5	17.5	17.5	17.5	18.0	18.0	17.5	17 5	17.5	17.5	16.5
3	18.0	17.5	17.5	17.5	18.0	17.0	17.0	17.0	17.0	17.5	17.5	17.0	16.5	17.5	17.0	15 5
4	18.0	17.5	17.5	17.5	18.0	17.0	17.0	17.0	17.0	17.5	17.5	17 0	16.5	17 5	17 0	15.5
5	19 0	18.5	18.5	18.5	19.0	18.0	18.0	18.0	18.5	18.5	18.5	18 5	18 0	18.5	18.0	16.5
6	19.0	18.5	18.5	18.5	19.0	18.0	18.0	18.0	18.5	18.5	18.5	18.5	18 0	18.5	18.0	16.5
Feb-1	20.0	19.5	19.0	19.5	20.5	19.0	19.0	19.5	19.5	19.5	19.5	20.5	19 5	20 0	18.5	18.0
2	20.0	19.5	19.0	19.5	20.5	19.0	19.0	19.5	19.5	19.5	19.5	20.5	19.5	20 0	18 5	18.0
3	21.0	20.5	20.0	20.5	22.0	20.0	20.0	20.5	21.0	20.5	21.0	22.0	20 5	21.0	19.5	19.5
4	21.0	20.5	20.0	20.5	22.0	20.0	20.0	20.5	21.0	20.5	21.0	22.0	20.5	21 0	19.5	19.5
5	24 5	23.0	22.5	23.0	23.5	22.0	22.5	23.5	23.5	22.5	23.0	23.5	22 5	23.0	23.0	22.0
6	24.5	23.0	22.5	23.0	23.5	22.0	22.5	23.5	23.5	22.5	23.0	23.5	22.5	23.0	23.0	22.0
Mar-1	29.0	26.0	25.0	25.0	25.0	24.0	24.5	26.0	26.5	24.5	25.0	25 0	24 5	25.5	27.0	24.0
2	29.0	26.0	25.0	25.0	25.0	24.0	24.5	26.0	26.5	24.5	25.0	25.0	24 5	25.5	27.0	24.0
3	31 0	27.0	25.5	25.0	24.5	24.5	25.0	26.5	27.5	24.5	25.0	24.5	24 0	25.5	28.0	24.5
4	31 0	27.0	25.5	25.0	24.5	24 5	25.0	26.5	27.5	24.5	25.0	24.5	24 0	25.5	28 0	24.5
5	52 5	51.0	51.0	50.5	50.5	50.5	51.0	51 5	51.0	50.5	50.5	50 5	50 0	50 5	51 5	50 5
6	52.5	51 0	51 0	50.5	50.5	50.5	51 0	51 5	51.0	50.5	50.5	50 5	50 0	50 5	51 5	50.5

Table B-2 Crop Water Requirement, CWR from CROPWAT (mm/5day)

Station : Bogra

Interval SI	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Apr-1	65.5	66.5	69.0	68.0	67.5	68.0	68.5	68.0	65.5	69.5	68.0	65.5	69.0	68.5	64.0	67.0
2	65.5	66.5	69.0	68.0	67.5	68.0	68.5	68.0	65.5	69.5	68.0	65.5	69.0	68.5	64.0	67.0
3	33.5	33.5	39.0	36.0	36.0	37.0	38.0	37.0	33.5	39.5	37.0	33.0	38.5	37.0	30.5	35.5
4	33.5	33.5	39.0	36.0	36.0	37.0	38.0	37.0	33.5	39.5	37.0	33.0	38.5	37.0	30.5	35.5
5	33.0	33.5	38.5	36.0	36.0	37.5	37.5	37.0	34.0	38.5	37.0	33.0	37.0	37.0	31.0	34.0
6	33.0	33.5	38.5	36.0	36.0	37.5	37.5	37.0	34.0	38.5	37.0	33.0	37.0	37.0	31.0	34.0
May-1	33.0	33.0	39.0	36.5	36.0	38.0	37.5	37.5	34.5	37.0	37.5	33.0	35.0	37.5	32.0	32.0
2	33.0	33.0	39.0	36.5	36.0	38.0	37.5	37.5	34.5	37.0	37.5	33.0	35.0	37.5	32.0	32.0
3	32.5	32.5	38.5	36.0	36.0	38.0	37.0	37.5	35.0	36.0	37.5	32.5	33.5	37.5	32.5	30.5
4	32.5	32.5	38.5	36.0	36.0	38.0	37.0	37.5	35.0	36.0	37.5	32.5	33.5	37.5	32.5	30.5
5	30.5	30.0	34.5	33.5	34.0	36.0	34.0	33.5	33.0	33.5	33.5	31.5	33.0	34.5	30.0	29.5
6	30.5	30.0	34.5	33.5	34.0	36.0	34.0	33.5	33.0	33.5	33.5	31.5	33.0	34.5	30.0	29.5
Jun-1	28.5	27.0	29.5	31.0	32.5	33.5	31.0	28.5	31.5	31.5	28.5	30.5	32.0	31.5	27.0	28.5
2	28.5	27.0	29.5	31.0	32.5	33.5	31.0	28.5	31.5	31.5	28.5	30.5	32.0	31.5	27.0	28.5
3	27.0	24.5	25.5	29.0	31.5	31.5	29.0	25.5	30.0	29.5	25.5	29.5	32.0	29.0	25.0	28.0
4	27.0	24.5	25.5	29.0	31.5	31.5	29.0	25.5	30.0	29.5	25.5	29.5	32.0	29.0	25.0	28.0
5	27.5	24.5	26.0	29.0	30.0	30.5	28.5	25.5	29.0	29.0	25.5	28.0	31.0	29.5	26.0	28.0
6	27.5	24.5	26.0	29.0	30.0	30.5	28.5	25.5	29.0	29.0	25.5	28.0	31.0	29.5	26.0	28.0
July-1	28.0	25.0	26.5	29.0	28.5	28.5	28.5	26.5	28.0	28.0	26.5	25.5	30.5	29.5	27.0	28.0
2	28.0	25.0	26.5	29.0	28.5	28.5	28.5	26.5	28.0	28.0	26.5	25.5	30.5	29.5	27.0	28.0
3	26.0	23.5	24.5	27.0	25.0	25.0	26.0	24.5	24.5	25.5	24.5	22.0	28.0	27.5	25.5	26.0
4	26.0	23.5	24.5	27.0	25.0	25.0	26.0	24.5	24.5	25.5	24.5	22.0	28.0	27.5	25.5	26.0
5	50.5	50.0	49.5	50.0	50.5	50.5	50.0	50.0	50.0	50.5	51.0	49.0	51.0	51.0	50.5	50.5
6	50.5	50.0	49.5	50.0	50.5	50.5	50.0	50.0	50.0	50.5	51.0	49.0	51.0	51.0	50.5	50.5
Aug-1	63.5	63.5	61.0	61.5	63.5	63.5	61.5	62.5	61.5	63.0	64.0	62.0	65.5	64.0	64.0	65.0
2	63.5	63.5	61.0	61.5	63.5	63.5	61.5	62.5	61.5	63.0	64.0	62.0	65.5	64.0	64.0	65.0
3	29.0	30.5	26.0	25.0	29.5	30.0	25.0	28.5	26.5	29.0	29.5	28.0	32.0	29.5	30.5	32.0
4	29.0	30.5	26.0	25.0	29.5	30.0	25.0	28.5	26.5	29.0	29.5	28.0	32.0	29.5	30.5	32.0
5	29.0	29.5	26.5	26.0	28.5	29.0	26.0	28.0	27.0	29.0	29.0	27.5	31.5	29.5	30.5	30.5
6	29.0	29.5	26.5	26.0	28.5	29.0	26.0	28.0	27.0	29.0	29.0	27.5	31.5	29.5	30.5	30.5
Sep-1	29.0	28.0	27.5	27.0	27.0	28.0	27.0	27.0	27.0	28.5	28.5	27.0	31.0	29.5	30.0	28.5
2	29.0	28.0	27.5	27.0	27.0	28.0	27.0	27.0	27.0	28.5	28.5	27.0	31.0	29.5	30.0	28.5
3	29.0	27.0	28.0	28.0	25.0	27.0	27.5	26.0	27.0	28.0	28.0	26.5	30.0	29.5	29.5	27.0
4	29.0	27.0	28.0	28.0	25.0	27.0	27.5	26.0	27.0	28.0	28.0	26.5	30.0	29.5	29.5	27.0
5	27.5	26.0	27.0	27.0	25.5	26.5	27.0	25.5	26.5	28.0	27.0	26.5	29.0	28.5	28.0	27.0
6	27.5	26.0	27.0	27.0	25.5	26.5	27.0	25.5	26.5	28.0	27.0	26.5	29.0	28.5	28.0	27.0
Oct-1	26.0	25.0	25.5	26.0	26.5	26.0	27.0	25.0	26.0	28.0	26.5	26.5	28.5	28.0	27.0	27.5
2	26.0	25.0	25.5	26.0	26.5	26.0	27.0	25.0	26.0	28.0	26.5	26.5	28.5	28.0	27.0	27.5
3	25.0	24.0	24.5	25.5	27.5	25.5	27.0	25.0	25.5	28.5	26.0	25.5	28.0	27.0	25.5	28.0
4	25.0	24.0	24.5	25.5	27.5	25.5	27.0	25.0	25.5	28.5	26.0	25.5	28.0	27.0	25.5	28.0
5	24.0	23.5	23.5	24.0	25.5	24.5	25.5	24.0	24.5	26.5	24.5	24.5	26.0	25.5	24.5	26.0
6	24.0	23.5	23.5	24.0	25.5	24.5	25.5	24.0	24.5	26.5	24.5	24.5	26.0	25.5	24.5	26.0
Nov-1	23.5	23.0	23.0	23.0	23.5	23.0	23.5	23.5	23.5	24.0	23.5	21.5	24.5	24.0	23.0	24.0
2	23.5	23.0	23.0	23.0	23.5	23.0	23.5	23.5	23.5	24.0	23.5	21.5	24.5	24.0	23.0	24.0
3	20.5	21.0	20.0	20.0	20.0	20.0	20.0	20.5	21.0	20.5	20.5	48.5	21.0	20.5	20.0	20.0
4	20.5	21.0	20.0	20.0	20.0	20.0	20.0	20.5	21.0	20.5	20.5	48.5	21.0	20.5	20.0	20.0
5	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.5	48.0	48.0	48.5	48.0	48.0	48.0	48.0
6	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.5	48.0	48.0	48.5	48.0	48.0	48.0	48.0
Dec-1	57.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0	59.0	57.0	57.0	57.5	57.0	57.0	56.5	57.0
2	57.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0	59.0	57.0	57.0	57.5	57.0	57.0	56.5	57.0
3	20.0	19.5	20.5	20.0	20.5	20.0	20.0	19.5	23.5	20.0	20.5	20.5	20.0	20.0	20.0	20.0
4	20.0	19.5	20.5	20.0	20.5	20.0	20.0	19.5	23.5	20.0	20.5	20.5	20.0	20.0	20.0	20.0
5	19.5	19.5	20.0	20.0	20.0	20.0	20.0	19.5	22.0	20.0	20.0	20.0	20.0	20.0	19.5	20.0
6	19.5	19.5	20.0	20.0	20.0	20.0	20.0	19.5	22.0	20.0	20.0	20.0	20.0	20.0	19.5	20.0
Jan-1	19.0	19.5	19.5	20.0	19.5	20.0	20.0	19.0	19.5	20.0	19.0	19.0	20.0	19.5	19.0	19.5
2	19.0	19.5	19.5	20.0	19.5	20.0	20.0	19.0	19.5	20.0	19.0	19.0	20.0	19.5	19.0	19.5
3	18.0	19.5	19.0	20.0	19.0	22.0	20.0	18.0	17.5	19.5	18.5	18.5	20.0	19.0	18.5	19.0
4	18.0	19.5	19.0	20.0	19.0	22.0	20.0	18.0	17.5	19.5	18.5	18.5	20.0	19.0	18.5	19.0
5	20.0	20.5	20.5	21.0	20.5	23.0	21.0	20.0	19.5	20.5	20.0	20.0	21.0	21.0	19.5	20.0
6	20.0	20.5	20.5	21.0	20.5	23.0	21.0	20.0	19.5	20.5	20.0	20.0	21.0	21.0	19.5	20.0
Feb-1	21.5	22.0	22.5	22.0	22.5	25.0	22.0	22.0	21.5	21.5	22.0	23.0	22.0	23.0	20.5	21.0
2	21.5	22.0	22.5	22.0	22.5	25.0	22.0	22.0	21.5	21.5	22.0	23.0	22.0	23.0	20.5	21.0
3	23.0	23.0	24.0	23.5	24.0	27.0	23.5	23.5	23.0	23.0	23.5	25.0	23.5	24.5	21.5	22.0
4	23.0	23.0	24.0	23.5	24.0	27.0	23.5	23.5	23.0	23.0	23.5	25.0	23.5	24.5	21.5	22.0
5	24.5	25.5	26.0	25.5	26.0	27.0	25.5	25.5	25.0	25.5	25.5	26.5	25.5	27.5	23.5	24.5
6	24.5	25.5	26.0	25.5	26.0	27.0	25.5	25.5	25.0	25.5	25.5	26.5	25.5	27.5	23.5	24.5
Mar-1	26.5	28.0	28.0	27.5	28.0	19.0	27.5	28.0	26.5	28.0	27.0	26.0	28.0	30.0	25.5	27.5
2	26.5	28.0	28.0	27.5	28.0	19.0	27.5	28.0	26.5	28.0	27.0	26.0	28.0	30.0	25.5	27.5
3	26.0	28.0	27.5	27.0	27.5	18.5	27.0	28.0	26.5	28.0	27.0	22.0	28.0	31.0	25.5	28.0
4	26.0	28.0	27.5	27.0	27.5	18.5	27.0	28.0	26.5	28.0	27.0	22.0	28.0	31.0	25.5	28.0
5	51.0	51.5	52.0	52.0	51.5	51.5	51.5	51.5	51.0	52.0	51.5	51.0	52.0	52.5	50.5	51.5
6	51.0	51.5	52.0	52.0	51.5	51.5	51.5	51.5	51.0	52.0	51.5	51.0	52.0	52.5	50.5	51.5

Table B-2 Crop Water Requirement, CWR from CROPWAT (mm/5day)

Station : Bogra

Interval SI.	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Apr-1	68.0	69.5	66.0	66.0	65.0	67.0	67.5	66.5	65.0	65.5	66.5	66.5	66.0	67.5	66.0	66.0
2	68.0	69.5	66.0	66.0	65.0	67.0	67.5	66.5	65.0	65.5	66.5	66.5	66.0	67.5	66.0	66.0
3	35.5	40.0	33.5	34.0	32.0	36.0	36.5	34.0	32.5	33.5	34.0	34.5	35.0	36.0	33.5	34.0
4	35.5	40.0	33.5	34.0	32.0	36.0	36.5	34.0	32.5	33.5	34.0	34.5	35.0	36.0	33.5	34.0
5	37.5	37.5	33.0	35.0	32.0	35.5	35.5	34.0	33.5	32.0	34.0	34.0	32.5	35.0	33.0	34.5
6	37.5	37.5	33.0	35.0	32.0	35.5	35.5	34.0	33.5	32.0	34.0	34.0	32.5	35.0	33.0	34.5
May-1	40.0	34.5	32.5	36.0	32.0	35.0	34.0	33.5	35.0	30.0	33.5	32.5	29.0	34.0	32.5	34.5
2	40.0	34.5	32.5	36.0	32.0	35.0	34.0	33.5	35.0	30.0	33.5	32.5	29.0	34.0	32.5	34.5
3	42.0	32.0	31.5	37.0	31.5	34.5	32.5	33.0	36.0	28.5	33.0	31.5	26.5	33.0	31.5	34.5
4	42.0	32.0	31.5	37.0	31.5	34.5	32.5	33.0	36.0	28.5	33.0	31.5	26.5	33.0	31.5	34.5
5	38.5	31.5	30.5	33.5	31.0	32.0	31.0	32.0	32.5	28.0	32.0	30.0	26.5	32.0	30.5	32.0
6	38.5	31.5	30.5	33.5	31.0	32.0	31.0	32.0	32.5	28.0	32.0	30.0	26.5	32.0	30.5	32.0
Jun-1	34.5	31.0	30.0	30.0	30.5	28.5	29.5	30.5	31.5	27.5	30.5	28.5	26.5	31.0	29.5	29.5
2	34.5	31.0	30.0	30.0	30.5	28.5	29.5	30.5	31.5	27.5	30.5	28.5	26.5	31.0	29.5	29.5
3	32.0	30.5	29.5	27.5	30.5	26.0	28.0	30.0	30.0	27.0	30.0	27.5	27.0	30.0	28.5	27.5
4	32.0	30.5	29.5	27.5	30.5	26.0	28.0	30.0	30.0	27.0	30.0	27.5	27.0	30.0	28.5	27.5
5	30.0	29.5	28.0	27.0	29.5	26.0	27.0	28.5	19.5	27.0	28.5	27.0	27.0	29.0	28.5	28.0
6	30.0	29.5	28.0	27.0	29.5	26.0	27.0	28.5	19.5	27.0	28.5	27.0	27.0	29.0	28.5	28.0
July-1	28.0	28.5	26.5	26.5	28.5	26.0	25.5	27.0	3.0	26.5	27.0	26.5	27.0	27.0	29.0	29.0
2	28.0	28.5	26.5	26.5	28.5	26.0	25.5	27.0	3.0	26.5	27.0	26.5	27.0	27.0	29.0	29.0
3	24.0	26.0	23.5	24.0	25.5	24.0	22.5	23.5	9.5	24.5	23.5	24.0	25.0	23.5	27.0	27.5
4	24.0	26.0	23.5	24.0	25.5	24.0	22.5	23.5	9.5	24.5	23.5	24.0	25.0	23.5	27.0	27.5
5	50.0	50.0	50.0	50.0	50.5	50.0	49.5	50.0	41.0	49.5	50.0	50.0	50.0	50.0	50.5	51.0
6	50.0	50.0	50.0	50.0	50.5	50.0	49.5	50.0	41.0	49.5	50.0	50.0	50.0	50.0	50.5	51.0
Aug-1	63.0	62.5	64.0	63.0	63.0	62.5	62.5	63.0	56.0	61.0	63.0	63.0	63.5	63.0	62.5	64.0
2	63.0	62.5	64.0	63.0	63.0	62.5	62.5	63.0	56.0	61.0	63.0	63.0	63.5	63.0	62.5	64.0
3	29.0	27.5	31.0	29.5	28.5	28.5	29.5	29.5	30.0	25.5	29.5	29.5	30.0	29.5	27.0	29.0
4	29.0	27.5	31.0	29.5	28.5	28.5	29.5	29.5	30.0	25.5	29.5	29.5	30.0	29.5	27.0	29.0
5	29.5	28.0	29.5	29.0	27.5	28.0	28.5	28.0	28.5	26.0	28.0	28.5	27.5	29.5	27.0	28.5
6	29.5	28.0	29.5	29.0	27.5	28.0	28.5	28.0	28.5	26.0	28.0	28.5	27.5	29.5	27.0	28.5
Sep-1	29.5	28.5	27.5	28.5	26.0	27.5	27.5	26.0	25.5	26.5	26.0	27.5	25.0	29.0	27.0	28.0
2	29.5	28.5	27.5	28.5	26.0	27.5	27.5	26.0	25.5	26.5	26.0	27.5	25.0	29.0	27.0	28.0
3	29.0	28.5	25.5	28.0	25.0	26.5	26.5	24.5	24.5	26.5	24.5	26.5	22.5	28.5	26.5	27.0
4	29.0	28.5	25.5	28.0	25.0	26.5	26.5	24.5	24.5	26.5	24.5	26.5	22.5	28.5	26.5	27.0
5	28.5	27.5	26.5	27.5	24.5	26.0	26.0	24.0	25.0	26.5	24.0	25.5	23.0	27.5	26.0	26.5
6	28.5	27.5	26.5	27.5	24.5	26.0	26.0	24.0	25.0	26.5	24.0	25.5	23.0	27.5	26.0	26.5
Oct-1	28.0	26.5	27.5	26.5	24.0	25.5	26.0	24.0	26.0	27.0	24.0	25.0	23.0	26.5	25.5	27.0
2	28.0	26.5	27.5	26.5	24.0	25.5	26.0	24.0	26.0	27.0	24.0	25.0	23.0	26.5	25.5	27.0
3	28.0	26.0	28.5	26.0	24.0	25.0	26.0	24.0	26.5	27.5	24.0	24.0	23.5	26.0	25.0	27.0
4	28.0	26.0	28.5	26.0	24.0	25.0	26.0	24.0	26.5	27.5	24.0	24.0	23.5	26.0	25.0	27.0
5	26.0	25.0	26.5	24.5	23.5	24.5	24.5	23.0	25.0	25.5	23.0	23.0	23.0	25.0	24.0	25.0
6	26.0	25.0	26.5	24.5	23.5	24.5	24.5	23.0	25.0	25.5	23.0	23.0	23.0	25.0	24.0	25.0
Nov-1	24.0	24.0	24.0	22.5	23.0	23.5	23.5	22.0	23.0	24.0	22.0	22.5	22.0	23.5	23.0	23.0
2	24.0	24.0	24.0	22.5	23.0	23.5	23.5	22.0	23.0	24.0	22.0	22.5	22.0	23.5	23.0	23.0
3	20.5	21.0	20.5	19.0	20.5	21.0	20.0	19.5	19.5	20.5	19.5	20.0	19.5	20.5	20.0	19.0
4	20.5	21.0	20.5	19.0	20.5	21.0	20.0	19.5	19.5	20.5	19.5	20.0	19.5	20.5	20.0	19.0
5	48.0	48.0	48.0	47.5	48.0	48.0	48.0	47.5	47.5	48.0	47.5	47.5	47.5	48.0	47.5	47.5
6	48.0	48.0	48.0	47.5	48.0	48.0	48.0	47.5	47.5	48.0	47.5	47.5	47.5	48.0	47.5	47.5
Dec-1	57.0	57.0	56.5	56.0	56.5	56.5	56.5	56.5	56.5	57.0	56.5	56.0	56.0	57.0	56.5	56.5
2	57.0	57.0	56.5	56.0	56.5	56.5	56.5	56.5	56.5	57.0	56.5	56.0	56.0	57.0	56.5	56.5
3	20.0	20.0	19.0	18.5	19.5	19.0	19.0	19.0	20.0	19.5	19.0	19.0	18.5	20.0	19.0	20.0
4	20.0	20.0	19.0	18.5	19.5	19.0	19.0	19.0	20.0	19.5	19.0	19.0	18.5	20.0	19.0	20.0
5	20.0	19.5	19.0	18.5	19.0	19.0	19.0	19.0	19.5	19.5	19.0	18.5	18.5	19.0	18.5	19.5
6	20.0	19.5	19.0	18.5	19.0	19.0	19.0	19.0	19.5	19.5	19.0	18.5	18.5	19.0	18.5	19.5
Jan-1	20.0	19.5	19.0	19.0	19.0	19.0	18.5	19.0	19.0	19.0	19.0	18.5	18.5	17.5	17.5	19.5
2	20.0	19.5	19.0	19.0	19.0	19.0	18.5	19.0	19.0	19.0	19.0	18.5	18.5	17.5	17.5	19.5
3	19.5	19.0	18.5	19.0	18.5	18.5	19.5	18.5	18.5	19.0	18.5	18.0	18.0	16.5	17.0	18.5
4	19.5	19.0	18.5	19.0	18.5	18.5	19.5	18.5	18.5	19.0	18.5	18.0	18.0	16.5	17.0	18.5
5	21.0	20.0	20.0	20.0	19.5	19.5	20.5	19.5	19.5	20.0	19.5	19.0	19.5	18.0	18.5	17.5
6	21.0	20.0	20.0	20.0	19.5	19.5	20.5	19.5	19.5	20.0	19.5	19.0	19.5	18.0	18.5	17.5
Feb-1	22.5	21.0	21.0	21.0	21.0	20.5	22.0	21.0	21.0	21.0	21.0	20.0	20.5	19.5	20.0	18.5
2	22.5	21.0	21.0	21.0	21.0	20.5	22.0	21.0	21.0	21.0	21.0	20.0	20.5	19.5	20.0	18.5
3	24.0	22.0	22.5	22.5	22.0	21.5	24.5	22.5	22.0	22.0	22.5	21.5	21.5	21.5	21.5	20.0
4	24.0	22.0	22.5	22.5	22.0	21.5	24.5	22.5	22.0	22.0	22.5	21.5	21.5	21.5	21.0	20.0
5	26.5	24.5	24.5	24.0	24.5	24.0	27.0	24.5	24.0	24.0	24.5	23.5	23.5	24.0	23.5	21.0
6	26.5	24.5	24.5	24.0	24.5	24.0	27.0	24.5	24.0	24.0	24.5	23.5	23.5	24.0	23.5	21.0
Mar-1	29.5	26.5	27.0	25.5	27.0	26.0	27.0	27.0	25.5	25.5	27.0	25.5	25.0	26.5	26.0	23.0
2	29.5	26.5	27.0	25.5	27.0	26.0	27.0	27.0	25.5	25.5	27.0	25.5	25.0	26.5	26.0	23.0
3	30.5	27.0	27.0	25.5	27.5	26.0	25.0	27.5	25.0	25.5	27.5	25.5	25.0	27.0	26.5	25.5
4	30.5	27.0	27.0	25.5	27.5	26.0	25.0	27.5	25.0	25.5	27.5	25.5	25.0	27.0	26.5	25.5
5	52.5	51.5	51.0	51.0	51.0	51.0	51.5	51.5	50.5	51.0	51.5	51.0	50.5	51.5	51.0	51.0
6	52.5	51.5	51.0	51.0	51.0	51.0	51.5	51.5	50.5	51.0	51.5	51.0	50.5	51.5	51.0	51.0

Table B-3 Availability of Crop Water Requirement, ACWR (mm/5day)

Station : Rangpur

Interval SI	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Apr-1	-67.0	-64.0	-63.5	-49.8	-66.0	-63.5	-50.3	-64.5	-64.5	-64 5	-63.5	-65.5	14 5	-65 0	-64 5	-64 0
2	-67.0	-64.0	-63.5	-64.5	-66.0	-63.5	-31.2	-54.3	-64.5	-34.0	-63.5	-65.5	-62.0	-65 0	-64 5	-34.8
3	-36.5	-18.3	-30.0	-27.9	-34.0	-31.0	-30.0	-32.5	-32.0	106.7	-31.0	-33.5	10.5	-32.5	-31 5	10.9
4	-36.0	-18.5	-0.3	-32.5	-30.9	7.1	-30.0	11.9	32.8	-15.5	-26.2	-33.5	1 5	-32.5	-31 5	-25.9
5	-34 0	-31.0	-9.7	-32.5	-30.0	-29.0	-31.0	4.3	-33.0	-32.0	-31.0	-31.5	-31 5	4 4	158 5	-31.0
6	-32.5	-29.0	-15.8	-32.5	-23.3	-32.0	-31.0	-22.3	-33.0	-32.0	-31.0	79.2	-19 1	-25 4	-10 3	-28.0
May-1	-14.8	17.9	12.7	-33.5	-34.5	-19.8	-26.1	-8.1	-35.0	-32.5	-31.0	32 8	-10 7	-32 0	-5.1	124.8
2	-7.6	-31.5	38.7	-22.1	-12.9	135.1	-32.5	-33.5	-35.0	-32.5	-31.0	-14 9	14 4	-32.5	60 9	91.7
3	-28.2	-2.0	-10.1	5.4	-26.4	-32.5	-33.0	-33.5	-25.3	-32.5	-31.0	51.3	0 2	49.3	-23.3	2.8
4	32.5	-31.0	19.2	-15.5	-34.5	-29.5	39.4	-33.5	40.7	-32.5	-31.0	6.1	46.8	-28.2	-0.5	-17.5
5	-4.9	39.4	-0.8	5.8	-21.6	130.5	-18.3	7.6	3.6	-31.0	154.6	32.4	-25 9	11.9	-29.0	49.7
6	23.2	-23.1	-29.5	-30.5	-14.5	-19.3	22.3	48.2	-28.2	-31.0	-2.1	7.6	4 8	47.5	-31.5	28.1
Jun-1	12.9	-28.0	-26.0	62.5	25.2	-20.3	-29.5	-4.6	84.8	-30.0	51.8	34.7	3 8	-13.7	-21.4	19.3
2	-2.1	187.9	-13.8	-27.5	-30.0	28.0	-6.6	37.2	99.2	-30.0	-19.8	-25.5	-13.0	1.8	207.2	104.3
3	-7.2	100.0	48.6	0.4	-23.4	40.4	45.7	75.3	-11.1	-29.0	-24.0	66 7	-28.0	-31.0	45.4	86.0
4	-20.4	297.1	79.6	-15.9	-5.1	2.6	167.7	76.6	-9.8	-29.0	105.6	129.8	11.1	32 6	-4.2	100.1
5	49.0	25.8	12.8	7.5	13.9	17.8	-10.2	-0.1	21.9	-28.5	-1.6	77 2	46 4	3 0	-27.5	69.8
6	-3.4	123.3	-12.8	37.2	25.9	-18.8	48.2	-25.5	20.4	-28.5	-21.2	381.5	16.9	-21.9	-0.8	81.1
July-1	92.9	12.7	-12.6	141.8	58.6	72.6	-27.5	75.5	6.2	-27.5	-21.4	-17.6	-2 5	49.8	51.5	-26.5
2	-23.7	11.1	64.4	152.8	59.0	213.8	150.3	52.8	20.2	-27.5	-19.9	9.3	-13 3	80.5	5.8	47.1
3	-28.0	58.5	92.3	-21.0	23.3	-19.2	86.8	-2.4	113.7	-24.5	-22.2	1.3	61 5	-10.7	129.7	69.5
4	104.6	13.9	53.4	-9.5	-14.8	74.8	15 7	90.3	9.5	-5.8	30.6	-24.7	120.7	164 8	-24.0	55.0
5	2.9	-21.3	29.9	-39.2	-50.0	-9.4	-31.0	-49.5	-5.8	19.3	47.6	51.1	48.7	62.6	-35.3	-25.1
6	62 4	115.6	164.1	255.8	11.6	-50.5	-50.0	-49.5	192.0	45.9	107.2	45.2	45.3	7.1	-50.5	79.7
Aug-1	-58.2	10.1	-55.9	12.9	-11.5	-64.0	2.0	-24.2	0.1	3.9	-27.7	-4.2	-58 7	-56.3	81.2	-46.0
2	-40.2	-17.3	-63.0	-58.7	33.7	22.4	-9.1	-22.9	51.2	-6.6	25.8	21.6	-29 0	-53.3	65.2	-61.0
3	-4.6	20.8	-8 6	79.7	8.5	-30.5	40.6	77.4	-1.6	14.7	22.0	-2 0	-12 1	-31.0	12.0	-0.3
4	54.5	-19.6	-5.4	18.0	91.5	-21.6	-26.0	100.2	-26.2	237.6	-17.5	-11.5	175.5	5.3	117.6	22.8
5	19.2	39.1	42.1	94.2	161.7	9.1	45.9	54.0	7.0	-18.9	-1.3	-17.8	13.1	12.1	-10.7	1.5
6	84.7	-17.8	-19.9	188.5	-0.9	-17.6	-26.5	33.1	31.2	10.1	-7.1	-10.6	1 8	-28 0	-9.5	-11.2
Sep-1	-27.5	-25.5	28.9	-15.6	-27.0	-15.3	-27.0	-27.0	-26.5	-26.5	-27.5	-3.1	-26 0	-26 0	65.4	142.5
2	0.2	-21.6	29.5	-0.3	2.7	139.6	-27.0	-27.0	-16.3	-26.5	-27.5	68.1	26.5	33.7	-18.3	1.5
3	36.0	-5.4	-21.5	-15.3	-27.5	-23.5	45.4	-27.5	25.3	-27.0	-27.0	0.9	10 6	1 4	4.5	-5.6
4	-8.5	10.9	46.9	19.7	-26.0	77.6	-27.0	-27.5	-0.1	-27.0	155.1	42.6	44 4	19.4	-28.5	50.2
5	9.5	3.5	-23.0	-18.9	-13.8	44.6	-13.8	90.8	14.4	-26.0	2.9	-26.0	-24 7	-6 0	-25.0	-24 5
6	34.7	-20.1	-25.0	-5.9	29.4	-14.8	26.8	-26.0	-24.2	-26.0	-26.5	59 6	18 4	35.5	-27.5	27.6
Oct-1	2.4	-14.4	-10.3	-24.5	35.5	-3.6	116.2	21.2	34.1	341.6	-27.0	25.1	-2 7	-19.9	-17.6	76.2
2	-25.5	-25.5	188.8	-23.7	-25.0	-1.1	-26.0	-5.5	-2.4	0.4	41 1	-25.2	-25 0	-26 5	-26.5	-9.0
3	-25.0	79.7	-18.9	-23.5	-18.1	-16.3	-26.0	-23.5	-24.0	-24.5	-27.5	6.2	-25 0	-2.6	-26.0	-18.1
4	-25 0	-24.5	-23.5	-23.5	-11.3	-27.0	-26.0	-23.5	-24.0	-24.5	-27.5	-25 0	-9 5	-27.0	42.6	-19.4
5	-23.5	86.7	89.0	7.7	-19.2	-25.5	-24.0	-22.5	80.6	-24.0	-25.5	-20.9	87.3	-25.5	-22.0	-20.7
6	41.3	-23.0	-12.3	-22.5	-23.0	-25.5	7.8	-3.5	-23.5	-8.8	-17.1	-20.5	4 9	-25.5	-24.5	-11.5
Nov-1	-22.5	-13.4	-22.5	-8.8	-21.5	-23.5	-22.5	-21.5	-22.5	4.2	-24.0	-22 5	-23 5	-23 5	-23.0	-7.8
2	-22.5	-22.5	-22.5	-21.5	-21.5	-23.5	-22.5	-21.5	-22.5	-20.5	-24.0	-2.1	-23 5	-23 5	-23.0	-7.5
3	-19.0	-19 5	-20.0	-18.5	-18.0	-20.0	-19.0	-0.7	-9.9	-20.5	-20.5	-19.2	-20 5	-20 0	-19 5	-19.0
4	-19.0	-19.5	-20.0	-18.5	-18.0	-20.0	-19.0	-18.5	-20.0	-20.5	-20.5	-17.7	-20.5	-20.0	-19.5	-19.0
5	-47.5	-47.5	-47.5	-47.5	-22.1	-47.5	-47.5	-47.5	-48.0	-48.0	-48.0	-47 5	-48 0	-47.5	-47.5	-47.5
6	-47.5	-47.5	-47.5	-47.5	-47.0	-47.5	-47.5	-47.5	-48.0	-48.0	-48.0	-47.5	-48.0	-47 5	-47.5	-47 5
Dec-1	-55.5	-56.0	-56.0	-55.5	-55.5	-56.0	-56.0	-55.5	-56.5	-57.0	-57.0	-56.0	-56 5	-56.5	-56.5	-56.0
2	-55.5	-56.0	-56.0	-55.5	-55.5	-56.0	-56.0	-55.5	-56.5	-57.0	-57.0	-14 4	-56 5	-56 5	-56.5	-56.0
3	-18 0	-18.5	-18.5	-18.0	-18.0	-19.0	-18.5	-18.0	-19.0	-20.0	-19.5	-19.0	-19 5	-19 0	-19.0	-18.5
4	-18.0	-18.5	-18.5	-18.0	-18.0	-19.0	-18.5	-18.0	-19.0	-20.0	-19.5	-19 0	-19 0	-19 0	-19.0	-18.5
5	-18.0	-18.5	-18.0	-16.0	-18.0	-18.5	-18.0	-18.0	-18.5	-19.5	-19.0	-19.0	-19 0	-19.0	-19.0	-18.5
6	-18.0	-18.5	-18.0	-18.0	-18.0	-18.5	-18.0	-18.0	-18.5	-19.5	-19.0	-19 0	-19 0	-19 0	-19 0	-7.8
Jan-1	-18.0	-18.0	-18.0	21.4	-17.5	-18.5	-18.0	-18.0	-18.0	-18.0	-18.5	-18.5	-18 5	-18 5	-18 5	-18 0
2	-18.0	-18.0	-18.0	-18.0	-5.8	19.6	-18.0	-18.0	-18.0	-18.0	-18.0	-5.3	-18 5	-18 5	-18 5	-18 0
3	-17 5	-15.0	-17 5	-18.0	-17.0	-5.3	-4.8	-18.0	-17.0	-17.0	-18.0	-12 2	-17 5	-18 5	-18 0	-18 0
4	-17.5	-17.5	-17.5	-18.0	-17.0	-18.0	-17.5	-18.0	-17.0	-17.0	-18.0	-18 0	-17 5	-18 5	-18 0	-18 0
5	-18 5	-19.0	-18.5	-19.0	-18.5	-19.0	-18.5	-5.0	-16 5	-18 5	-18.5	-19 0	-16 5	-19 5	-19 5	-17 0
6	-18 5	-19 0	-18 5	-19.0	-18 5	-19.0	-18.5	-19.0	-9.6	-18.5	-18 5	-19 0	-19 0	-19 5	-17 4	-18 5
Feb-1	-20.0	-20.0	-19.5	-20.0	-20.0	-20.0	-19.5	-20.0	-20.0	-12.7	-19.5	-20 5	-10 6	-20 5	-9 1	-19 5
2	-20 0	-20.0	-19.5	-20.0	-20.0	-20.0	-19.5	-20.0	-20.0	-13.7	-19.5	-20 5	-20 5	-20 5	-20 5	-9 4
3	-21.5	-21.5	-20.5	-21.0	-21.5	-21.5	-20.5	-21.0	-21.5	-15.2	-20.5	-21 5	-22 0	-21 5	-21 5	-20 5
4	-21.5	-21.5	-20 5	-21.0	-21.5	-21 5	-20.5	-7.0	-21.5	-21.0	-16.9	-21 5	-22 0	-21 5	-21 5	-20 5
5	-23.0	-19.7	-22.5	-22.5	-24.0	-22.5	-22.0	-22.5	-22.8	-23 0	-22.0	-23.5	-23 5	-23 5	-20 1	-22.5
6	-23.5	-23.0	-22 5	-22.5	-24.0	-22.5	-22.0	-22 5	-17.4	-23.0	51.7	-23 5	-23 5	-23 5	-24 0	-22.5
Mar-1	-25 5	-25.0	-25.0	-24.0	-26.0	-23.5	-23.0	-24.0	-24.5	-25.0	-24.0	-25.5	-25 0	-25 0	-26.0	-24.5
2	-25.5	-25.0	-25.0	-22.5	-26.0	-23 5	-23.0	-24 0	-24.5	-24.5	-14.8	-25 5	-25 0	-9 8	-26 0	-24.5
3	-19.9	-24.5	-25.0	-23.5	52.7	-23.0	-22.5	-23.5	-24 0	-24.5	-23.5	-25.0	-24 5	-25 0	-26 0	-16 4
4	-25.5	19.2	-25.0	-23.5	-26.0	-23.0	-3.5	-23.5	-24 0	-24.5	-23.5	-25 0	-24 5	-25 0	-26 0	-22.0
5	-51 0	-47.7	-22.8	-50.0	-22.0	-50.0	26.7	-50.0	-49.5	-50.5	-50.0	-1.5	-50 5	-50 5	-50 5	-45 4
6	-51.0	-50.5	-49.5	-50.0	-50.0	-50.0	-49.5	-50.0	-49 5	-50 5	-50 0	-10 2	-50 5	-50 5	-50 5	-41 9

Table B-3 Availability of Crop Water Requirement, ACWR (mm/5day)

Station : Rangpur

Interval Sl.	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Apr-1	-62.9	-65.0	-66.0	-33.5	-64.0	-66.5	-67.0	-67.0	-29.4	-61.0	-65.0	-66.5	-43.5	-65.5	-67.5	-64.5
2	-68.0	-65.0	-66.0	-64.0	-64.0	-64.5	-67.0	-67.0	-56.1	-43.2	-65.0	-66.5	-31.0	-64.3	-67.5	-64.5
3	5.9	-0.3	-34.0	32.0	-5.4	-28.2	-36.5	-35.5	-15.8	-32.0	-33.0	-35.5	-28.5	-24.0	-36.0	-14.2
4	36.1	-19.8	-19.3	80.0	-6.9	-25.4	-36.5	-35.5	-31.0	-23.1	8.9	-35.5	-19.5	-33.0	-36.0	-19.8
5	-10.6	0.0	-11.4	-24.7	-26.9	-31.0	-33.5	5.1	24.4	3.1	-16.2	-34.5	-29.5	12.5	-34.5	16.2
6	-14.4	-11.7	-27.9	0.8	-10.7	5.8	19.0	-24.3	37.0	21.8	-16.8	-34.5	-26.5	-30.5	-10.0	-11.7
May-1	28.7	-35.5	96.0	-29.7	-34.0	38.1	59.1	-17.8	58.2	92.5	31.0	-33.0	3.5	8.7	64.5	-27.3
2	-29.0	-35.5	48.4	-20.8	-20.0	-30.5	38.6	-17.3	-16.8	-13.2	-19.1	-33.0	5.5	-26.5	-33.0	148.7
3	53.5	-1.9	58.9	-7.4	16.6	48.2	120.5	90.6	-24.4	-34.5	-3.1	44.9	-6.0	40.2	-25.0	-6.0
4	4.8	-37.5	44.5	47.0	-35.5	-13.0	4.7	-31.5	23.8	-34.5	-28.5	-4.3	-1.0	-0.7	-6.2	105.1
5	75.9	-24.8	-30.0	8.1	-19.0	74.7	10.6	43.7	-24.1	-16.2	74.1	23.1	61.5	75.2	-29.5	-26.5
6	97.1	-35.0	69.9	33.7	-0.3	-24.4	46.4	-24.9	-27.2	-23.9	140.2	244.0	20.0	129.9	-13.8	-20.1
Jun-1	68.6	-32.5	-8.2	-11.7	15.5	-29.0	26.1	193.4	-29.5	17.2	-27.5	26.8	67.0	-3.5	12.3	-2.4
2	71.4	-23.4	106.4	-25.7	32.0	-25.2	278.5	-26.0	-29.5	61.9	16.0	16.7	88.3	43.2	-11.6	45.6
3	56.9	22.3	27.7	-29.0	-15.8	-23.1	20.3	-27.5	42.1	-22.7	95.7	56.0	-4.0	64.6	45.4	189.2
4	-18.5	-27.2	46.7	-2.1	27.3	37.9	148.2	71.6	-13.7	-7.4	177.0	6.8	-20.0	37.7	-12.5	170.7
5	174.3	-24.2	-8.5	-13.3	3.4	-28.5	50.4	7.0	-22.9	130.7	396.4	3.5	93.5	5.7	68.5	-27.5
6	19.8	-1.8	-16.8	33.7	1.5	29.4	-23.5	3.0	74.9	-14.1	-25.7	-20.1	-9.0	4.0	8.4	142.4
July-1	-25.2	9.8	-9.7	112.3	-26.5	108.9	-14.6	-18.2	64.4	1.4	132.1	393.3	146.5	-20.2	-13.1	68.0
2	17.7	-26.5	45.3	-3.3	23.0	17.2	113.6	102.8	38.0	71.4	225.4	6.5	60.0	182.5	104.3	-3.5
3	38.8	47.8	32.9	-8.1	17.2	-25.0	120.4	4.6	29.3	32.4	73.8	121.3	2.2	-10.9	61.4	44.6
4	61.0	242.4	120.1	126.8	3.2	-18.2	11.1	32.6	-15.1	-14.6	-7.5	7.5	31.1	92.6	76.8	18.3
5	11.8	58.3	-5.5	-44.4	156.8	-27.1	-10.2	-3.8	108.8	152.2	-2.5	-50.0	30.5	39.1	-40.4	260.0
6	-31.5	88.1	-17.0	9.3	91.2	16.1	100.7	-17.7	7.1	150.3	-43.2	136.5	76.8	-9.7	0.0	-45.2
Aug-1	-23.4	-62.5	-46.7	-39.5	50.5	53.3	-30.0	-44.7	53.8	210.4	-54.2	-56.0	-6.9	91.3	-53.0	-0.3
2	-33.0	-62.5	-2.2	-58.7	-37.8	-44.5	-62.5	-34.5	-28.7	-48.8	-49.6	-55.0	-25.5	7.5	23.9	-52.6
3	-30.5	-25.8	5.5	-20.4	-1.3	-16.6	-28.5	29.9	-21.4	148.5	101.2	-25.7	8.5	-22.5	-29.0	-27.0
4	18.3	36.0	31.0	27.2	-10.2	-19.1	7.3	-3.6	-29.0	23.5	-24.5	-24.6	-30.5	-15.5	-31.0	-13.1
5	-18.8	24.1	19.5	143.4	3.6	64.0	8.3	49.0	6.8	107.9	15.9	38.4	-29.0	0.5	13.2	80.9
6	28.1	-27.0	-6.7	70.5	82.0	27.9	81.0	-25.5	14.4	68.5	63.6	15.5	44.3	40.8	20.3	31.3
Sep-1	11.9	-28.5	83.5	-25.2	-28.0	-6.5	105.1	-10.8	20.2	-8.8	46.4	-26.0	27.0	1.2	-27.0	83.0
2	-10.8	7.1	27.5	-16.3	14.5	5.0	61.3	12.3	-21.7	-19.4	-25.5	12.1	-18.5	-3.4	-29.0	65.4
3	56.3	-28.0	81.8	75.6	-3.4	39.2	81.9	57.8	20.9	-24.0	-0.6	43.5	-7.5	36.6	-21.5	95.9
4	34.0	-17.8	3.0	-25.0	-27.0	79.7	0.9	46.9	-1.9	-16.1	39.3	31.1	18.0	84.0	-1.7	-13.8
5	135.6	-27.0	18.8	37.2	-12.5	-18.4	51.0	-18.6	-19.7	-9.0	47.7	198.7	68.0	51.4	-18.7	-25.5
6	7.3	-27.0	45.1	31.4	6.2	-23.5	-17.4	88.1	-23.0	21.7	105.3	69.8	101.5	57.5	-11.2	-18.1
Oct-1	-24.7	3.0	0.6	-25.5	-25.5	-12.6	123.8	-16.9	13.8	-20.7	41.1	-25.0	30.0	14.2	-16.1	27.3
2	-25.5	-15.9	31.9	-25.5	-25.5	146.4	-2.2	-10.5	312.1	-24.5	-7.9	-14.0	120.5	-17.0	-25.5	-19.8
3	-25.0	-25.5	-24.5	-26.0	-24.5	188.9	8.3	47.9	21.9	-25.0	-25.5	-25.5	-13.1	-13.4	96.1	2.2
4	-25.0	-25.5	187.9	-26.0	-24.5	-23.0	-23.5	46.5	-16.1	-5.9	-25.5	-4.0	-20.5	-23.5	-22.5	-17.1
5	-23.5	-19.7	117.0	-26.5	3.7	-14.6	-23.0	-23.5	-22.0	-23.5	-24.5	-24.0	-22.0	-23.0	-20.0	-23.5
6	-23.5	-23.5	-23.5	-26.5	-23.0	-22.5	-23.0	-23.5	-22.0	-23.5	-24.5	-24.0	-22.0	-22.9	-23.5	-23.5
Nov-1	-12.6	-22.0	-22.5	-27.5	-21.5	-22.0	-22.5	-22.0	-21.0	-21.5	-23.0	-22.5	-22.0	-22.0	-22.5	-22.5
2	-22.0	-22.0	-22.5	-27.5	-16.2	-22.0	-22.5	-22.0	-7.1	-21.5	-21.7	-22.5	-22.0	-22.0	-22.5	-22.5
3	-18.5	-18.5	-19.5	-26.0	-7.1	-19.5	-20.0	-19.0	-18.5	0.6	-20.0	-19.5	-20.0	-19.0	-20.0	-19.5
4	-18.5	-18.5	-19.5	-26.0	-18.0	-19.5	-20.0	-19.0	-18.5	-18.5	-20.0	-19.5	-20.0	-19.0	-20.0	-19.5
5	-47.5	-47.0	-47.5	-49.0	-47.0	-47.5	-47.5	-47.5	-47.5	-47.5	-47.5	-47.5	-47.5	-46.7	-40.6	-47.5
6	-47.5	-35.6	-47.5	-49.0	-47.0	-47.5	-47.5	-47.5	-47.5	-47.5	46.7	-47.5	-47.5	-47.5	-47.5	-47.5
Dec-1	-55.5	-18.2	-55.5	-57.0	-54.5	-55.5	-56.0	-55.5	-55.5	-55.5	-55.5	-56.0	-55.5	-56.5	-55.5	-56.0
2	-55.5	-55.5	-55.5	-30.3	-54.5	-55.5	-56.0	-55.5	-55.5	-55.5	-56.0	-55.5	-56.5	-55.5	-56.0	-56.0
3	-18.0	-18.0	-18.0	40.7	-17.0	-17.5	-14.2	-18.0	23.9	-7.0	-18.5	-18.0	-19.0	-18.0	-18.0	-19.0
4	-18.0	-18.0	-18.0	-17.0	-17.0	-17.5	-18.0	-18.0	-18.0	-18.5	-18.5	-18.0	-19.0	-18.0	-18.0	-19.0
5	-18.5	-18.0	-18.0	-17.0	-17.5	-17.5	-17.5	-18.0	-18.0	-18.5	-18.5	-18.0	-18.5	-17.5	-18.0	-18.0
6	-18.5	-18.0	-18.0	-17.0	-17.5	12.7	-17.5	-15.5	-18.0	-18.5	-18.5	-13.0	-18.5	-17.5	-18.0	-18.0
Jan-1	-18.5	-9.6	-17.5	-17.5	-17.5	-17.5	-17.5	-17.5	-17.5	-18.0	-18.0	-17.5	-17.5	-17.5	-17.5	-16.5
2	-18.5	-18.0	19.6	-17.5	-17.5	-17.5	-17.5	-17.5	-17.5	-18.0	-18.0	-17.5	-17.5	-17.5	75.2	-16.5
3	-18.0	-17.5	-11.1	-17.5	-18.0	-17.0	-17.0	-17.0	-17.0	-17.5	-17.5	-17.0	-16.4	-17.5	-17.0	-15.5
4	-10.1	-17.5	-13.7	-17.5	-18.0	-9.1	-17.0	-17.0	-17.0	-17.5	-17.5	-17.0	-16.5	-17.5	-17.0	0.3
5	-19.0	-18.5	-14.9	-18.5	-19.0	-18.0	-18.0	-18.0	-18.5	-18.5	-18.5	-18.5	-18.0	-18.5	-18.0	-16.5
6	-17.7	-18.5	-18.5	-18.5	-11.4	-18.0	-18.0	-18.0	-18.5	-18.5	-18.5	-18.5	-18.0	-18.5	-18.0	-11.1
Feb-1	-17.0	-16.5	-19.0	-19.5	-20.5	-19.0	-19.0	-19.5	-19.5	-19.5	-19.5	-20.5	6.2	-18.7	-16.2	-14.1
2	-13.1	-19.5	-7.6	-19.5	-20.5	-19.0	-19.0	-19.5	-19.5	-19.5	-19.5	-20.5	-19.5	-13.1	-18.5	-9.1
3	-21.0	-20.5	-12.4	-20.5	-22.0	-20.0	-20.0	-20.5	-21.0	-20.5	-21.0	-18.3	-20.5	-21.0	-19.5	-19.5
4	-21.0	-20.5	-20.0	-20.5	-22.0	-20.0	-20.0	-20.5	-21.0	-20.5	-16.2	0.5	-20.5	-21.0	-16.3	-19.5
5	-20.2	-23.0	-22.5	-23.0	-23.5	-5.5	-22.5	-23.5	-23.5	23.2	-23.0	-23.5	-22.5	-23.0	-23.0	-11.6
6	-24.5	-23.0	-22.5	-23.0	-23.5	-22.0	-22.5	-23.5	-23.5	-22.5	-23.0	-20.0	-22.5	-21.3	-23.0	-22.0
Mar-1	-29.0	-21.7	-25.0	-14.1	-25.0	-24.0	-24.5	-26.0	-26.5	-24.5	-25.0	-25.0	-24.5	-25.5	-27.0	-24.0
2	-22.4	-21.7	-25.0	-3.4	-25.0	-24.0	-24.5	-26.0	-26.5	-24.5	-25.0	-25.0	-24.5	-25.5	-27.0	-24.0
3	-31.0	-27.0	-25.5	-25.0	-24.5	-24.5	-25.0	-26.5	-8.4	54.2	-25.0	-20.5	-24.0	-25.5	-28.0	-24.5
4	-31.0	-27.0	-25.5	-25.0	-10.2	-24.5	-25.0	-26.5	-23.7	-17.9	-25.0	-24.5	-24.0	-25.5	-28.0	-24.5
5	-52.5	-51.0	-39.6	-50.5	-50.5	-50.5	-51.0	-51.5	-51.0	-50.5	-50.5	-40.7	-40.1	-50.5	-51.5	-50.5
6	-52.5	-49.7	-39.1	-50.5	-50.5	-48.0	-51.0	-51.5	-51.0	-50.5	-50.5	-50.5	-42.7	-50.5	-38.4	-50.5

Table B-4 Availability of Cropwater Requirement, ACWR (mm/5day)

Station : Bogra

Interval SI.	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Apr-1	-65.5	-66.5	-54.3	-68.0	-67.5	-55.3	33.0	-68.0	-65.5	-69.5	-68.0	13.0	-69.0	-68.5	-64.0	-61.9
2	-65.5	-66.5	-69.0	-68.0	-67.5	-36.2	10.3	-68.0	-35.0	-69.5	-68.0	-63.5	-69.0	-68.5	-34.8	-67.0
3	-20.3	-33.5	-34.4	-36.0	-36.0	-37.0	-16.4	-37.0	105.2	-39.5	-37.0	9.0	-38.5	-37.0	11.4	5.9
4	-20.5	-3.8	-39.0	-32.9	2.1	-37.0	76.3	27.8	-17.0	-34.7	-37.0	0.0	-38.5	-37.0	-25.4	36.1
5	-32.5	-12.7	-38.5	-32.0	-33.0	-37.5	-37.5	-37.0	-34.0	-38.5	-36.0	-33.0	0.4	53.5	-31.0	-11.1
6	-30.5	-18.8	-38.5	-25.3	-36.0	-37.5	-37.5	-37.0	-34.0	-38.5	74.7	-20.6	-29.4	-15.3	-28.0	-14.9
May-1	16.4	11.7	-39.0	-36.5	-23.3	-31.6	-0.7	-37.5	-34.5	-37.0	26.8	-12.7	-34.5	-9.6	124.3	27.7
2	-33.0	37.7	-27.6	-14.9	131.6	-38.0	0.6	-37.5	-34.5	-37.0	-20.9	12.4	-35.0	56.4	91.2	-30.0
3	-3.5	-10.1	0.4	-27.9	-36.0	-38.0	65.9	-27.3	-35.0	-36.0	44.3	-1.3	48.3	-27.3	1.8	51.5
4	-32.5	19.2	-20.5	-36.0	-33.0	34.4	88.7	38.7	-35.0	-36.0	-0.9	45.3	-29.2	-4.5	-18.5	2.8
5	38.4	-1.3	1.8	-23.1	128.5	-23.3	46.5	2.1	-33.0	150.6	27.4	-27.4	10.9	-32.0	48.7	75.4
6	-24.1	-30.0	-34.5	-16.0	-21.3	17.3	25.6	-29.7	-33.0	-6.1	2.6	3.3	46.5	-34.5	27.1	96.6
Jun-1	-28.5	-27.0	60.5	24.2	-20.8	-33.5	-31.0	84.8	-31.5	48.3	32.7	2.3	-14.2	-23.9	18.8	70.6
2	187.4	-14.8	-29.5	-31.0	27.5	-10.6	-31.0	99.2	-31.5	-23.3	-27.5	-14.5	1.3	204.7	103.8	73.4
3	100.0	47.6	-0.1	-23.9	40.9	42.2	-29.0	-11.1	-30.0	-26.5	66.2	-29.5	-32.0	43.4	85.5	60.4
4	297.1	78.6	-16.4	-5.6	3.1	164.2	-29.0	-9.8	-30.0	103.1	129.3	9.6	31.6	-6.2	99.6	-15.0
5	25.3	12.3	7.0	13.4	18.3	-12.7	88.3	21.9	-29.0	-3.6	78.2	44.9	2.5	-29.5	69.3	176.3
6	122.8	-13.3	36.7	25.4	-18.3	45.7	-28.5	20.4	-29.0	-23.2	382.5	15.4	-22.4	-2.8	80.6	21.8
July-1	12.2	-13.1	141.3	57.6	73.1	-28.5	17.2	5.2	-28.0	-22.9	-15.6	-3.5	48.8	50.5	-27.0	-24.7
2	10.6	63.9	152.3	58.0	214.3	149.3	-9.5	19.2	-28.0	-21.4	11.3	-14.3	79.5	4.8	46.6	18.2
3	58.0	91.8	-21.5	22.3	-18.7	86.8	-26.0	112.7	-24.5	-23.2	4.3	60.5	-11.7	128.7	69.0	37.8
4	13.4	52.9	-10.0	-15.8	75.3	15.7	-26.0	8.5	-5.8	29.6	-21.7	119.7	163.8	-25.0	54.5	60.0
5	-21.8	29.4	-39.2	-50.0	-9.4	-31.5	-50.0	-6.3	18.8	47.1	51.1	48.7	62.6	-35.8	-25.1	11.8
6	115.1	163.6	255.8	11.6	-50.5	-50.5	-31.0	191.5	45.4	106.7	45.2	45.3	7.1	-51.0	79.7	-31.5
Aug-1	9.1	-56.4	12.9	-12.0	-63.5	0.0	-61.5	-0.4	3.9	-28.7	-4.7	-60.2	-57.3	80.2	-46.5	-24.4
2	-18.3	-63.5	-58.7	33.2	22.9	-11.1	-61.5	50.7	-6.6	24.8	21.1	-30.5	-54.3	64.2	-61.5	-34.0
3	19.8	-9.1	79.2	8.0	-29.5	36.6	-7.2	-2.1	14.2	20.5	-2.5	-13.6	-32.0	11.0	-1.3	-32.0
4	-20.6	-5.9	17.5	91.0	-20.6	-30.0	-25.0	-26.7	237.1	-19.0	-12.0	174.0	4.3	116.6	21.8	16.8
5	38.1	41.6	94.2	161.2	9.6	43.4	-26.0	6.0	-19.4	-2.8	-18.3	12.1	9.6	-11.7	0.0	-19.8
6	-18.8	-20.4	188.5	-1.4	-17.1	-29.0	-26.0	30.2	9.6	-8.6	-11.1	0.8	-30.5	-10.5	-12.7	27.1
Sep-1	-26.5	28.4	-16.1	-27.0	-14.3	-28.0	-27.0	-27.0	-27.0	-28.5	-4.1	-27.0	-30.5	64.4	141.5	10.9
2	-22.6	29.0	-0.8	2.7	140.6	-28.0	-27.0	-16.8	-27.0	-28.5	67.1	25.5	29.2	-19.3	0.5	-11.8
3	-6.4	-22.0	-15.8	-28.0	-22.0	45.4	-27.5	24.8	-27.0	-28.0	-0.1	9.6	-4.1	3.5	-6.6	55.8
4	9.9	46.4	19.2	-26.5	79.1	-27.0	-27.5	-0.6	-27.0	154.1	41.6	43.4	13.9	-29.5	49.2	33.5
5	2.5	-24.0	-19.9	-14.3	45.6	-13.8	-27.0	13.9	-26.5	1.4	-27.0	-25.7	-10.0	-26.0	-25.5	134.6
6	-21.1	-26.0	-6.9	28.9	-13.8	26.8	-27.0	-24.7	-26.5	-28.0	58.6	17.4	31.5	-28.5	26.6	6.3
Oct-1	-14.9	-10.8	-25.5	34.5	-3.6	116.2	-27.0	33.6	340.6	-28.0	24.1	-4.2	-21.9	-19.1	74.7	-26.7
2	-26.0	188.3	-24.7	-26.0	-1.1	-26.0	-27.0	-2.9	-0.6	40.1	-26.2	-26.5	-28.5	-28.0	-10.5	-27.5
3	79.2	-19.4	-24.5	-19.1	-16.8	-25.5	-27.0	-25.0	-25.5	-28.5	5.2	-25.5	-3.6	-27.0	-19.1	-28.0
4	-25.0	-24.0	-24.5	-12.3	-27.5	-25.5	-27.0	-25.0	-25.5	-28.5	-26.0	-10.0	-28.0	41.6	-20.4	-28.0
5	86.2	88.5	6.7	-20.2	-25.5	-24.5	-25.5	80.1	-24.5	-26.5	-21.9	86.8	-26.0	-23.0	-22.2	-26.0
6	-23.5	-12.8	-23.5	-24.0	-25.5	7.3	-25.5	-24.0	-9.3	-18.1	-21.5	4.4	-26.0	-25.5	-13.0	-26.0
Nov-1	-14.4	-23.0	-10.3	-23.0	-23.5	-23.0	-23.5	-23.5	3.7	-24.0	-23.5	-21.5	-24.5	-24.0	-8.8	-14.6
2	-23.5	-23.0	-23.0	-23.0	-23.5	-23.0	-23.5	-23.5	-21.0	-24.0	-3.1	-21.5	-24.5	-24.0	-8.5	-24.0
3	-20.5	-21.0	-20.0	-20.0	-20.0	-20.0	-20.0	-10.4	-21.0	-20.5	-20.2	-48.5	-21.0	-20.5	-20.0	-20.0
4	-20.5	-21.0	-20.0	-20.0	-20.0	-20.0	-20.0	-20.5	-21.0	-20.5	-18.7	-48.5	-21.0	-20.5	-20.0	-20.0
5	-48.0	-48.0	-48.0	-23.1	-48.0	-48.0	-48.0	-48.0	-48.5	-48.0	-48.0	-48.5	-48.0	-48.0	-48.0	-48.0
6	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0	-48.5	-48.0	-48.0	-48.5	-48.0	-48.0	-48.0	-48.0
Dec-1	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-59.0	-57.0	-57.0	-57.5	-57.0	-57.0	-56.5	-57.0
2	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-59.0	-57.0	-15.4	-57.5	-57.0	-57.0	-56.5	-57.0
3	-20.0	-19.5	-20.5	-20.0	-20.5	-20.0	-20.0	-19.5	-23.5	-20.0	-20.5	-20.5	-20.0	-20.0	-20.0	-20.0
4	-20.0	-19.5	-20.5	-20.0	-20.5	-20.0	-20.0	-19.5	-23.5	-20.0	-20.5	-20.0	-20.0	-20.0	-20.0	-20.0
5	-19.5	-19.5	-18.0	-20.0	-20.0	-20.0	-20.0	-19.5	-22.0	-20.0	-20.0	-20.0	-20.0	-20.0	-19.5	-20.0
6	-19.5	-19.5	-20.0	-20.0	-20.0	-20.0	-20.0	-19.5	-22.0	-20.0	-20.0	-20.0	-20.0	-20.0	-8.8	-20.0
Jan-1	-19.0	-19.5	19.9	-20.0	-19.5	-20.0	-20.0	-19.0	-19.5	-20.0	-19.0	-19.0	-20.0	-19.5	-19.0	-19.5
2	-19.0	-19.5	-19.5	-8.3	18.6	-20.0	-20.0	-19.0	-19.5	-6.8	-19.0	-19.0	-20.0	-19.5	-19.0	-19.5
3	-15.5	-19.5	-19.0	-20.0	-6.3	-9.3	-20.0	-18.0	-17.5	-19.5	-12.7	-18.5	-20.0	-19.0	-18.5	-19.0
4	-18.0	-19.5	-19.0	-20.0	-19.0	-22.0	-20.0	-18.0	-17.5	-19.5	-18.5	-18.5	-20.0	-19.0	-18.5	-11.1
5	-20.0	-20.5	-20.5	-21.0	-20.5	-23.0	-7.0	-18.0	-19.5	-20.5	-20.0	-17.5	-21.0	-21.0	-18.0	-20.0
6	-20.0	-20.5	-20.5	-21.0	-20.5	-23.0	-21.0	-11.1	-19.5	-20.5	-20.0	-20.0	-21.0	-18.9	-19.5	-18.7
Feb-1	-21.5	-22.0	-22.5	-22.0	-22.5	-25.0	-22.0	-22.0	-14.7	-21.5	-22.0	-13.1	-22.0	-11.6	-20.5	-18.0
2	-21.5	-22.0	-22.5	-22.0	-22.5	-25.0	-22.0	-22.0	-15.7	-21.5	-22.0	-23.0	-22.0	-23.0	-10.4	-14.1
3	-23.0	-23.0	-24.0	-23.5	-24.0	-27.0	-23.5	-23.5	-17.2	-23.0	-23.5	-25.0	-23.5	-24.5	-21.5	-22.0
4	-23.0	-23.0	-24.0	-23.5	-24.0	-27.0	-9.5	-23.5	-23.0	-19.4	-23.5	-25.0	-23.5	-24.5	-21.5	-22.0
5	-21.2	-25.5	-26.0	-25.5	-26.0	-27.0	-25.5	-25.3	-25.0	-25.5	-25.5	-26.5	-25.5	-23.6	-23.5	-20.2
6	-24.5	-25.5	-26.0	-25.5	-26.0	-27.0	-25.5	-19.9	-25.0	48.2	-25.5	-26.5	-25.5	-27.5	-23.5	-24.5
Mar-1	-26.5	-28.0	-28.0	-27.5	-28.0	-19.0	-27.5	-28.0	-26.5	-28.0	-27.0	-26.0	-28.0	-30.0	-25.5	-27.5
2	-26.5	-28.0	-26.5	-27.5	-28.0	-19.0	-27.5	-28.0	-26.0	-18.8	-27.0	-26.0	-12.8	-30.0	-25.5	-20.9
3	-26.0	-28.0	-27.5	51.7	-27.5	-18.5	-27.0	-28.0	-26.5	-28.0	-27.0	-22.0	-28.0	-31.0	-17.4	-28.0
4	17.7	-28.0	-27.5	-27.0	-27.5	0.5	-27.0	-28.0	-26.5	-28.0	-27.0	-22.0	-28.0	-31.0	-23.0	-28.0
5	-48.2	-24.8	-52.0	-24.0	-51.5	24.7	-51.5	-51.5	-51.0	-52.0	-2.5	-51.0	-52.0	-52.5	-45.4	-51.5
6	-51.0	-51.5	-52.0	-52.0	-51.5	-51.5	-51.5	-51.5	-51.0	-52.0	-11.2	-51.0	-52.0	-52.5	-41.9	-51.5

Table B-4 Availability of Cropwater Requirement, ACWR (mm/5day)

Station Bogra

Interval SI	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Apr-1	-68.0	-69.5	-35.5	-66.0	-65.0	-67.0	-67.5	-30.9	-65.0	-65.5	-66.5	-47.5	-66.0	-67.5	-66.0	-57.9
2	-68.0	-69.5	-66.0	-66.0	-65.0	-67.0	-67.5	-57.6	-47.2	-65.5	-66.5	-35.0	-64.8	-67.5	-66.0	-66.0
3	-4.3	-40.0	29.5	-8.4	-28.2	-36.0	-36.5	-18.8	-32.5	-33.5	-34.0	-34.5	-26.0	-36.0	-15.7	-34.0
4	-23.8	-25.3	77.5	-9.9	-25.4	-36.0	-36.5	-34.0	-23.6	8.4	-34.0	-25.5	-35.0	-36.0	-21.3	-27.5
5	-4.0	-15.9	-26.7	-29.4	-32.0	-35.5	4.1	21.9	2.1	-16.7	-34.0	-34.0	10.5	-35.0	13.7	-4.3
6	-15.7	-32.4	-1.2	-13.2	4.8	17.0	-25.3	34.5	20.8	-17.3	-34.0	-31.0	-32.5	-10.5	-14.2	-34.5
May-1	-40.0	93.0	-31.2	-36.0	36.6	53.6	-18.8	56.7	91.5	31.0	-33.5	1.0	6.2	63.5	-30.8	-34.5
2	-40.0	45.4	-22.3	-22.0	-32.0	33.1	-18.3	-18.3	-14.2	-19.1	-33.5	3.0	-29.0	-34.0	145.2	-28.5
3	-6.4	57.4	-8.4	15.1	46.2	112.5	89.6	-25.4	-36.0	-3.1	43.9	-7.5	37.2	-26.5	-9.5	-34.5
4	-42.0	43.0	46.0	-37.0	-15.0	-3.3	-32.5	22.8	-36.0	-28.5	-5.3	-2.5	-3.7	-7.7	101.6	-10.6
5	-28.3	-31.5	7.6	-20.0	73.2	5.1	42.7	-25.6	-17.2	74.1	22.1	60.5	72.7	-31.0	-29.5	-26.9
6	-38.5	68.4	33.2	-1.3	-25.9	40.9	-25.9	-28.7	-24.9	140.2	243.0	19.0	127.4	-15.3	-23.1	49.5
Jun-1	-34.5	-9.7	-12.2	15.0	-30.5	24.1	192.9	-30.5	14.2	-27.5	26.8	67.0	-5.5	11.3	-4.4	0.4
2	-25.4	104.9	-26.2	31.5	-26.7	276.5	-26.5	-30.5	58.9	16.0	16.7	88.3	41.2	-12.6	43.6	5.8
3	21.3	26.2	-29.5	-15.8	-24.1	20.3	-28.0	41.1	-26.2	96.2	56.0	-4.0	62.6	44.9	187.7	68.3
4	-28.2	45.2	-2.6	27.3	36.9	148.2	71.1	-14.7	-10.9	177.5	6.8	-20.0	35.7	-13.0	169.2	9.0
5	-25.2	-9.5	-13.8	3.4	-29.5	50.4	6.5	-23.4	136.7	396.4	3.5	93.5	4.7	68.0	-28.5	-4.3
6	-2.8	-17.8	33.2	1.5	28.4	-23.5	2.5	74.4	-8.1	-25.7	-20.1	-9.0	3.0	7.9	141.4	19.3
July-1	8.3	-10.2	111.3	-26.5	108.4	-14.6	-18.7	64.4	22.4	132.1	392.8	146.5	-20.7	-13.1	67.0	41.9
2	-28.0	44.8	-4.3	23.0	16.7	113.6	102.3	38.0	92.4	225.4	6.0	60.0	182.0	104.3	-4.5	-22.5
3	46.3	32.4	-9.6	16.7	-25.5	119.9	4.1	29.8	43.9	73.3	120.3	2.7	-10.9	61.4	44.1	-27.5
4	240.9	119.6	125.3	2.7	-18.7	10.6	32.1	-14.6	-3.1	-8.0	6.5	31.6	92.6	76.8	17.8	-27.5
5	57.8	-5.5	-44.9	156.8	-27.6	-10.2	-3.8	108.8	160.2	-2.5	-50.0	30.5	39.1	-40.4	260.0	25.6
6	87.6	-17.0	8.8	91.2	15.6	100.7	-17.7	7.1	158.3	-43.2	136.5	76.8	-9.7	0.0	-45.2	-13.4
Aug-1	-63.0	-47.2	-41.0	50.5	52.8	-30.0	-44.7	53.8	214.9	-54.7	-55.0	-6.4	90.8	-52.0	-0.3	-49.6
2	-63.0	-2.7	-60.2	-37.8	-45.0	-62.5	-34.5	-28.7	-44.3	-50.1	-54.0	-25.0	7.0	24.9	-52.6	-64.0
3	-25.8	5.0	-21.9	-1.3	-17.1	-28.5	29.4	-21.9	144.5	100.2	-23.2	9.5	-23.5	-27.5	-27.0	97.2
4	36.0	30.5	-31.0	-10.2	-19.6	7.3	-4.1	-29.5	19.5	-25.5	-22.1	-29.5	-16.5	-29.5	-13.1	-29.0
5	23.6	18.5	-29.5	3.6	63.5	8.3	48.5	6.3	104.9	14.9	39.9	-28.5	0.0	13.7	80.9	9.8
6	-27.5	-7.7	-29.5	82.0	27.4	81.0	-26.0	13.9	65.5	62.6	17.0	44.8	40.3	20.8	31.3	4.4
Sep-1	-29.5	82.5	-27.5	-28.5	-7.0	104.1	-11.8	19.7	-9.8	45.4	-26.0	27.0	0.7	-27.0	82.5	-28.0
2	6.1	26.5	-27.5	14.0	4.5	60.3	11.3	-22.2	-20.4	-26.5	12.1	-18.5	-3.0	-29.0	64.9	-22.0
3	-29.0	80.8	-25.5	-4.4	38.7	80.9	56.8	19.9	-24.5	-1.1	42.0	-7.5	36.1	-22.0	95.4	-3.1
4	-18.8	2.0	-25.5	-28.0	79.2	-0.1	45.9	-2.9	-16.6	38.8	29.6	18.0	83.5	-2.2	-14.3	-27.0
5	-28.5	17.8	-26.5	-14.0	-19.4	50.0	-19.6	-20.7	-10.0	47.2	198.2	67.5	50.9	-19.7	-26.0	33.3
6	-28.5	44.1	-26.5	4.7	-24.5	-18.4	87.1	-24.0	20.7	104.8	69.3	101.0	57.0	-12.2	-18.6	2.8
Oct-1	1.0	-0.4	-27.5	-26.5	-13.6	122.3	-18.4	12.8	-22.2	39.6	-24.0	28.5	14.7	-17.1	26.8	-15.1
2	-17.9	30.9	-27.5	-26.5	145.4	-3.7	-12.0	311.1	-26.0	-9.4	-13.0	119.0	-16.5	-26.5	-20.3	132.7
3	-28.0	-26.0	-28.5	-26.0	187.9	6.8	46.4	20.4	-26.5	-27.5	-24.0	-14.6	-13.4	94.6	2.2	-27.0
4	-28.0	186.4	-28.5	-26.0	-24.0	-25.0	45.0	-17.6	-7.4	-27.5	-2.5	-22.0	-23.5	-24.0	-17.1	-27.0
5	-22.2	115.5	-26.5	2.2	-15.6	-24.5	-24.5	-23.0	-25.0	-25.5	-23.0	-23.0	-23.0	-21.5	-24.0	-25.0
6	-26.0	-25.0	-26.5	-24.5	-23.5	-24.5	-24.5	-23.0	-25.0	-25.5	-23.0	-23.0	-22.9	-25.0	-24.0	-8.5
Nov-1	-24.0	-24.0	-24.0	-22.5	-23.0	-23.5	-23.5	-22.0	-23.0	-24.0	-22.0	-22.5	-22.0	-23.5	-23.0	-23.0
2	-24.0	-24.0	-24.0	-17.2	-23.0	-23.5	-23.5	-8.1	-23.0	-22.7	-22.0	-22.5	-22.0	-23.5	-23.0	-21.0
3	-20.5	-21.0	-20.5	-8.1	-20.5	-21.0	-20.0	-19.5	-0.4	-20.5	-19.5	-20.0	-19.5	-20.5	-20.0	-19.0
4	-20.5	-21.0	-20.5	-19.0	-20.5	-21.0	-20.0	-19.5	-19.5	-20.5	-19.5	-20.0	-19.5	-20.5	-20.0	-19.0
5	-48.0	-48.0	-48.0	-47.5	-48.0	-48.0	-48.0	-47.5	-47.5	-48.0	-47.5	-47.5	-46.7	-41.1	-47.5	-45.5
6	-36.6	-48.0	-48.0	-47.5	-48.0	-48.0	-48.0	-47.5	-47.5	46.2	-47.5	-47.5	-47.5	-48.0	-47.5	-47.5
Dec-1	-19.7	-57.0	-56.5	-56.0	-56.5	-56.5	-56.5	-56.5	-56.5	-57.0	-56.5	-56.0	-56.0	-57.0	-56.5	-56.5
2	-57.0	-57.0	-56.5	-56.0	-56.5	-56.5	-56.5	-56.5	-56.5	-57.0	-56.5	-56.0	-56.0	-57.0	-56.5	-56.5
3	-20.0	-20.0	-19.0	-18.5	-19.5	-15.2	-19.0	22.9	-8.5	-19.5	-19.0	-19.0	18.5	-20.0	-19.0	-20.0
4	-20.0	-20.0	-19.0	-18.5	-19.5	-19.0	-19.0	-19.0	-20.0	-19.5	-19.0	-19.0	-18.5	-20.0	-19.0	-20.0
5	-20.0	-19.5	-19.0	-18.5	-19.0	-19.0	-19.0	-19.0	-19.5	-19.5	-19.0	-18.5	-18.5	-19.0	-18.5	-19.5
6	-20.0	-19.5	-19.0	-18.5	11.2	-19.0	-16.5	-19.0	-19.5	-19.5	-14.0	-18.5	-18.5	-19.0	-18.5	-19.5
Jan-1	-11.6	-19.5	-19.0	-19.0	-19.0	-19.0	-18.5	-19.0	-19.0	-19.0	-19.0	-16.8	-18.5	-17.5	-17.5	-19.5
2	-20.0	17.6	-19.0	-19.0	-19.0	-19.0	-18.5	-19.0	-19.0	-19.0	-19.0	-18.5	-18.5	75.2	-17.5	-6.5
3	-19.5	-12.6	-18.5	-19.0	-18.5	-18.5	-19.5	-18.5	-18.5	-19.0	-18.5	-17.9	-18.0	-16.5	-17.0	-18.5
4	-19.5	-15.2	-18.5	-19.0	-10.6	-18.5	-19.5	-18.5	-18.5	-19.0	-18.5	-18.0	-18.0	-16.5	-1.2	-18.5
5	-21.0	-16.4	-20.0	-20.0	-19.5	-19.5	-20.5	-19.5	-19.5	-20.0	-19.5	-19.0	-19.5	-18.0	-18.5	-17.5
6	-21.0	-20.0	-20.0	-12.4	-19.5	-19.5	-20.5	-19.5	-19.5	-20.0	-19.5	-19.0	-19.5	-18.0	-13.1	-17.5
Feb-1	-19.5	-21.0	-21.0	-21.0	-21.0	-20.5	-22.0	-21.0	-21.0	-21.0	-21.0	5.7	-19.2	-17.2	-16.1	-18.5
2	-22.5	-9.6	-21.0	-21.0	-21.0	-20.5	-22.0	-21.0	-21.0	-21.0	-21.0	-20.0	-13.6	-19.5	-11.1	-17.1
3	-24.0	-14.4	-22.5	-22.5	-22.0	-21.5	-24.5	-22.5	-22.0	-22.0	-18.8	-21.5	-21.5	-21.5	-21.0	-20.0
4	-24.0	-22.0	-22.5	-22.5	-22.0	-21.5	-24.5	-22.5	-22.0	-17.2	0.0	-21.5	-21.5	-18.3	-21.0	-13.6
5	-26.5	-24.5	-24.5	-24.0	-8.0	-24.0	-27.0	-24.5	21.7	-24.0	-24.5	-23.5	-23.5	-24.0	-13.1	-12.3
6	-26.5	-24.5	-24.5	-24.0	-24.5	-24.0	-27.0	-24.5	-24.0	-24.0	-21.0	-23.5	-21.8	-24.0	-23.5	-21.0
Mar-1	-25.2	-26.5	-16.1	-25.5	-27.0	-26.0	-27.0	-27.0	-25.5	-25.5	-27.0	-25.5	-25.0	-26.5	-26.0	-23.0
2	-25.2	-26.5	-5.4	-25.5	-27.0	-26.0	-27.0	-27.0	-25.5	-25.5	-27.0	-25.5	-25.0	-27.0	-26.5	-25.5
3	-30.5	-27.0	-27.0	-25.5	-27.5	-26.0	-25.0	-8.4	53.7	-25.5	-23.5	-25.5	-25.0	-27.0	-26.5	-25.5
4	-30.5	-27.0	-27.0	-11.2	-27.5	-26.0	-25.0	-23.7	-18.4	-25.5	-27.5	-25.5	-25.0	-27.0	-26.5	-25.5
5	-52.5	-40.1	-51.0	-51.0	-51.0	-51.0	-51.5	-51.5	-50.5	-51.0	-41.7	-41.1	-50.5	-51.5	-51.0	-51.0
6	-51.2	-39.6	-51.0	-51.0	-48.5	-51.0	-51.5	-51.5	-50.5	-51.0	-51.5	-43.7	-50.5	-38.4	-51.0	-34.5

Table B-5 Hypothetical Probabilities with P1(+) = 0.5 and P1(-) = 0.5

		Case 1		Case 2		Case 3		Case 4	
i	Time Interval	Pi(+/+)	Pi(-/-)	Pi(+/+)	Pi(-/-)	Pi(+/+)	Pi(-/-)	Pi(+/+)	Pi(-/-)
1	Apr-1	0.025	0.975	0.975	0.025	0.025	0.975	0.975	0.025
2	2	0.050	0.950	0.950	0.050	0.975	0.025	0.975	0.025
3	3	0.075	0.925	0.925	0.075	0.025	0.975	0.975	0.025
4	4	0.100	0.900	0.900	0.100	0.975	0.025	0.975	0.025
5	5	0.125	0.875	0.875	0.125	0.025	0.975	0.975	0.025
6	6	0.150	0.850	0.850	0.150	0.975	0.025	0.975	0.025
7	May-1	0.175	0.825	0.825	0.175	0.025	0.975	0.975	0.025
8	2	0.200	0.800	0.800	0.200	0.975	0.025	0.975	0.025
9	3	0.225	0.775	0.775	0.225	0.025	0.975	0.975	0.025
10	4	0.250	0.750	0.750	0.250	0.975	0.025	0.975	0.025
11	5	0.275	0.725	0.725	0.275	0.025	0.975	0.975	0.025
12	6	0.300	0.700	0.700	0.300	0.975	0.025	0.975	0.025
13	Jun-1	0.325	0.675	0.675	0.325	0.025	0.975	0.975	0.025
14	2	0.350	0.650	0.650	0.350	0.975	0.025	0.975	0.025
15	3	0.375	0.625	0.625	0.375	0.025	0.975	0.975	0.025
16	4	0.400	0.600	0.600	0.400	0.975	0.025	0.975	0.025
17	5	0.425	0.575	0.575	0.425	0.025	0.975	0.975	0.025
18	6	0.450	0.550	0.550	0.450	0.975	0.025	0.975	0.025
19	July-1	0.475	0.525	0.525	0.475	0.025	0.975	0.975	0.025
20	2	0.500	0.500	0.500	0.500	0.975	0.025	0.975	0.025
21	3	0.525	0.475	0.475	0.525	0.025	0.975	0.975	0.025
22	4	0.550	0.450	0.450	0.550	0.975	0.025	0.975	0.025
23	5	0.575	0.425	0.425	0.575	0.025	0.975	0.975	0.025
24	6	0.600	0.400	0.400	0.600	0.975	0.025	0.975	0.025
25	Aug-1	0.625	0.375	0.375	0.625	0.025	0.975	0.975	0.025
26	2	0.650	0.350	0.350	0.650	0.975	0.025	0.975	0.025
27	3	0.675	0.325	0.325	0.675	0.025	0.975	0.975	0.025
28	4	0.700	0.300	0.300	0.700	0.975	0.025	0.975	0.025
29	5	0.725	0.275	0.275	0.725	0.025	0.975	0.975	0.025
30	6	0.750	0.250	0.250	0.750	0.975	0.025	0.975	0.025
31	Sep-1	0.775	0.225	0.225	0.775	0.025	0.975	0.975	0.025
32	2	0.800	0.200	0.200	0.800	0.975	0.025	0.975	0.025
33	3	0.825	0.175	0.175	0.825	0.025	0.975	0.975	0.025
34	4	0.850	0.150	0.150	0.850	0.975	0.025	0.975	0.025
35	5	0.875	0.125	0.125	0.875	0.025	0.975	0.975	0.025
36	6	0.900	0.100	0.100	0.900	0.975	0.025	0.975	0.025
37	Oct-1	0.925	0.075	0.125	0.875	0.025	0.975	0.025	0.975
38	2	0.900	0.100	0.150	0.850	0.975	0.025	0.025	0.975
39	3	0.875	0.125	0.175	0.825	0.025	0.975	0.025	0.975
40	4	0.850	0.150	0.200	0.800	0.975	0.025	0.025	0.975
41	5	0.825	0.175	0.225	0.775	0.025	0.975	0.025	0.975
42	6	0.800	0.200	0.250	0.750	0.975	0.025	0.025	0.975
43	Nov-1	0.775	0.225	0.275	0.725	0.025	0.975	0.025	0.975
44	2	0.750	0.250	0.300	0.700	0.975	0.025	0.025	0.975
45	3	0.725	0.275	0.325	0.675	0.025	0.975	0.025	0.975
46	4	0.700	0.300	0.350	0.650	0.975	0.025	0.025	0.975
47	5	0.675	0.325	0.375	0.625	0.025	0.975	0.025	0.975
48	6	0.650	0.350	0.400	0.600	0.975	0.025	0.025	0.975
49	Dec-1	0.625	0.375	0.425	0.575	0.025	0.975	0.025	0.975
50	2	0.600	0.400	0.450	0.550	0.975	0.025	0.025	0.975
51	3	0.575	0.425	0.475	0.525	0.025	0.975	0.025	0.975
52	4	0.550	0.450	0.500	0.500	0.975	0.025	0.025	0.975
53	5	0.525	0.475	0.525	0.475	0.025	0.975	0.025	0.975
54	6	0.500	0.500	0.550	0.450	0.975	0.025	0.025	0.975
55	Jan-1	0.475	0.525	0.575	0.425	0.025	0.975	0.025	0.975
56	2	0.450	0.550	0.600	0.400	0.975	0.025	0.025	0.975
57	3	0.425	0.575	0.625	0.375	0.025	0.975	0.025	0.975
58	4	0.400	0.600	0.650	0.350	0.975	0.025	0.025	0.975
59	5	0.375	0.625	0.675	0.325	0.025	0.975	0.025	0.975
60	6	0.350	0.650	0.700	0.300	0.975	0.025	0.025	0.975
61	Feb-1	0.325	0.675	0.725	0.275	0.025	0.975	0.025	0.975
62	2	0.300	0.700	0.750	0.250	0.975	0.025	0.025	0.975
63	3	0.275	0.725	0.775	0.225	0.025	0.975	0.025	0.975
64	4	0.250	0.750	0.800	0.200	0.975	0.025	0.025	0.975
65	5	0.225	0.775	0.825	0.175	0.025	0.975	0.025	0.975
66	6	0.200	0.800	0.850	0.150	0.975	0.025	0.025	0.975
67	Mar-1	0.175	0.825	0.875	0.125	0.025	0.975	0.025	0.975
68	2	0.150	0.850	0.900	0.100	0.975	0.025	0.025	0.975
69	3	0.125	0.875	0.920	0.080	0.025	0.975	0.025	0.975
70	4	0.100	0.900	0.930	0.070	0.975	0.025	0.025	0.975
71	5	0.075	0.925	0.940	0.060	0.025	0.975	0.025	0.975
72	6	0.050	0.950	0.950	0.050	0.975	0.025	0.025	0.975
Average		0.475	0.525	0.548	0.452	0.500	0.500	0.500	0.500

Table B-6 Actual Probabilities for Truncation Level, xo(t) = Normal

		Station : Bogra		Station : Rangpur	
		P1(-) = 0.7813 and P1(+) = 0.2188		P1(-) = 0.8125 and P1(+) = 0.1875	
i	Time Interval	Pi(-/-)	Pi(+/+)	Pi(-/-)	Pi(+/+)
1	Apr-1	0.720	0.143	0.731	0.000
2	2	0.760	0.286	0.760	0.286
3	3	0.619	0.273	0.682	0.300
4	4	0.652	0.222	0.652	0.222
5	5	0.684	0.538	0.650	0.417
6	6	0.650	0.500	0.714	0.455
7	May-1	0.632	0.462	0.579	0.462
8	2	0.545	0.100	0.652	0.111
9	3	0.571	0.273	0.636	0.300
10	4	0.619	0.364	0.353	0.200
11	5	0.579	0.385	0.600	0.417
12	6	0.632	0.462	0.632	0.462
13	Jun-1	0.444	0.357	0.500	0.357
14	2	0.619	0.273	0.600	0.333
15	3	0.563	0.500	0.500	0.500
16	4	0.619	0.273	0.667	0.364
17	5	0.636	0.300	0.682	0.300
18	6	0.609	0.000	0.591	0.100
19	July-1	0.632	0.462	0.556	0.357
20	2	0.684	0.615	0.684	0.615
21	3	0.529	0.467	0.556	0.429
22	4	0.714	0.545	0.632	0.462
23	5	0.632	0.462	0.650	0.417
24	6	0.529	0.467	0.500	0.500
25	Aug-1	0.444	0.286	0.444	0.286
26	2	0.700	0.500	0.650	0.500
27	3	0.600	0.250	0.550	0.333
28	4	0.727	0.500	0.619	0.273
29	5	0.619	0.273	0.600	0.333
30	6	0.684	0.615	0.611	0.429
31	Sep-1	0.591	0.200	0.636	0.200
32	2	0.579	0.462	0.600	0.333
33	3	0.500	0.250	0.579	0.308
34	4	0.556	0.500	0.529	0.533
35	5	0.682	0.300	0.667	0.455
36	6	0.579	0.462	0.529	0.467
37	Oct-1	0.545	0.100	0.619	0.273
38	2	0.720	0.000	0.731	0.000
39	3	0.833	0.500	0.833	0.500
40	4	0.731	0.000	0.731	0.000
41	5	0.800	0.286	0.760	0.286
42	6	0.760	0.143	0.750	0.250
43	Nov-1	0.852	0.200	0.815	0.200
44	2	0.778	0.000	0.778	0.000
45	3	0.760	0.143	0.857	0.250
46	4	0.000	0.935	0.250	0.500
47	5	0.893	0.250	0.900	0.000
48	6	0.900	0.000	0.900	0.000
49	Dec-1	0.935	0.000	0.900	0.000
50	2	0.935	0.000	0.900	0.000
51	3	0.897	0.333	0.857	0.250
52	4	0.684	0.615	0.625	0.625
53	5	0.750	0.800	0.643	0.667
54	6	0.821	0.000	0.821	0.000
55	Jan-1	0.815	0.200	0.862	0.000
56	2	0.808	0.167	0.815	0.200
57	3	0.750	0.250	0.808	0.167
58	4	0.769	0.167	0.857	0.000
59	5	0.739	0.333	0.808	0.167
60	6	0.750	0.250	0.815	0.000
61	Feb-1	0.783	0.444	0.750	0.250
62	2	0.833	0.500	0.808	0.167
63	3	0.722	0.643	0.800	0.286
64	4	0.840	0.429	0.815	0.200
65	5	0.846	0.167	0.769	0.000
66	6	0.815	0.000	0.862	0.000
67	Mar-1	0.526	0.308	0.444	0.286
68	2	0.769	0.000	0.720	0.143
69	3	0.815	0.200	0.857	0.250
70	4	0.760	0.143	0.778	0.000
71	5	0.720	0.143	0.720	0.143
72	6	0.769	0.000	0.778	0.000
Average		0.688	0.305	0.688	0.262

Table B-7 Actual Probabilities for Truncation Level, xo(t) = 40th Percentile

		Station : Bogra		Station : Rangpur	
		P1(-) = 0.5313 and P1(+) = 0.4688		P1(-) = 0.5625 and P1(+) = 0.4375	
i	Time Interval	Pi(-/-)	Pi(+/+)	Pi(-/-)	Pi(+/+)
1	Apr-1	0.412	0.267	0.500	0.429
2	2	0.500	0.438	0.500	0.429
3	3	0.526	0.308	0.526	0.308
4	4	0.579	0.385	0.526	0.385
5	5	0.684	0.538	0.632	0.462
6	6	0.632	0.538	0.632	0.462
7	May-1	0.632	0.462	0.579	0.462
8	2	0.444	0.357	0.526	0.231
9	3	0.474	0.308	0.579	0.462
10	4	0.474	0.308	0.474	0.154
11	5	0.579	0.385	0.526	0.385
12	6	0.632	0.462	0.632	0.462
13	Jun-1	0.526	0.385	0.526	0.385
14	2	0.474	0.231	0.526	0.308
15	3	0.737	0.538	0.684	0.538
16	4	0.526	0.308	0.579	0.385
17	5	0.526	0.308	0.526	0.308
18	6	0.526	0.231	0.474	0.231
19	July-1	0.632	0.462	0.579	0.308
20	2	0.684	0.615	0.684	0.615
21	3	0.526	0.308	0.526	0.308
22	4	0.632	0.538	0.632	0.462
23	5	0.632	0.462	0.632	0.462
24	6	0.579	0.385	0.526	0.308
25	Aug-1	0.474	0.231	0.474	0.231
26	2	0.684	0.538	0.684	0.615
27	3	0.526	0.231	0.474	0.308
28	4	0.684	0.615	0.632	0.462
29	5	0.632	0.462	0.526	0.308
30	6	0.684	0.615	0.579	0.308
31	Sep-1	0.474	0.308	0.526	0.308
32	2	0.579	0.462	0.632	0.462
33	3	0.421	0.231	0.579	0.308
34	4	0.526	0.385	0.526	0.385
35	5	0.500	0.286	0.632	0.462
36	6	0.579	0.462	0.526	0.308
37	Oct-1	0.368	0.154	0.526	0.308
38	2	0.474	0.231	0.474	0.308
39	3	0.611	0.500	0.611	0.500
40	4	0.471	0.467	0.579	0.385
41	5	0.632	0.462	0.579	0.462
42	6	0.588	0.467	0.579	0.385
43	Nov-1	0.429	0.500	0.471	0.467
44	2	0.429	0.556	0.438	0.500
45	3	0.600	0.647	0.611	0.500
46	4	0.533	0.588	0.556	0.429
47	5	0.000	0.900	0.400	0.852
48	6	0.000	0.900	0.400	0.852
49	Dec-1	0.722	0.643	0.556	0.429
50	2	0.722	0.643	0.500	0.500
51	3	0.722	0.714	0.600	0.647
52	4	0.684	0.615	0.625	0.625
53	5	0.750	0.800	0.643	0.667
54	6	0.769	0.789	0.538	0.632
55	Jan-1	0.417	0.650	0.824	0.800
56	2	0.444	0.739	0.765	0.733
57	3	0.333	0.550	0.500	0.500
58	4	0.462	0.579	0.632	0.462
59	5	0.563	0.563	0.125	0.667
60	6	0.688	0.688	0.286	0.760
61	Feb-1	0.667	0.800	0.364	0.667
62	2	0.733	0.765	0.538	0.684
63	3	0.722	0.643	0.438	0.438
64	4	0.647	0.600	0.467	0.529
65	5	0.778	0.643	0.438	0.438
66	6	0.684	0.538	0.438	0.438
67	Mar-1	0.526	0.308	0.444	0.286
68	2	0.579	0.385	0.400	0.471
69	3	0.632	0.462	0.684	0.538
70	4	0.632	0.385	0.400	0.471
71	5	0.333	0.550	0.667	0.643
72	6	0.600	0.588	0.529	0.533
Average		0.559	0.491	0.541	0.461

Table B-8 Actual Probabilities for Truncation Level, Xo(t) = Median

		Station : Bogra		Station : Rangpur	
		P1(-) = 0.4375 and P1(+) = 0.5625		P1(-) = 0.375 and P1(+) = 0.625	
i	Time Interval	Pi(-/-)	Pi(+/+)	Pi(-/-)	Pi(+/+)
1	Apr-1	0.357	0.444	0.333	0.600
2	2	0.500	0.438	0.333	0.600
3	3	0.438	0.438	0.438	0.438
4	4	0.533	0.588	0.500	0.500
5	5	0.688	0.688	0.500	0.500
6	6	0.467	0.588	0.500	0.500
7	May-1	0.500	0.500	0.438	0.500
8	2	0.375	0.438	0.500	0.438
9	3	0.438	0.438	0.500	0.563
10	4	0.313	0.375	0.313	0.250
11	5	0.438	0.438	0.375	0.438
12	6	0.563	0.563	0.563	0.563
13	Jun-1	0.375	0.375	0.375	0.375
14	2	0.500	0.438	0.438	0.438
15	3	0.563	0.500	0.500	0.500
16	4	0.438	0.438	0.375	0.375
17	5	0.500	0.500	0.500	0.500
18	6	0.438	0.375	0.375	0.375
19	July-1	0.563	0.500	0.438	0.375
20	2	0.563	0.625	0.500	0.563
21	3	0.500	0.500	0.500	0.500
22	4	0.500	0.563	0.438	0.438
23	5	0.563	0.563	0.563	0.500
24	6	0.563	0.563	0.500	0.500
25	Aug-1	0.313	0.313	0.313	0.313
26	2	0.500	0.500	0.563	0.625
27	3	0.375	0.313	0.375	0.438
28	4	0.563	0.625	0.563	0.563
29	5	0.563	0.500	0.625	0.563
30	6	0.688	0.688	0.688	0.625
31	Sep-1	0.438	0.500	0.500	0.500
32	2	0.500	0.563	0.500	0.438
33	3	0.375	0.375	0.438	0.375
34	4	0.563	0.563	0.500	0.563
35	5	0.375	0.313	0.438	0.438
36	6	0.438	0.438	0.500	0.500
37	Oct-1	0.313	0.375	0.375	0.313
38	2	0.500	0.500	0.500	0.563
39	3	0.563	0.563	0.533	0.588
40	4	0.500	0.563	0.500	0.611
41	5	0.429	0.556	0.375	0.438
42	6	0.500	0.556	0.500	0.611
43	Nov-1	0.429	0.500	0.286	0.760
44	2	0.429	0.556	0.438	0.500
45	3	0.600	0.647	0.182	0.524
46	4	0.533	0.588	0.250	0.500
47	5	0.000	0.900	0.400	0.852
48	6	0.000	0.900	0.400	0.852
49	Dec-1	0.000	0.900	0.500	0.792
50	2	0.000	0.900	0.500	0.500
51	3	0.200	0.815	0.600	0.647
52	4	0.000	0.821	0.625	0.625
53	5	0.750	0.800	0.643	0.667
54	6	0.769	0.789	0.538	0.632
55	Jan-1	0.417	0.650	0.571	0.840
56	2	0.444	0.739	0.600	0.889
57	3	0.333	0.550	0.500	0.500
58	4	0.462	0.579	0.333	0.696
59	5	0.563	0.563	0.125	0.667
60	6	0.688	0.688	0.286	0.760
61	Feb-1	0.667	0.800	0.364	0.667
62	2	0.733	0.765	0.538	0.684
63	3	0.733	0.765	0.438	0.438
64	4	0.643	0.722	0.467	0.529
65	5	0.786	0.778	0.438	0.438
66	6	0.615	0.684	0.438	0.438
67	Mar-1	0.467	0.471	0.222	0.696
68	2	0.400	0.471	0.400	0.471
69	3	0.467	0.471	0.462	0.579
70	4	0.273	0.571	0.400	0.471
71	5	0.333	0.550	0.429	0.840
72	6	0.600	0.588	0.400	0.889
Average		0.465	0.572	0.449	0.552

Table B-9 Actual Probabilities for Truncation Level, xo(t) = 60th Percentile

		Station : Bogra		Station : Rangpur	
		P1(-) = 0.375 and P1(+) = 0.625		P1(-) = 0.375 and P1(+) = 0.625	
i	Time Interval	Pi(-/-)	Pi(+/+)	Pi(-/-)	Pi(+/+)
1	Apr-1	0.417	0.600	0.333	0.600
2	2	0.417	0.600	0.333	0.600
3	3	0.385	0.526	0.308	0.526
4	4	0.462	0.579	0.385	0.579
5	5	0.615	0.684	0.222	0.696
6	6	0.538	0.737	0.462	0.632
7	May-1	0.385	0.579	0.462	0.632
8	2	0.308	0.579	0.462	0.579
9	3	0.538	0.684	0.538	0.684
10	4	0.308	0.526	0.231	0.421
11	5	0.308	0.526	0.231	0.526
12	6	0.385	0.579	0.385	0.579
13	Jun-1	0.308	0.526	0.385	0.526
14	2	0.462	0.579	0.462	0.579
15	3	0.462	0.579	0.385	0.579
16	4	0.385	0.526	0.308	0.526
17	5	0.538	0.684	0.538	0.684
18	6	0.333	0.550	0.308	0.526
19	July-1	0.385	0.526	0.385	0.526
20	2	0.308	0.579	0.385	0.632
21	3	0.231	0.474	0.231	0.474
22	4	0.385	0.579	0.538	0.632
23	5	0.462	0.632	0.462	0.579
24	6	0.417	0.650	0.462	0.632
25	Aug-1	0.231	0.474	0.308	0.526
26	2	0.308	0.526	0.308	0.579
27	3	0 385	0.526	0.385	0.579
28	4	0.385	0.632	0.462	0.632
29	5	0.615	0.684	0.462	0.579
30	6	0.462	0.632	0.538	0.632
31	Sep-1	0.462	0.632	0.385	0.579
32	2	0.308	0.579	0.462	0.579
33	3	0.308	0.474	0.385	0.526
34	4	0.385	0.579	0.308	0.579
35	5	0.308	0.474	0.385	0.579
36	6	0.385	0.579	0.385	0.579
37	Oct-1	0.154	0.421	0.231	0.421
38	2	0.385	0.579	0.385	0.579
39	3	0.455	0.714	0.273	0.619
40	4	0.462	0.632	0.462	0.632
41	5	0.385	0.579	0.308	0.579
42	6	0.455	0.667	0.333	0.808
43	Nov-1	0.429	0.800	0.286	0.760
44	2	0.571	0.840	0.333	0.808
45	3	0.167	0.769	0.182	0.524
46	4	0.167	0.769	0.250	0.500
47	5	0.000	0.900	0.400	0.852
48	6	0.000	0.900	0.400	0.852
49	Dec-1	0.000	0.900	0.500	0.792
50	2	0.000	0.900	0.571	0.840
51	3	0.200	0.815	0.600	0.818
52	4	0 000	0.821	0 600	0.818
53	5	0.750	0.800	0.833	0.925
54	6	0.769	0.789	0.538	0.632
55	Jan-1	0.417	0.650	0.571	0.840
56	2	0.444	0.739	0.600	0.889
57	3	0.333	0.550	0.375	0.750
58	4	0.462	0 579	0 333	0.696
59	5	0.500	0.727	0.125	0.667
60	6	0.500	0.727	0.286	0.760
61	Feb-1	0.667	0.800	0.364	0.667
62	2	0.692	0.737	0.538	0.684
63	3	0.667	0.750	0.500	0.773
64	4	0 545	0.714	0.500	0.773
65	5	0.692	0.737	0.375	0.750
66	6	0.615	0.684	0.400	0.727
67	Mar-1	0.500	0.727	0.222	0.696
68	2	0.273	0.571	0.250	0.750
69	3	0.300	0.636	0.462	0.579
70	4	0.273	0.571	0.333	0.739
71	5	0.333	0.550	0.429	0.840
72	6	0.400	0.852	0.400	0.889
Average		0.392	0.650	0.396	0.654

Table B-10 Probabilities p1, p2, q1, q2, and Ldm, Lsm, Sdm and Ssm at Rangpur for Truncation Level, xo(t) = Normal

Year	Np1	Nq1	Np2	Nq2	p1	q1	p2	q2	Ldm (5days)	Lsm (5days)	Sdm (mm)	Ssm (mm)
1962-63	15	57	2	42	0.21	0.79	0.14	0.75	20	2	157.4	60.2
1963-64	20	52	5	35	0.28	0.72	0.26	0.69	10	4	239.6	475.3
1964-65	21	51	9	38	0.29	0.71	0.45	0.76	17	5	154.0	205.9
1965-66	19	53	6	40	0.26	0.74	0.33	0.77	11	3	208.2	231.6
1966-67	17	55	8	44	0.24	0.76	0.50	0.81	12	4	263.8	259.8
1967-68	14	58	3	46	0.19	0.81	0.23	0.81	20	2	150.9	189.8
1968-69	24	48	8	32	0.33	0.67	0.35	0.68	9	3	174.5	148.1
1969-70	23	49	8	33	0.32	0.68	0.36	0.69	6	4	180.9	184.2
1970-71	18	54	9	40	0.25	0.75	0.53	0.75	13	3	182.8	228.2
1971-72	14	58	9	52	0.19	0.81	0.69	0.91	20	5	894.7	322.3
1972-73	15	57	4	45	0.21	0.79	0.29	0.80	13	3	290.1	137.7
1973-74	25	47	11	33	0.35	0.65	0.46	0.72	13	4	206.9	521.2
1974-75	19	53	6	40	0.26	0.74	0.33	0.77	16	4	205.9	132.7
1975-76	11	61	2	51	0.15	0.85	0.20	0.85	31	2	270.5	163.3
1976-77	18	54	6	41	0.25	0.75	0.35	0.77	13	4	258.6	278.9
1977-78	31	41	14	24	0.43	0.57	0.47	0.60	7	8	84.5	320.5
1978-79	28	44	14	29	0.39	0.61	0.52	0.67	7	7	199.5	312.5
1979-80	18	54	7	42	0.25	0.75	0.41	0.79	14	4	599.9	293.3
1980-81	30	42	14	26	0.42	0.58	0.48	0.63	7	4	148.2	318.7
1981-82	21	51	9	39	0.29	0.71	0.45	0.78	13	4	238.0	167.8
1982-83	19	53	6	39	0.26	0.74	0.33	0.75	9	3	278.7	241.7
1983-84	21	51	7	36	0.29	0.71	0.35	0.72	10	3	266.8	87.5
1984-85	25	47	13	34	0.35	0.65	0.54	0.74	11	5	133.1	244.4
1985-86	18	54	5	40	0.25	0.75	0.29	0.75	18	3	176.8	107.6
1986-87	22	50	8	35	0.31	0.69	0.38	0.71	15	3	194.2	324.5
1987-88	24	48	10	33	0.33	0.67	0.43	0.70	13	4	163.9	456.1
1988-89	19	53	9	42	0.26	0.74	0.50	0.81	16	4	236.2	560.4
1989-90	23	49	9	34	0.32	0.68	0.41	0.71	8	5	166.7	290.4
1990-91	26	46	13	34	0.36	0.64	0.52	0.76	16	5	110.0	262.1
1991-92	22	50	10	37	0.31	0.69	0.48	0.76	15	4	121.8	170.9
1992-93	17	55	5	43	0.24	0.76	0.31	0.80	12	3	508.7	109.0
1993-94	31	41	14	23	0.43	0.57	0.47	0.58	6	7	98.0	295.8
Median	20.5	51.5	8	38.5	0.28	0.72	0.41	0.75	13	4	196.9	243.0
Mean	21	51	8	38	0.29	0.71	0.40	0.74	13	4	236	253
Variance	25	25	12	46	0.005	0.005	0.013	0.005	27	2	25385	14985

Table B-11 Probabilities p1, p2, q1, q2 and Ldm, Lsm, Sdm and Ssm at Rangpur for Truncation Level at xo(t) = Median

Year	Np1	Nq1	Np2	Nq2	p1	q1	p2	q2	Ldm (5days)	Lsm (5days)	Sdm (mm)	Ssm (mm)
1962-63	35	37	21	23	0.49	0.51	0.62	0.64	7	12	124.2	118.0
1963-64	40	32	23	17	0.56	0.44	0.59	0.55	6	12	70.9	671.5
1964-65	46	26	34	15	0.64	0.36	0.76	0.60	4	10	85.2	279.7
1965-66	42	30	33	22	0.58	0.42	0.80	0.76	8	18	121.9	357.2
1966-67	39	33	30	24	0.54	0.46	0.79	0.75	8	22	112.7	330.5
1967-68	32	40	17	26	0.44	0.56	0.55	0.67	7	11	83.8	236.8
1968-69	44	28	31	16	0.61	0.39	0.72	0.59	6	22	117.3	164.6
1969-70	49	23	37	12	0.68	0.32	0.77	0.55	4	15	126.5	249.6
1970-71	34	38	18	23	0.47	0.53	0.55	0.62	5	11	75.8	267.7
1971-72	30	42	24	37	0.42	0.58	0.83	0.90	18	9	599.3	359.5
1972-73	29	43	18	33	0.40	0.60	0.64	0.79	13	14	176.3	161.8
1973-74	35	37	25	27	0.49	0.51	0.74	0.75	13	10	136.7	601.5
1974-75	33	39	18	24	0.46	0.54	0.56	0.63	15	4	83.0	193.4
1975-76	22	50	10	38	0.31	0.69	0.48	0.78	18	5	77.5	206.1
1976-77	28	44	14	31	0.39	0.61	0.52	0.72	11	4	161.8	337.1
1977-78	54	18	43	8	0.75	0.25	0.81	0.47	4	15	52.2	469.6
1978-79	42	30	28	16	0.58	0.42	0.68	0.55	6	10	37.5	397.9
1979-80	40	32	28	20	0.56	0.44	0.72	0.65	9	14	247.7	353.8
1980-81	52	20	40	8	0.72	0.28	0.78	0.42	3	23	72.9	286.6
1981-82	36	36	25	26	0.50	0.50	0.71	0.74	13	8	142.9	226.4
1982-83	39	33	27	21	0.54	0.46	0.71	0.66	8	16	92.7	294.8
1983-84	52	20	43	12	0.72	0.28	0.84	0.63	5	35	161.5	384.7
1984-85	47	25	36	13	0.65	0.35	0.78	0.54	5	18	64.4	650.0
1985-86	42	30	29	16	0.58	0.42	0.71	0.55	8	22	87.4	113.6
1986-87	44	28	33	17	0.61	0.39	0.77	0.63	6	26	125.4	416.1
1987-88	49	23	37	12	0.68	0.32	0.77	0.55	4	15	104.8	509.2
1988-89	40	32	25	16	0.56	0.44	0.64	0.52	5	6	122.9	624.8
1989-90	44	28	31	13	0.61	0.39	0.72	0.48	8	16	100.2	351.2
1990-91	53	19	43	10	0.74	0.26	0.83	0.56	6	18	69.6	226.0
1991-92	49	23	33	8	0.68	0.32	0.69	0.36	4	15	45.8	248.9
1992-93	33	39	21	27	0.46	0.54	0.66	0.71	8	14	121.8	145.6
1993-94	50	22	36	9	0.69	0.31	0.73	0.43	3	20	60.4	352.4
Median	41	31	29	17	0.57	0.43	0.72	0.63	6.5	14.5	102.5	312.625
Mean	41	31	28	19	0.57	0.43	0.70	0.62	8	15	121	331
Variance	67	67	76	70	0.01	0.01	0.01	0.01	17	46	9496	23151

Table B-12 Probabilities p1, p2, q1, q2 and Ldm, Sdm, Lsm and Ssm at Bogra for Truncation Level, xo(t) = Normal

Year	Np1	Nq1	Np2	Nq2	p1	q1	p2	q2	Ldm (5days)	Lsm (5days)	Sdm (mm)	Ssm (mm)
1962-63	20	52	5	36	0.28	0.72	0.26	0.71	10	4	221.5	482.6
1963-64	22	50	9	36	0.31	0.69	0.43	0.73	18	5	148.5	214.5
1964-65	17	55	6	44	0.24	0.76	0.38	0.81	29	4	238.6	324.8
1965-66	14	58	6	49	0.19	0.81	0.46	0.86	12	4	268.3	277.7
1966-67	14	58	3	46	0.19	0.81	0.23	0.81	15	2	178.2	195.6
1967-68	24	48	10	34	0.33	0.67	0.43	0.72	10	5	193.0	149.5
1968-69	13	59	7	53	0.18	0.82	0.58	0.91	28	5	1003.1	256.2
1969-70	19	53	5	38	0.26	0.74	0.28	0.73	7	3	148.6	231.7
1970-71	17	55	10	47	0.24	0.76	0.63	0.87	20	5	881.0	324.3
1971-72	15	57	2	43	0.21	0.79	0.14	0.77	9	2	286.9	138.0
1972-73	24	48	9	33	0.33	0.67	0.39	0.70	13	4	183.6	525.8
1973-74	22	50	8	36	0.31	0.69	0.38	0.73	16	4	201.7	140.3
1974-75	11	61	2	51	0.15	0.85	0.20	0.85	21	2	252.3	169.3
1975-76	16	56	6	45	0.22	0.78	0.40	0.82	13	4	249.2	287.2
1976-77	32	40	15	23	0.44	0.56	0.48	0.59	7	8	72.2	327.6
1977-78	30	42	17	28	0.42	0.58	0.59	0.68	11	7	157.7	324.4
1978-79	15	57	6	47	0.21	0.79	0.43	0.84	14	4	614.9	298.7
1979-80	29	43	14	28	0.40	0.60	0.50	0.67	9	4	145.8	231.2
1980-81	14	58	4	48	0.19	0.81	0.31	0.84	23	2	707.3	142.9
1981-82	19	53	6	39	0.26	0.74	0.33	0.75	9	3	260.3	243.7
1982-83	21	51	8	37	0.29	0.71	0.40	0.74	12	3	263.2	321.6
1983-84	25	47	12	33	0.35	0.65	0.50	0.72	9	4	112.0	225.0
1984-85	18	54	5	40	0.25	0.75	0.29	0.75	18	3	165.1	182.6
1985-86	24	48	11	35	0.33	0.67	0.48	0.74	15	3	190.7	319.8
1986-87	26	46	11	30	0.36	0.64	0.44	0.67	11	4	165.5	478.6
1987-88	24	48	11	34	0.33	0.67	0.48	0.72	13	4	225.7	565.3
1988-89	25	47	11	32	0.35	0.65	0.46	0.70	8	5	148.6	303.9
1989-90	32	40	16	25	0.44	0.56	0.52	0.64	7	5	90.8	268.5
1990-91	27	45	13	30	0.38	0.63	0.50	0.68	10	4	121.2	184.7
1991-92	25	47	13	35	0.35	0.65	0.54	0.76	7	10	238.6	119.2
1992-93	34	38	17	20	0.47	0.53	0.52	0.54	10	9	100.6	301.2
1993-94	24	48	11	35	0.33	0.67	0.48	0.74	8	10	176.6	117.5
Median	22	50	9	36	0.31	0.69	0.44	0.74	11.5	4.0	191.9	262.4
Mean	22	50	9	37	0.30	0.70	0.42	0.74	13	4.5	262.9	271.1
Variance	35.1	35.1	16.9	64.9	0.007	0.007	0.013	0.006	32.4	4.2	45893.3	12499.9

Table B-13 Probabilities p1, p2, q1, q2 and Ldm, Lsm, Sdm and Ssm at Bogra for Truncation Level, xo(t) = Median

Year	Np1	Nq1	Np2	Nq2	p1	q1	p2	q2	Ldm (5days)	Lsm (5days)	Sdm (mm)	Ssm (mm)
1962-63	44	28	30	15	0.61	0.39	0.70	0.56	6	12	55.8	688.45
1963-64	36	36	26	25	0.50	0.50	0.74	0.71	16	8	74.6	333.8
1964-65	28	44	17	33	0.39	0.61	0.63	0.77	22	11	113.2	381.95
1965-66	33	39	23	28	0.46	0.54	0.72	0.74	12	13	97.1	347.35
1966-67	25	47	12	33	0.35	0.65	0.50	0.72	15	6	107.3	246.65
1967-68	35	37	22	24	0.49	0.51	0.65	0.67	9	11	103.1	175.65
1968-69	23	49	15	41	0.32	0.68	0.68	0.85	25	8	543.9	294.6
1969-70	34	38	20	23	0.47	0.53	0.61	0.62	6	14	82.0	289.2
1970-71	29	43	22	37	0.40	0.60	0.79	0.88	18	7	569.9	378
1971-72	22	50	9	36	0.31	0.69	0.43	0.73	10	6	175.7	158.4
1972-73	39	33	27	21	0.54	0.46	0.71	0.66	11	8	108.1	613.65
1973-74	43	29	28	15	0.60	0.40	0.67	0.54	7	6	71.3	155.95
1974-75	22	50	10	37	0.31	0.69	0.48	0.76	15	6	87.0	215
1975-76	26	46	14	33	0.36	0.64	0.56	0.73	7	6	98.9	347.65
1976-77	62	10	53	2	0.86	0.14	0.87	0.22	2	38	47.2	489.4
1977-78	45	27	31	13	0.63	0.38	0.70	0.50	6	8	36.5	416.95
1978-79	23	49	13	38	0.32	0.68	0.59	0.79	14	6	350.4	302.5
1979-80	48	24	35	11	0.67	0.33	0.74	0.48	5	9	57.3	282.85
1980-81	35	37	28	31	0.49	0.51	0.82	0.86	24	12	371.2	225.8
1981-82	48	24	36	13	0.67	0.33	0.77	0.57	6	17	75.1	314.6
1982-83	48	24	37	14	0.67	0.33	0.79	0.61	4	20	128.8	383.4
1983-84	49	23	40	14	0.68	0.32	0.83	0.64	7	26	57.9	627.4
1984-85	34	38	21	24	0.47	0.53	0.64	0.65	12	12	81.8	145.6
1985-86	50	22	39	11	0.69	0.31	0.80	0.52	4	30	116.8	400.4
1986-87	55	17	46	9	0.76	0.24	0.85	0.56	4	39	102.6	549.5
1987-88	52	20	41	10	0.72	0.28	0.80	0.53	5	12	100.8	642.75
1988-89	48	24	39	14	0.67	0.33	0.83	0.61	8	29	78.7	389.45
1989-90	59	13	51	6	0.82	0.18	0.88	0.50	4	42	57.1	381.35
1990-91	60	12	49	2	0.83	0.17	0.83	0.18	3	40	34.9	276.35
1991-92	38	34	27	23	0.53	0.47	0.73	0.70	8	21	99.6	166.35
1992-93	56	16	45	6	0.78	0.22	0.82	0.40	3	33	54.9	363.9
1993-94	47	25	35	14	0.65	0.35	0.76	0.58	6	31	153.7	102.4
Median	41	31	28	18	0.57	0.43	0.74	0.63	7	12	98.0	340.6
Mean	41	32	29	21	0.56	0.44	0.72	0.62	10	17	134.1	346.5
Variance	136	136	146	124	0.026	0.026	0.013	0.024	36.7	132.9	16723.7	21959.1

APPENDIX-C

APPENDIX - C

C.1 Penman-Monteith Formula in CROPWAT

The calculation procedure of the computer program CROPWAT is based on the Penman-Monteith formula as follows:

$$ET_0 = \frac{0.0353\Delta}{\Delta + \gamma(1+0.34u)}[(1-\alpha)R_s - R_{nl}] + \frac{86400\gamma}{\Delta + \gamma(1+0.34u)}E_{aero}$$

where:

ET_o is reference evapotranspiration in mm/day,

R_s is the incoming solar radiation in W/m^2, can be measured directly

R_{nl} is the outgoing long-wave radiation in W/m^2,

E_{aero} is the aerodynamic evaporation equivalent to kg/m^2.s

α is the 'albedo', the reflection coefficient, α =0.23 for the reference crop,

Δ is the slope of the vapor pressure curve in kPa/°C,

γ is the psychometric constant in kPa/°C, and is given as

$\gamma = 66.8\times10^{-3}[1-2.22\times10^{-6}H]^{5.26}$; H is the altitude in meter

u is the wind speed measured at 2 m above the ground surface in m/s.

The above terms are explained in the following paragraphs.

The long-wave outgoing radiation, R_{nl} in MegaJ/m^2.day, in the CROPWAT program depends on minimum and maximum temperature T in °K, T = t+273, the actual vapor pressure e_a in kPa, and the relative sunshine fraction n/N, where n is duration of bright sunshine and N is the maximum possible sunshine hours or the day length. The value of R_{nl} reads in W/m^2 as

$$R_{nl} = \sigma \frac{T_{min}^4 + T_{max}^4}{2}(0.34 - 0.139\sqrt{e_a})(0.10 + 0.90\frac{n}{N})$$

in which σ is the Stefan-Boltzmann constant, $\sigma = 4.90 \times 10^{-9}$ MJ/m^2 .°C^4.day.

In SI-units, the above equation would read for a long-wave outgoing radiation R_{nl} in W/m^2, and the actual vapor pressure e_a in kPa and Stefan-Boltzmann constant, $\sigma = 5.6745 \times 10^{-8}$ W/m^2.°C^4.

The incoming solar radiation can be calculated as:

$$R_s = R_A\left(a + b\frac{n}{N}\right)$$

where, a and b are the Angstrom coefficients depending on the latitude of the station and R_A is the extraterrestrial radiation or 'Angot value'. Same values of a and b are shown in Table C.1.

Table C.1 Some Angstrom coefficients a and b

Countries	Latitude	a	b
UK	52°N	0.18	0.55
The Netherlands	52°N	0.18	0.54
Canada	52°N	0.25	0.62
France, Versailles	49°N	0.23	0.50
USA, Wisconsin	43°N	0.18	0.55
Australia, Canberra	35°N	0.25	0.54
Israel	31°N	0.41	0.36
India, New Delhi	29°N	0.31	0.46
Senegal, Dakar	15°N	0.10	0.70
India, Madras	13°N	0.31	0.49
Nigeria, Kano	12°N	0.26	0.54
Indonesia, Jakarta	6°S	0.29	0.59
Singapur	1°N	0.21	0.48
Kenya, Kabete	1°S	0.24	0.59
As standard used by the CROPWAT program (Smith, 1993)		0.25	0.50

*Source: Doorenbos, 1977

The extra-terrestrial radiation R_A in W/m^2 follows from the latitude φ of the location, and the day I of the year:

- the latitude φ is expressed in radians, with a positive φ for the northern latitude and a negative φ for the southern latitude:

$$\varphi = \frac{\varphi^o}{360} 2\pi = \frac{\varphi^o}{57.3^o}$$

- the day I of the year follows from I = 1 for 1 January. Generally the evaporation is calculated as a monthly average, and the day I of the year follows from the number M of the month, M = 1 for January (Bos, 1996)

$$I = 30.42 \times M - 15.23$$

The extra-terrestrial radiation R_A in W/m^2 can be calculated from the following series of formulae (Allen, 1994[b]; Bos, 1996):

$$R_A = R_{sc}.d_r\left[\omega_s.\sin\left(\frac{\varphi^o}{57.3^o}\right).\sin\delta + \cos\left(\frac{\varphi^o}{57.3^o}\right).\cos\delta.\sin\omega_s\right]$$

in which:

- the solar radiation R_{sc} is given by (Allen, 1994[b]; Bos, 1996):

$$R_{sc} = 435 \text{ W/m}^2$$

- the relative distance d_r between the earth and the sun amounts to (Allen, 1994[b]; Bos, 1996):

$$d_r = 1 + 0.033\cos\left(\frac{I}{365}2\pi\right) = 1 + 0.033\cos(0.523M - 0.262)$$

- the sunset-hour angle ω_s in radians (Allen, 1994[b]; Bos, 1996):

$$\omega_s = \arccos[-\tan\varphi.\tan\delta] = \arccos\left[-\tan\left(\frac{\varphi^o}{57.3^o}\right).\tan\delta\right]$$

- the declination δ of the sun in radians (Allen, 1994[b]; Bos, 1996):

$$\delta = 0.4093\sin\left(\frac{I+284}{365}2\pi\right) = 0.4093\sin(0.523M + 4.62)$$

The sunset-hour angle ω_s in radian determines also the maximum possible sunshine hours N through the formula (Allen, 1994[b]):

$$N = \frac{24}{\pi}\omega_s = 7.64\omega_s$$

The aerodynamic evaporation equivalent E_{aero} in kg/m^2.s has been defined by Penman as

$$E_{aero} = \frac{\varepsilon \rho_a}{p_a}\frac{e_s - e_a}{r_a}$$

when the density ρ_a of moist air is substituted, the above equation becomes:

$$E_{aero} = \frac{0.622}{p_a}\frac{p_a}{0.287(t+273)}\frac{e_s - e_a}{r_a} = \frac{2.17}{(t+273)}\frac{e_s - e_a}{r_a}$$

where:

E_{aero} is the aerodynamic evaporation equivalent in kg/m^2.s,

p_a is the atmospheric pressure in kPa,

ε is the ratio of molecular masses of water vapor over dry air, $\varepsilon = 0.622$,

ρ_a is the density of moist air in kg/m^3,

t is the average temperature in °C,

e_a is the actual vapor pressure in kPa,

e_s is the saturated vapor pressure at temperature t in kPa,

r_a is the aerodynamic diffusion resistance in s/m.

The aerodynamic diffusion resistance r_a in s/m depends on the aerodynamic wind profile and can be approximated by

$$r_a = \frac{208}{u}$$

where u is the wind speed measured at 2 m above the ground surface in m/s. Thus the aerodynamic evaporation equivalent E_{aero} in kg/m^2.s becomes:

$$E_{aero} = \frac{2.17}{(t+278)}\frac{u}{208}(e_s - e_a) = \frac{10.42x10^{-3}}{(t+273)}u(e_s - e_a)$$

The elimination of the terms R_{nl} and E_{aero} in the above Penman-Monteith equation, leads to the CROPWAT formula:

$$ET_0 = \frac{0.0353\Delta}{\Delta + \gamma(1+0.34u)}[(1-\alpha)R_s]$$
$$-\frac{10^{-9}\Delta}{\Delta + \gamma(1+0.34u)}[(T_{\min}^4 + T_{\max}^4)(0.34 - 0.139\sqrt{e_a})(0.10 + 0.90\frac{n}{N})]$$
$$+\frac{900\gamma}{\Delta + \gamma(1+0.34u)}[\frac{u}{(t+273)}(e_s - e_a)]$$

Saturated vapor pressure e_s can be given as

$$e_s = \frac{e_{s,\min} + e_{s,\max}}{2}$$

where

$e_{s,min}$ is vapor pressure in kPa at minimum temperature t_{min} and is given by

$$e_{s,\min} = 0.611\exp\left(\frac{17.27t_{\min}}{t_{\min}+273.3}\right)$$

and $e_{s,max}$ is vapor pressure in kPa at maximum temperature t_{max} and is given by

$$e_{s,\max} = 0.611\exp\left(\frac{17.27t_{\max}}{t_{\max}+273.3}\right)$$

The slope, Δ in kPa/°C of the vapor pressure curve at the saturated vapor pressure e_s does not depend on the mean temperature t in °C, but on the air temperature t_E in °C, that matches the saturated vapor pressure and that can be calculated with Teten's formula (Smith 1993, Allen 1994).

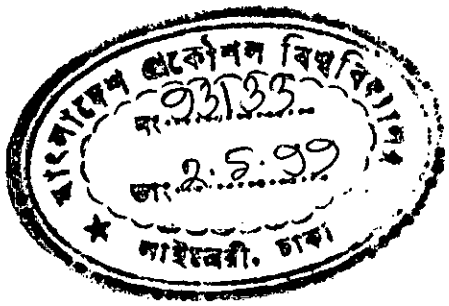
$$e_s = 0.611 \exp\left(\frac{17.27 t_E}{t_E + 273.3}\right)$$

in which

$$t_E = \frac{273 \ln e_s + 135}{16.78 - \ln e_s}$$

The slope of the vapor pressure curve, Δ is given by

$$\Delta = \frac{4098 e_s}{(t_E + 273.3)^2}$$

The actual vapor pressure e_a in kPa can be calculated from the minimum relative humidity RH_{min} in percent and the maximum relative humidity RH_{max} in percent as follows:

$$e_a = \frac{\frac{RH_{min} + RH_{max}}{2}}{\frac{50}{e_{s,min}} + \frac{50}{e_{s,max}}}, \quad \text{or:} \quad e_a = \frac{RH}{\frac{50}{e_{s,min}} + \frac{50}{e_{s,max}}}$$