DETERMINATION OF AGRICULTURAL LAND DRAINAGE COEFFICIENT USING RAINFALL PROBABILITY ANALYSIS FOR OSMANABAD DISTRICT

DISSERTATION

Submitted to the Vasantrao Naik Marathwada Krishi Vidyapeeth in

partial fulfillment of the requirements

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in

IRRIGATION AND DRAINAGE ENGINEERING

by

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B.Tech.(Agril. Engg)

UNDER THE GUIDANCE OF

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2017

AFFECTIONATELY

DEDICATED

TO

MY BELOVED

PARENTS,

SISTER & BROTHER

CANDIDATE'S DECLARATION

I hereby declare that the entire work embodied in this thesis or part thereof has not been previously submitted by me for a degree or Diploma of any University or Institute

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CERTIFICATE – I

This is to certify that the dissertation entitled **"Determination of Agricultural Land Drainage Coefficient using Rainfall Probability Analysis for Osmanabad district"** submitted in partial fulfillment of the requirements for the degree of **Master of Technology** in the subject of **Irrigation and Drainage Engineering** is a record of dissertation carried out by **Ms.Kamble Ashvini Ashokrao, Reg. No. 2015AE/04M** under my guidance and supervision.

I also certify that the dissertation has not been previously submitted by her for the award of any other Degree or Diploma of any University or Institute.

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Advisory Committee

CERTIFICATE – II

This is to certify that the dissertation entitled **"Determination of Agricultural Land Drainage Coefficient using Rainfall Probability Analysis for Osmanabad district"**submitted by **Ms Kamble Ashvini Ashokrao** to the Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani in partial fulfillment of the requirements for the degree of **Master of Technology (Agril.Engg.)** inthe specialization of **Irrigation and Drainage Engineering**has been approved by the student's advisory committee after viva-voce examination in collaboration with the external examiner.

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LIST OF ABBREVIATIONS

%	:	Per cent
Agric.	:	Agriculture
Agril.	:	Agricultural
AICRP	:	All India Coordinated Research Project
APRN	:	Asian Research Publishing Network
ASCE	:	American Society of Civil Engineers
B.Tech.	:	Bachelor of Technology
CAE	:	College of Agricultural Engineering
Can.	:	Canadian
C_v	:	Coefficient of variation
C_s	:	Coefficient of skewness
Cons.	:	Conservation
cm	:	Centimeter
cm hr^{-1}	:	Centimeter per hour
^0C	:	Degree celsius
D.C.	:	Drainage coefficient
Dept.	:	Department
Engg.	:	Engineering
et al.	:	And all
etc.	:	Excetra
ET_o	:	Evapotranspiration
FAO	:	Food and Agricultural Organization
Fig.	:	Figure
Geophys.	:	Geophysics

GIS		Geographical Information System
hr	:	Hour
i.e.	:	That is
Ib	:	Infiltration rate
IS	:	Indian Standard
ISAE	:	Indian Society of Agricultural Engineers
J	:	Journal
K	:	Frequency factor
log	:	Logarithm
V.N.M.K.V.	:	VsantraoNauikMarathwada Krishi Vidyapeeth
mm	:	Milimeter
mm day^{-1}	:	Milimeter per day
mm hr^{-1}	:	Milimeter per hour
msl	:	Mean Sea Level
M.P.K.V.	:	Mahatma Phule Krishi Vidyapeeth
M. Tech	:	Master of Technology
Mg m^{-3}	:	Miligram per cubic meter
MS Excel	:	Microsoft Excel
m	:	Number of interval
No.	:	Number
Publ.	:	Publication
P	:	Probability
R.I.	:	Recurrence Interval
Res.	:	Research

Sci.	:	Science
Soc.	:	Society
Sr. No.	:	Serial Number
T	:	Return Period
σ_x	:	Standard deviation of x
σ_y	:	Standard deviation of y
Viz.	:	Namely
VNMKV	:	Vasantrao Naik Marathwada Krishi Vidyapeeth
X	:	Annual Maximum Rainfall
$\overline{x}$	:	Mean value of x
χ	:	Chi-square
$\overline{y}$	:	Mean value of y
Z	:	Standard normal variate

INTRODUCTION

CHAPTER-I

INTRODUCTION

India is an agricultural based country and agriculture sector occupies a key position in Indian economy because of its contribution to overall economic growth through supplies of food, fodder and many raw materials including major exports. Agriculture is a source of livelihood for majority of Indian population, which provides large-scale employment to the people. It has often been observed that the Indian economy fluctuates with the agricultural production in the country. Water is a precious natural resource, a basic human need and a prime important resource for Agricultural production. In India per capita availability of surface water is very less compared to many other countries. Hence long term perspective planning of available water resources is essential to achieve goal of economic prosperity and quality of life on sustainable basis.

India has geographical area of about 329 Mha out of which 195 Mha is gross cropped area and 141 Mha is net cultivable area (Anonymous, 2015). In spite of continuous efforts, the irrigation potential in the country has merely increased to 65.3 Mha keeping about 60 percent of the total cultivable area still dependent on rainfall. Three main characteristics of rainfall are its amount, frequency and intensity, the values of which vary from place to place on daily, monthly and yearly basis. The area and extent of rain fed agriculture varies from region to region depending upon intensity and pattern of rainfall. The rainfed areas mostly fall under semi arid tropics where rainfall with great degree of uncertainty is less than the evapotranspiration in most of the months. The early or delay of onset of monsoon, early or late withdrawal of monsoon, dry spell or unusual heavy rainfall during the critical growth stages of crops may disturb the normal crop growth, its development and ultimately the crop production. Extreme climatic conditions and high inter-annual / seasonal variability of climatic parameters could adversely affect productivity (Li *et al.*,

2006) because in these areas rainfall governs the crop yields and determines the choice of the crops that can be grown.

On the other hand, the situations in heavy rainfall areas or irrigated lands are different. In these areas surface stagnation of water occurs when rain or irrigation water remain on the cropland for prolonged periods without infiltrating in to the soil. Surface stagnation of water in the cropped land is now assuming a more serious dimension because of the unplanned development, restricted drainage, rising water tables in irrigation commands, inadequate capacity of drainage system capacity and improper upkeep and maintenance of the drainage system (Gupta *et al.*, 2004). Surface water stagnation has negative effects on agricultural productivity because oxygen deficiency and excessive carbon dioxide levels in the root zone hamper germination and nutrient uptake, thereby reducing crop yields. In temperate climates, wet places have relatively low soil temperature in spring, which delays the start of the growing season and has a negative impact on crop yields. Excess water in the top soil layer also affects its workability. The extent of agricultural areas suffering from water logging and salinity on a global scale has not been well documented. It is estimated that water logging and salinization are a serious threat to some 100-120 million ha of irrigated land in arid and semi-arid regions. It is estimated that 20-30 Mha area is seriously affected by water logging and salinization and that the problem is growing by 0.5-1.0 million ha per year (FAO, 2001). Similarly 7 Mha of land have been abandoned because of salinity (Scherr and Yadav, 2001)

Using inadequate and improperly designed irrigation systems, large quantity of water is lost by seepage and deep percolation below the root zone. This may develop accumulation of water and salt in the subsoil thereby creating water logging and salt accumulation. The high water table, which is considered harmful, depends upon the type of crop, soil and quantity of water. As per reports of Central Ground Water Board, the areas with water table within 2 m below ground level are considered as prone to water logging and 2-

3 m below ground surface are viewed as critical (Sharma *et al.*, 2009). Water logging causes depletion of oxygen and increase of carbon dioxide in the root zone of crops which causes loss of useful microorganism. It also causes chemical degradation due to accumulation of salts in surface soil. Because of intensive irrigation in many areas, low lying lands have become unproductive due to water logging and salt accumulation. Similarly, under intensive and heavy rainfall, these lands cannot remove excess water and become water logged. Pressures on available water resources are increasing throughout the world with the intensive competition among industrial, domestic and agricultural sectors, particularly in arid and semi-arid areas. Hence there is a dire need to adopt controlled drainage system combining irrigation and drainage management to save the water and improve water quality. An age-old practice of drainage can be a simple and practicable solution to improve the saline, alkaline and water logged soils under such situation.

Drainage is the natural or artificial removal of surface or sub-surface water from an area. The main purpose of agricultural drainage is to provide favourable root environment that is suitable for optimum growth of the plants. Drainage on wet agricultural soils allows timely field operations and helps plant growth to begin early, continue vigorously and achieve improved levels of productivity. In lands under agricultural production system, improved drainage has been found to reduce runoff, peak outflow rates and sediment losses compared to undrained agricultural land (Anonymous, 2008). For proper drainage, it is necessary to know the desirable drainage rate (drainage coefficient) which depends on the rainfall intensity and the amount of surface water admitted to drainage system. Drainage discharge is a key factor for deciding the design capacity of drainage system. For estimating drainage rate from agricultural crops one need to know the total rainfall over the duration of crop tolerance period (Bhattacharya and Sarkar, 1982).

Rainfall is one of the important hydrologic variable with availability of historical data and hence probability based analysis of various aspects of the rainfall is possible. Different aspects of the rainfall are its intensity, daily, seasonal or annual totals, onset of monsoon, occurrence of the consecutive non-rainy / rainy days, etc. Each of these is relevant for different activities in the agricultural production process such as sowing, irrigation, drainage, crop operations and harvesting. Rainfall intensity is required to estimate the peak rate of run-off (Schwab *et al.*, 1981); knowledge of onset of effective monsoon is useful for planning land preparation and sowing; and daily or moving total rainfall is required for drainage system design.

Rainfall data are being analyzed in different ways depending on the problem under consideration. Analysis of consecutive days maximum rainfall is more relevant for drainage design of agricultural lands (Bhattacharya and Sarkar, 1982; Upadhaya and Singh, 1998) whereas analysis of weekly rainfall data is more useful for planning cropping pattern and its management. The analysis of rainfall data deals with interpreting past record of rainfall events in terms of future probabilities of occurrence. The expected rainfall of a given frequency is commonly computed by utilizing different probability distributions. Frequency analysis of rainfall data had been done earlier for different places in India (Jeevrathnam and Jaykumar, 1979; Sharda and Bhushan, 1985; Prakash and Rao, 1986; Aggarwal *et al.*, 1988; Rizvi *et al.*,2001).

The drainage requirement of any region varies with the geographical location, land use, area, rainfall intensity, frequency and duration besides other climatic factors. Osmanabad District largely comes under Assured rainfall zone (700 to 900 mm), except Bhoom and Paranda Taluka which are in scarcity zone (500 to 700 mm). The district is located towards South of Balaghat ranges in Sina, Bhima and Manjra basin which is in the Southern part of state on Deccan plateu. The Sina river basin drains the top north-west part of the district particularly Paranda taluka of the district.

The farmers of the district are shifting to high water requiring cash crops such as sugarcane withoutproper planning of drainage system. Studies on the estimation of drainage coefficient through rainfall analysis were conducted at many places in India including some districts of Marathwada (Bhattacharya and Sarkar, 1982; Rao, 1985; Ray *et al*., 1985; Patle *et al*., 2005; Pawar, 2012; Kapse, 2015; Khandare, 2015) to find out the rate of excess water removal and thereby capacity of drainage system. However, the conditions at these places are different than Osmanabad district. At present talukawise rainfall data of district in Marathwada region are available. Hence, it is necessary to determine talukawise drainage coefficient for Osmanabad district based on rainfall and water tolerance period of major crops in the district. Such study evolving certain drainage criteria based on amount and duration of maximum rainfall at various return periods will help in designing of drainage system and crop planning for Osmanabad district.

Keeping in view the above points, the present study entitled "Determination of Agricultural Land Drainage Coefficient using Rainfall Analysis for Osmanabad district" is planned with the following specific objectives

1. To analyze taluka-wise historical daily rainfall data for Osmanabad district.
2. Probability analysis of 1, 2, 3, 4 and 5 consecutive days maximum rainfall at various stations.
3. To determine taluka-wise drainage coefficient for Osmanabad district.
4. To develop drainage coefficient maps for Osmanabad district using GIS.

REVIEW OF LITERATURE

CHAPTER-II

REVIEW OF LITERATURE

The rate of drainage is a key factor for deciding design capacity of a drainage system in any agricultural watershed or command area. For design of surface drainage, amount of excess water that has to be removed should be measured directly or can be estimated by indirect methods such as the computation of discharge from rainfall data. In recent years, drainage coefficient is being estimated by using concept of rainfall probability analysis. Literature available on various aspects including probability analysis of 1 to 5 consecutive days maximum rainfall and estimation of drainage coefficient have been reviewed and reported in this chapter. The research literature on infiltration rate of soil and crop tolerance to water logging has also been reviewed.

2.1 Probability Analysis of Rainfall

Water requirement of crops can be met either by rainfall or irrigation. For efficient utilization of natural precipitation, its close estimation is essential (Gupta and Chauhan, 1985). Rainfall analysis also serves as indirect method of estimation of drainage coefficient. Kessler and De Raad (1974) described the design rainfall as function of recurrence interval, duration and area under study for different kinds of drainage problems. Therefore, frequency analysis of rainfall is necessary for solving various water management problems associated with drainage and to assess the crop failure due to deficiency or excess of rainfall. The rainfall distribution in India is most uneven and vary widely both in space and time. Hence, the average rainfall of a week, month or year may show the particular year as a year of normal year though temporal distribution is uneven (Kumar *et al*., 2007). Hence, theoretical probability distributions are being used to predict the rainfall of different magnitudes and return periods. The most suitable distribution to predict the observed data may depend on rainfall pattern of the place and as pattern varies from place to place, the most suitable distribution may also vary with location (Singh, 2001).

2.2 Frequency Analysis and Probability Distribution Functions

Kurothe and Chandra (1986) carried out probability analysis of annual maximum daily rainfall by using 20 years rainfall data. The probability distributions namely Gumbel extreme value, Log Normal and Log Pearson type III were used for frequency analysis. Comparison of three probability distributions by Chi-square test for goodness of fit showed that the extreme value function was the best fit with observed value.

Bazaraa and Ahmed (1991) analyzed rainfall data of 28 years (1962-1989) to assess variability and to develop relevant intensity-duration-frequency relationship with some inadequate data at Doha, Qatar. They used four probability distributions to fit the maximum rainfall in 24 hours and the annual rainfall depth. Gumbel distribution was found to have best fit. They concluded that annual rainfall depth in an arid area can be small compared to well watered areas of the world. However the intensities of the storms in an arid region may be high over short durations.

Dalabehera *et al.* (1993) statistically analyzed daily rainfall data of 23 years (1967 to 1989) for Regional Research Station, Bhawanipatna in Kalahandi Orissa using three different theoretical distributions viz., Log Pearson Type III, Lognormal and Gumbel. The theoretical frequency values were found to be in close agreement with observed data for all the three distributions. Their analysis showed that the Lognormal and Gumbel distributions gave closest fit to observed data.

Subudhi (1995); Subudhi *et al.* (1996) and Subudhi *et al.* (1998) conducted probability analysis of annual, seasonal and monthly (1-day maximum) rainfall data of 22 years (1975 to 1996) at various probability levels (90, 80, 70, 60, 50, 40, 30, 20, and 10) at Baliguda, Kandhamal (Orissa) and concluded that at 70% probability level rainfall during June to September is 990 mm which is sufficient for paddy crop. They suggested using daily, weekly, monthly, seasonal and annual rainfall probabilities for planning cropping programme as well as for water management practices.

Bhatt *et al.* (1996) analyzed rainfall data of 24 years (1968-1991) for frequency analysis of one day maximum rainfall of Datia. The observed values were estimated by Weibull's formula and expected values were estimated by three probability distributions viz., Gumbel, Lognormal and Log Pearson Type III. Comparison showed that Log Pearson Type III distribution gave closest fit to observed data. Chi-square test was performed for goodness of fit. Lowest Chi-square value was found to be 8.91 for Log Pearson Type III as compared to 11.01 and 10.25 for Gumbel and Lognormal, respectively. This can help in hydrologic structure designs, planning of soil conservation structures and flood control in the region.

George and Kolappadan (2002) analyzed annual maximum daily rainfall data for 16 years (1980-1996) at 9 raingauge stations in Periyar river basin in Kerala for various return periods. Comparison of three probability distributions namely Log Pearson Type III, Lognormal and Gumbel distribution for goodness of fit by Chi-square test showed that Log Pearson Type III was the best in predicting one day maximum rainfall for the areas having similar rainfall pattern and maximum daily rainfall can be predicted directly from frequency curves for hydrological uses.

Suresh (2003) analyzed daily rainfall data of 38 years (1964-2001) at Pusa, Bihar and predicted daily rainfall at different levels of probability by using Weibull's method of frequency analysis and reported probability analysis of rainfall as a valuable guideline for economic planning and design of hydraulic structures and for flood forecasting. He found Log Pearson Type III distribution as the best for probability model for predicting annual maximum daily rainfall for this region.

Patle *et al* (2005) in his study, he estimated expected values of maximum rainfall were found out by three well known probability distributions viz Gumbel, Log Normal and Log Pearson type III and the best fit distribution was decided by Chi-square test for their goodness of fit.

Sethy *et al.* (2005) computed various probability distributions and transformations to estimate 1-day as well as 2 to 6 consecutive days maximum rainfall of 48 years (1956-2003) of South-Eastern Rajasthan. Four commonly used probability functions (Normal, Lognormal, Log Pearson Type III, Extreme value type-I) were tested by comparing Chi-Square values. They also developed relationship between 1-day and consecutive days maximum rainfall for predicting magnitude of rainfall with evaluation of developed model using Thein's U-statistics. Results revealed that Log-normal distribution was the most fitting representative function for rainfall frequency analysis of South-Eastern Rajasthan. They also suggested use of developed relationship for predicting magnitude of rainfall corresponding to rainfall of 2 to 100 years return periods in the region.

Dingre and Atre (2005) analyzed 19 years data of Shrinagar and predicted annual maximum daily rainfall using Lognormal, Log Pearson Type III and Gumbel distributions for various return periods. Sum of Chi-square values for Log Pearson Type III, Lognormal and Gumbel distribution were found to be 5.764, 0.388 and 1.638 respectively and hence Log-normal distribution was found to be the best for predicting maximum daily rainfall of Shrinagar.

Chavan (2005) analyzed weather data of 12 years (1991-2002) for 5 locations of Marathwada for irrigation planning including estimation of reference crop evapotranspiration. He reported that weekly rainfall pattern of Parbhani show close association with Normal distribution when compared with Lognormal and Gamma distributions.

Lee (2005) studied the rainfall distribution characteristics of Chia-Nan plain area, by using different statistical analyses such as normal distribution, log-normal distribution, extreme value type I distribution, Pearson type III distribution, and log-Pearson type III distribution. They selected 178 stations having annual rainfall data over ten years to perform frequency analysis. Results showed that the log-Pearson type III distribution performed the best in probability distribution, occupying 50% of the total station number. This study also applied principal component analysis to derive two principal components of the rainfall spatial distribution. Results indicated that the Eigen values of the two principal components were capable of explaining 73% of the total variance of annual rainfall, with first principal component occupied 55.7% and the second principal component occupied 17.5%. These two components can be used to replace most of the original variables in satisfying the requirement of component independence and data reduction

Panday and Bisht (2006) reported probability analysis of annual maximum daily rainfall data of 35 years (1964-1998) for Hawalbagh, Uttaranchal India by using probability distributions namely Gumbel, Log Pearson Type III and Lognormal. Their results indicated Gumbel distribution as the best fit distribution.

Ravi babu *et al* (2006) analysed daily rainfall data of 21 years (1983-2003) for Bankura district of west Bengal to ascertain their fit to several probability distributions. The series generated by using Weibull's plotting position formula was treated as observed series. The expected values were estimated by Gumbel, Log pearson type III and Log Normal probability distribution functions. It was concluded that Log Pearson Type – III distribution is the best distribution for Bankura district to predict maximum one day rainfall for design return period. Hence, appropriate planning and hydrological design of different soil and water conservation measures in and around Bankura district can be based upon maximum one-day rainfall predicted from Log Pearson Type III distribution.

Bhakar *et al.* (2006) used three commonly used probability distributions viz., Normal, Lognormal and Gamma distribution and transformations to estimate 1-day and 2 to 5 consecutive days annual maximum rainfall at various return periods tested by comparing the Chi-square value at Banswara Rajasthan, India. The magnitudes of 1-day as well as 2 to 5 consecutive days annual maximum rainfall corresponding to 2 to 100 years return period were estimated using Gamma distribution function which was found to be the best for the region.

Dabral *et al* (2006) in his study analyzed daily rainfall data (1988-2004) for Doimukh (Itanagar), Arunachal Pradesh to determine mean weekly, monthly, seasonal and yearly rainfall using probability distribution functions. Annual rainfall was found to be in fluctuating trend. The distribution of rainfall was observed to be close towards normal during the monsoon period as compared to other periods of the year.

Wadatkar and Singh (2006) analyzed maximum weekly pan evaporation data of 8 stations of Maharashtra using Log Pearson Type III, Gumbel and Weibull (Maxima) distributions. Chi-square test for goodness of fit of the observed data to theoretical distribution was performed at various probabilities (40, 50, 60, 70 and 80 per cent).

Kumar *et al*. (2007) analyzed annual maximum daily rainfall data of 36 years (1968-2003) for Almora, Uttarakhand to estimate engineering design parameters of small and medium hydraulic structures. Their results showed that Log Pearson Type III probability distribution can be used to design hydraulic and soil and water conservation structures.

Subudhi (2007) used Normal, two parameter Lognormal, three parameter Lognormal and Log Pearson Type III frequency distributions for meteorological data of 22 years (1975-1996) for Kandhamal district in Orissa. Results showed that normal distribution is the best model for predicting annual rainfall for area.

Kumar *et al.* (2007) analyzed daily rainfall data of 45 years (1955-1999) for Saharanpur to compute the weekly rainfall amount at different probability levels (50, 60, 70, 80 and 90 per cent) and suggested to use 70 per cent probability level for assured rainfall for crop planning.

Xeflide and Duke (2007) recorded that annual one day maximum rainfall and two to five consecutive day’s maximum rainfall corresponding to a return period of 2 to 100 years has been conducted for Accra, Ghana. Three commonly used probability distributions; normal, lognormal and gamma distribution were tested to determine best fit probability distribution that describes annual one day maximum and two to five consecutive day's maximum rainfall series by comparing with Chi-square value. The results revealed that log-normal distribution was the best fit probability distribution for one day annual maximum as well as two to five consecutive days maximum rainfall for region.

Patle (2008) conducted probability analysis of annual maximum rainfall of 1 to 4 consecutive days of 25 years (1974-1998) for Akola, India. Weibull's formula was used to calculate the observed and expected rainfall values were calculated using probability distributions like Gumbel, Lognormal and Log Pearson Type III. The Lognormal distribution gave closest fit to observed value using Chi-square test.

Shelat and Shete (2008) tested 17 different types of continuous probability distributions by Chi-square test using Easyfit statistical software for Patan, Gujrat using daily rainfall data from 7 rain gauge stations for 43 years (1961-2003). Results indicated that based on the rankings, the Weibull distribution was overall fitted well to 1-day and consecutive 2 to 7 days maximum rainfall.

Sahoo *et al.* (2008) evaluated daily rainfall data for annual, seasonal and monthly analysis at different probability levels for Udhagamandalam considering 43 years rainfall data from 1960 to 2002 to obtain the rainfall distribution pattern. They reported that at 80 per cent probability level, rainfall available in the season were more than water requirement of crops. Annual maximum daily rainfall at different return period can be useful for design of any water harvesting and soil conservation structures.

Babu and Sahoo (2009) analyzed daily rainfall data from Sulur in Tamilnadu for fitting one day maximum, average weekly, monthly and seasonal rainfall data at probability levels of 20, 40, 60 and 80 per cent. They concluded that based on the D-Index, Gumbel and Lognormal distributions were best fitted for annual maximum one day, weekly and monthly rainfall whereas Normal distribution was best fitted for total annual rainfall values and gave reliable estimates.

Panda *et al* (2009) used selected probability distribution functions for analyzing rainfall of Koraput district of Orissa for judicious crop planning. The data indicated that (1969 - 2007), mean maximum of 391.8 mm rainfall was observed during the month of August, whereas 29th week (July 15 - July 21) experienced maximum rainfall of 110.9 mm. Rainfall variability of less than 100% is observed during 26th to 35th and 37th to 39th weeks and similarly during May to October implying uniform wetness period. Three probability distribution models viz. two and three parameter Gamma distribution and Log Pearson Type III functions were found to be the best fitted to the weekly, monthly and annuall rainfall data series. Two parameter or three parameter Gamma distribution functions were found best fitted to the rainfall data series except January and March and paired t test revealed that there is no difference between the observed and theoretical distributed values. Through water balance analysis, it was found that there was only 4.3 mm rainfall available during rabi season at 70% probability level indicating need of judicious planning for conservation of the *rabi* crop. An attempt was also made to explore possibility of conserving 50% of surplus rainwater in excavated pond. It was deduced that a suitable combination of crops like wheat + tomato, wheat + potato, tomato + bean and potato + cabbage can be successfully grown by the farmers during *rabi* season from the harvested water.

Olofintoye *et al* (2009) studied the peak daily rainfall distribution characteristics in Nigeria, by using different statistical analyses such as Gumbel, Log-Gumbel, Normal, Log-Normal, Pearson and Log-Pearson distributions. They selected 20 stations having annual rainfall data of fifty-four (54) to perform frequency analysis. Mathematical equation for the probability distribution functions were established for each station and used to predict peak rainfall. Predicted values were subjected to goodness of fit tests such as chi-square, Fisher's test, correlation coefficient and coefficient of determination to determine how best they fits. Results showed that the log-Pearson type III distribution performed best by occupying 50% of total station number, while Pearson type III performed second best by occupying 40% and log-Gumbel occupying 10% of total stations.

Pradeep and Babu (2010) analyzed rainfall data of 34 years for Chandrabanda in Raichur district of Karnataka to obtain rainfall distribution of annual one day maximum, monthly and annual rainfall at different probability levels (10, 25, 50 and 75 per cent) using Normal, Lognormal, Gumbel and Log Pearson Type III distributions. Based on minimum D-index, lognormal distribution for annual one day maximum rainfall and maximum monthly rainfall was best fitted whereas for annual rainfall Normal and Log Pearson Type III were best fitted distributions for the study area.

Sharma and Singh (2010) collected the daily rainfall data of 37 years from IMD approved Meteorological Observatory situated at GB Pant University of Agriculture and Technology, Pantnagar, India. The data were processed to identify maximum rainfall received on any one day (24hrs duration), in any week (7 days), in a month (4 weeks), in a monsoon season (4 months) and in a year (365 days period). The data showed that annual daily maximum rainfall received at any time ranged between 49.32mm (minimum) to 229.40mm (maximum) indicating a very large range of fluctuation during the period of study. It was observed that the best probability distributions obtained for the maximum daily rainfall for different data set are different. The lognormal and gamma distribution were found as the best fit probability distribution for annual and monsoon season period of study, respectively.

Momin *et al.* (2011) carried out the probability analysis of annual 1-day and 2 to 5 consecutive day's maximum rainfall of 44 years (1976-2010) at various return periods for Southern Telangana. The magnitude of 1-day and 2 to 5 consecutive day's maximum rainfall corresponding to 2 to 100 years return periods were estimated by Gumbel's method for extreme event frequency analysis. Their results can be used by design engineers and hydrologists for economic planning, design of small and medium hydrologic structures and determination of drainage parameters for agricultural lands in the region.

Chakraborty *et al.* (2012) tested different probability distributions namely Normal, Lognormal, Log Pearson type III and Gumbel for Raipur region comparing Chi-square test. Results showed that Gumbel distribution was best fit for one day maximum rainfall while Log Pearson Type III distribution was found to be the best for 2 to 4 consecutive days maximum rainfall. Normal distribution was found to best fitted for 5 consecutive days maximum rainfall. They suggested using the developed equations in study for prediction of 2 to 5 consecutive days maximum rainfall from one day annual maximum rainfall for the Raipur region.

Shah *et al.* (2014) conducted study on annual one day maximum rainfall and two, three, four, five, six and seven consecutive day's maximum rainfall corresponding to a return period of 2 to 100 years for the Panam dam, Gujarat, India. Three commonly used probability distributions were normal, lognormal and gamma distribution tested to determine the best fit probability distribution by comparing observed values with tabulated Chi-square value. The results showed that log-normal distribution was the best fit probability distribution for one day annual maximum as well as two, three and four consecutive days, while for five and seven consecutive days maximum rainfall gamma distribution and for six days normal distribution fits better for the region.

Hussein (2014) analysed annual rainfall in the Catchment of holy Karbala for the purpose of finding the appropriate frequency distribution of the data. He applied theory of probability distributions, namely Normal, Log-Normal, Log-Normal Type III, Gamma, Pearson Type III, Log-Pearson Type III and Weibull Type III distribution for modeling at-site annual rainfall using several plotting positions formulas at Euphrates river basin in

Kerbala. Frequency curves based on each of these distributions were derived. Goodness of fit tests, namely Chi-square, Anderson-Darling and Kolmnogorov-Smirnove were applied to fit theoretical distributions for observed data. The study showed that Gamma distribution is the best model for annual rainfall in the Catchment of holy Karbala.

Mehendale *et al* (2014) collected daily rainfall data of Kolhapur for the year 2012-13 and used Normal, Log-normal and Gumbel distributions of probability. From the analysis it was concluded that Log- pearson type III distribution was the best probability distribution of rainfall in Kolhapur region.

Win &Win (2014) studied rainfall data at four stations for Kuantan river basin in Malaysia with the objectives to perform the frequency analysis, to identify the most appropriate probability distribution and to estimate the maximum annual daily rainfall for selected return periods. In this study, Normal, 2P and 3P Lognormal, Gamma, Gumbel, Generalized Extreme Value, Pearson Type III and Log-Pearson Type III were identified to evaluate the best fit probability for rainfall distribution.

Based on the analysis of goodness of fit test, Generalised Extreme Value distribution proved to be the most appropriate distribution for annual maximum daily rainfall at all stations under study. They suggested to use estimated extreme rainfall with various frequencies as the basic inputs in hydrologic design such as in the design of storm sewers, culverts and many other structures as well as inputs to rainfall runoff models.

Kumar and Bhardwaj (2015) studied probability analysis of return period of daily maximum rainfall in annual data set of Ludhiana, Punjab with daily rainfall data of 38 years. One day maximum rainfall was sorted to estimate the probable one day maximum rainfall for different return periods by using probability distribution function. The mean value of annual one day maximum rainfall was found to be 105.9 mm with standard deviation and coefficient of variation and skewness of 64% 0.604% and 2.2 respectively. The results revealed that the Log Pearson Type-III distribution was the best fit probability distribution to describe annual one day maximum rainfall as compared to Lognormal and Gumbel distribution. Based on the best fit probability distribution, the maximum of 373.42 mm rainfall could be received with 25 years return period at Ludhiana.

Sabarish *et al* (2015) studied probability analysis for consecutive-day maximum rainfall for Tiruchirapalli city using 100 years of rainfall data. The best fit probability distribution was evaluated for 1, 2, 3, 4, 5 and 6 days of continuous maximum rainfall. The results of the goodness of fit using Chi square test indicate that log-Pearson type III method is the overall best-fit probability distribution for 1-day maximum rainfall and consecutive 2, 3, 4, 5 and 6-day maximum rainfall series of Tiruchirapalli.

Tabish *et al* (2015) conducted study for probability analysis of previous 20 years (1993-2012) with the prime objective of prediction of annual maximum rainfall of one to five consecutive days of Ambedker Nagar (Tanda). The observed values were computed by Weibull's formula. The maximum rainfall values were predicted using Gumbel, Log Pearson Type III, Log Normal and Gamma distributions at 9.52, 23.81, 47.62 and 95.24 percent probability levels. The goodness of fit was tested by Chi square formula proposed by Hogg and Tanis. The comparison between the measured and predicted maximum value of rainfall clearly showed that the developed model can be efficiently used for the prediction of rainfall. The statistical comparison indicateed that the Log normal distribution was the best model for prediction and Gumbel distribution showed very close relation with observed rainfall for two consecutive day's annual maximum rainfall (mm).

Asim and Nath (2016) The investigated rainfall probability analysis of previous 34 years data (1980-2013) with the prime objective of prediction of annual rainfall of Allahabad district. The observed values were computed by Weibulls formula and estimated values by proposed prediction models Gumbel and Log Normal. The rainfall data in the above distribution and their corresponding rainfall events were estimated at 2.9, 11.4, 20.0, 40.0, 51.4, 60.0, 80.0 and 97.1 percent probability level. Gumbel distribution was found to be the best model for predicting the annual rainfall (mm) basedon Chi square test while Log Normal distribution was fairly close to the observed annual rainfall (mm).

Sharma and Kumar (2016) studied the frequency analysis of rainfall data of Dharamshala region using 20 years of annual rainfall data useful for the prediction of annual one to seven days consecutive days maximum rainfall corresponding to return period varying from 2 to 20 years for the economic planning, by design engineers and hydrologists, design of small and medium hydrologic structures and determination of drainage coefficient for agricultural fields. The probability distributions Normal, Log Normal and Gamma were applied to estimate one to seven consecutive days annual maximum rainfall of various return periods. The mean value of one- day annual maximum rainfall at Dharamshala was found to be 142.9 mm with standard deviation and coefficient of variation of 54.8 and 51.34, respectively. The coefficient of skewness was 1.1. For 2 to 7 days consecutive annual maximum rainfall, values for mean, standard deviation, coefficient of variation and coefficient of skewness were 201-393.4 mm , 70.17-146.5, 41.65-30.47 and 0.726-1.593. It was observed that all distribution function fitted significantly.

2.3 Plotting Position Techniques

Weibull (1962) expressed that the probability of an event can be obtained using a plotting position technique in which the data is to be arranged in increasing or decreasing order of magnitude and order number ‘m’ is assigned to the ranked values. The most efficient and commonly used formula for computing plotting positions for unspecified distribution is :

$$P = m / n + 1 \qquad \ldots (2.1)$$

In Weibull’s method the maximum annual rainfall values are arranged in descending order irrespective of the year of the occurrence. Then data is to be plotted on probability paper using the log scale and per cent chance of occurrence of rainfall on probability scale.

Since above Weibull's formula is biased and gives largest rainfall values at very small return period. Hence, he suggested using Gringorten (1963) formula which is the best for analysis of selected maximum and minimum values of data sets. In Gringorten's plotting position method the values of maximum rainfall for 1-day as well as 2 to 6 consecutive days are to be arranged in descending order of magnitude by assigning the rank number to them. The probabilities of exceedance [$P(Y \geq Y_m)$] for all the rainfall series are to be computed by following formula :

$$P(Y \geq Y_m) = (m-b) / (n+1-2b) \qquad \ldots(2.2)$$

Where, m is the rank number, n is total number of years under consideration and value of b is 0.44.

Chow *et al* (1988) reported that Weibull's formula is theoretically suitable for plotting the annual maximum series. According to him, all the methods of determining the plotting positions gave practically, the same results in the middle of a distribution but produced different positions near the 'tails' of the distribution and hence choice of a plotting position formula becomes important. Upadhyaya and Singh (1998) compared relative performance of seven probability distributions and one step power transformation technique with respect to Gringorten's plotting position method applied to estimate 1-day as well as 2 to 6 consecutive days maximum rainfall of 42 years (1950-1991) at Bhubaneswar. Their analysis showed that for one day maximum rainfall, one step power transformation whereas for 2 to 6 consecutive days maximum rainfall Log extreme value predicted the closer values to the Gringorten's plotting position method. They also reported that for the return period of 2 to 10 years Gringorten's potting position method gave lowest values whereas for the return periods of 15 to 20 years it gave highest values.

Jacobs and Satti (2001) reported a modification in Weibull's plotting position formula when precipitation has some zero values in it.

Dingre and Shahi (2006) used rainfall data of 19 years (1985-2003) to study relationship between 1-day and 2 to 6 days consecutive days maximum rainfall of Srinagar in Kashmir valley corresponding to various return periods. They used Gringorten's equation with logarithmic equation curve fitting for computation of consecutive days maximum rainfall. They observed that rainfall values of consecutive days were significantly related with one day rainfall over 1 to 20 years return period. Hence, these relationships can reduce the tedious, time consuming and cumbersome analysis of long-term rainfall data.

Sethi and Kumar (2008) used frequency analysis of monthly and daily rainfall for Nayagarh, Orissa to find out relationship between one day maximum rainfall, consecutive days maximum rainfall and its applicability for planning and designing of water conservation and recharge structures to maximize water storage capacity and recharge potential. They compared consecutive days rainfall values computed by Normal, Lognormal, Pearson, Gamma and Gumbel distributions with rainfall values obtained by Gringorten's plotting position method and showed that all the distributions predicted higher values of rainfall than obtained from Gringorten's plotting method.

Singh *et al* (2012) analysed daily rainfall data of 39 years (1973-2011) to determine annual one day maximum rainfall of Jhalarapatan area of Rajasthan, India. The observed values were estimated by Weibull's plotting position and compared with expected values of probability distribution functions *viz.*, normal, log-normal, log-Pearson type-III and Gumbel. The results showed that based on Chi square test Log-Pearson type-III distribution was best fit probability distribution to forecast annual one day maximum rainfall for different return periods.

Agbede and Abiona (2012) analysed 51 years rainfall data of Lagos metropolis to synthesize a suitable rainfall intensity for a return period for design of drainage channels within the metropolis. Various graphical plotting formulae such as Hazen, Weibull, Blom, Gringorten, Tukey, California and Chegodayev were adopted to arrive at different best fitting equations. The fitted equations were used to determine various rainfall intensities with corresponding return periods. The fitted equations were used to determine various rainfall intensities with corresponding return periods.

Kotei *et al*. (2013) developed intensity-duration-frequency (IDF) curves developed for Mampong-Ashanti Municipal area using autographic rainfall data, which is commonly required for planning and designing of various hydrological resource projects. Rainfall data of recording rainguage of Ashanti region were analysed for total of six different durations ranging from 5 minutes to 60 minutes for return periods of 1, 2, 3, 4, 6, 7, 11 and 22 years. The IDF curves for area were developed using available rainfall data, Weibull plotting position and empiricism.

Ray *et al* (2013) attempted frequency analysis of daily rainfall data for 28 years (1983-2010) of Central Meghalaya, Nongstoin station for maximum daily rainfall. The annual maximum daily rainfall data was fitted to five different probability distribution functions viz; Normal, Log-normal, Pearson Type-III, Log Pearson Type-III and Gumbel Type-I extreme. The probable rainfall value estimated for different return periods were compared with values obtained by Weibull's Method. The analysis indicated that the Gumbel distribution gave the closet fit to the observed data. Hence, they suggested that the Gumbel distribution may be used to predict maximum rainfall for economic planning and design of small and medium hydraulic structures.

2.3.1 Straight line plotting

Ogrosky and Mockus (1957) developed the 'computing method' for plotting frequency line by computation of plotted points. This method has advantage of obtaining identical frequency line by any two persons and being mathematically sound.

Ram Babu *et al*. (2001) analyzed rainfall intensity-duration-return period equations for 24 stations situated in Madhya Pradesh. They used Gumbel extreme value technique for computation of return period values and the frequency lines were plotted after computing the plotted points using 'Computed method'.

2.4 Infiltration Rate of Soil

Singh *et al.* (1994); Saha *et al*. (1995); Patwary *et al.* (1997) and Dewangan *et al*.(1999) expressed that infiltration rate of soil is one of the basic and important parameter for planning soil water conservation measures and drainage system in agricultural lands. It is single parameter to measure composite effect of texture, structure, porosity and hydraulic conductivity of soil. Infiltration process has been studied in different parts of the country.

Raghunath *et al*. (2006) studied basic infiltration rates of soils with different texture at 44 locations in the Eastern Ghats of Kerala. They reported infiltration rate ranging from 0.4 to 87.6 cm hr^{-1} according to soil textural classes. It was found that the loamy soil had highest mean infiltration rate (39.9 cm hr^{-1}) whereas the silt loam soil was characterized with the lowest value.

Kumar *et al.* (2006) conducted infiltration studies at 5 locations of Pantnagar (Uttaranchal) and reported steady state infiltration rate between 0.24 to 3.61 cm hr^{-1}. The steady state and cumulative infiltration rates were found to be the lowest as 0.24 cm hr^{-1} in silt clay loam and highest as 52.64 cm hr^{-1} in sandy loam soil. They suggested using modified Kostikov’s and Kostikov’s models for predicting the infiltration rates in the region.

Dagadu and Nimbalkar (2012) calculated constant infiltration rates of different soils under different soil conditions black cotton clay and sandy soils at Sangola, district Solapur of Maharashtra region using double ring infiltrometer. The study aimed to determine constant infiltration rates of those soils under different soil conditions and comparing it with the infiltration rates obtained by Kostiakov, Modified Kostiakov, Horton’s and Green-Ampt infiltration models. The values of various constants of the models were calculated by method of averages suggested by Davis (1943) and by graphical approach. For getting best fitting model for particular soil and soil condition the results obtained from various infiltration models were compared with observed field data and graphs were drawn. The parameters considered for best fitting of model were correlation coefficient and standard error. The results showed that the Horton's model and Green – Ampt model were best fitting to observed field data to estimate infiltration rates at any given time with high degree of correlation coefficient and minimum degree of standard error.

2.5 Tolerance of Crop to Water logging

Surface stagnation of rain or irrigation water in the cropped land is a serious problem. (Gupta *et al.*, 2000). Most of the crops cannot sustain wet-land conditions and receive a severe setback when water stagnates even for a short period (Kumar, 1991).The extent of damage or yield reduction depends upon the crop and its growth stage, duration of water stagnation/flooding, type of soil and prevailing agro-climatic condition. In order to provide drainage system of an adequate capacity with minimum cost, the designers must be aware of relative tolerance of crops grown in a particular area

Verhallen and Tenta (2001) through their study proposed that corn can tolerate excess water stress for only 24 hours when soil temperatures are greater than 24^0C.

Thakur *et al.* (2003) presented quantitative information on relative tolerance of three rabi crops (wheat, mustard and barley), which were grown at same time to assess the performance of Mass and Hoffman (1977) model for describing the crop production under excess water stress due to short-term surface stagnation. The water stagnation was allowed for 1, 2, 4 and 6 days and compared with treatment in which excess water was drained through drainage channel after 12 hrs of irrigation. They reported that amongst the three crops wheat seems to be most sensitive to water stagnation followed by mustard and barley.

Gupta *et al.* (2004) assessed the relative tolerance of 8 different crops to water stagnation. They observed that under normal agro-climatic conditions with short term stagnation, the crop yields were adversely affected because of poor aeration resulting in reduced uptake of plant nutrients especially N, P, K and Zn. They revealed that in order to keep the yield losses below 10 per cent, water stagnation must be removed from the crop land within one day for sunflower, wheat and mustard; within two days for sorghum, pearl millet, pigeon pea and berseem (seed); and within 3 to 4 days for barley. Their study indicated barley to be most tolerant crop for water stagnation.

Sharma *et al.* (2005) conducted study to quantitatively evaluate the effects of time and duration of water stagnation in pigeon pea crop. Their study indicated that for ensuring optimum yield of pigeon pea in moderately sodic soils; standing water must be drained within one day of irrigation or rains. Water stagnation must be avoided at early growth stages such as vegetative (35 days after sowing) and flowering (75 days after sowing) stages of pigeon pea.

Akhtar and Nazir (2013) studied the effect of water logging and drought stress in plant and reported that water logging and drought affects a number of biological and chemical processes, which can impact crop growth in both the short and long term, in plants and soils. They also reported that germinating seeds are very sensitive to water logging and drought as their level of metabolism is high. Plant growing under stress condition also demonstrated the formation of adventitious roots and formation of aerenchyma.

2.6 Drainage Coefficient

Sharma and Irwin (1975) reported that a satisfactory return period can be selected based on the submergence tolerance of crops, economics involved in installation and maintenance of drainage system. The probability analysis of drainage rates provides a sound basis for selection of an appropriate drainage coefficient.

Bhattacharya and Sarkar (1982) analyzed 40 years (1931-1970) daily rainfall data and suggested that one day annual rainfall at 20 per cent probability if divided by 72 hours (3 days) would give a drainage coefficient of 56 mm day^{-1} which is quite high (40%). They also reported that if a drainage system is designed for crops which has only one day tolerance to excess water at 50 per cent probability, the drainage coefficient was found to be 89 mm day^{-1} (10.3 liters per sec per hectare) that was much larger than usually adopted value of 10 cusec per square mile. They observed that a length of data varying between 15 to 30 years will be required to have a reasonable confidence on the predicted 5 year rainfall value.

Aujla and Aujla (1985) conducted probability analysis of dry days for proper planning of drainage area and reported that dry spell analyses along with rainfall characteristics are essential to estimate the water requirement of different crops during the dry period.

Ray *et al.* (1985) analyzed point rainfall data of Bhubaneswar for the period of 30 years from 1930 to 1978. Expected monthly, seasonal and annual rainfall at different percent chances were worked out by Weibull's method. The successive totals, moving totals and maximum totals technique was applied for all durations up to 7 days and computed the drainage coefficient from depth-duration-frequency (DDF) analysis. The drainage coefficient values worked out were 3, 5.4 and 8.6 cm day^{-1} for returns periods of 5, 10 and 20 years, respectively for designing surface drainage system for the areas around Bhubaneswar.

Rao (1985) analyzed daily rainfall data of monsoon (June to October) for a length of 50 years (1926-1975) collected at Sagar Island (Sundarbans, West Bengal) for probable monthly rainfall, expected dates of receiving different cumulative rainfall, rainfall depth-duration-frequency data and probable continuous dry spells. The rainfall depth-duration-frequency curves were used for computing drainage coefficient required for design of various components of drainage system. He estimated drainage coefficient of 37.5 mm day^{-1} which can drain away excess water in 7 days resulted from 5 days duration rainfall for 5 years return period.

Khandelwal (1988) analyzed daily rainfall data of 25 years at Canning for comparison of one day annual maximum rainfall with theoretical frequency distributions by Lognormal, Gumbel and Log Pearson Type III and observed that Log Pearson Type III (C_v=0.382) and Lognormal (C_v=0.43) distributions were close to observed distribution (C_v=0.439) than Gumbel (C_v=0.675) for one day annual maximum rainfall. The drainage coefficient based on 5 days annual maximum rainfall for 5 year return periods was found to be 40 mm day^{-1}, with removal time of 7 days.

Sharma *et al*. (1997) analyzed 33 years daily rainfall data of Tawa command for its depth-duration-frequency analysis to arrive at 1 to 4 consecutive days rainfall values for 2, 5, 10 and 20 years recurrence interval (RI). Computed drainage coefficient indicated that soils of Tawa command having basic infiltration rate of 8, 9, 10 and 11 mm day^{-1} may not need surface drainage system for one day period rainfall at 2, 5, 10 and 20 years RI. The corresponding values in case of two consecutive days rainfall are 6, 7, 8 and 9 mm day^{-1}. In case of one day rainfall drainage coefficient varies between 161 to 209 mm day^{-1} for 5 years RI and between 197 to 245 mm day^{-1} for 10 years RI, in clayey soils of Tawa command having basic infiltration rate between 1 to 3 mm hr^{-1}. This revealed that soils at Tawa command are predominantly clayey soils with basic infiltration rate between 1 to 3 mm hr^{-1} may necessarily have to be provided with surface drainage system for its major existing crop sequence soybean followed by wheat.

Upadhyaya and Singh (1998) analyzed daily rainfall data of 42 years (from 1950 to 1991) for OUAT, Bhubaneswar and suggested that maximum rainfall of 2 to 6 consecutive days varying from 2 to 20 years recurrence interval and crop tolerance period helped in determination of drainage coefficient for agricultural fields.

Andersen *et al* (1999) studied the role of urban surfaces in regulating drainage and evaporation. Result demonstrated that evaporation, drainage and retention in the structures were strongly influenced by the particle size distribution of the bedding material and by water retention in the surface blocks. In general, an average of 55% of one-hour duration, 15 mm h^{-1} rainfall event could be retained by an initially air-dry structure. Subsequent simulations demonstrated that 30% of a one-hour duration, 15 mm h^{-1} rainfall event could be stored by an initially wet structure.

Patle *et al.* (2005) analyzed 25 years daily rainfall data of CRS, Akola for its depth-duration-frequency analysis to arrive at 1 to 4 consecutive days rainfall values for 2, 5, 10 and 20 years recurrence interval. Computed drainage coefficient indicated that the soils of CRS having basic infiltration rate above 3, 5, 7 and 8 mm hr^{-1} may not need surface drainage system for one day period rainfall of 2, 5, 10 and 20 years RI respectively. The corresponding values in case of two consecutive day's rainfall are 2, 3, 3 and 4 mm hr^{-1} and for three consecutive day's rainfall are 1, 2, 2 and 3 mm hr^{-1}. In case of one day rainfall, drainage coefficient varies between 64.14 to 112.14 mm $day^{-1}$for 5 years RI and between 102.06 to 150.06 mm day^{-1} for 10 years RI, in clayey soils of CRS having basic infiltration rate between 1 to 3 mm hr^{-1}. Study further revealed that soils at CRS are predominantly clayey soils with basic infiltration rate between 1 to 3 mm hr^{-1} which may necessarily have to be provided with agricultural land drainage for its major existing crops.

S. R. Bhakar *et al.* (2006) studied three commonly used probability distributions (viz: Normal, Log Normal and Gamma distribution were tested by comparing the Chi-square value. Gamma distribution was found to be best fit for the Banswara, Rajasthan.

Skaggs *et al* (2006) analysed the drainage design coefficient for eastern United States. A simulation study was conducted to determine the drain spacing corresponding to predicted maximum economic return for corn production on four soils at 10 locations. Drainage Design Coefficient varied with growing season rainfall and ranged from an average of 0.58 cm/day at Toledo (OH) to 1.61cm/day at Baton Rouge, (LA) variations of DDR among the four soils was least for low rainfall locations and highest where growing season rainfall was high.

Shrivastava and Patel (2008) used annual rainfall data for a period of 1971 to 1998 and daily rainfall data for 1988 to 2007 at Navsari to estimate 1 to 5 consecutive days maximum rainfall using Weibull, Gumbel, Log Pearson Type III and Lognormal distributions. They designed drainage system on the basis of drainage coefficient, which usually depends on 1 to 5 consecutive days maximum rainfall corresponding to return period varying from 2 to 10 years and crop tolerance period considering sugarcane and banana crops.

Barkotulla *et al* (2009) studied probability distributions to predict rainfall status of various return period estimating one to seven consecutive days annual maximum rainfall of Boalia, Rajshahi, Bangladesh using three probability distributions Normal, Log Normal and Gamma distribution. Results showed that the log-normal distribution was the best fit probability distribution for one to seven consecutive day's annual maximum rainfall for the region.

Wadatkar *et al* (2011) studied drainage requirement of agricultural land through rainfall analysis for Nagpur and Akola using daily rainfall data for 35 years. They estimated drainage coefficient for Nagpur with vegetable crops as 106.03, 82.03, 58.03, 34.03 and 10.03 mm day-1 and for oil seed crops drainage coefficients were 67.76, 43.76 and 19.76 mm/day for soil having basic infiltration rate 1, 2 and 3 mm/hr respectively. For crops like cotton, sorghum, maize, bajra and other similar crops drainage coefficients were 45.04 and 21.04 mm/day for with basic infiltration rate as 1 and 2 mm/hr respectively. For Akola the values of drainage coefficients were lower as compared to Nagpur.

Singal *et at.* (2014) studied the rainfall intensity and frequency estimation for Gandak basin, region prone to high floods with an unrealized and unexplored hydro-potential. The two popular gridded precipitation datasets i.e.: (1) APHRODITE, and (2) IMD, for the years 1969-2005, were used to calculate the mean basin precipitation through Thiessen polygon method on the Arc-GIS interface. The computed data was used to find out the 1-day, 2-day to 5-day consecutive maximum precipitation series and fitted into various well-known probability distribution functions viz., Normal, Gamma, Exponential, etc. According to the best fit data in these functions, the quantities were determined corresponding to a return period of 2, 10, 20, 25, 50 and 100 years. The results revealed that the best fit for 1-day was achieved with the normal distribution.

Kapse (2015) analysed talukawise daily rainfall data of 35 years (1983-2012) were analyzed to ascertain 1 to 5 days consecutive maximum rainfall of Hingoli district. The estimated talukawise drainage coefficient of Hingoli district showed that the soil of Aundha, Sengaon, Basmat, Hingoli, Kalamnuri stations having infiltration rate between 1 to 8 mm/ hr necessarily have to be provided with agricultural land drainage system based on tolerance of different crops to water logging. Similarly Khandare (2015) analysed talukawise daily rainfall data of 30 years (1983-2012) for Nanded district to ascertain 1 to 5 days consecutive maximum rainfall. The talukawise drainage coefficient of Nanded district for the soil of Ardhapur, Hadgaon, Mahur, Naigaon stations having infiltration rate between 1 to 8 mm/hr were developed.

2.7 GIS Mapping

Ayalew and Yamagishi (2004) Developed the landslide susceptibilty maps in the Kakuda-Yahiko mountains, Central Japan using GIS based logistic regression. This study showed that the landslide are more common in Yahiko than Kakuda and in mid altitude slopes than in high lands and lowland.

Rathod and Aruchamy (2010) performed the spatial analysis and developed rainfall variation in Coimbture district, Tamilnadu using GIS. They collected 49 years monthly rainfall data of 33 rain gauge stations. They found that maximum rainfall occurs at Upper Nidam 1202.01 mm in the month of July and lowest at Coimbture town 4.1 mm in the month of February.

Gurugnanam *et al.* (2010) made an attempt to understand the rainfall fluctuations with respect to spatial distribution in Salem district of Tamilnadu through GIS techniques. Variation in rainfall during winter, summer, southwest monsoon and north-east monsoon were analyzed for period of 1998 to 2007. The results were taken into GIS platform to prepare the spatial distribution maps. This study showed that Salem district receives meagre amount of rainfall overall in last ten years.

Mohamad *et al.* (2014) estimated and mapped the rainfall distribution in Duhok Governorate (Iraq) using IDW (Inverse Distance Weighing) method in

GIS. For this study they collected the data of 2000 and 2001 for 25 rainfall stations. This study evaluated the relationship between interpolation accuracy and critical parameters of IDW (power α value and rainfall radius of influence).

2.8 Critiques on the Literature Reviewed

The drainage need of agricultural lands usually is expressed in terms of drainage coefficient. The rainfall data analysis for the purpose of drainage systems design is different from the conventional methods of rainfall analysis such as intensity-duration-frequency analysis or depth-area-duration analysis. Rainfall analysis using probability distribution function for estimating consecutive days maximum rainfall is the best indirect method for determination of drainage coefficient of any region. Although many scientists have worked on the rainfall analysis leading to prediction of consecutive day maximum rainfall, the climatic parameters change with the geographical locations. Contradictory findings are reported in the Literature regarding the best fit probability distribution for estimating consecutive days maximum rainfall at various locations in India and elsewhere. Even within a region different probability distribution function were found to the best fitted. Hence, evaluation of best fit probability distribution function for various location in Osmanabad district is required to estimate consecutive days maximum rainfall. Similarly, the drainage coefficient for any region varies with geographical location, land use, size of area, rainfall intensity, frequency and duration and other climatic factors. Such study is not conducted for different locations of Osmanabad district of Marathwada region. Hence the present study to estimate the drainage coefficient of agricultural lands at various locations Osmanabad district is required to be undertaken.

The result of the study will be useful for hydrologists and design engineers for planning and design of hydrologic structures. Drainage coefficient developed for Osmanabad district will be useful in the design of surface drainage system in the district.

MATERIAL AND METHODS

CHAPTER-III

MATERIAL AND METHODS

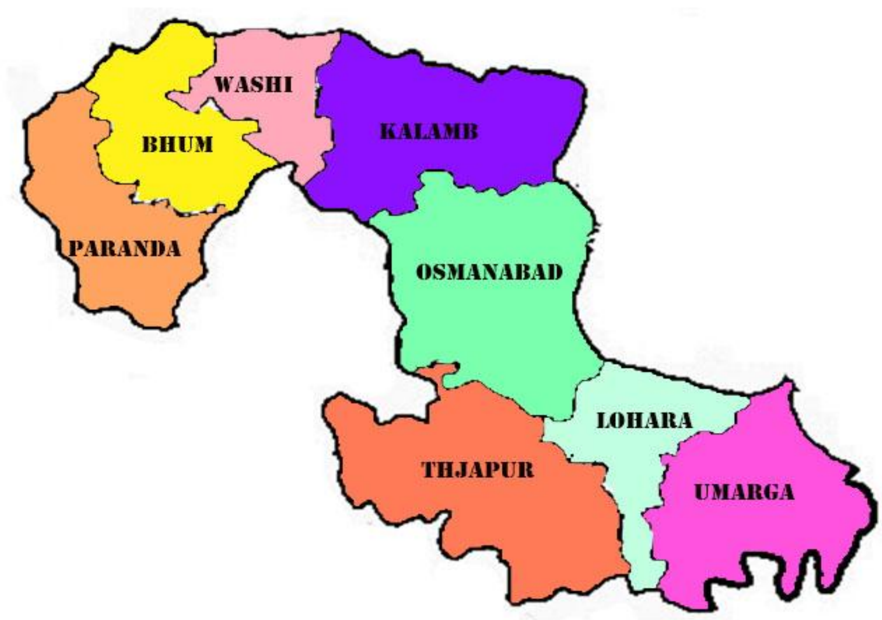
In order to fulfil the objectives of present research project, data pertaining to rainfall was collected and analyzed to determine the drainage coefficient of agricultural land. In this chapter description of area under the study, basic resources, materials used and methods adopted for data analysis and development of drainage coefficient for the agricultural land are presented. The standard methods adopted and utilized to fulfil the research objectives are discussed in succeeding section.

Marathwada occupies following three agro climatic zones out of nine of Maharashtra state.

1. Scarcity rainfall zone or famine area which includes western part of Beed, Aurangabad (Kannad Taluka) and Osmanabad (Bhoom and Paranda Taluka) districts. The average annual rainfall in the area ranges between 550 to 700 mm.
2. Assured rainfall zone covers larger area than the other zones and occupies some part of Latur, Osmanabad, Beed, Aurangabad, Jalna, western part of Parbhani and southern part of Nanded districts. The average annual rainfall of this zone ranges between 700 to 900 mm.
3. Moderate to moderately high rainfall zone includes Hingoli and remaining part of Nanded and Parbhani districts. The average annual rainfall of this zone ranges between 900 to 1150 mm.

Osmanabad district largely comes under assured rainfall zone (700 to 900 mm), except Bhoom and Paranda Taluka which are in scarcity zone (500 to 700 mm). It is located towards South of Balaghat ranges and lies in the Southern part of state on Deccan plateu. The district is situated mainly in Sina, Bhima and Manjra basin. The Sina river basin drains the top north-west part of the district particularly Paranda taluka of the district. The district is situated on the east side of the Marathwada region within North Latitude 17^0 35’ to 18^0 40’ degrees and East longitude 75^0 16' to 76^0 40' degrees with an elevation of 600 m above mean sea level. The location map of Osmanabad district is shown in Fig 3.1. The rainfall in the district is mainly contributed due to South-West monsoon extending from June to September. The average annual rainfall in the district is 730 mm with maximum temperature of 42.5°C and minimum temperature 8.5 °C.

3.1 Location



Location Map of Osmanabad District

Table 3.1 Location details and average annual rainfall of different talukas of Osmanabad district

Sr.No.	Talukas	Lattitude	Longitude	Elevation	Average annual rainfall (mm)
1.	Bhoom	18.46	75.65	588.00	905.9
2.	Kallam	18.57	76.02	666.00	715.6
3.	Lohara	17.98	76.32	633.00	799.0
4.	Umarga	17.83	76.62	578.00	799.0
5.	Osmanabad	18.18	76.03	600.00	730
6.	Paranda	18.27	75.45	523.00	615.5
7.	Tuljapur	18.01	76.07	645.00	837.4
8.	Washi	18.54	75.77	724.00	715.6

3.2 Soils in Study Area

The soils of the Marathwada region are classified in three major soil orders viz., Vertisols, Inceptisols and Entisols. The infiltration rate of soil has to be used in determination of drainage coefficient for this region. The average infiltration rate of soils in the Marathwada region is 4.17, 2.70 and 1.98 cm hr^{-1} for shallow, medium deep and deep soils respectively (Bharambe and shelke, 2001).

Soil found in Osmanabad district is red and black (Comprehensive District Agricultural Plan for Osmanabad district, 2016). The soils of the district are basically derived from Deccan Trap Basalt and are broadly classified into three major types. Shallow Soils occur in small patches in western and northwestern parts of the district. These soils are light brown to dark grey in color and loamy to clayey loamy in texture. Medium Soils are found in parts of Bhoom, Kallam and Osmanabad talukas. They are dark brown to dark grey in colour. Medium deep soils occur in patches in Tuljapur taluka. The colour of these soils varies from dark grey brown to very dark grey. They are clayey in texture. (CGWB, 2013**)**

3.3 Collection and Arrangement of data

The talukawise daily rainfall data of Osmanabad district for the period of 31 years (January 1986 to December 2016) was collected from Maharashtra Engineering Research Institute (MERI) Nashik. The collected daily rainfall data, in a particular year was converted into 1 to 5 consecutive day's maximum rainfall by summing up the maximum rainfall of consecutive days. The daily rainfall data was arranged year wise in descending order to work out consecutive days (1 to 5 days) maximum rainfall.

3.4 Statistical Analysis

The probability analysis of talukawise daily rainfall values were carried out by using Gumbel, Lognormal, Log Pearson Type III and Normal distributions with Chi-square test for goodness of fit. The best fit distribution was then used for estimating expected consecutive days maximum rainfall and determination of drainage coefficient.

The data in respect of rainfall, runoff, temperature, pan evaporation etc. can be treated as a statistical variable (Chow, 1988 ; Mutreja, 1986) and is therefore considered as a random variable. The random variables are of two kinds, discrete and continuous. The present study deals with probability analysis of daily rainfall which is a continuous variable. For continuous random variable, the probability and variate can be considered as probability P (x) of a discrete value grouped in range from x to X + x. As X is continuous value, x becomes dx; the probability becomes continuous function and called as probability density. The cumulative probability P[X < x] is an integer function of probability density and is given by equation;

$$P[X < x] = \int_{-\infty}^{X} P[x]dx \qquad \text{.... (3.1)}$$

The continuous probability distributions are Normal, Lognormal, Gamma, Log Pearson (Type I and III), extreme (Type I, II and III), beta and exponential. Earlier studies show that Normal, Lognormal, Gamma distributions are mostly used for analysis of hydrological variables involving the amount of variable over certain period such as amount of rainfall in week, month and annual runoff etc. (Varshney, 1989). The other distributions such as extreme and Pearson are used for analysis of hydrological variable involving extreme (maximum and minimum) values such as flood, annual daily maximum rainfall etc. (Kundu, 1973; Senapati et al., 1979 ; Sharda and Bhushan, 1985).

3.4.2 Fitting of Probability Distribution

There are two manual methods which can be used in the rainfall probability analysis; viz plotting position or graphical method and parametric method.

3.4.2.1 Plotting positions of probability

The probability of an event can be obtained by using the plotting position relationship as presented by Chow (1964). In this case, 1 to 5 consecutive days maximum rainfall data was arranged in ascending or descending order of magnitude and the order number was assigned to the rank values. The most efficient and commonly used formula for computing plotting position for unspecified distribution, the Weibull's plotting relationship was used as:

$$P = \frac{m}{n+1} \times 100 \qquad \text{.... (3.2)}$$

in which,

P - Plotting position per cent chance

m- Rank number when data are arranged in descending order of magnitude with highest value marked as 1 and

n - Total number of years for which the data are available

After computing the probabilities by above formula, the obtained values of probabilities were plotted on probability paper (log–log paper) against maximum rainfall. The values of maximum rainfall (mm) were plotted on X-axis whereas the calculated probability values were plotted on Y-axis. The frequency line was plotted after computing the plotted points using 'computed method' suggested by Ogrosky and Mockus (1957).

For this the three points were plotted at 50, 15.9 and 84.1 per cent chance of probability by calculating the values of mean, mean + standard deviation and mean – standard deviation of rainfall. Using the three probability levels of 50, 15.9 and 84.1 per cent and the corresponding values of mean, mean + standard deviation and mean – standard deviation of particular consecutive days maximum rainfall, three points were marked and joined as a straight line on the graph. Using the straight line, the observed rainfall values were determined at different selected probability levels of 50, 20, 10, 5, 2 and 1 per cent from the graph. These values were used as estimated values of maximum consecutive days rainfall.

3.4.2.2 Parametric method

In Parametric method, the maximum daily rainfall of each year was arranged year-wise according to ascending or descending order. The data set arranged was used for further analysis. The statistical parameters such as mean, standard deviation, coefficient of variation and coefficient of skewness were calculated for each of the selected distribution (Gumbel, Lognormal, Log Pearson Type III and Normal). Coefficient of variation indicates that the large scale variability in daily annual maximum rainfall during different years and coefficient of skewness indicates that rainfall did not always follow particular distribution from year to year.

The 1-day maximum rainfall values of theoretical distributions were calculated at different selected probabilities of 50, 20, 10, 5, 2 and 1 per cent with the help of frequency factor. The rainfall values of theoretical distributions were termed as expected rainfall values. Same procedure was adopted for estimating 2 to 5 consecutive day's maximum rainfall. These expected values were used in further analysis.

The probability distributions functions are used in the present study are described below;

Gumbel Distribution

This distribution results from any initial distribution of exponential type which converges to an exponential function as variate 'x' increases. The probability density of this distribution is given by:

$$P[x] = \frac{1}{\alpha}\exp[-\frac{x-u}{\alpha} - \exp(-\frac{x-u}{\alpha})] \qquad \text{....(3.3)}$$

in which,

x is variate with values $-\infty < x < \infty$;

u and α are parameters

By the method of moment, the parameters can be evaluated as:

$$u = \mu - \gamma\alpha \qquad \text{...(3.4)}$$

and $\alpha = \sqrt{6\sigma} / \pi$ …(3.5)

where,

γ = 0.57721 which is known as Euler's constant

μ is the mean and σ is the standard deviation

α and γ are the statistical parameters

Chow has derived the statistical parameters for X

Average annual maximum daily rainfall, $\bar{x} = \Sigma X / n$ …(3.6)

Standard deviation,

$$\sigma_y = \sqrt{\frac{\sum Y^2 - (\sum Y)^2/n}{n-1}} \quad \text{…(3.7)}$$

$$\sigma_x = 100 * \sigma_y \quad \text{….(3.8)}$$

$$C_v = \sigma_x / \bar{x} \quad \text{….(3.9)}$$

$$C_s = 3C_v + {C_v}^3 \quad \text{…(3.10)}$$

In which,

T is return period in years; Y=x/100; σ_y is standard deviation of Y; σ_x is standard deviation of x; C_v is coefficient of variation and C_s is coefficient of skewness.

The frequency factor K was determined by using following equation

$$K = -\frac{\sqrt{6}}{\pi}\left\{0.57721 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\} \quad \text{…(3.11)}$$

By using above equation values of X (theoretical annual maximum rainfall) for 1-day and 2 to 5 consecutive days for corresponding probability were computed using the relation:

$$X = \overline{x} + K\,\sigma_x \quad \text{…(3.12)}$$

Where $\overline{x}$ is the mean rainfall

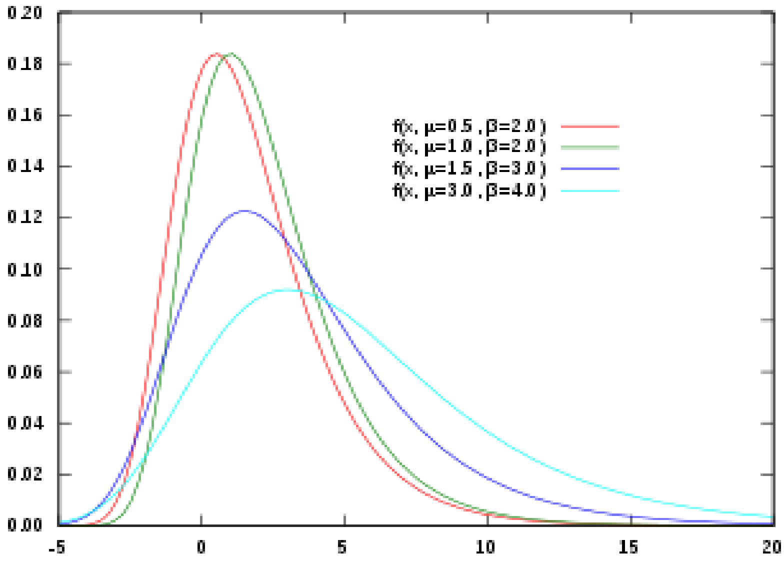


Fig. 3.2 Graph for the Gumbel Probability Distribution

Lognormal Distribution

A random variable x is said to follow a Lognormal distribution if the logarithm (usually natural logarithm) of x is normally distributed. The probability density function of such a variable is given by:

$$P[x] = \frac{1}{\sigma_y\sqrt{2\pi}} e^{\left(-\frac{(y-\mu_y)^2}{2\sigma_y{}^2}\right)} \qquad \text{...(3.13)}$$

where, Y= ln (x); x is a variate; $\mu_y$is the mean of y and $\sigma_y$is the standard deviation of y.

The statistical parameters σ_x, σ_y, C_v and C_s can be estimated using equations 3.7, 3.8, 3.9 and 3.10 respectively. The values of frequency factor 'K' for Lognormal distribution were taken from standard normal density function table (Mutreja, 1986) for skewness coefficient (λ) of a given rainfall for computing theoretical probability.

$$\frac{X}{\bar{x}} = 1 + C_v \qquad \text{...(3.14)}$$

By substituting mean, coefficient of variation and the frequency factor in equation 3.14 can compute 1-day and consecutive days maximum rainfall corresponding to return periods can be computed.

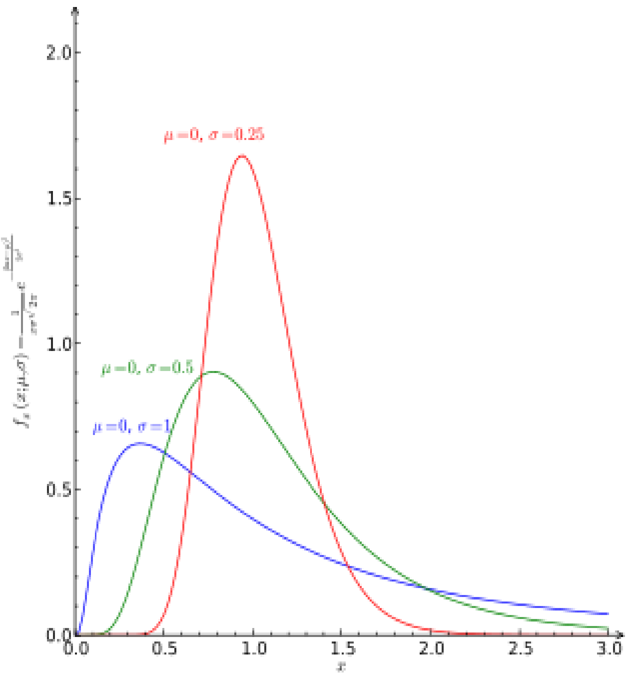


Fig. 3.3 Graph for the Lognormal Probability Distribution

Log Pearson Type III Distribution

For Log Pearson Type III distribution all values of annual maximum rainfall were transformed to corresponding logarithmic magnitudes. Assuming the initial values to be $x_1, x_2, x_3, \ldots, x_n$ the corresponding log magnitudes are $y_1, y_2, y_3, \ldots\ldots\ldots, y_n$.

Where, $y_n = \log (x_n)$

The probability density function of this distribution is estimated as:

$$P[x] = \frac{\lambda^{\beta}(y-\epsilon)^{\beta-1}e^{-\lambda(y-\epsilon)}}{x\Gamma(\beta)} \quad \ldots(3.15)$$

With $\log x \geq \epsilon$

where,

$y = \log x$;

$\lambda = S_y / \sqrt{\beta}$;

$\beta = [2/C_s(y)]^2$ and

$\epsilon = \bar{y} - S_y\sqrt{\beta}$

$\bar{y}$, S_y and $C_s(y)$ are the mean, standard deviation and coefficient of skewness of variate y, respectively and λ is a gamma function.

Chow, (1964) has derived the statistical parameters for Y as

$\bar{y} = \Sigma\, Y / n$ ....(3.16)

$\bar{\mu}_2 = \Sigma\, (Y - y)^2 / n$ ....(3.17)

$S_y^2 = \Sigma\, (Y - y)^2 / n-1$ ....(3.18)

$\hat{\mu_3} = S_y^2 / n$ ....(3.19)

Skewness coefficient, $\lambda = \frac{N^2}{(N-1)(N-2)} \frac{\mu_3}{\mu_2^{3/2}}$ ....(3.20)

Where, N is number of observations.

The values of frequency factor 'K' for Lognormal distribution were taken from standard normal density function table (Mutreja, 1986) for skewness coefficient (λ) of a given rainfall for computing theoretical probability.

After substituting mean, standard deviation of log transformed series and the frequency factor in equation 3.12 yields log Y is calculated. By taking antilog of log Y can 1-day and consecutive days maximum rainfall corresponding use to return periods was computed.

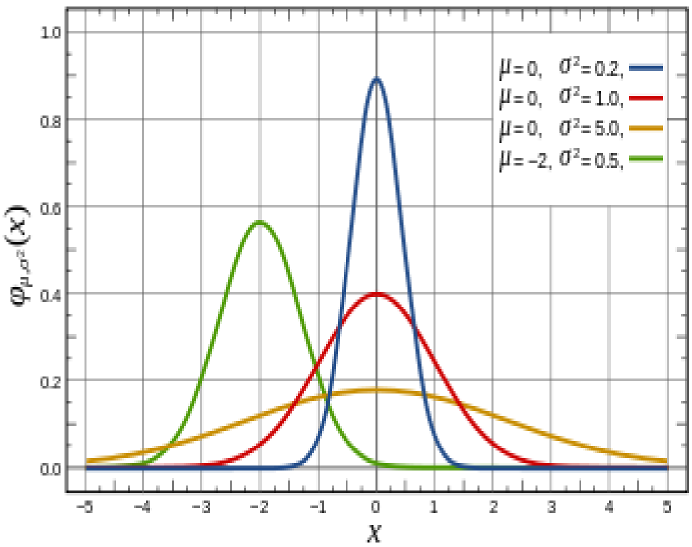


Fig. 3.4 Graph for the Lognormal Probability Distribution

Normal Distribution

Normal distribution is a symmetrical, bell shaped continuous distribution theoretically representing the distribution of accidental errors of their mean or the so called Gaussian law of error and the probability density function is given by:

$$P[x] = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\left(x-\mu^2/2\sigma^2\right)} \quad ....(3.21)$$

Where,

x is variate ; μ is the mean of variate and σ is the standard deviation.

For the normal distribution the frequency factor can be expressed by the following equation:

$$K_T = Z = [x_T - \mu / \sigma] \quad ....(3.22)$$

The value of Z can be found from standard normal density function tables or could be calculated using the equation as below:

$$Z = W - \left[\frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788 + 0.189269W^2 + 0.001308W^3}\right] ....(3.23)$$

where, $W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{1/2}$ ....(3.24)

When $p \geq 0.5$, (1- p) is substituted for p in equation (3.24). In this case the value of Z is computed by equation (3.23) is given a negative sign (Bhakar et al., 2006).

By substituting mean, standard deviation and the frequency factor in equation 3.12 can compute 1 to 5 consecutive days maximum rainfall corresponding to return periods was computed.

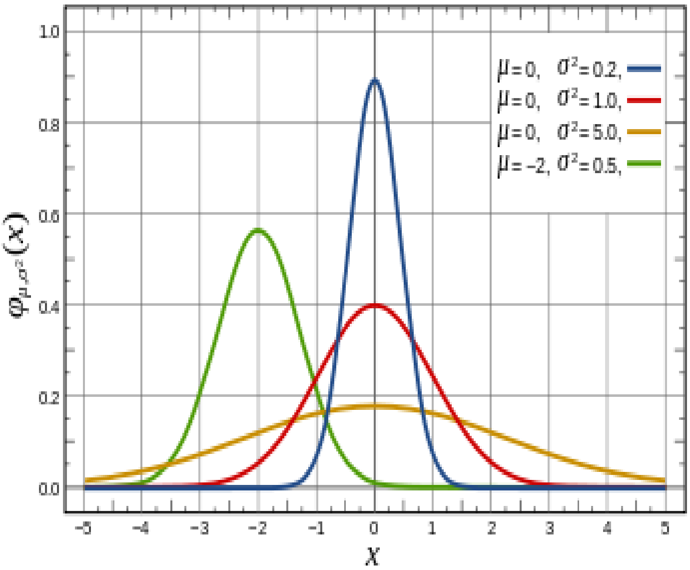


Fig. 3.5 Graph for Normal Probability Distribution

3.5 Selection of Return Period

The rainfall data were arranged in descending order of magnitude and the return period in years was computed by following formula:

$$T = \frac{n+1}{m} \quad \text{....(3.25)}$$

where, T is return period in years; n is number of years of record and m is rank number of rainfall magnitude of descending order

Return periods, can be computed from equation (3.25) for 1-day and 2 to 5 consecutive days maximum rainfall. The magnitudes of the rainfall were plotted against the corresponding return periods.

3.6 Chi-Square Test for Goodness of Fit

One of the most commonly used tests for testing the goodness of fit of empirical data to specify theoretical frequency distribution is the Chi-square test (Haan, 1994). For applying the Chi-square test, the data were grouped into suitable frequency classes. The test compares the actual number of observations (expected values were calculated based on the distribution) that fall in the class intervals. The numbers were calculated by multiplying the expected relative frequency by the total number of observation. Chi-square value was calculated from the relationship.

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \qquad ....(3.26)$$

where, K is the number of years; O_i is the observed rainfall values in the i^{th} year and E_i is the expected rainfall values in the i^{th} year.

The calculated value of Chi-square was compared with the table value of Chi-square for (n-1) degrees of freedom at 5 per cent level of significance. If the $\chi^2_{cal\ 5\%} > \chi^2_{tab.}$, the difference between observed and theoretical rainfall value was considered to be significant. The smallest value of Chi-square test was taken as the best for selecting the best probability distribution (Bhatt, 1996).

3.7 Infiltration Rate of Soil

The infiltration characteristic of soil is one of the dominant variable influencing irrigation and drainage. Infiltration rate is the velocity or speed at which water enters into the soil and is usually measured depth of water (mm) that enters the soil per hour. Infiltration rate decreases during irrigation or when rain continues. As time elapsed, a constant infiltration rate develops which is called as basic infiltration rate. This is useful in designing drainage system. For the present study the basic infiltration rate of 1 to 8 mm/hr were used. The studies reported by Bharambe and Shelke, (2001) for Marathwada soils were referred for selection of infiltration rate.

3.8 Crop Tolerance to Water-logging

Crops and crops varieties differ widely among themselves in their tolerance to water logging. The damage due to water logging varies from crop to crop, within varieties and for same crop and the variety with the stage of growth at which surface stagnation occurs. Crop tolerance to water logging varying from 1 to 7 days was considered as the base for determining the values of drainage coefficient for the area. General guidelines on the number of days within which water should be removed from the cropland as shown in Table 3.2. Depending upon the tolerance of crops, the tolerance period varies from 1 to 7 days which was considered as basis in the present study.

Table 3.2 Recommended period of water disposal for different crops based on Tolerance limit of crops to ponding (IS 8835-1978)

Name of Crop	Tolerance to days of water stagnation
Vegetables	1
Oil seeds	2
Cotton, Maize, Sorghum, Pearl millet and Other similar crops	3
Paddy, Sugarcane, Banana	7

3.9 Determination of drainage coefficient

Amongst four widely used probability distribution methods, the method which gives lowest Chi-square value was chosen to estimate 1 to 5 consecutive days maximum rainfall at different return periods of 2, 5 and 10 years. The drainage coefficient was estimated for 2, 5 and 10 year return period by subtracting basic infiltration rate from the estimated maximum consecutive days rainfall. The drainage coefficient for different return periods were estimated by considering the fact that soils were saturated and evapotranspiration, surface retention and raindrop interception were negligible as far as land drainage is concerned.

The drainage coefficient was determined using the equation:

$$q = \frac{1}{n}[R - nI] \qquad \ldots(3.27)$$

where,

q= Drainage rate (drainage coefficient) in mm day^{-1}

R= Rainfall at a given probability for the duration under consideration in mm

I = Basic infiltration rate in mm day^{-1}

n= Number of days of crop tolerance

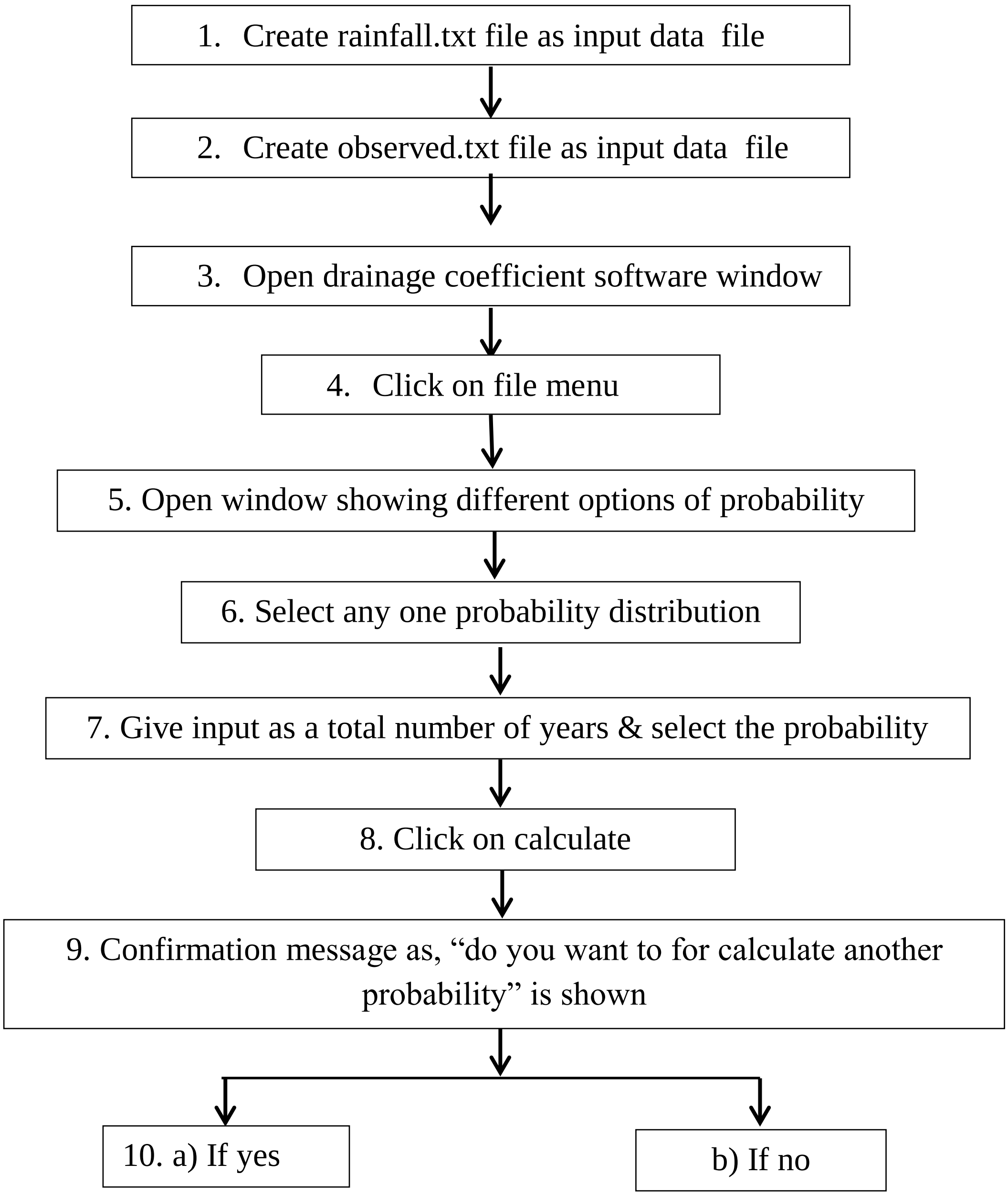
3.10Data Analysis Using VNMKV_DCS Software

In order to reduce time required for computation of drainage coefficient VNMKV_DCS software was used which is developed by Department of Irrigation & Drainage Engineering, College of Agriculture Engineering &

Technology, VNMKV Parbhani. The Visual basic (VB.NET) computer language is used to develop this software. The software has a graphical user interface and a compatibility to run on nearly all types of operating systems having a Microsoft frame work 2.0 with service pack 2. It has seven windows to estimate the drainage coefficient for computation of expected rainfall under each distribution under each probability.

3.10.1 Running VNMKV_DCS Software

The flowchart for running VNMKV_DCS Software for determination of drainage coefficient is shown in Fig. 3.6.



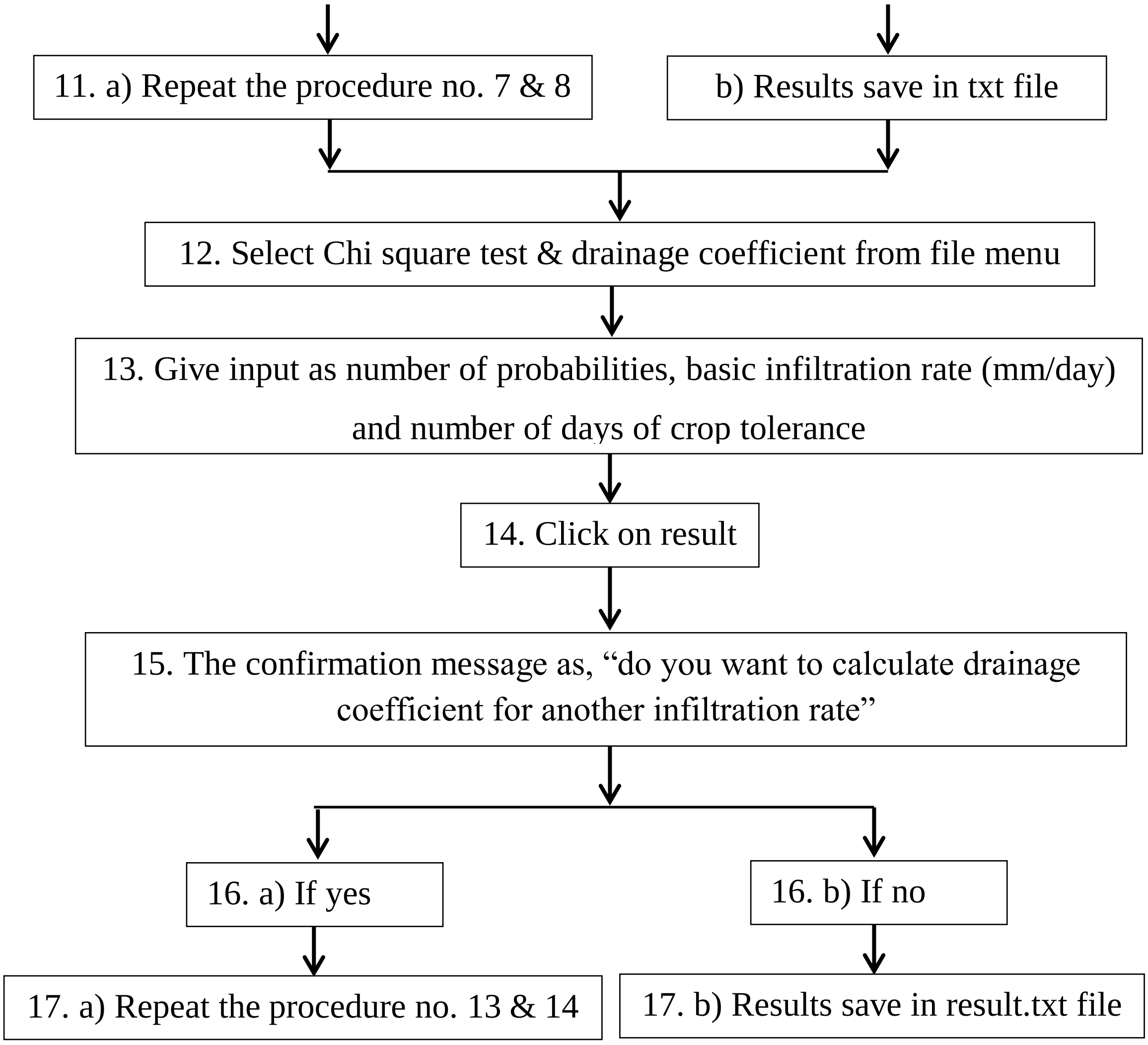


Fig. 3.6 Flow chart for running VNMKV_DCS software

In this software click on the result button calculate Chi square values for all the distribution and gives the best fit distribution for further calculation. Similarly the Chi square values and values of drainage coefficients are saved in the “result.txt” file in the same folder of software. The process has to be repeated for every distribution and for one to five consecutive days maximum rainfall given in input “rainfall.txt” and “observed.txt” file. The operational windows of VNMKV_DCS software are shown in Fig. 3.7 to Fig. 3.13.

Fig 3.7: Software window showing different options

Fig. 3.7 shows window on file menu, the four methods of probability distributions are shown. If the input data file is not created click on any one option, will display the message.

Hence, it is necessary to create input data file containing rainfall data as shown in Fig. 3.8.

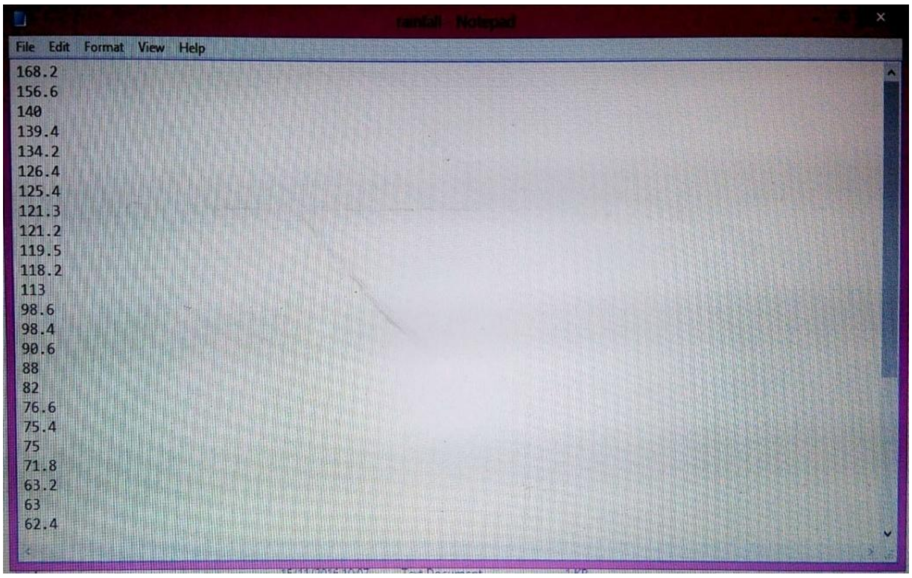


Fig. 3.8: Input data text file

Using input file (Fig. 3.8) user can compute the theoretical probability using any one method listed in the file menu in Fig. 3.7.

Just a click on Gumbel Distribution the new window will appear on screen to calculate theoretical probability using Gumbel Distribution as shown in Fig 3.9.

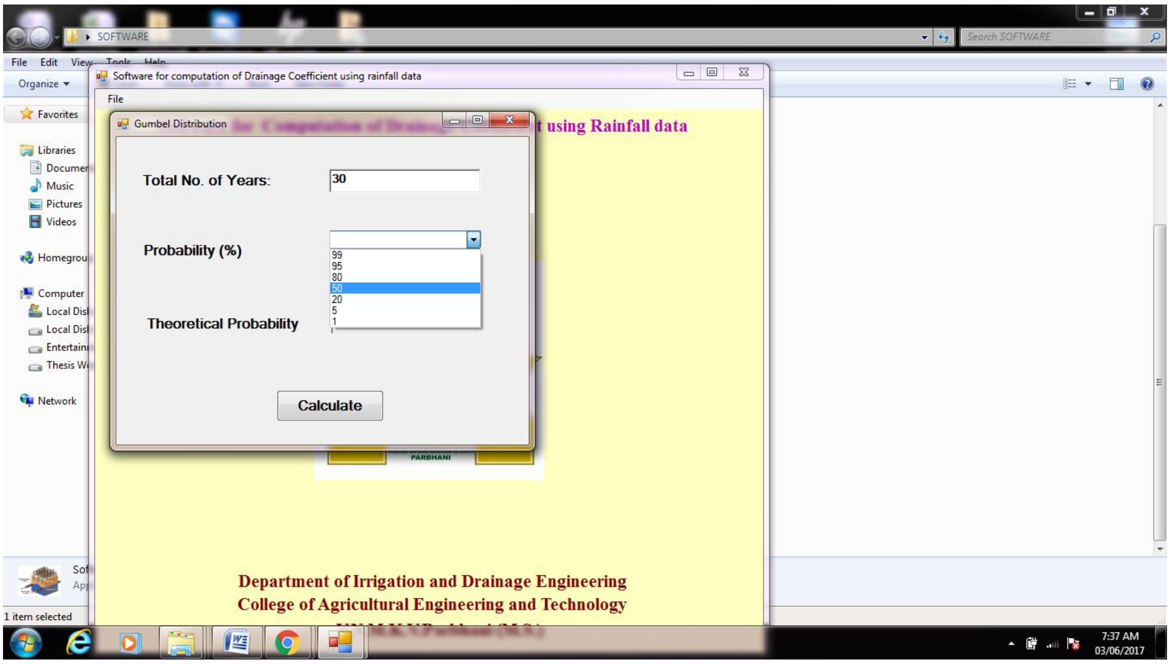


Fig. 3.9 Window of Gumbel distribution

In this window, mention the total no of years and probability percentage value for which theoretical probability is to be calculated. Accordingly, after single click on calculate menu Sx- standard deviation of X and theoretical probability can be calculated. In order to calculate the theoretical probability for different probability level the message will appear.

Simple click on ‘Yes’ will ensure us to calculate theoretical probability for next probability level or if user click on ‘No’ the result will be saved in a text file as “Gumbel.txt” in the same folder. Accordingly, by clicking on Log Normal, Log person Type III and Normal distribution adopting similar process and the theoretical probabilities at required levels can be computed.

Now create the input text file using observed values for particular distribution of 1 to 5 consecutive day maximum rainfall as shown in Fig 3.10.

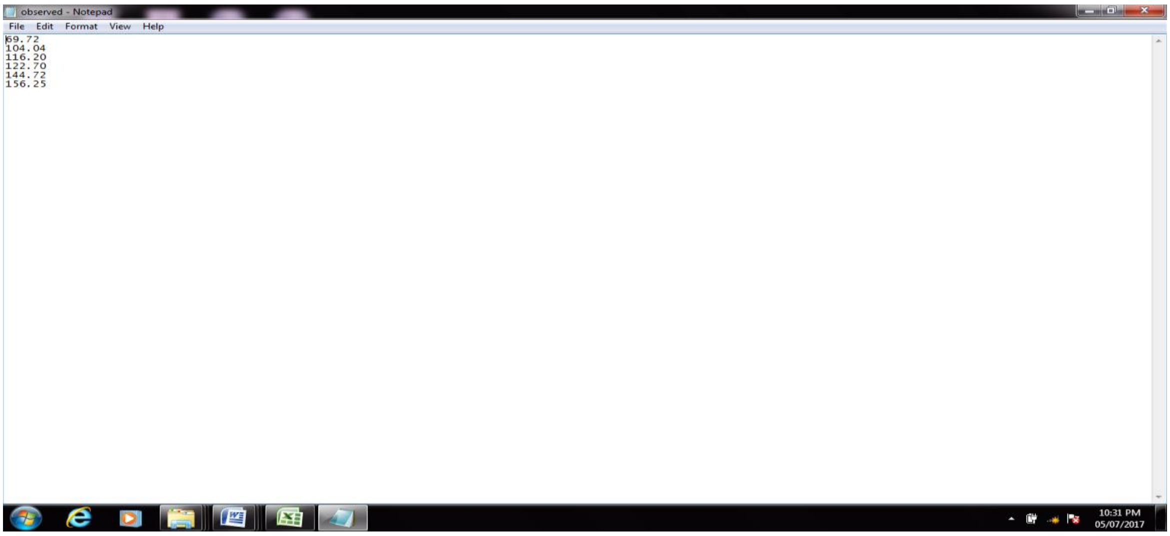


Fig. 3.10: input text file of observed values.

Go to the first window and click on file menu for the chi-square test and drainage coefficient. This will open a new window as shown in Fig. 3.11.

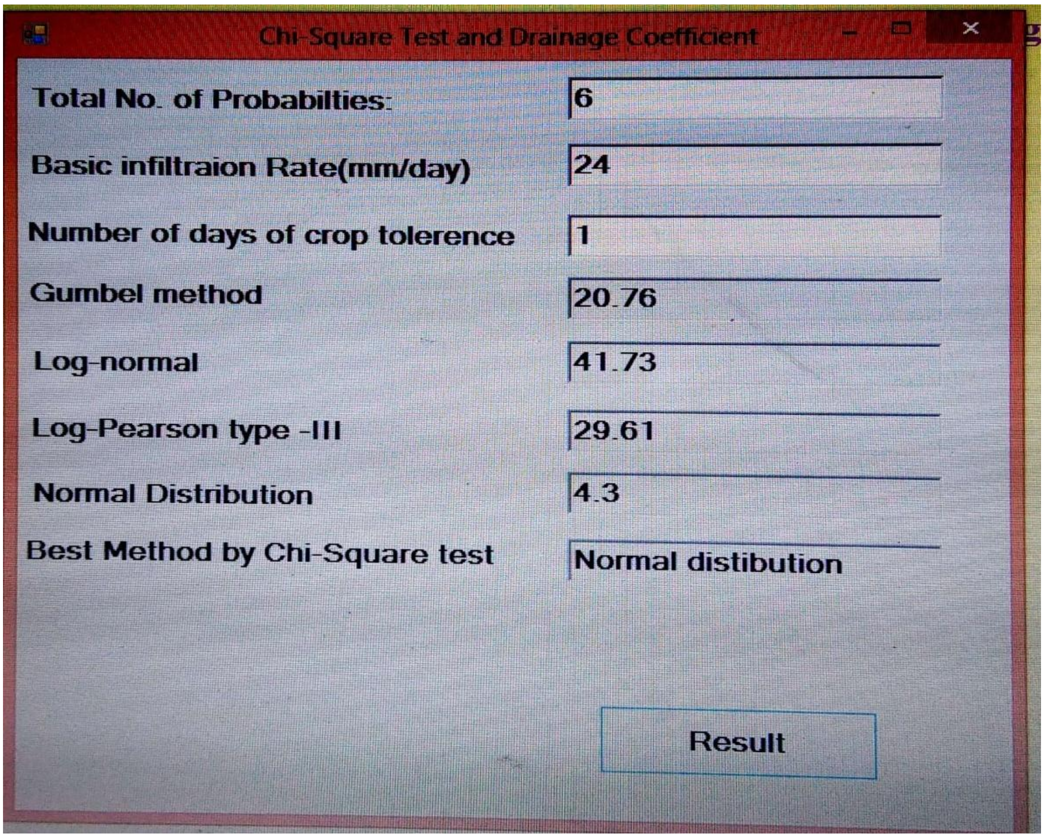


Fig. 3.11 .Window showing Chi-Square test.

In this window user has to enter the total number of probabilities, the basic infiltration rate (mm/day), and the number of days of crop tolerance for which he wants to calculate the chi-square values. After feeding this information, a click on result button will calculate Chi-square values for all distributions and also will give the best suited distribution for further calculations. Simultaneously, the result containing all Chi-square values and the values of Drainage Coefficients will be saved in the text file as “result.txt” in the same folder where software is located as shown in Fig. 3.12.

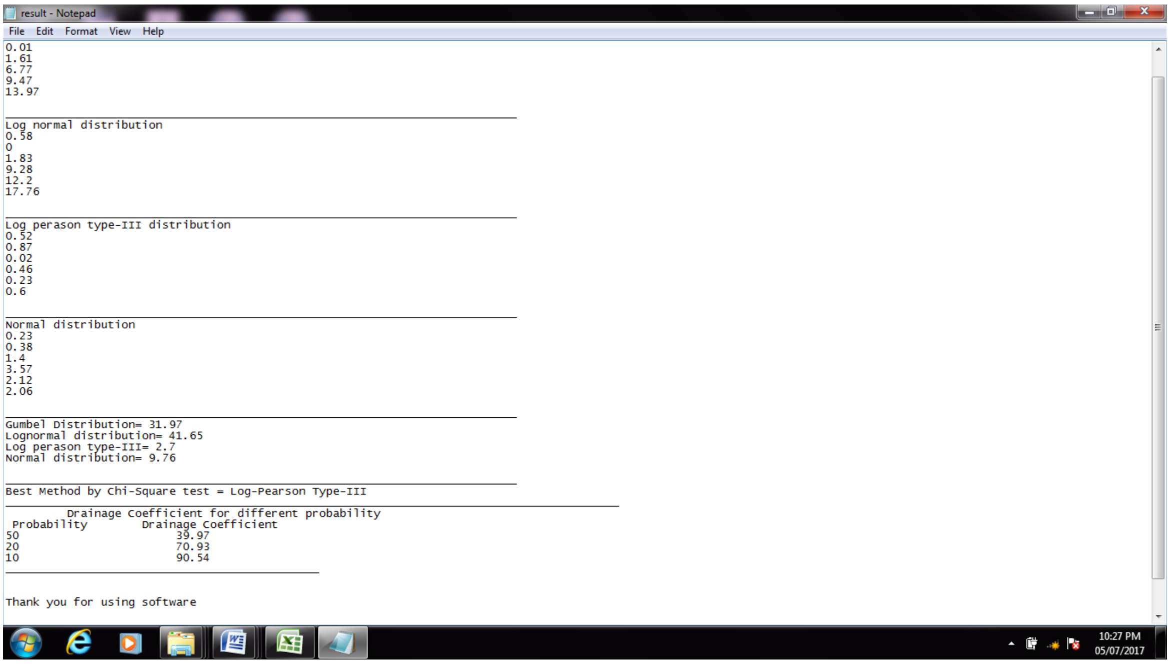


Fig.3.12: Window showing Chi-square test and drainage coefficient

3.11 Development of drainage coefficients maps:

The spatial distribution maps of drainage coefficients were developed using the Arc GIS 9.3 software using Inverse distance weight (IDW) interpolation technique. The step by step procedure adopted to develop drainage coefficient maps is given below:

1: Go to start menu → Programme →Microsoft Excel

2: Arrange the data in a column such as station, latitude, longitude and 1/2/3/4/5 day maximum rainfall.

3: Go to Start Menu → Programme →Arc Map

4: To create new empty map select new empty map option and then click ok

5: Creating shape file for 1/2/3/4/5 day maximum rainfall.

5.1 Go to add data toolbox

6: Adding excel sheet

6.1 Go to tool

6.2 Add XY data

7: Add excel file

7.1 Click on Browse and select excel file

8: Click on Edit

8.1 Click on Select button

8.2 Select Geographic Coordinate Systems from Coordinate system tool

8.3 Click on Add

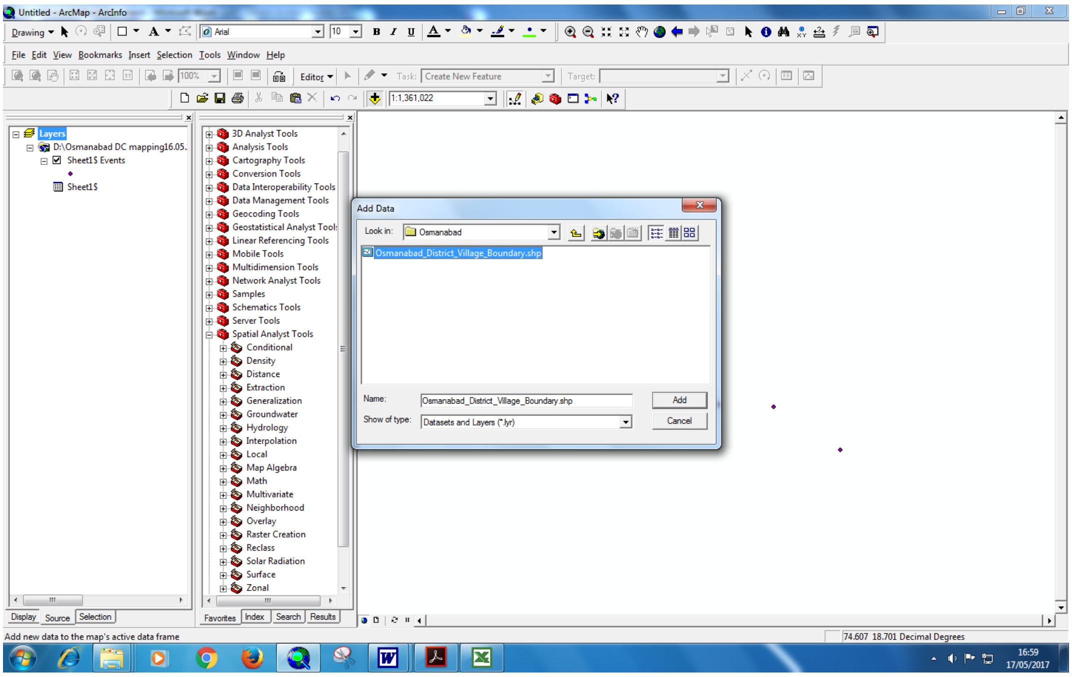
9: Select world and click on add button

10: Select WGS1984.prj file

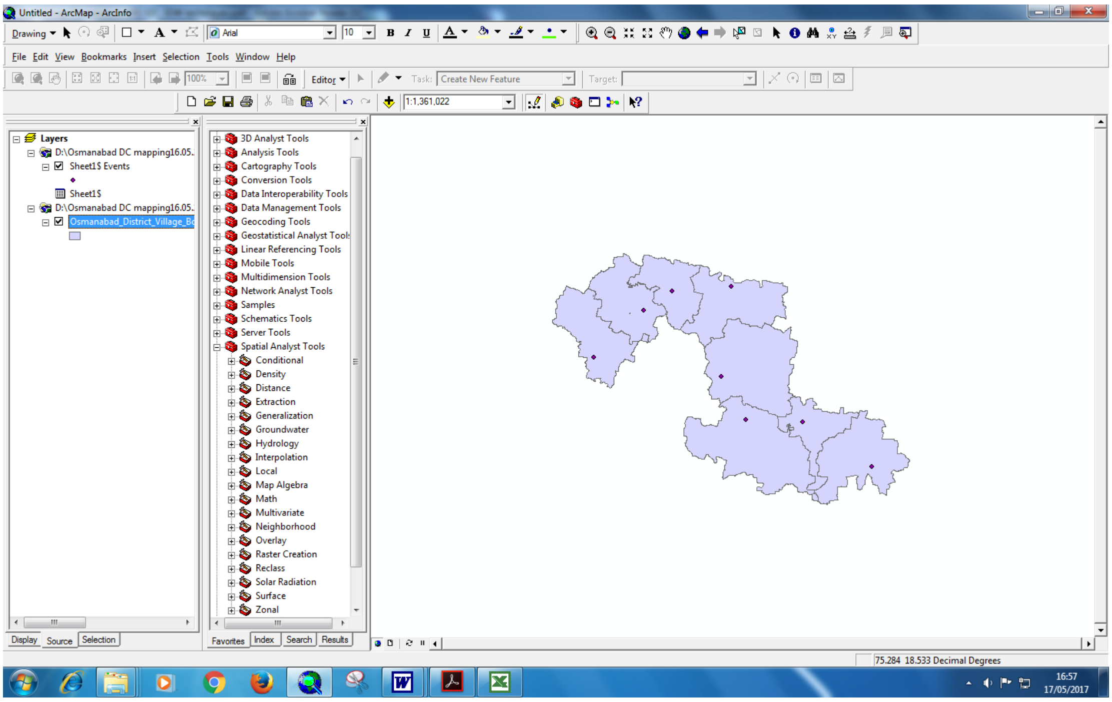
10.1 Click on Add

11: After adding click on Apply button

12. Add shape file



13. Taluka boundary map of Osmanabad district and its data point generated

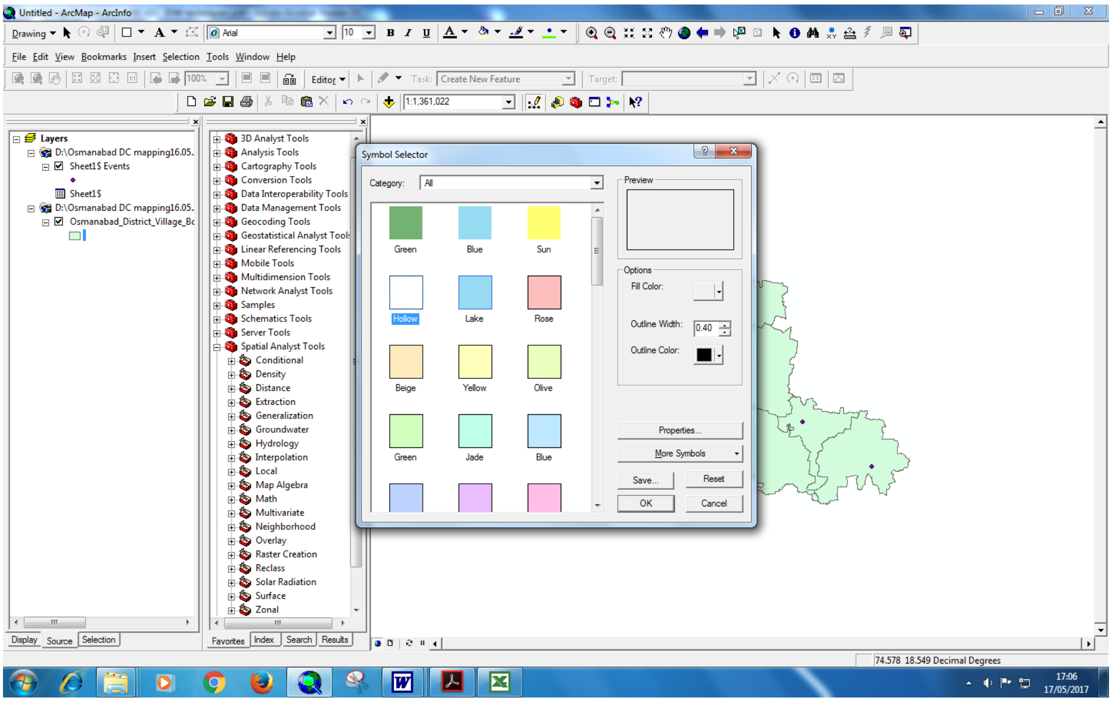


14: Click on Symbol

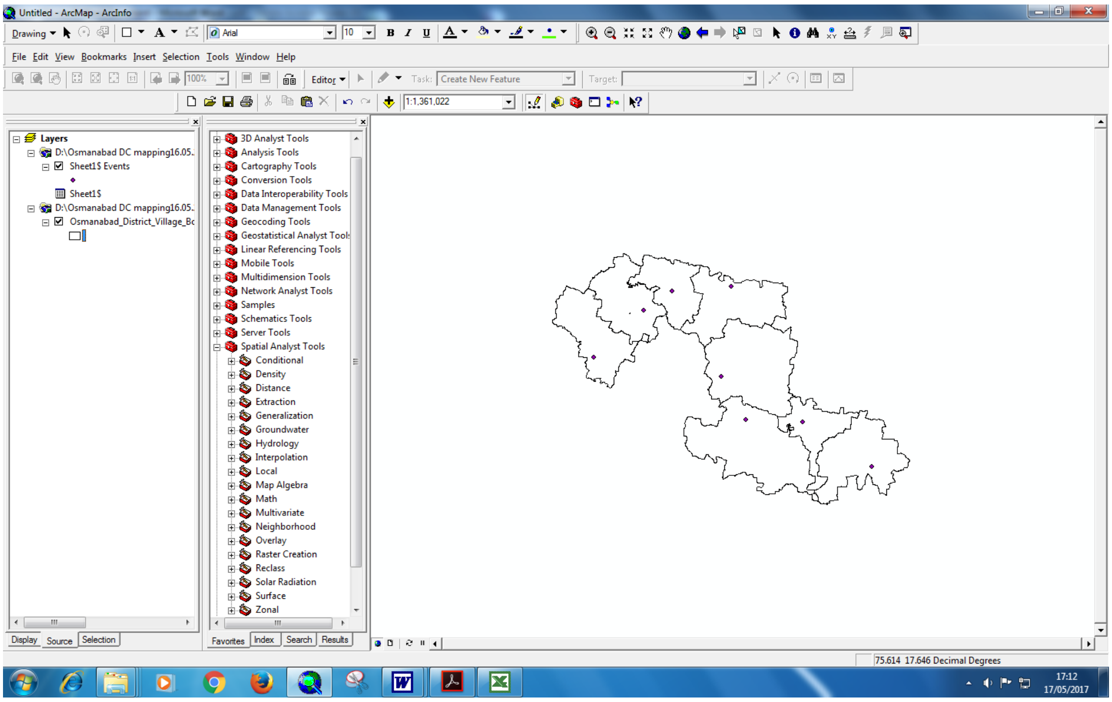
14.1 Select on Hallow symbol

14.2 Adjust outline width

14.3 Click on Ok



15: Map will be generated with outline



16: Go to Arc toolbox

16.1 Spatial Analyst tool

17. Go to Spatial Analyst Tool

17.1 Click on interpolation tool

18. After click on Interpolation tool

    18.1 Click on IDW

    18.2 Go to Add Input point features

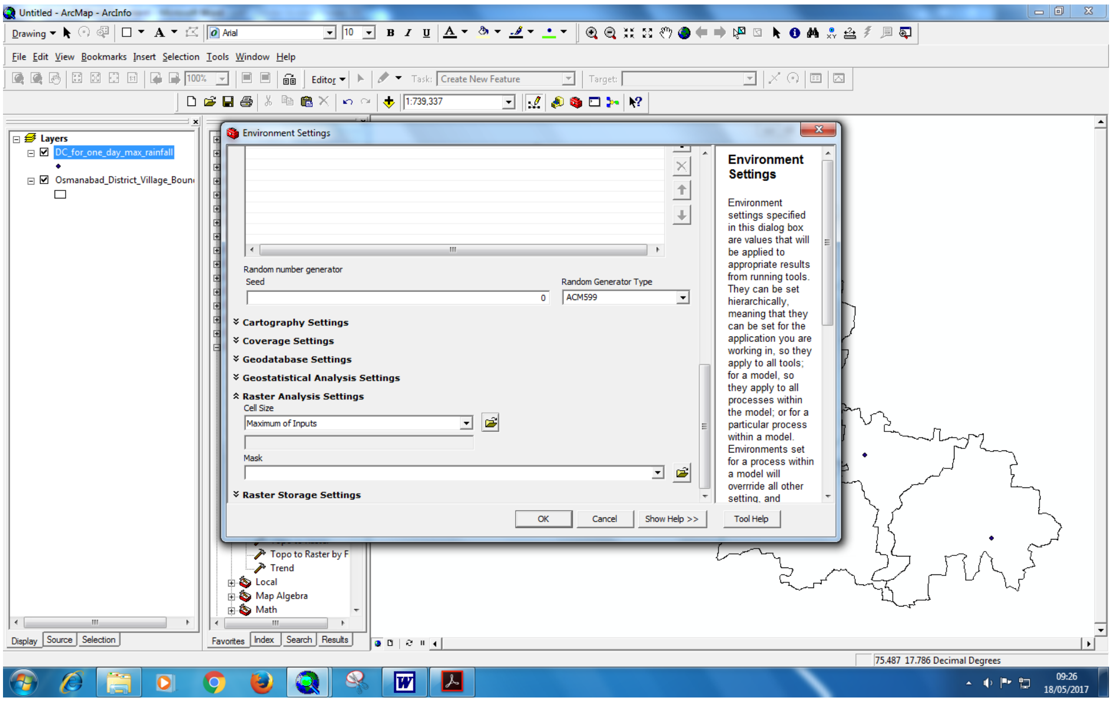
19. Go to environment

20. Go to extent

21. Go to geostatistical analysis setting

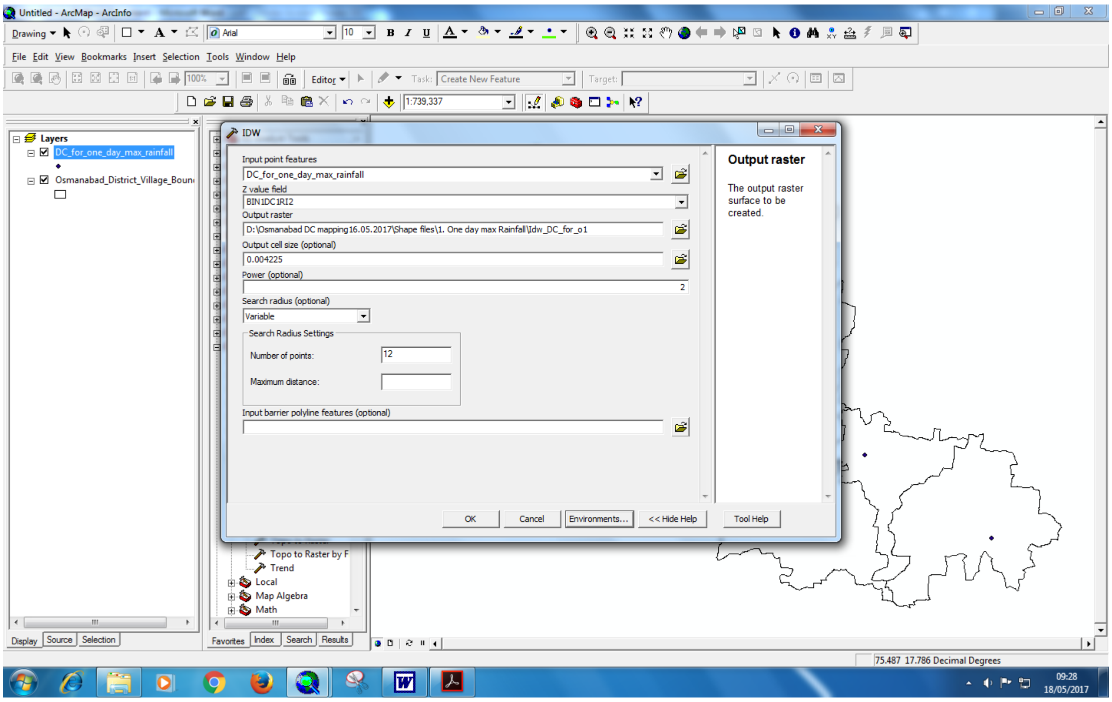
22. Select include all

23. Go to raster analysis setting

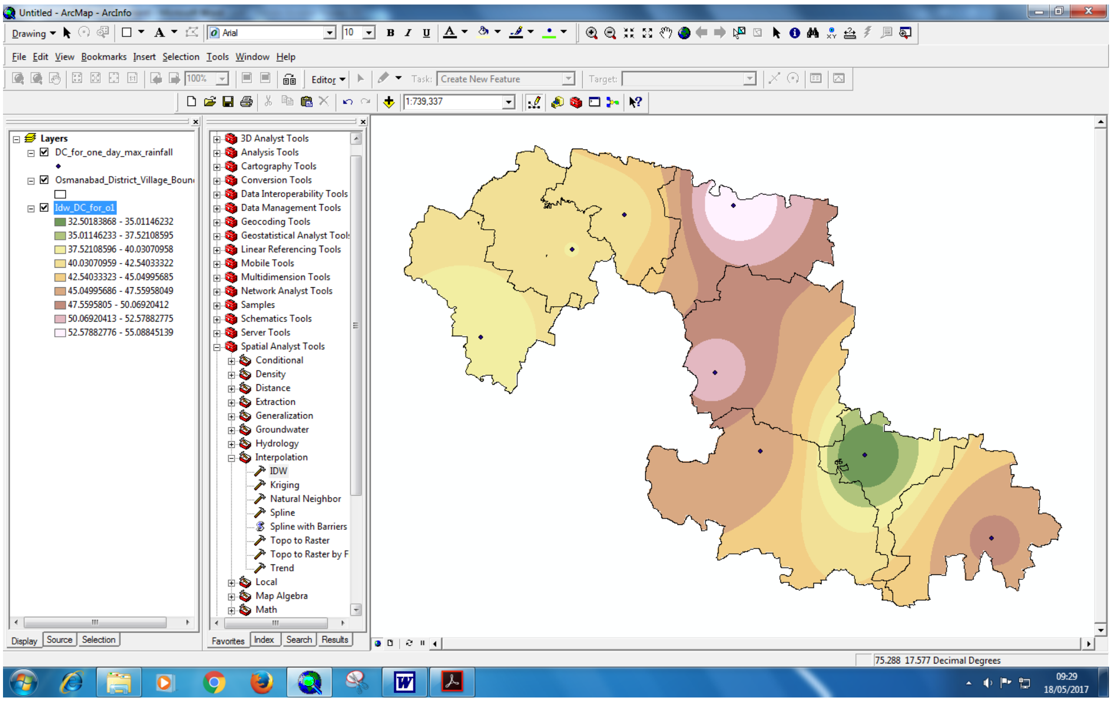


24. Go to mask

25. Click on ok



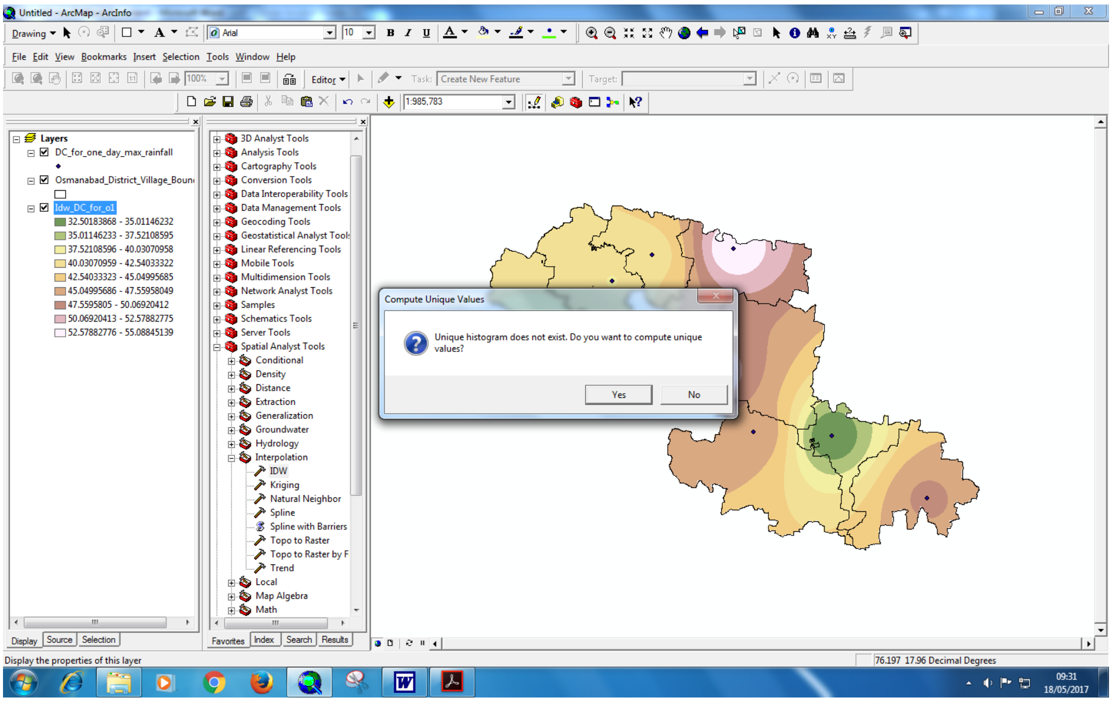
26. Maps generated



27. Right click on layer tool

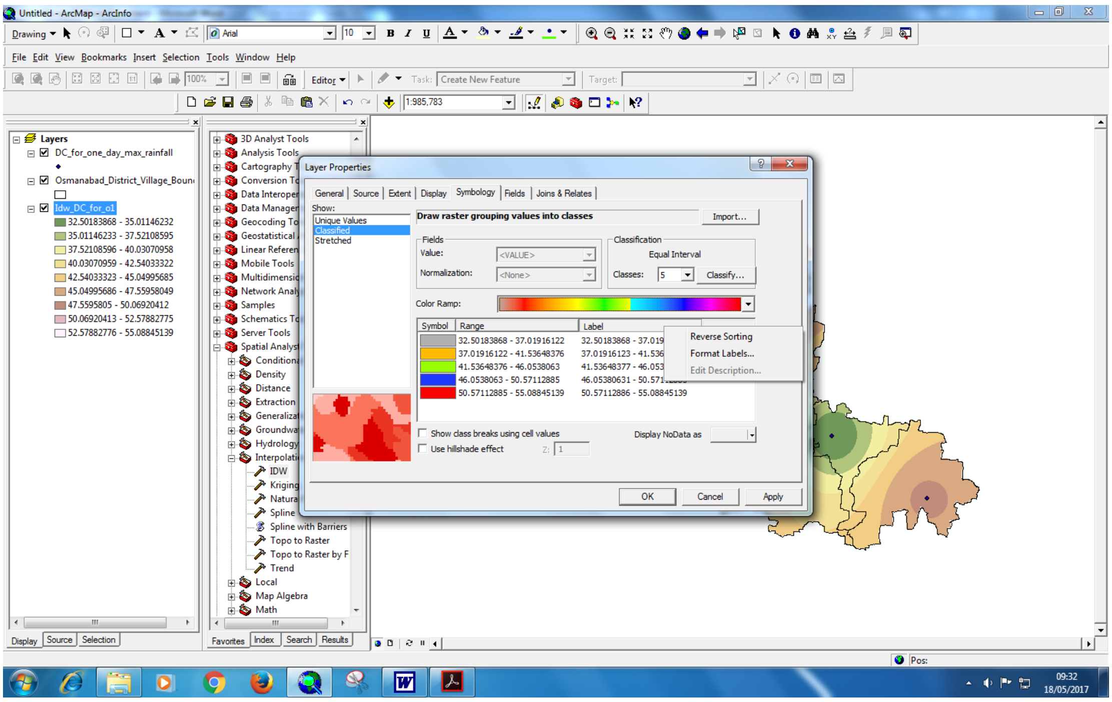
27.1 Click on properties

28. Click on yes



29. Go to classes

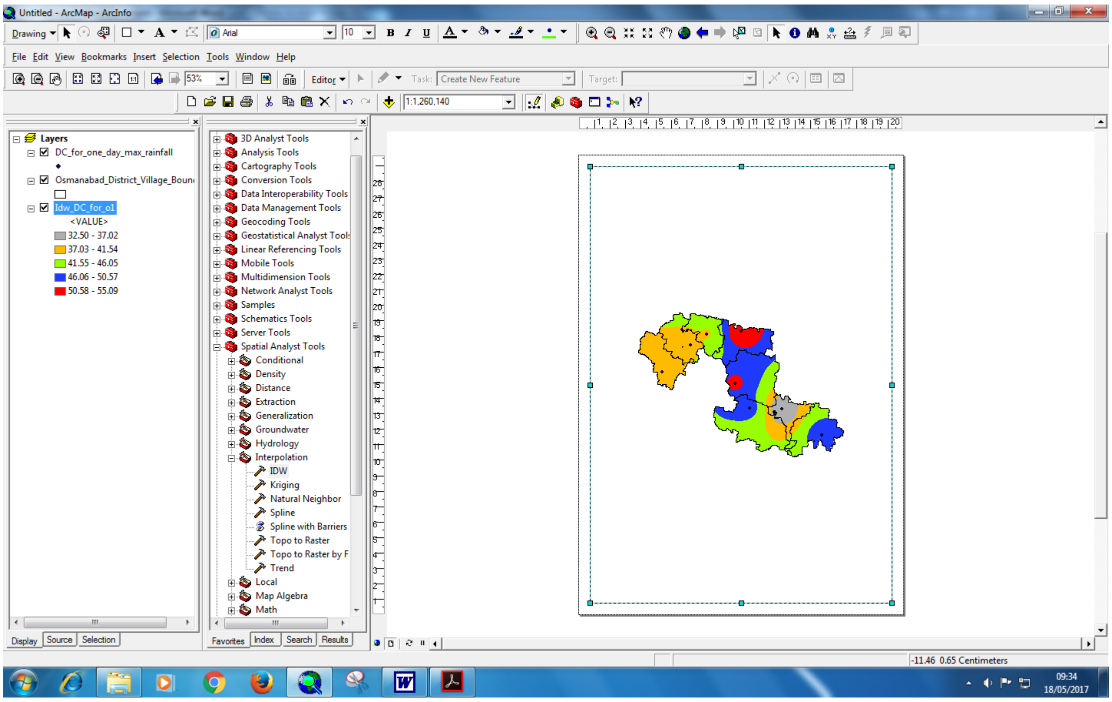
30. Click on label



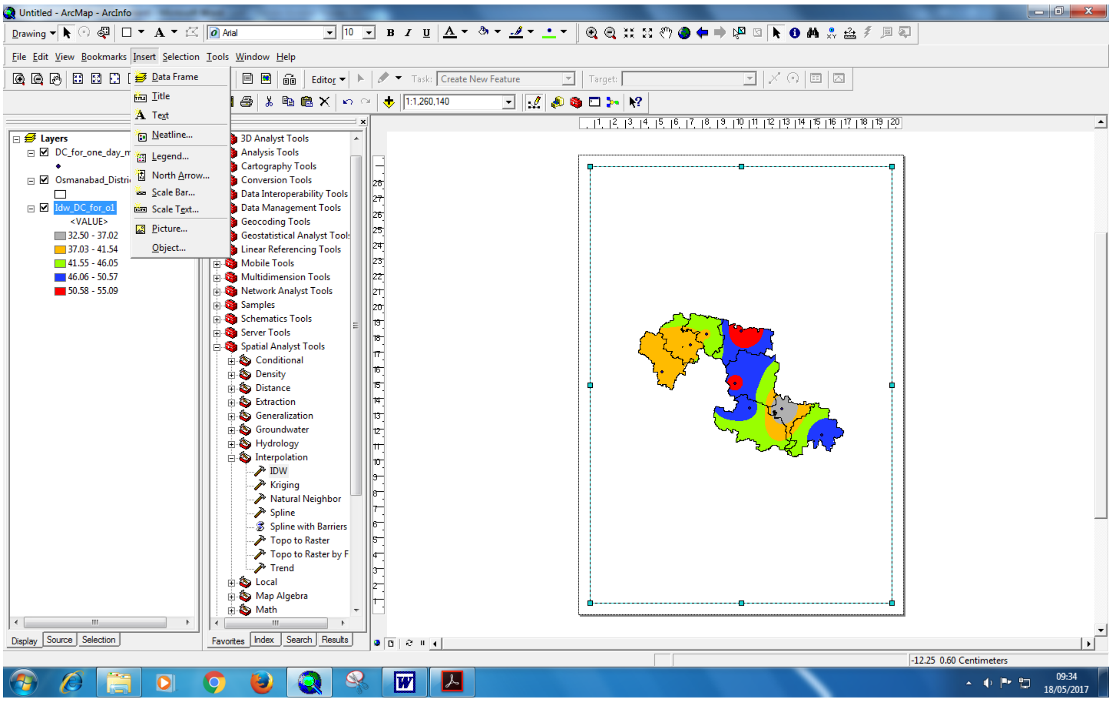
31. Click on ok

32. Click on apply

33. Go to layout



34. Go to insert



35. Select north arrow

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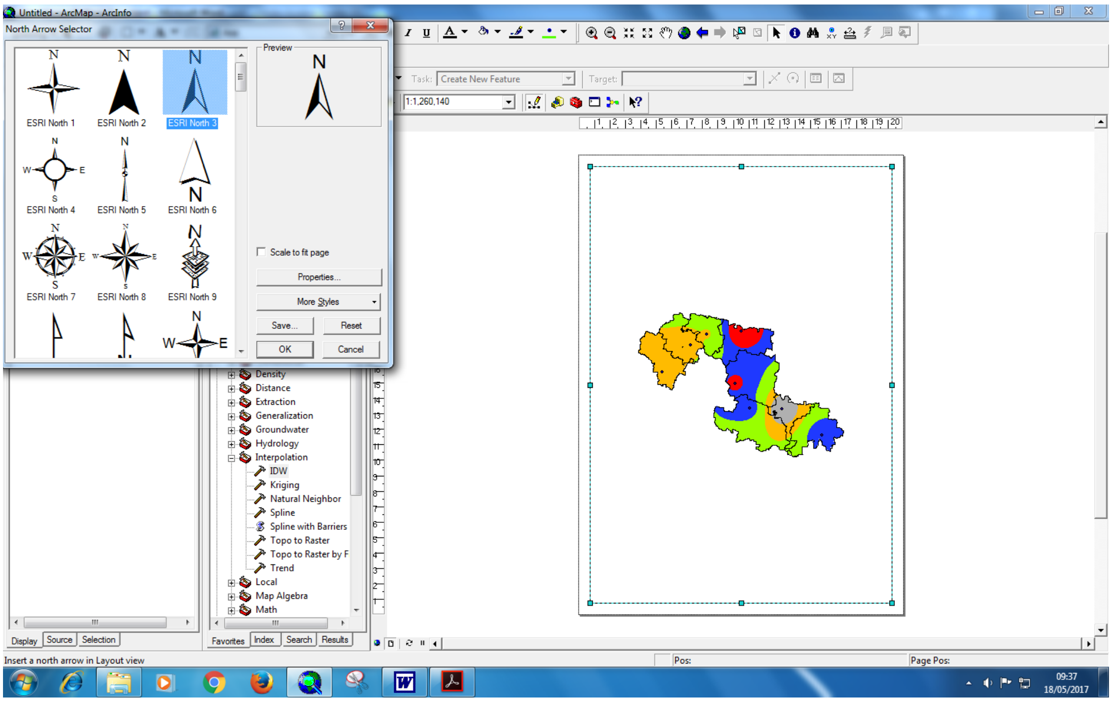

37. Again go to insert and select legends and scale text

37.1 next

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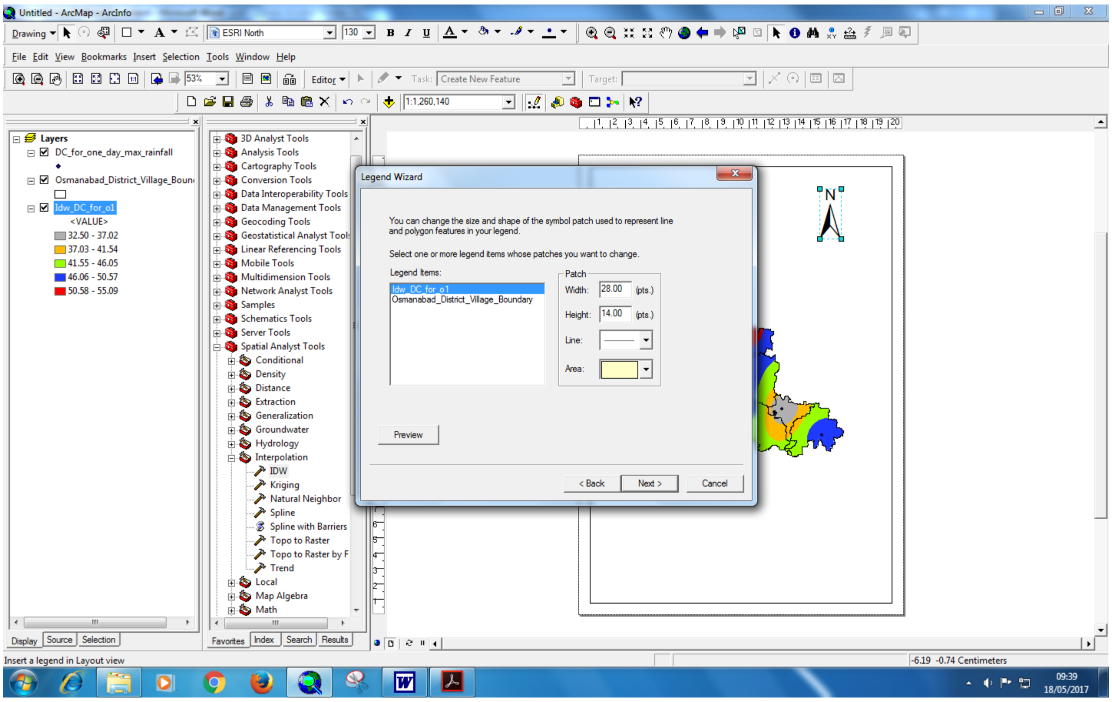

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37.6 click on finish

37.7 Click on legends

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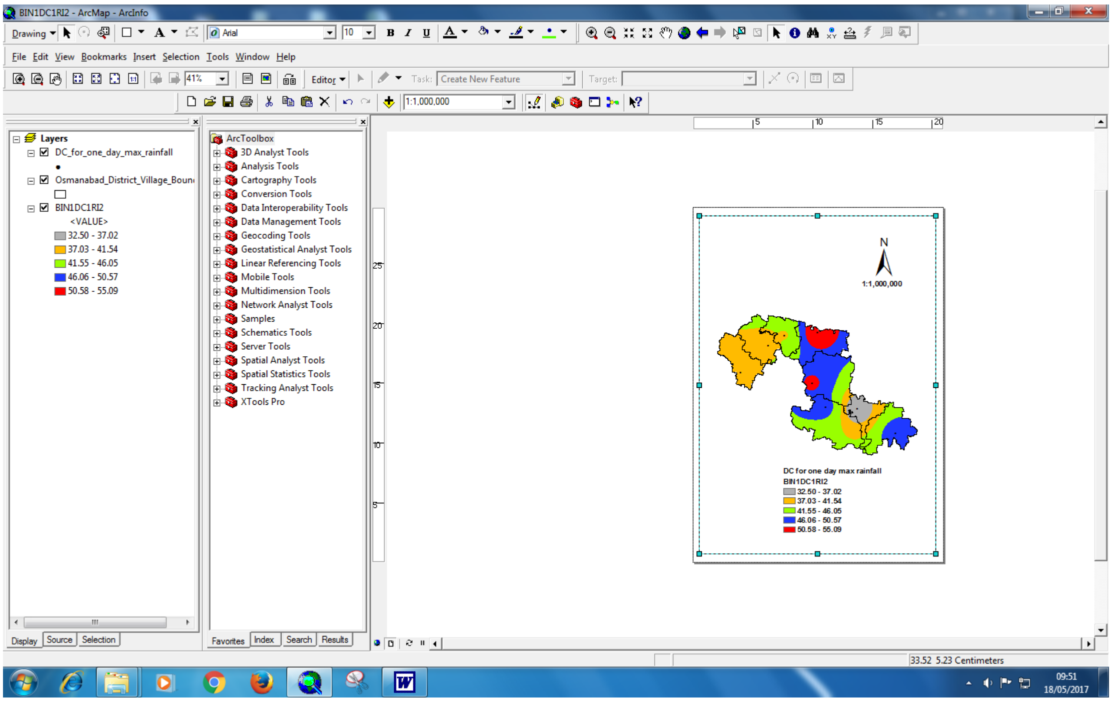
38. Select size 18

39 Save the map

40. Map saved in JPEG format



RESULTS AND DISCUSSION

CHAPTER-IV

RESULTS AND DISCUSSION

The drainage coefficient (D.C.) of agricultural land through analysis of talukawise daily rainfall data of 31 years (1986-2016) for eight talukas of Osmanabad district namely Bhoom, Kallam, Lohara, Umarga, Osmanabad, Paranda, Tuljapur and Washi was estimated. The observed values of 1 to 5 consecutive day's maximum rainfall for different probabilities were estimated using Weibull's method. The expected consecutive maximum rainfall values were estimated by four widely used probability distributions viz., Gumbel, Lognormal, Log Pearson Type III and Normal. The expected values for 1 to 5 consecutive day's maximum rainfall obtained under different probability distribution functions were compared with observed values derived by Weibull's method using Chi-square test for goodness of fit. The expected consecutive day's maximum rainfall values estimated by the best fit probability distribution function were used for determination of drainage coefficient. The drainage rate for different return periods of 2, 5 and 10 years were determined by subtracting the basic infiltration rate of soil from estimated consecutive day's maximum rainfall.

In order to reduce the time required for computation of drainage coefficient VNMKV_DCS Software was used. Similarly Arc GIS was used to develop drainage coefficient maps for Osmanabad district. The results of present investigation are presented and discussed in the succeeding sections.

4.1 Analysis of consecutive day's maximum rainfall

The annual daily rainfall data of 31 years for 8 taluka stations of Osmanabad district of Marathwada region was analysed for 1 to 5 consecutive day's maximum rainfall. The analysis was carried out by two methods i.e. i) Plotting position of 1 to 5 consecutive day's maximum rainfall data by Weibull method and ii) Using probability distribution functions.

The process of data analysis and estimation of drainage coefficient was carried out for all the eight taluka stations of Osmananbad district viz.

Bhoom, Kallam, Lohara, Paranda, Osmanabad, Umarga, Tuljapur and Washi in discussed in section 4.2 to 4.9, respectively.

4.2 Estimation of Drainage Coefficient for Bhoom

4.2.1 Arrangement of consecutive day's maximum rainfall

Daily rainfall data (1986-2016) for Bhoom station was analysed to obtain 1 to 5 consecutive day's maximum rainfall. The data so obtained was arranged in descending order and the ranks were assigned for each year which is presented in Table 4.1.

Table 4.1 Year -wise 1 to 5 consecutive day's maximum rainfall for Bhoom Station

Sr. No.	One day (mm)	Two day (mm)	Three day (mm)	Four day (mm)	Five day (mm)	Probability (%)	Recurrence interval (years)
1	220	224.5	239.6	243.4	243.4	3.12	32.00
2	215	221	225.5	225.5	226.6	6.25	16.00
3	119	150	171	180.8	222	9.38	10.66
4	103	128	154	175	211	12.5	8.00
5	92	124.4	153.4	167.4	179.9	15.62	6.40
6	83.2	116	150	162.4	168	18.76	5.33
7	80.2	112.4	138	159	162.4	21.88	4.57
8	79	105.2	137.4	144	161.8	25	4
9	78	99.3	136.7	140.4	153.4	28.16	3.55
10	76.1	99	124.8	135	148	31.25	3.2
11	75.3	98	121.4	126	143	34.48	2.90
12	73.6	97.2	112	124.8	142	37.59	2.66
13	72	96.2	105	124.5	134	40.65	2.46
14	72	94.3	101	121	132	43.85	2.28
15	70	93	100.3	117.3	123.7	46.94	2.13
16	70	85	100.1	111.5	114	50	2
17	67	84	100	103.4	111.2	53.19	1.88
18	62	78.3	99.7	101.5	103.8	56.49	1.77
19	58	76.1	86.4	99.4	103.8	59.52	1.68
20	56.2	66.3	80.3	95.9	101.6	62.5	1.6
21	52.2	65.2	79.6	90.3	99	65.78	1.52
22	51.3	64	71.2	89.2	96.3	68.96	1.45
23	50	58.4	70.4	86	94	71.94	1.39
24	47	56.1	69.6	86	93	75.18	1.33
25	45.6	54	65	83	91.6	78.12	1.28
26	43	51.6	62	81	86.3	81.30	1.23
27	42.8	49.5	61.3	68	84	84.74	1.18
28	42.4	49.2	56.3	59.5	69.6	87.71	1.14
29	33	47.6	50.2	56.2	60.8	90.90	1.10
30	32.2	43.2	47.6	47.6	49.8	94.33	1.06
31	27.6	37.6	43.2	45.2	47.6	97.08	1.03

4.2.2 Plotting positions of consecutive day maximum rainfall by Weibull's Method

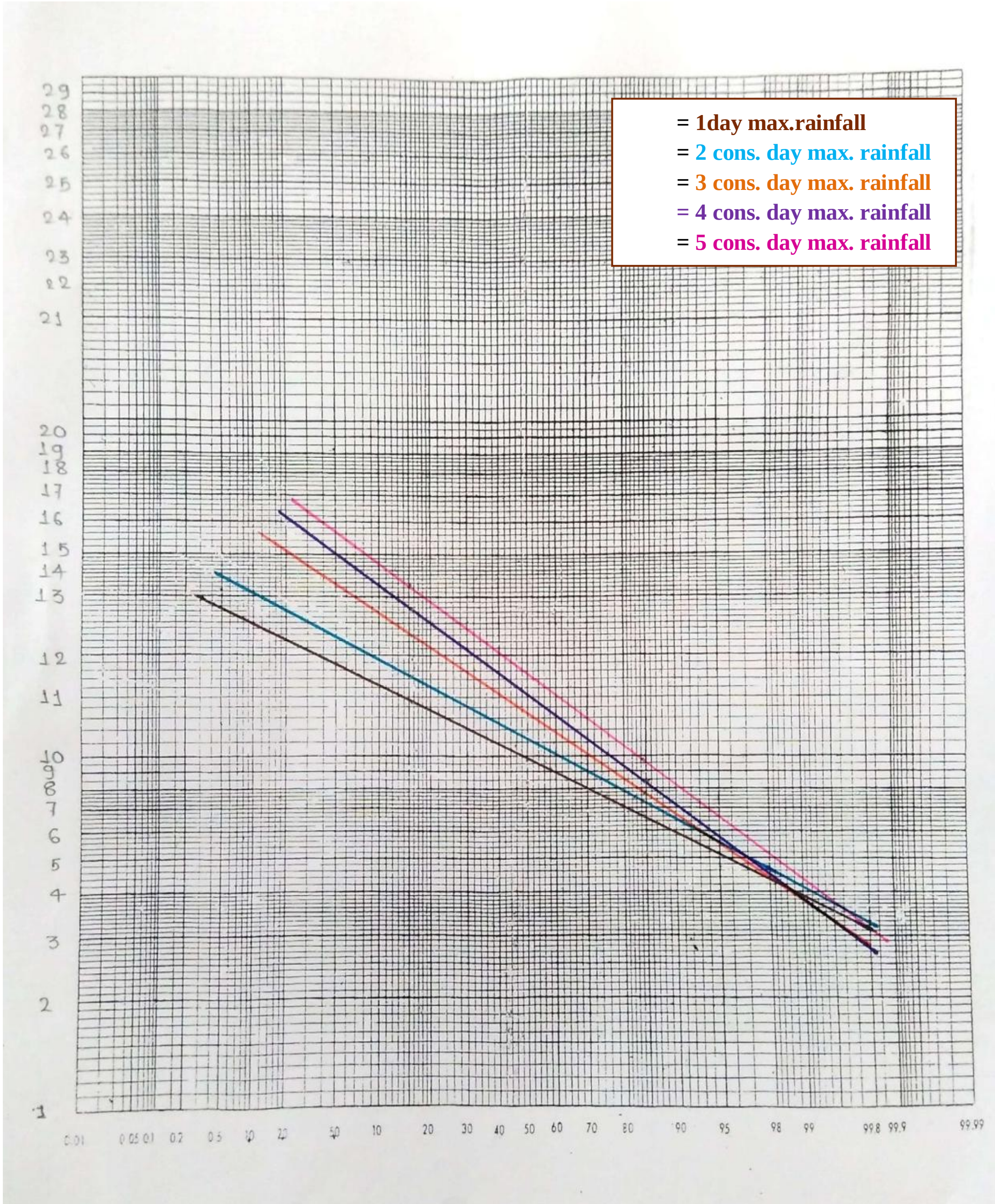
In order to know the magnitude of annual maximum 1 to 5 consecutive day's maximum rainfall for different return periods, probability analysis was carried out by Weibull's method. Using Weibull's equation the probability of occurrence of 1 to 5 consecutive day's maximum rainfall was derived and presented in Table 4.1. The calculated probability values as presented in Table 4.1 were plotted on X-axis whereas the corresponding values of maximum rainfall (mm) was plotted on Y-axis. The frequency line was drawn after computing the plotted points using 'computed method' suggested by Ogrosky and Mockus (1957).

Table 4.2 Computed values of consecutive day's maximum rainfall for different percent chance of probability

Sr No.	Per cent chance of probability	Computed values of Mean, Mean+ S.D and Mean- S.D. for 1 to 5 consecutive day's maximum rainfall				
		1 day	2 day	3 day	4 day	5 day
1	15.9(mean+ SD)	10.98	11.45	12.34	12.82	13.32
2	50 (mean)	8.32	9.30	10.09	10.63	11.07
3	84.1(mean-SD)	6.68	7.15	7.84	8.44	8.82

In the computed method three points were plotted at 15.9, 50 and 84.1 per cent chance of probability by calculating the values of mean, mean + standard deviation and mean – standard deviation of rainfall. The data is represented in Table 4.2. The three probability levels of 15.9, 50, 84.1 per cent and the corresponding values of mean, mean+standard deviation, mean-standard deviation of rainfall were plotted. These three points were joined as a straight line on the graph as shown in Fig 4.1.Using straight line, the observed rainfall values were determined at different selected probability levels of 50, 20, 10, 5, 2 and 1 per cent from Fig. 4.1. These rainfall values are the observed values of rainfall which are presented in Table 4.3. These were used for chi square test to test the hypothesis.

Rainfall, √x



Probability (%)

Fig 4.1 Frequency analysis of 1 to 5 consecutive day's maximum rainfall for Bhoom station

Table 4.3 Observed values of consecutive day's maximum rainfall at different probabilities for Bhoom

Sr. No.	Probability (P)	Observed values				
		1 day	2 day	3 day	4 day	5 day
1	50	69.72	104.24	106.09	110.25	120.78
2	20	104.04	122.54	132.25	139.24	156.25
3	10	116.20	153.76	156.25	157.25	170.30
4	5	122.76	163.84	158.76	166.41	184.96
5	2	144.72	171.61	172.30	174.24	197.40
6	1	156.25	174.24	182.25	182.79	210.25

4.2.3 Prediction of consecutive day's maximum rainfall using probability distribution

The expected maximum rainfall values for 1 to 5 consecutive day's were estimated by four probability distributions viz., Gumbel, Lognormal, Log Pearson type-III and Normal. The computed expected values for these probability distribution are presented in Table 4.4. Among these four probability distributions the best fit probability distribution was decided by Chi-square test for their goodness of fit. The observed maximum rainfall presented in Table 4.3 and computed maximum rainfall presented in Table 4.4 was used for Chi square test to find the goodness of fit.

Table 4.4 Annual maximum consecutive day's rainfall under different frequency distribution for Bhoom

Sr. No.	Probability (P)	Consecutive day's maximum rainfall (mm) Gumbel Distribution				
		1 day	2 day	3 day	4 day	5 day
1	50	66.68	83.76	98.95	109.84	119.20
	20	105.19	123.4	141.81	152.46	164.57
	10	130.69	149.65	170.2	180.68	194.6
	5	155.14	174.81	197.42	207.73	223.40
	2	186.77	207.38	232.65	245.75	260.66
	1	210.53	231.83	259.1	269.03	288.64
		Log Normal Distribution				
2	50	63.36	92.07	98.98	110.76	120.57
	20	103.87	124.43	142.84	153.95	167.41
	10	131.74	151.05	171.31	180.80	195.76
	5	161.40	178.03	199.44	207.41	223.68
	2	193.28	208.75	229.02	235	252.81
	1	218.85	228.81	252.10	256.71	327.21
		Log Pearson Type III Distribution				
3	50	**63.97**	82.41	96.87	112.41	**120.47**
	20	**94.93**	117.89	130.72	153.90	**163.77**
	10	**114.54**	140.44	160.32	177.41	**187.47**
	5	130.43	169.58	180.56	195.73	208.28
	2	150.66	189.67	200.37	221.90	228.55
	1	166.24	210.77	222.65	235.17	242.70
		Normal Distribution				
4	50	73.81	**91.10**	**106.86**	**117.73**	127.61
	20	110.48	**128.85**	**147.69**	**158.31**	170.80
	10	129.67	**148.57**	**169.06**	**179.55**	193.40
	5	145.50	164.9	186.7	197.07	212.05
	2	163.33	183.25	206.55	216.8	233.05
	1	175.23	195.49	219.72	229.97	247.06

4.2.4 Goodness of fit of probability distributions

Using observed and estimated annual maximum consecutive day's rainfall Chi square values were estimated under each probability distribution and presented in Table 4.5. The lowest value of Chi square among various probability distributions was considered for their goodness of fit.

Table 4.5 Calculated Chi square values under different probability distribution for Bhoom

Probability	χ^2 calculated value				
	1 day	2 day	3 day	4 day	5 day
Gumbel	31.97	26.25	48.28	59.39	46.72
Log normal	32.18	22.44	44.32	49.57	64.70
Log Pearson type-III	**8.42**	15.46	24.63	30.02	**13.12**
Normal	9.76	**5.44**	**18.87**	**28.34**	18.76

Data presented in Table 4.5 clearly indicates that Normal probability distribution was the best fit probability distribution for two, three and four consecutive day's maximum rainfall. However Log Pearson Type III probability distribution was the best fit probability distribution for one and five consecutive day's maximum rainfall for Bhoom station.

4.2.5 Estimation of consecutive day's maximum rainfall

The expected values of 1 to 5 consecutive day's maximum rainfall for recurrence intervals of 2, 5 and 10 years were estimated with best fitted probability distribution and presented in Table 4.6. It is reveals that for 2 years recurrence interval (50% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 87.88 mm to 142.81 mm, for 5 years recurrence interval (20% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 118.85 mm to 197.25 mm and for 10 years recurrence interval (10% probability) these values varied from 135.07 mm to 233.36 mm.

Table 4.6 Consecutive day maximum rainfall for different recurrence intervals for Bhoom

Sr. No.	Recurrence interval (years)	Rainfall for consecutive day's (mm)				
		1 day	2 day	3 day	4 day	5 day
1	2	87.88	112.14	119.21	132.91	142.81
2	5	118.85	149.89	165.37	187.23	197.25
3	10	135.07	169.64	195.98	223.25	233.36

4.2.6 Determination of Drainage Coefficient

The drainage coefficients for Bhoom were calculated by subtracting basic infiltration rate from consecutive day's maximum rainfall for various recurrence intervals.

The drainage coefficients estimated for Bhoom taluka station is presented in Table 4.7. The data reveals that drainage coefficient for one day maximum rainfall and 2, 5 and 10 years recurrence interval varied from 15.97 to 39.97 mm, 21.32 to 69.32 mm and 18.81 to 90.81 mm, respectively. However in case of two consecutive day's maximum rainfall for 5 and 10 years recurrence interval, it is 16.43 mm and varied from 2.28 to 26.28 mm,respectively. For three consecutive day's maximum rainfall drainage coefficient for 5 and 10 years recurrence interval was 1.23 and 8.35 mm, respectively.

Table 4.7 Estimated Drainage Coefficients (mm/day) for Bhoom

Basic infiltration rate (mm/hr)	D. C. for 1 day for R. I. (yrs.)			D. C. for 2 day for R. I. (yrs.)			D. C. for 3 day for R. I. (yrs.)		
	2	5	10	2	5	10	2	5	10
1	39.97	69.32	90.81	-	16.43	26.28	-	1.23	8.35
2	15.97	45.32	66.81	-	-	2.28	-	-	-
3	-	21.32	42.81	-	-	-	-	-	-
4	-	-	18.81	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-

4.3 Estimation of Drainage Coefficient for Kallam

4.3.1 Arrangement of consecutive day's maximum rainfall

Daily rainfall data (1986-2016) for Kallam station was analysed to obtain 1 to 5 consecutive day's maximum rainfall. The data so obtained was arranged in descending order and the ranks were assigned for each year which is presented in Table 4.8.

Table 4.8 Year-wise One to five consecutive day's maximum rainfall for Kallam

Sr. No.	One day (mm)	Two day (mm)	Three day (mm)	Four day (mm)	Five day (mm)	Probability (%)	Recurrence interval (years)
1	187	208	208	252	278	3.12	32.00
2	155	187	190	248.4	265.3	6.25	16.00
3	150	158	189.8	208.6	249.4	9.38	10.66
4	125	156	188	208	244.6	12.5	8.00
5	123	155.8	187.4	205.6	233.6	15.62	6.40
6	120	148	177	204	208	18.76	5.33
7	100	141	176.8	195.6	196.6	21.88	4.57
8	100	137.2	162.8	192	196	25	4
9	93	136.8	154	178.4	193	28.16	3.55
10	91	127	151.8	176	188.4	31.25	3.2
11	85.6	125	150.6	175.6	179	34.48	2.90
12	85	124.8	147	171.4	177.4	37.59	2.66
13	83	124.5	147	168.4	171.4	40.65	2.46
14	80.8	121	143.8	156.9	168.4	43.85	2.28
15	80	117	141.8	152	158.3	46.94	2.13
16	80	114	141	150	155	50	2
17	79	111	138	145	153	53.19	1.88
18	74	106.4	136.4	143.2	152	56.49	1.77
19	71.8	103	127	139.4	150	59.52	1.68
20	67	101	121	134	147	62.5	1.6
21	65	96.4	117	121.6	144.4	65.78	1.52
22	65	94.1	113	119	142	68.96	1.45
23	64.4	94	101	118.4	142	71.94	1.39
24	62	90	96.9	108.6	125.3	75.18	1.33
25	56	84	84	94	120	78.12	1.28
26	55	76.2	78.8	91.1	96.6	81.30	1.23
27	52.7	61	78.7	88.4	95.2	84.74	1.18
28	50.3	57.7	76.2	86	94.3	87.71	1.14
29	50	56	74	76.2	88.3	90.90	1.10
30	47.7	55	67	71	77.5	94.33	1.06
31	37.5	53.3	62.2	63.4	65.5	97.08	1.03

4.3.2 Plotting positions consecutive day maximum rainfall by Weibull's method

In order to know the magnitude of annual maximum 1 to 5 consecutive day's maximum rainfall for different return periods, probability analysis was carried out by Weibull's method. Using Weibull's equation the probability of occurrence of 1 to 5 consecutive day's maximum rainfall was derived and presented in Table 4.8. The calculated probability values as presented in Table 4.9 were plotted on X-axis whereas the corresponding values of maximum rainfall (mm) were plotted on Y-axis. The frequency line was drawn after computing the plotted points using 'computed method' suggested by Ogrosky and Mockus (1957).

Table 4.9 Computed values of consecutive day's maximum rainfall for different percent chance of probability

Sr No.	Per cent chance of probability (%)	Computed values of Mean, Mean+ S.D and Mean-S.D. for 1 to 5 consecutive day's maximum rainfall				
		1 day	2 day	3 day	4 day	5 day
1	15.9(mean+ SD)	10.8	12.32	13.26	14.19	14.77
2	50 (mean)	9.05	10.50	11.39	12.05	12.58
3	84.1(mean-SD)	7.3	8.68	9.52	9.91	10.39

In the computed method three points were plotted at 15.9, 50 and 84.1 per cent chance of probability by calculating the values of mean, mean + standard deviation and mean – standard deviation of rainfall. The data is represented in Table 4.9. The three probability levels of 15.9, 50, 84.1 per cent and the corresponding values of mean, mean + standard deviation, mean-standard deviation of rainfall were plotted. These three points were joined as a straight line on the graph as shown in Fig 4.2.Using straight line, the observed rainfall values were determined at different selected probability levels of 50, 20, 10, 5, 2 and 1 per cent from Fig. 4.2. These rainfall values are the observed values of rainfall which are presented in Table 4.10. These were then used for chi square test to test the hypothesis.

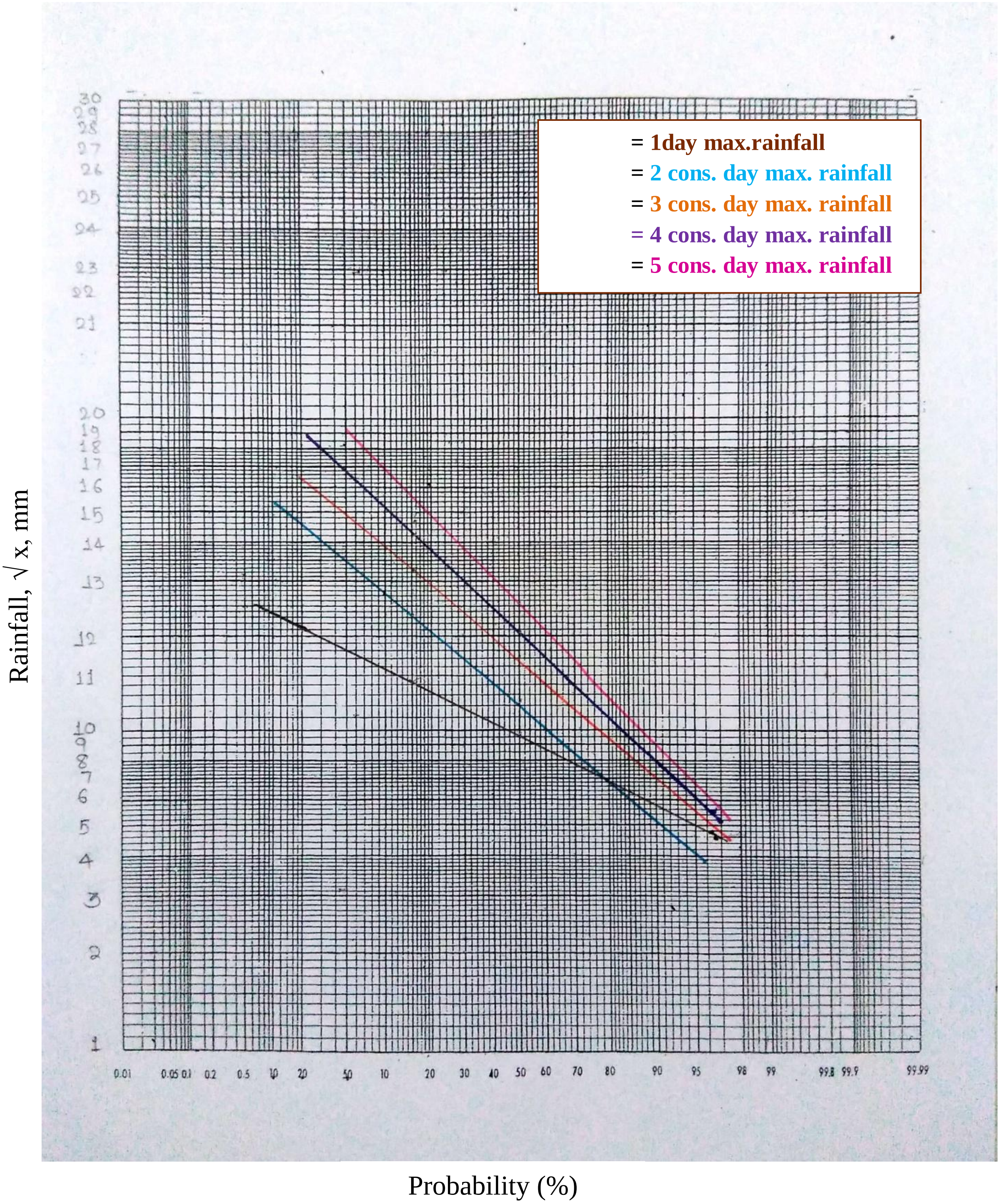


Fig 4.2 Frequency analysis of 1 to 5 consecutive day's maximum rainfall for Kallam station

Table 4.10 Observed values of consecutive day's maximum rainfall at different probabilities for Kallam

Sr. No.	Probability (P)	Observed values				
		1 day	2 day	3 day	4 day	5 day
1	50	64.80	110.25	125.44	132.25	139.24
2	20	81.00	136.89	168.74	201.64	207.36
3	10	90.25	161.29	196.00	272.25	282.24
4	5	100.00	182.25	225.00	416.16	420.25
5	2	102.01	219.04	275.56	424.36	422.30
6	1	106.09	256.00	289.00	441.00	484.00

4.3.3 Prediction of consecutive day's maximum rainfall using probability distribution

The expected maximum rainfall values for 1 to 5 consecutive day's were estimated by four probability distributions viz., Gumbel, Lognormal, Log Pearson type-III and Normal. The computed expected values for these probability distribution are presented in Table 4.11. Among these four probability distributions the best fit probability distribution was decided by Chi-square test for their goodness of fit. The observed consecutive day's maximum rainfall presented in Table 4.10 and computed maximum rainfall is presented in Table 4.11 which were used then for Chi square test to find the goodness of fit.

4.11 Annual maximum rainfall for 1 to 5 consecutive day's underdifferent frequency distribution for Kallam

Sr. no.	Probability (P)	Consecutive day's maximum rainfall (mm) Gumbel Distribution				
		1 day	2 day	3 day	4day	5 day
1	50	80.02	**107.28**	**126.32**	**141.36**	**154.07**
	20	110.16	**141.11**	**163.17**	**186.52**	**202.62**
	10	130.6	**152.55**	**188.56**	**216.41**	**234.75**
	5	150.19	184.99	210.95	245.07	265.56
	2	175.55	212.79	241.22	282.16	305.43
	1	194.59	233.66	263.94	310.00	335.36
		Log Normal Distribution				
2	50	76.85	106.66	126.32	142.18	155.51
	20	108.48	141.46	164.75	189	205.82
	10	130.25	163.79	189.00	218.11	236.28
	5	153.41	186.43	213.89	247	266.31
	2	178.30	210.41	239.10	277.29	297.49
	1	198.26	231.67	259.11	300.72	321.49
		Log Pearson Type III Distribution				
3	50	**79.09**	105.96	128.52	143.19	160.03
	20	**106.91**	142.10	169.14	189.66	209.19
	10	**123.86**	164.05	192.59	215.37	235.35
	5	140.29	191.59	215.51	238.31	257.99
	2	157.78	210.20	237.19	261.16	279.95
	1	170.98	228.96	253.71	277.12	294.80
		Normal Distribution				
4	50	85.01	113.54	133.15	149.73	163.03
	20	114.03	145.76	168.23	192.72	209.28
	10	129.22	162.62	186.58	215.21	233.46
	5	141.75	176.53	201.74	233.78	253.42
	2	155.55	191.85	218.79	254.67	275.88
	1	165.27	202.65	230.17	268.62	290.87

4.3.4 Goodness of fit of probability distributions

Using observed and estimated annual maximum consecutive day's rainfall Chi square values were estimated under each probability distribution and presented in Table 4.12. The lowest value of Chi square among various probability distributions was considered for their goodness of fit.

4.12 Calculated Chi square values under different probability distribution for Kallam

Probability distribution	χ^2 calculated value				
	1 day	2 day	3 day	4 day	5 day
Gumbel	110.91	**3.07**	**8.71**	**264.58**	**211.86**
Log normal	115.21	3.31	10.01	275.70	234.14
Log Pearson type-III	**73.89**	4.42	11.76	349.80	307.92
Normal	78.04	18.72	33.38	384.80	329.45

Data presented in Table 4.12 clearly indicates that Log Pearson Type III probability distribution was the best fit probability distribution for one day maximum rainfall. However Gumbel probability distribution was the best fit for two, three, four and five consecutive day's maximum rainfall for Kallam station.

4.3.5 Estimation of consecutive day's maximum rainfall for recurrence interval

The expected values of 1 to 5 consecutive day's maximum rainfall for recurrence intervals of 2, 5 and 10 years were estimated with best fitted probability distribution and presented in Table 4.13. It is reveals that for 2 years recurrence interval (50% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 79.09 mm to 154.07 mm, for 5 years recurrence interval (20% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 106.91 mm to 202.62 mm and for 10 years recurrence interval (10% probability) these values varied from 123.86 mm to 234.75 mm

Table 4.13 Consecutive day maximum rainfall for different recurrence intervals for Kallam

Sr. No.	Recurrence interval (years)	Rainfall for consecutive day's (mm)				
		1 day	2 day	3 day	4 day	5 day
1	2	79.09	107.28	126.32	141.36	154.07
2	5	106.91	141.11	163.17	186.52	202.62
3	10	123.86	152.55	188.56	216.41	234.75

4.3.6 Determination of drainage coefficient for Kallam

The drainage coefficient estimated for Kallam taluka station is presented in Table 4.14. The data reveals that drainage coefficient for one day maximum rainfall and 2, 5 and 10 years recurrence interval varied from 7.09 to 55.09 mm, 10.91 to 82.91 mm and 3.86 to 99.86 mm, respectively. However in case of two consecutive day's maximum rainfall for 2, 5 and 10 years recurrence interval varied from 5.63 mm, 22.25 mm and 4.27 to 28.27 mm, respectively.

Table 4.14 Estimated Drainage Coefficient (mm/day) for Kallam

Basic infiltration rate (mm/hr)	D. C. for 1 day for R. I. (yrs.)			D. C. for 2 day for R. I. (yrs.)			D. C. for 3 day for R. I. (yrs.)		
	2	5	10	2	5	10	2	5	10
1	55.09	82.91	99.86	5.63	22.55	28.27	-	-	-
2	31.09	58.91	75.86	-	-	4.27	-	-	-
3	7.09	34.91	51.86	-	-	-	-	-	-
4	-	10.91	27.86	-	-	-	-	-	-
5	-	-	3.86	-	-	-	-	-	-

4.4 Estimation of Drainage Coefficient For Lohara

4.4.1 Arrangement of consecutive day's maximum rainfall

Daily rainfall data (2000-2016) for Lohara station was analysed to obtain 1 to 5 consecutive day's maximum rainfall. The data so obtained was arranged in descending order and the ranks were assigned for each year which is presented in Table 4.15

Table 4.15 Year-wise one to five consecutive day's maximum rainfall for Lohara

Sr. No.	One day (mm)	Two day (mm)	Three day (mm)	Four day (mm)	Five day (mm)	Probability (%)	Recurrence interval (years)
1	84.3	126	147	200	200	3.12	32.00
2	80	103	113.4	122.4	142.1	6.25	16.00
3	73	89.3	111.7	113.4	135	9.38	10.66
4	71	86	101	107	124	12.5	8.00
5	66.3	82	93	102.7	118	15.62	6.40
6	62	80.4	90	98	113.4	18.76	5.33
7	60	79	89.3	93	110	21.88	4.57
8	60	75.7	88	88	107	25	4
9	59	73	83	86	104.8	28.16	3.55
10	56	71	82	84.3	96.4	31.25	3.2
11	53	70	76	84	95.3	34.48	2.90
12	52	67	72	82.7	92	37.59	2.66
13	46	64	69.3	81.3	86	40.65	2.46
14	42	56	68.3	78	82.4	43.85	2.28
15	38.3	50.3	66	70.3	82.3	46.94	2.13
16	38	44.3	58.7	68.2	73.6	50	2

4.4.2 Plotting positions of consecutive day's maximum rainfall by Weibull's method

In order to know the magnitude of annual maximum 1 to 5 consecutive day's maximum rainfall for different return periods, probability analysis was carried out by Weibull's method. Using Weibull's equation the probability of occurrence of 1 to 5 consecutive day's maximum rainfall was derived and presented in Table 4.15. The calculated probability values, as presented in Table 4.15 were plotted on X-axis whereas the corresponding values of maximum rainfall (mm) were plotted on Y-axis. The frequency line was drawn after computing the plotted points using 'computed method' suggested by Ogrosky and Mockus (1957).

Table 4.16 Computed values of consecutive day's maximum rainfall for different per cent chance of probability

Sr No.	Per cent chance of probability (%)	Computed values of Mean, Mean+ S.D and Mean- S.D. for 1 and 2 to 5 consecutive day's maximum rainfall				
		1 day	2 day	3 day	4 day	5 day
1	15.9(mean+ SD)	8.52	9.76	10.44	11.16	11.77
2	50 (mean)	7.61	8.65	9.31	9.77	10.41
3	84.1(mean-SD)	6.7	7.54	8.18	8.38	9.05

In the computed method three points were plotted at 15.9, 50 and 84.1 per cent chance of probability by calculating the values of mean, mean + standard deviation and mean – standard deviation of rainfall. The data is represented in Table 4.16. The three probability levels of 15.9, 50, 84.1 per cent and the corresponding values of mean, mean + standard deviation, mean-standard deviation of rainfall were plotted. These three points were joined as a straight line on the graph as shown in Fig 4.3. Using straight line, the observed rainfall values were determined at different selected probability levels of 50, 20, 10, 5, 2 and 1 per cent from Fig.4.3. These rainfall values are the observed values of rainfall which are presented in Table 4.17. These were then used for chi square test to test the hypothesis.

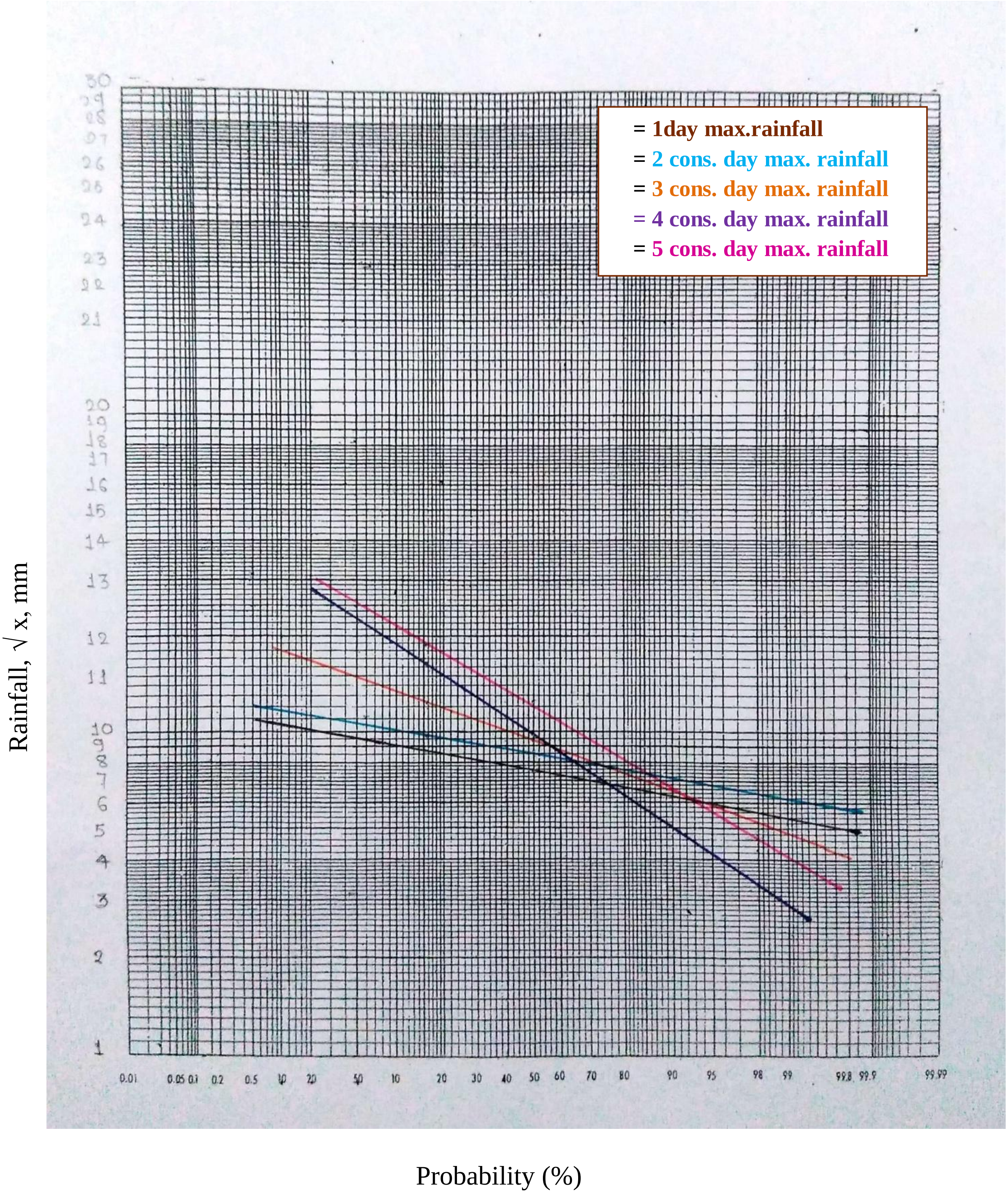


Fig. 4.3 Frequency analysis of 1 to 5 consecutive day's maximum rainfall for Lohara station

Table 4.17 Observed values of consecutive day’s maximum rainfall at different probabilities for Lohara station

Sr. No.	Probability (P)	Observed values				
		1 day	2 day	3 day	4 day	5 day
1	50	54.02	76.56	97.02	100.00	106.04
2	20	67.24	90.25	104.04	110.25	116.64
3	10	80.82	100.00	108.16	116.64	120.78
4	5	81.00	105.06	110.25	121.00	127.69
5	2	90.25	106.09	116.64	132.25	134.56
6	1	100.00	110.25	118.81	134.56	136.89

4.4.3 Prediction of consecutive day’s maximum rainfall using probability distribution

The expected maximum rainfall values for 1 to 5 consecutive day’s were estimated by four probability distributions viz., Gumbel, Lognormal, Log Pearson type-III and Normal. The computed expected values for these probability distribution are presented in Table 4.18. Among these four probability distributions the best fit probability distribution was decided by Chi-square test for their goodness of fit. The observed maximum rainfall presented in Table 4.17 and computed maximum rainfall values presented in Table 4.18 were used for Chi square test to find the goodness of fit.

Table 4.18 Annual maximum consecutive day's rainfall under different frequency distribution for Lohara Station

Sr. No.	Probability (P)	Consecutive day's maximum rainfall (mm)				
		Gumbel Distribution				
		1 day	2 day	3 day	4 day	5 day
1	50	**56.51**	72.80	91.68	92.34	105.09
	20	**68.81**	90.37	104.06	119.87	132.30
	10	**76.95**	102	111.59	138.10	150.30
	5	84.75	113.15	129.55	155.57	167.57
	2	94.85	127.58	112.88	178.19	189.92
	1	102.43	138.42	157.83	195.16	206.69
		Lognormal Distribution				
2	50	55.46	72.48	84.40	92.11	105.89
	20	68.37	90.84	104.85	125.17	133.33
	10	77.25	102.57	117.70	145.72	149.86
	5	86.70	114.67	130.76	166.13	166.16
	2	96.86	127.37	144.43	187.51	183.08
	1	105.00	137.10	155.08	204.06	196.11
		Log Pearson Type III				
3	50	56.92	73.06	**86.44**	**95.73**	101.18
	20	69.18	90.19	**104.12**	**114.81**	127.12
	10	76.03	100.00	**113.77**	**125.89**	145.97
	5	82.41	111.73	122.46	136.45	167.29
	2	88.92	119.45	131.16	145.42	192.71
	1	93.84	126.76	137.33	151.55	214.89
		Normal Distribution				
4	50	58.79	**76.05**	88.03	97.44	**110.13**
	20	70.50	**92.78**	106.75	123.65	**136.03**
	10	76.62	**101.53**	116.55	137.37	**149.58**
	5	81.68	108.76	124.64	148.69	160.77
	2	87.37	116.89	133.74	161.43	173.08
	1	91.16	122.32	139.81	169.93	181.76

4.4.4 Goodness of fit of probability distributions

Using observed and estimated annual maximum consecutive day's rainfall Chi square values were estimated under each probability distribution and presented in Table 4.19. The lowest value of Chi square among various probability distributions was considered for their goodness of fit.

Table 4.19 Calculated Chi square values under different probability distribution for Lohara

Probability distribution	χ^2 calculated value				
	1 day	2 day	3 day	4 day	5 day
Gumbel	**0.79**	10.16	13.08	43.06	56.86
Log normal	1.28	9.92	19.72	60.48	47.41
Log Pearson type-III	0.94	4.21	**6.9**	**5.75**	60.52
Normal	1.73	**2.41**	8.6	22.44	**35.11**

Data presented in Table 4.19, clearly indicates that Log Pearson Type III probability distribution was the best fit probability distribution for three and four consecutive day's maximum rainfall. However Gumbel probability distribution was the best fit probability distribution for one day maximum rainfall and Normal probability distribution was the best fit probability distribution for two and five consecutive day's maximum rainfall for Lohara station.

4.4.5 Estimation of consecutive day's maximum rainfall

The expected values of 1 to 5 consecutive day's maximum rainfall for recurrence intervals of 2, 5 and 10 years were estimated with best fitted probability distribution and presented in Table 4.20. It is reveals that for 2 years recurrence interval (50% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 56.51 to 110.13 mm, for 5 years recurrence interval (20% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall from 68.81 to 136.03 mm and for 10 years recurrence interval (10 % probability) these values varied from 76.95 mm to 149.58 mm.

Table 4.20 Consecutive day maximum rainfall for different recurrence intervals for Lohara Station

Sr. No.	Recurrence interval (years)	Rainfall for consecutive day's (mm)				
		1 day	2 day	3 day	4 day	5 day
1	2	56.51	76.05	86.44	95.73	110.13
2	5	68.81	92.78	104.12	114.81	136.03
3	10	76.95	101.53	113.77	125.89	149.58

4.4.6 Drainage coefficient for Lohara

The drainage coefficient estimate for Lohara taluka station is presented in Table 4.21. The data reveals that drainage coefficient one day maximum rainfall and 2, 5 and 10 years recurrence interval varied from 8.50 to 32.50 mm, 20.81 to 44.81 and 4.95 to 52.95 mm, respectively. However in case of two consecutive day's maximum rainfall and 10 years recurrence interval it is 2.76 mm.

Table 4.21 Estimated Drainage Coefficient (mm/day) for Lohara Station

Basic infiltration rate (mm/hr)	D. C. for 1 day for R. I. (yrs.)			D. C. for 2 day for R. I. (yrs.)			D. C. for 3 day for R. I. (yrs.)		
	2	5	10	2	5	10	2	5	10
1	32.50	44.81	52.95	-	-	2.76	-	-	-
2	8.50	20.81	28.95	-	-	-	-	-	-
3	-	-	4.95	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-

4.5 Estimation of Drainage Coefficient For Osmanabad

4.5.1 Arrangement of consecutive day's maximum rainfall

Daily rainfall data (1986-2016) for Osmanabad station was analysed to obtain 1 to 5 consecutive day's maximum rainfall. The data so obtained was arranged in descending order and the ranks were assigned for each year which is presented in Table 4.22.

Table 4.22 Year-wise one to five consecutive day's maximum rainfall for Osmanabad

Sr. no.	One day (mm)	Two day (mm)	Three day (mm)	Four day (mm)	Five day (mm)	Probability (%)	Recurrence interval (years)
1	180	194.2	201.4	202.8	214	3.12	32.00
2	122.3	135.5	157.2	178.2	203	6.25	16.00
3	112	132.2	149.8	174.9	197.5	9.38	10.66
4	111.2	125.2	144.4	171.4	196.6	12.5	8.00
5	107	125	141	160.2	193	15.62	6.40
6	100.2	121	140.5	160.2	182	18.76	5.33
7	98.2	120.4	139	157	178.2	21.88	4.57
8	91	115	135.5	154	174.8	25	4
9	86	112	135	145.7	167.2	28.16	3.55
10	81	112	129	143	164.2	31.25	3.2
11	81	100.2	124.4	136	141	34.48	2.90
12	81	98.6	116	135.5	135.9	37.59	2.66
13	80	94	111	134	135.8	40.65	2.46
14	77.1	92	108.2	129.1	135.5	43.85	2.28
15	76	87	98.6	114	134.6	46.94	2.13
16	75	86	97	111	124.1	50	2
17	67.3	79.8	82.7	106.9	120	53.19	1.88
18	65.2	79.4	81.9	89.4	114	56.49	1.77
19	62.2	77.4	80.4	84.6	100	59.52	1.68
20	57.2	75	79.8	84	99.4	62.5	1.6
21	56.3	73.2	78.2	82.7	86.4	65.78	1.52
22	56	72.4	75.2	82.2	83.9	68.96	1.45
23	55	70.2	75	78	82.2	71.94	1.39
24	52.8	68.2	73.7	77.1	79.7	75.18	1.33
25	52	68	72.4	75.2	77.6	78.12	1.28
26	51.3	63.2	70.1	72.7	75.2	81.30	1.23
27	48	61.9	67.9	70.1	72.7	84.74	1.18
28	45.2	57.5	66.8	68.1	71.1	87.71	1.14
29	44.6	54.1	61	66.5	71	90.90	1.10
30	41.6	52	58.5	61.5	66.5	94.33	1.06
31	31.3	43.5	46.9	48.4	61.5	97.08	1.03

4.5.2 Plotting positions of consecutive day maximum rainfall by Weibull's method

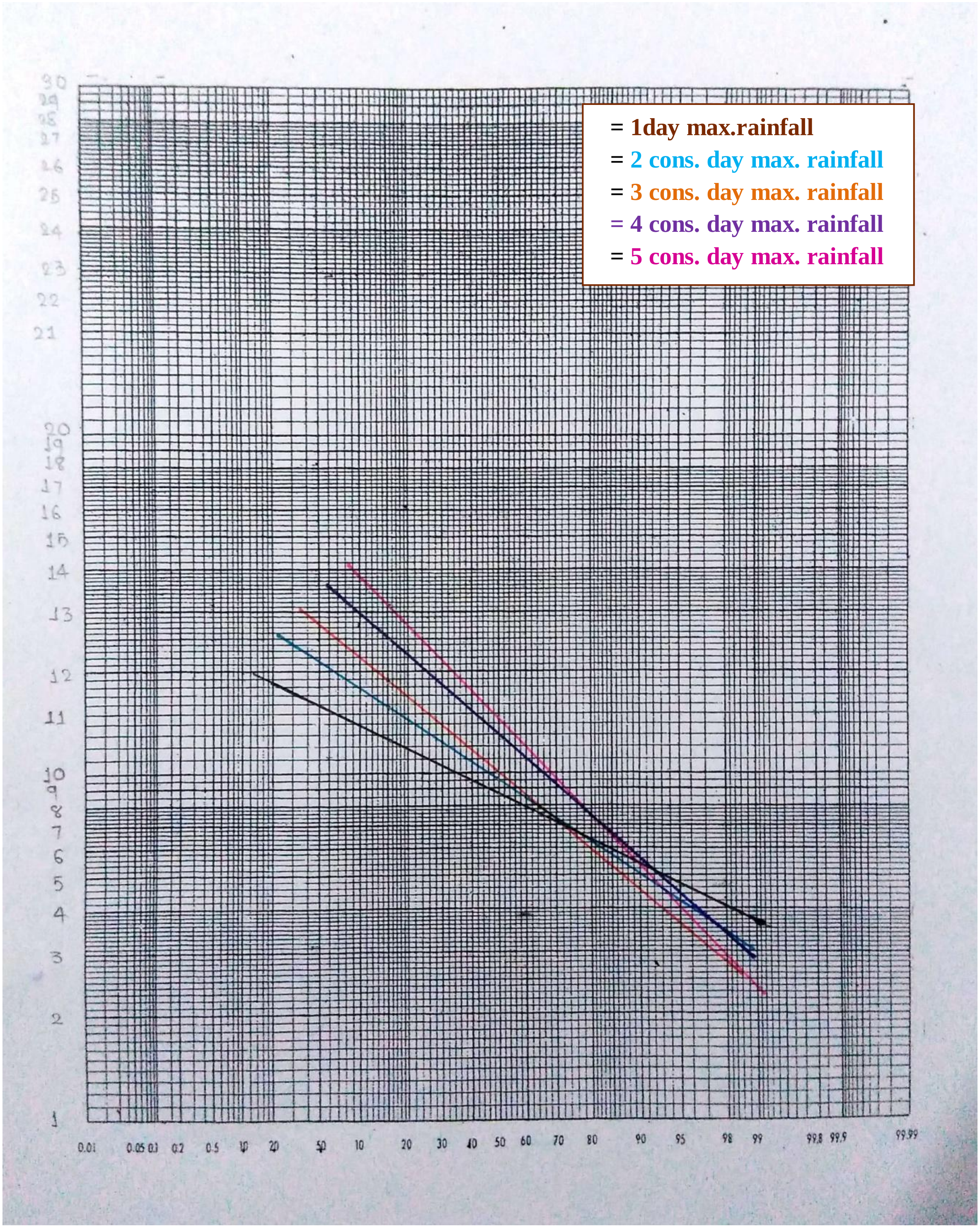
In order to know the magnitude of annual maximum 1 to 5 consecutive day's maximum rainfall for different return periods, probability analysis was carried out by Weibull's method. Using Weibull's equation the probability of occurrence of 1 to 5 consecutive day's maximum rainfall was derived and presented in Table 4.22. The calculated probability values as presented in Table 4.22 were plotted on X-axis whereas the corresponding values of maximum rainfall (mm) was plotted on Y-axis. The frequency line was drawn after computing the plotted points using 'computed method' suggested by Ogrosky and Mockus (1957).

Table 4.23 Computed values of consecutive day's maximum rainfall for different percent chance of probability

Sr No.	Per cent chance of probability (%)	Computed values of Mean, Mean+ S.D and Mean-S.D. for 1 and 2 to 5 consecutive day's maximum rainfall				
		1 day	2 day	3 day	4 day	5 day
1	15.9(mean+ SD)	10.58	11.05	11.78	12.5	13.22
2	50 (mean)	8.54	9.44	10.00	10.52	11.06
3	84.1(mean-SD)	6.90	7.83	8.22	8.54	8.9

In the computed method three points were plotted at 15.9, 50 and 84.1 per cent chance of probability by calculating the values of mean, mean + standard deviation and mean – standard deviation of rainfall. The data is represented in Table 4.23. The three probability levels of 15.9, 50, 84.1 per cent and the corresponding values of mean, mean+standard deviation, mean-standard deviation of rainfall were plotted. These three points were joined as a straight line on the graph as shown in Fig 4.4.Using straight line, the observed rainfall values were determined at different selected probability levels of 50, 20, 10, 5, 2 and 1 per cent from Fig. 4.4. These rainfall values are the observed values of rainfall which are presented in Table 4.24. These were then used for chi square test to test the hypothesis.

Rainfall, √x, mm



Probability (%)

Fig. 4.4 Frequency analysis of 1 to 5 consecutive day's maximum rainfall for Osmanabad station

Table 4.24 Observed values of consecutive day's maximum rainfall at different probabilities for Osmanabad Station

Sr. No.	Probability (P)	Observed values				
		1 day	2 day	3 day	4 day	5 day
1	50	72.25	81.00	97.02	104.04	121.00
2	20	102.01	116.64	125.44	144.00	169.00
3	10	110.25	127.69	148.84	162.56	196.00
4	5	121.44	144.00	162.56	165.12	232.56
5	2	142.80	156.25	182.25	171.61	292.56
6	1	145.20	167.19	196.00	225.00	361.00

4.5.3 Prediction of consecutive day's maximum rainfall using probability distribution

The expected maximum rainfall values for 1 to 5 consecutive day's were estimated by four probability distributions viz., Gumbel, Lognormal, Log Pearson type-III and Normal. The computed expected values for these probability distribution are presented in Table 4.25. Among these four probability distributions the best fit probability distribution was decided by Chi-square test for their goodness of fit. The observed maximum rainfall presented in Table 4.24 and computed maximum rainfall presented in Table 4.25 were used for Chi square test to find the goodness of fit.

4.25 Annual maximum consecutive day's rainfall under different frequency distribution for Osmanabad Station

Sr. No.	Probability (P)	Consecutive day's maximum rainfall (mm) Gumbel Distribution				
		1 day	2 day	3 day	4 day	5 day
1	50	70.67	86.54	97.13	107.70	119.09
	20	97.44	114.85	129.65	145.12	161.99
	10	115.16	133.58	151.16	169.89	141.85
	5	132.16	151.54	171.80	193.63	217.60
	2	154.15	174.79	198.50	224.36	252.83
	1	170.65	192.24	218.54	247.43	279.28
		Log Normal Distribution				
2	50	68.37	86.04	97.14	108.38	**120.36**
	20	96.51	115.60	130.92	147.18	**164.80**
	10	115.88	134.57	152.38	171.29	**191.72**
	5	136.48	153.93	173.84	192.39	218.24
	2	158.63	174.38	196.53	220.33	245.79
	1	176.39	190.41	214.16	239.74	266.99
		Log Pearson Type III Distribution				
3	50	70.48	87.65	99.34	111.02	123.29
	20	95.10	115.14	131.42	145.29	165.34
	10	109.90	131.59	150.16	169.12	188.13
	5	124.58	151.96	167.73	187.72	208.04
	2	140.01	165.69	185.96	206.30	227.52
	1	151.65	179.39	199.28	219.32	240.78
		Normal Distribution				
4	50	**75.63**	**91.79**	**103.16**	**114.64**	127.04
	20	**101.12**	**118.73**	**134.11**	**151.10**	167.87
	10	**114.45**	**132.83**	**150.30**	**168.90**	189.24
	5	125.46	144.47	163.67	184.28	206.88
	2	137.85	157.56	178.71	201.59	226.73
	1	146.12	166.31	188.75	213.15	239.97

4.5.4 Goodness of fit of probability distributions

Using observed and estimated annual maximum consecutive day's rainfall Chi square values were estimated under each probability distribution and presented in Table 4.26. The lowest value of Chi square among various probability distributions was considered for their goodness of fit.

4.26 Calculated Chi square values under different probability distribution for Osmanabad

Probability distribution	χ^2 calculated value				
	1 day	2 day	3 day	4 day	5 day
Gumbel	5.96	7.24	4.32	19.12	53.85
Log normal	22.1	5.89	8.36	16.23	**45.15**
Log Pearson type-III	0.95	2.36	3.32	9.4	84.93
Normal	**0.63**	**1.53**	**3.13**	**8.64**	86.9

Data presented in Table 4.26 clearly indicates that Normal probability distribution was the best fit probability distribution for one, two, three and four consecutive day's maximum rainfall at Osmanabad. However lognormal probability distribution was the best fit for five consecutive day's maximum rainfall for Osmanabad.

4.5.5 Estimation of consecutive day's maximum rainfall for recurrence interval

The expected values of 1 to 5 consecutive day's maximum rainfall for recurrence intervals of 2, 5 and 10 years were estimated with best fitted probability distribution and presented in Table 4.27. It reveals that for 2 years recurrence interval (50% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 75.63 to 120.36 mm, for 5 years recurrence interval (20% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 101.12 to 164.80 mm and for 10 years recurrence interval (10% probability) these values varied from 114.45 to 191.72 mm.

Table 4.27 Consecutive day maximum rainfall for different recurrence intervals for Osmanabad

Sr. No.	Recurrence interval (years)	Rainfall for consecutive day's (mm)				
		1 day	2 day	3 day	4 day	5 day
1	2	75.63	91.79	103.16	114.64	120.36
2	5	101.12	118.73	134.11	151.10	164.80
3	10	114.45	132.83	150.30	168.90	191.72

4.5.6 Determination of drainage coefficient

The drainage coefficient estimated for Osmanabad taluka station is presented in Table 4.28. The data reveals that drainage coefficient for one day maximum rainfall and 2, 5 and 10 years recurrence interval varied from 3.64 to 51.64 mm, 5.14 to 77.14 mm and 18.45 to 90.45 mm respectively. However in case of two consecutive day's maximum rainfall and 5 and 10 years recurrence interval it is from 11.38 mm and 18.41 mm, respectively.

Table 4.28 Estimated drainage coefficient (mm/day) for Osmanabad

Basic infiltration rate (mm/hr)	D. C. for 1 day for R. I. (yrs.)			D. C. for 2 day for R. I. (yrs.)			D. C. for 3 day for R. I. (yrs.)		
	2	5	10	2	5	10	2	5	10
1	51.64	77.14	90.45	-	11.38	18.41	-	-	-
2	27.64	53.14	66.45	-	-	-	-	-	-
3	3.64	29.14	42.45	-	-	-	-	-	-
4	-	5.14	18.45	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-

4.6 Estimation of Drainage Coefficient for Paranda

4.6.1 Arrangement of consecutive day's maximum rainfall

Daily rainfall data (1986-2016) for Paranda station was analysed to obtain 1 to 5 consecutive day's maximum rainfall. The data so obtained was arranged in descending order and the ranks were assigned for each year which is presented in Table 4.29

Table 4.29 Year-wise one to five consecutive day's maximum rainfall for Paranda station.

Sr. No.	One day (mm)	Two day (mm)	Three day (mm)	Four day (mm)	Five day (mm)	Probability (%)	Recurrence interval (years)
1	125	130	166	166	166	3.12	32.00
2	116	127	145	148	160.4	6.25	16.00
3	97	117.6	132	145	159.2	9.38	10.66
4	93	116	123.4	140	156	12.5	8.00
5	90.4	107.4	122	133.2	150	15.62	6.40
6	85.2	102.2	119	132	132	18.76	5.33
7	84.8	98	117.6	127.5	132	21.88	4.57
8	74.6	93.6	116.9	127	127.7	25	4
9	67.2	93.2	111.6	124.2	127	28.16	3.55
10	65	90.6	110.8	123	124.2	31.25	3.2
11	64	86	106.8	122	123	34.48	2.90
12	63	86	99.2	115.8	122	37.59	2.66
13	62	85	99.2	112.8	120.4	40.65	2.46
14	61.2	84.8	99.2	110.8	117.2	43.85	2.28
15	60	83.4	98	109	115.8	46.94	2.13
16	56	83	93.2	105.4	112.8	50	2
17	53.6	79.4	91.6	104.3	110.8	53.19	1.88
18	52	73.8	90	100.2	109.8	56.49	1.77
19	51.2	72	90	99.6	104.3	59.52	1.68
20	48.6	72	89	96.6	104	62.5	1.6
21	47.8	70.6	88.2	95.2	102.2	65.78	1.52
22	46.8	68	85	91	99.4	68.96	1.45
23	45.4	63	84.2	90	97	71.94	1.39
24	45	60.1	82	89.2	96.4	75.18	1.33
25	41.2	59.8	75.4	86	89	78.12	1.28
26	40.8	58.8	73.4	83	89	81.30	1.23
27	40.2	57	69.6	78.8	85.4	84.74	1.18
28	36.4	55.4	69.6	76.8	76.8	87.71	1.14
29	36.2	51.5	63	63	64	90.90	1.10
30	32	51.2	51.5	55	62	94.33	1.06
31	31.1	36.2	40	40	40.2	97.08	1.03

4.6.2 Plotting positions of consecutive day maximum rainfall by weibull's method

In order to know the magnitude of annual maximum 1 to 5 consecutive day's maximum rainfall for different return periods, probability analysis was carried out by Weibull's method. Using Weibull's equation the probability of occurrence of 1 to 5 consecutive day's maximum rainfall was derived and presented in Table 4.29. The calculated probability values as presented in Table 4.29 were plotted on X-axis whereas the corresponding values of maximum

rainfall (mm) was plotted on Y-axis. The frequency line was drawn after computing the plotted points using ‘computed method’ suggested by Ogrosky and Mockus (1957).

Table 4.30 Computed values of consecutive day’s maximum rainfall for different percent chance of probability

Sr. No.	Per cent chance of probability (%)	Computed values of Mean, Mean+ S.D and Mean- S.D. for 1 and 2 to 5 consecutive day’s maximum rainfall				
		1 day	2 day	3 day	4 day	5 day
1	15.9(mean+ SD)	9.17	10.2	11.11	11.63	11.95
2	50 (mean)	7.72	8.91	9.74	10.20	10.48
3	84.1(mean-SD)	6.27	7.62	8.37	8.17	9.01

In the computed method three points were plotted at 15.9, 50 and 84.1 per cent chance of probability by calculating the values of Mean, Mean + Standard Deviation and Mean – Standard deviation of rainfall. The data is represented in Table 4.30. The three probability levels of 15.9, 50, 84.1 per cent and the corresponding values of mean, mean+standard deviation, mean-standard deviation of rainfall were plotted. These three points were joined as a straight line on the graph as shown in Fig 4.5.Using straight line, the observed rainfall values were determined at different selected probability levels of 50, 20, 10, 5, 2 and 1 per cent from Fig. 4.5. These rainfall values are the observed values of rainfall which are presented in Table 4.31. These were then used for chi square test to test the hypothesis.

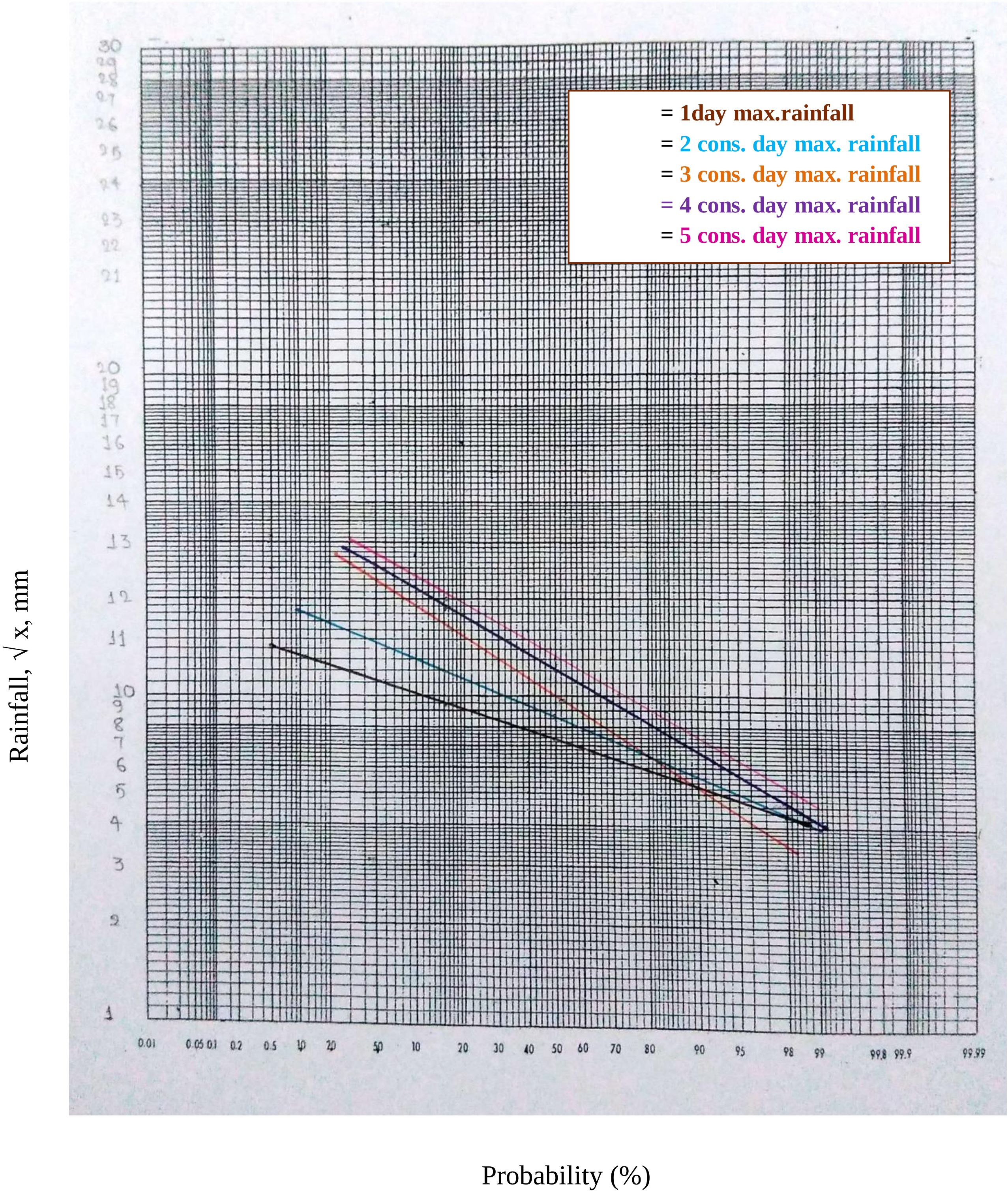


Fig. 4.5 Frequency analysis of 1 to 5 consecutive day's maximum rainfall for Paranda station

Table 4.31 Observed values of consecutive day's maximum rainfall at different probabilities for Paranda Station.

Sr. No.	Probability (P)	Observed values				
		1 day	2 day	3 day	4 day	5 day
1	50	50.12	69.72	87.42	111.30	110.25
2	20	81.00	100.00	116.64	128.82	132.25
3	10	100.00	101.00	136.89	144.00	148.84
4	5	106.09	107.12	151.29	152.52	156.25
5	2	110.25	111.30	156.25	167.70	168.74
6	1	114.49	116.64	169.00	182.25	183.60

4.6.3 Prediction of consecutive day's maximum rainfall using probability distribution

The expected maximum rainfall values for 1 to 5 consecutive day's were estimated by four probability distributions viz., Gumbel, Lognormal, Log Pearson type-III and Normal. The computed expected values for these probability distribution are presented in Table 4.32. Among these four probability distributions the best fit probability distribution was decided by Chi-square test for their goodness of fit. The observed maximum rainfall values presented in Table 4.31 and computed maximum rainfall presented in Table 4.32 were used for Chi square test to find the goodness of fit.

4.32 Annual maximum consecutive day's rainfall under different frequency distribution for Paranda

Sr. no.	Probability (P)	Consecutive day's maximum rainfall (mm)				
		1 day	2 day	3 day	4day	5 day
1	50	57.77	77.24	92.48	**101.52**	**107.25**
	20	78.92	97.77	116.00	**126.40**	**133.48**
	10	92.91	111.36	131.57	**142.87**	**150.85**
	5	106.33	124.39	146.50	158.66	167.50
	2	123.70	141.26	165.82	179.10	189.05
	1	136.73	153.92	180.32	194.70	205.22
		Log Normal Distribution				
2	50	55.96	76.87	92.49	101.97	108.02
	20	78.17	98.31	116.96	127.76	135.20
	10	93.45	112.13	132.40	143.80	151.66
	5	109.71	126.13	147.95	159.71	168.03
	2	127.19	140.97	164.30	176.66	184.72
	1	140.49	152.60	177.04	189.31	197.69
		Log Pearson Type III Distribution				
3	50	58.73	78.38	**94.92**	104.94	111.50
	20	78.66	99.72	**117.92**	131.90	139.67
	10	90.72	112.20	**133.45**	146.28	154.22
	5	102.36	127.39	146.20	158.84	166.60
	2	114.71	137.40	159.19	171.12	178.23
	1	124.00	147.49	168.83	179.58	186.37
		Normal Distribution				
4	50	**61.69**	**81.04**	96.84	106.13	112.11
	20	**81.82**	**100.59**	119.23	129.82	137.08
	10	**92.35**	**110.82**	130.95	142.21	150.15
	5	101.04	119.26	140.62	152.44	160.94
	2	110.83	128.76	151.50	163.96	173.08
	1	117.36	135.10	158.77	171.64	181.18

4.6.4 Goodness of fit of probability distributions

Using observed and estimated annual maximum consecutive day's rainfall Chi square values were estimated under each probability distribution and presented in Table 4.33. The lowest value of Chi square among various probability distributions was considered for their goodness of fit.

4.33 Calculated Chi square values under different probability distribution for Paranda

Probability distribution	χ^2 calculated value				
	1 day	2 day	3 day	4 day	5 day
Gumbel	6.68	19.52	1.92	**2.77**	**5.34**
Log normal	8.36	19.38	1.27	1.89	3.37
Log Pearson type-III	3.32	16.72	**0.92**	0.86	1.78
Normal	**3.13**	**8.59**	2.87	1.03	0.49

Data presented in Table 4.33 clearly indicates that Normal probability distribution was the best fit probability distribution for one and two consecutive day's maximum rainfall. However Gumbel probability distribution was the best fit for four and five consecutive day's maximum rainfall and Log Pearson Type III distribution was the best fit for three consecutive day's maximum rainfall for Paranda station.

4.6.5 Estimation of consecutive day's maximum rainfall

The expected values of 1 to 5 consecutive day's maximum rainfall for recurrence intervals of 2, 5 and 10 years were estimated with best fitted probability distribution and presented in Table 4.34. It is reveals that for 2 years recurrence interval (50% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 61.69 to 107.25 mm, for 5 years recurrence interval (20% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 81.82 to 133.48 and for 10 years recurrence interval (10% probability) these values varied from 92.35 to 150.85 mm.

Table 4.34 Consecutive day maximum rainfall for different recurrence intervals for Paranda

Sr. No.	Recurrence interval (years)	Rainfall for consecutive day's (mm)				
		1 day	2 day	3 day	4 day	5 day
1	2	61.69	81.04	94.92	101.52	107.25
2	5	81.82	100.59	117.92	126.40	133.48
3	10	92.35	110.82	133.45	142.87	150.85

4.6.6 Determination of drainage coefficient

The data presented in Table 4.35 reveals that drainage coefficient for one day maximum rainfall and 2, 5 and 10 years recurrence interval varied between 13.70 to 37.70 mm, 9.83 to 57.83 mm and 20.35 to 68.35 mm, respectively. However in case of two consecutive day's maximum rainfall and 5 and 10 years recurrence interval it is 2.3 mm and 7.41 mm, respectively.

Table 4.35 Estimated Drainage Coefficient (mm/day) for Paranda

Basic infiltration rate (mm/hr)	D. C. for 1 day for R. I. (yrs.)			D. C. for 2 day for R. I. (yrs.)			D. C. for 3 day for R. I. (yrs.)		
	2	5	10	2	5	10	2	5	10
1	37.70	57.83	68.35	-	2.3	7.41	-	-	-
2	13.7	33.83	44.35	-	-	-	-	-	-
3	-	9.83	20.35	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-

4.7 Estimation of drainage coefficient for Tuljapur station of Osmanabad district

4.7.1 Arrangement of consecutive day's maximum rainfall

Daily rainfall data (1986-2016) for Tuljapur station was analysed to obtain 1 to 5 consecutive day's maximum rainfall. The data so obtained was arranged in descending order and the ranks were assigned for each year which is presented in Table 4.36

Table 4.36 Year-wise one to five consecutive day's maximum rainfall for Tuljapur station.

Sr. No.	One day (mm)	Two day (mm)	Three day (mm)	Four day (mm)	Five day (mm)	Probability (%)	Recurrence interval (years)
1	156	330	332	335.8	379.2	3.12	32.00
2	134	232	290.6	307.8	356.8	6.25	16.00
3	130.6	146	194.8	211.8	226.2	9.38	10.66
4	102.2	144	179	189	204	12.5	8.00
5	93	132.2	170	170.4	178	15.62	6.40
6	90	127.8	150.4	170	177	18.76	5.33
7	89.8	120	137.4	160	174.2	21.88	4.57
8	84.6	119.8	134	155.6	170.7	25	4
9	81.8	118.2	132.2	134	158.6	28.16	3.55
10	79.6	110.4	129.2	134	157.2	31.25	3.2
11	79.4	110	123	132.2	147	34.48	2.90
12	78.7	107.6	121	129.2	145.9	37.59	2.66
13	70	107.4	118	122.6	143	40.65	2.46
14	69	106.2	115.3	121.7	141.2	43.85	2.28
15	65	92.6	115.2	121.4	137.6	46.94	2.13
16	62	90	105	116.4	129.2	50	2
17	61.2	86	102	115	122.3	53.19	1.88
18	60.3	83	95.6	110.2	116	56.49	1.77
19	60	81.3	92.2	107.2	114	59.52	1.68
20	59.4	78.9	91.2	107	112.2	62.5	1.6
21	57.4	78	91.2	105.2	107.4	65.78	1.52
22	56.2	72.4	90.4	97.7	107	68.96	1.45
23	55	72.2	90	95.2	98.8	71.94	1.39
24	53.4	70.4	87.9	95	97.7	75.18	1.33
25	51.9	67.4	85.2	94.2	94.2	78.12	1.28
26	49.6	62.6	75.4	92	94	81.30	1.23
27	43.2	59	71.2	85.4	87.4	84.74	1.18
28	38.3	57.4	70.2	74	85.4	87.71	1.14
29	37.7	55.6	64	70.2	74	90.90	1.10
30	33.4	47.8	56.7	64	64	94.33	1.06
31	21.8	45.3	54.8	56	56.4	97.08	1.03

4.7.2 Plotting positions of consecutive day maximum rainfall by Weibull's method

In order to know the magnitude of annual maximum 1 to 5 consecutive day's maximum rainfall for different return periods, probability analysis was carried out by Weibull's method. Using Weibull's equation the probability of occurrence of 1 to 5 consecutive day's maximum rainfall was derived and presented in Table 4.36. The calculated probability values as presented in Table 4.36 were plotted on X-axis whereas the corresponding values of maximum

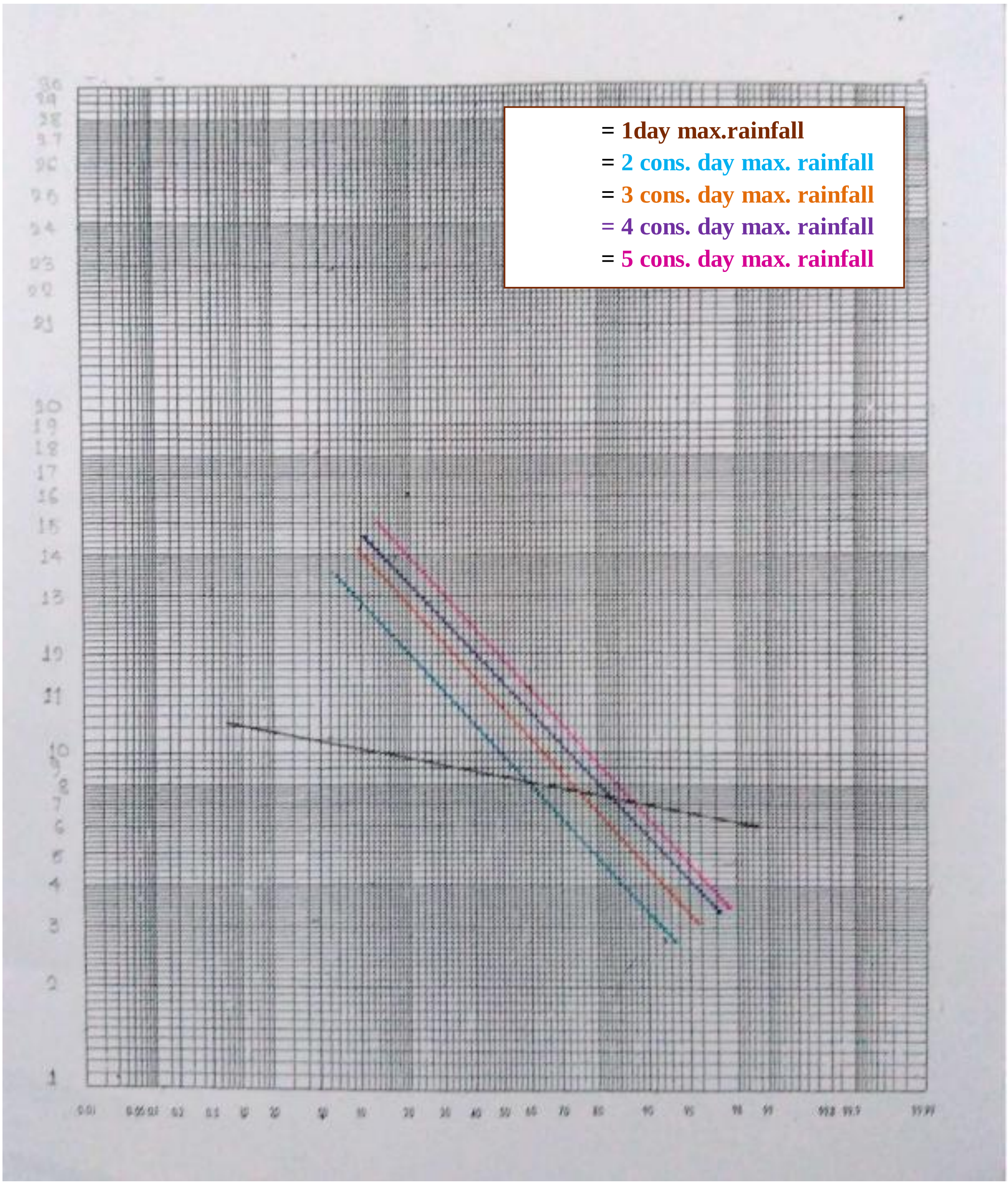
rainfall (mm) were plotted on Y-axis. The frequency line was drawn after computing the plotted points using ‘computed method’ suggested by Ogrosky and Mockus (1957).

Table 4.37 Computed values of consecutive day’s maximum rainfall for different percent chance of probability

Sr No.	Per cent chance of probability (%)	Computed values of Mean, Mean+ S.D and Mean- S.D. for 1 and 2 to 5 consecutive day’s maximum rainfall				
		1 day	2 day	3 day	4 day	5 day
1	15.9(mean+ SD)	9.96	12.26	13.2	13.64	13.80
2	50 (mean)	8.26	9.90	10.75	11.22	11.75
3	84.1(mean-SD)	6.56	7.54	8.3	8.8	9.20

In the computed method three points were plotted at 15.9, 50 and 84.1 per cent chance of probability by calculating the values of mean, mean + standard deviation and mean – standard deviation of rainfall. The data is represented in Table 4.37. The three probability levels of 15.9, 50, 84.1 per cent and the corresponding values of mean, mean+standard deviation, mean-standard deviation of rainfall were plotted. These three points were joined as a straight line on the graph as shown in Fig 4.6.Using straight line, the observed rainfall values were determined at different selected probability levels of 50, 20, 10, 5, 2 and 1 per cent from Fig. 4.6. These rainfall values are the observed values of rainfall which are presented in Table 4.38. These were then used for chi square test to test the hypothesis.

Rainfall, √ x, mm



Probability (%)

Fig. 4.6 Frequency analysis of 1 to 5 consecutive day's maximum rainfall for Tuljapur station

Table 4.38 Observed values of consecutive day's maximum rainfall at different probabilities for Tuljapur Station

Sr. no.	Probability (P)	Observed values				
		1 day	2 day	3 day	4 day	5 day
1	50	72.25	90.25	104.04	125.44	136.36
2	20	87.42	141.61	156.25	170.30	185.44
3	10	100	166.41	196	223.50	250.87
4	5	101.40	193.21	252.81	254.40	275.35
5	2	101.80	252.81	342.25	331.24	378.70
6	1	106.90	320.41	420.25	408.04	420.65

4.7.3 Prediction of consecutive day's maximum rainfall using probability distribution

The expected maximum rainfall values for 1 to 5 consecutive day's were estimated by four probability distributions viz., Gumbel, Lognormal, Log Pearson type-III and Normal. The computed expected values for these probability distribution are presented in Table 4.39. Among these four probability distributions the best fit probability distribution was decided by Chi-square test for their goodness of fit. The observed maximum rainfall presented in Table 4.38 and computed maximum rainfalls presented in Table 4.39 were used for Chi square test to find the goodness of fit.

4.39 Annual maximum consecutive rainfall day's under different frequency distribution for Tuljapur

Sr. No.	Probability (P)	Consecutive day's maximum rainfall (mm) Gumbel Distribution				
		1 day	2 day	3 day	4day	5 day
1	50	66.22	94.35	**111.38**	**121.40**	131.92
	20	92.54	144.12	**165.65**	**176.43**	195.70
	10	109.95	177.11	**201.57**	**212.84**	237.90
	5	126.66	208.72	236.02	247.76	278.37
	2	148.27	249.62	280.59	292.96	330.74
	1	164.49	280.32	314.06	326.88	370.06
		Log Normal Distribution				
2	50	64.11	93.46	111.39	122.45	133.82
	20	91.22	145.49	167.84	179.17	199.93
	10	110.64	179.02	203.63	214.41	239.98
	5	129.74	212.99	239.56	249.43	279.45
	2	151.08	248.99	277.35	286.12	320.43
	1	168.19	277.23	306.79	314.52	351.98
		Log Pearson Type III Distribution				
3	50	65.91	**94.87**	113.48	125.66	**137.23**
	20	91.94	**134.88**	157.39	170.26	**187.93**
	10	108.14	**160.23**	184.42	195.34	**216.19**
	5	124.12	192.90	210.03	217.92	240
	2	141.31	215.66	237.11	240.59	265.24
	1	154.42	238.93	257.18	256.51	281.90
		Normal Distribution				
4	50	**71.10**	103.58	121.44	131.60	143.75
	20	**96.15**	150.98	173.10	183.98	204.45
	10	**109.26**	175.79	200.14	211.38	236.21
	5	120.08	196.26	222.45	234.01	262.43
	2	132.25	219.31	247.56	259.47	291.93
	1	140.38	234.69	264.32	299.47	311.62

4.7.4 Goodness of fit of probability distributions

Using observed and estimated annual maximum consecutive day's rainfall Chi square values were estimated under each probability distribution and presented in Table 4.40. The lowest value of Chi square among various probability distributions was considered for their goodness of fit.

4.40 Calculated Chi square values under different probability distribution for Tuljapur

Probability distribution	χ^2 calculated value				
	1 day	2 day	3 day	4 day	5 day
Gumbel	41.47	7.81	**51.88**	**26.58**	34.52
Log normal	46.80	9.73	59.45	35.93	50.43
Log Pearson type-III	31.27	**34.99**	160.26	133.84	**30.48**
Normal	**19.49**	39.21	136.57	62.99	56.80

Data presented in Table 4.40 clearly indicates that Normal probability distribution was the best fit probability distribution for one day's maximum rainfall. However Log Pearson Type III probability distribution was the best fit for two and five consecutive day's maximum rainfall and Gumbel distribution was the best fit for three and four consecutive day's maximum rainfall for Tuljapur.

4.7.5 Estimation of consecutive day's maximum rainfall for Recurrence Interval

The expected values of 1 to 5 consecutive day's maximum rainfall for recurrence intervals of 2, 5 and 10 years were estimated with best fitted probability distribution and presented in Table 4.41. It is reveals that for 2 years recurrence interval (50% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 61.69 to 107.25 mm, for 5 years recurrence interval (20% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 81.82 to 133.48 mm and for 10 years recurrence interval (10% probability) these values varied from 92.35 to 150.85 mm

Table 4.41 Consecutive day maximum rainfall for different recurrence intervals for Tuljapur

Sr. No.	Recurrence interval (years)	Rainfall for consecutive day's (mm)				
		1 day	2 day	3 day	4 day	5 day
1	2	61.69	81.04	94.92	101.52	107.25
2	5	81.82	100.59	117.92	126.40	133.48
3	10	92.35	110.82	133.45	142.87	150.85

4.7.6 Determination of Drainage Coefficient

The drainage coefficient estimated for Tuljapur taluka station is presented in Table 4.42. The data reveals that drainage coefficient for one day maximum rainfall and 2, 5 and 10 years recurrence interval varied from 23.11 to 47.11 mm, 0.16 to 72.16 mm and 13.26 to 85.26 mm respectively. However in case of two consecutive day's maximum rainfall and 5 and 10 years recurrence interval varied from 0.6 to 24.06 mm and 16.55 to 40.55 mm, respectively.

Table 4.42 Estimated Drainage Coefficient (mm/day) for Tuljapur

Basic infiltration rate (mm/hr)	D. C. for 1 day for R. I. (yrs.)			D. C. for 2 day for R. I. (yrs.)			D. C. for 3 day for R. I. (yrs.)		
	2	5	10	2	5	10	2	5	10
1	47.11	72.16	85.26	-	24.06	40.55	-	-	-
2	23.11	48.16	61.26	-	0.6	16.55	-	-	-
3	-	24.16	37.26	-	-	-	-	-	-
4	-	0.16	13.26	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-

4.8 Estimation of Drainage Coefficient for Umarga

4.8.1 Arrangement of consecutive day's maximum rainfall for Umarga station

Daily rainfall data (1986-2016) for Umarga station was analysed to obtain 1 to 5 consecutive day's maximum rainfall. The data so obtained was arranged in descending order and the ranks were assigned for each year which is presented in Table 4.43.

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Table 4.43 Year-wise one to five consecutive day's maximum rainfall for Umarga station.

Sr. no.	One day (mm)	Two day (mm)	Three day (mm)	Four day (mm)	Five day (mm)	Probability (%)	Recurrence interval (years)
1	161	182.4	240.8	307.2	307.2	3.12	32.00
2	130.2	178.4	205	238	285.4	6.25	16.00
3	115	174.4	178.4	182.6	188.4	9.38	10.66
4	114.2	150.4	171.4	182	184.6	12.5	8.00
5	100	140.8	164	178.4	184.2	15.62	6.40
6	99.4	116.4	140.4	149.8	161.9	18.76	5.33
7	95.8	111.8	130.7	142.3	160.4	21.88	4.57
8	91.6	108	130.4	140.6	152.5	25	4
9	89.8	106.1	123.4	140.4	151.9	28.16	3.55
10	78.6	100	113.2	134.6	144.2	31.25	3.2
11	77	98.7	112.1	126.2	134	34.48	2.90
12	74.8	98.2	108	125.6	130.6	37.59	2.66
13	74	97.6	107.2	120.3	129.2	40.65	2.46
14	71.4	96.6	105.5	116.6	126.2	43.85	2.28
15	62.4	87.2	99	108	125.2	46.94	2.13
16	60.4	87	98.2	106.4	119.6	50	2
17	59.8	85	94	106	117	53.19	1.88
18	59.2	78.1	93.6	104.9	116	56.49	1.77
19	58	77.5	90.2	99	110.9	59.52	1.68
20	55	70.6	87.6	89.2	100.5	62.5	1.6
21	54.2	70.4	85	85	96	65.78	1.52
22	53.9	67.4	84.9	84.9	93.1	68.96	1.45
23	51	65	79	79	92.2	71.94	1.39
24	50	61.2	68	74.6	85.7	75.18	1.33
25	50	59.2	67.4	73.6	83.4	78.12	1.28
26	47.6	59	62.4	72.5	82	81.30	1.23
27	46.4	58	61.9	71.1	78.7	84.74	1.18
28	46	56.6	61.1	67.4	75.2	87.71	1.14
29	44.6	46	58	61.2	67.4	90.90	1.10
30	33	44.2	56.6	56.6	56.6	94.33	1.06
31	26.5	34.2	36.8	36.8	37.5	97.08	1.03

4.8.2 Plotting positions of consecutive day maximum rainfall data by Weibull's method

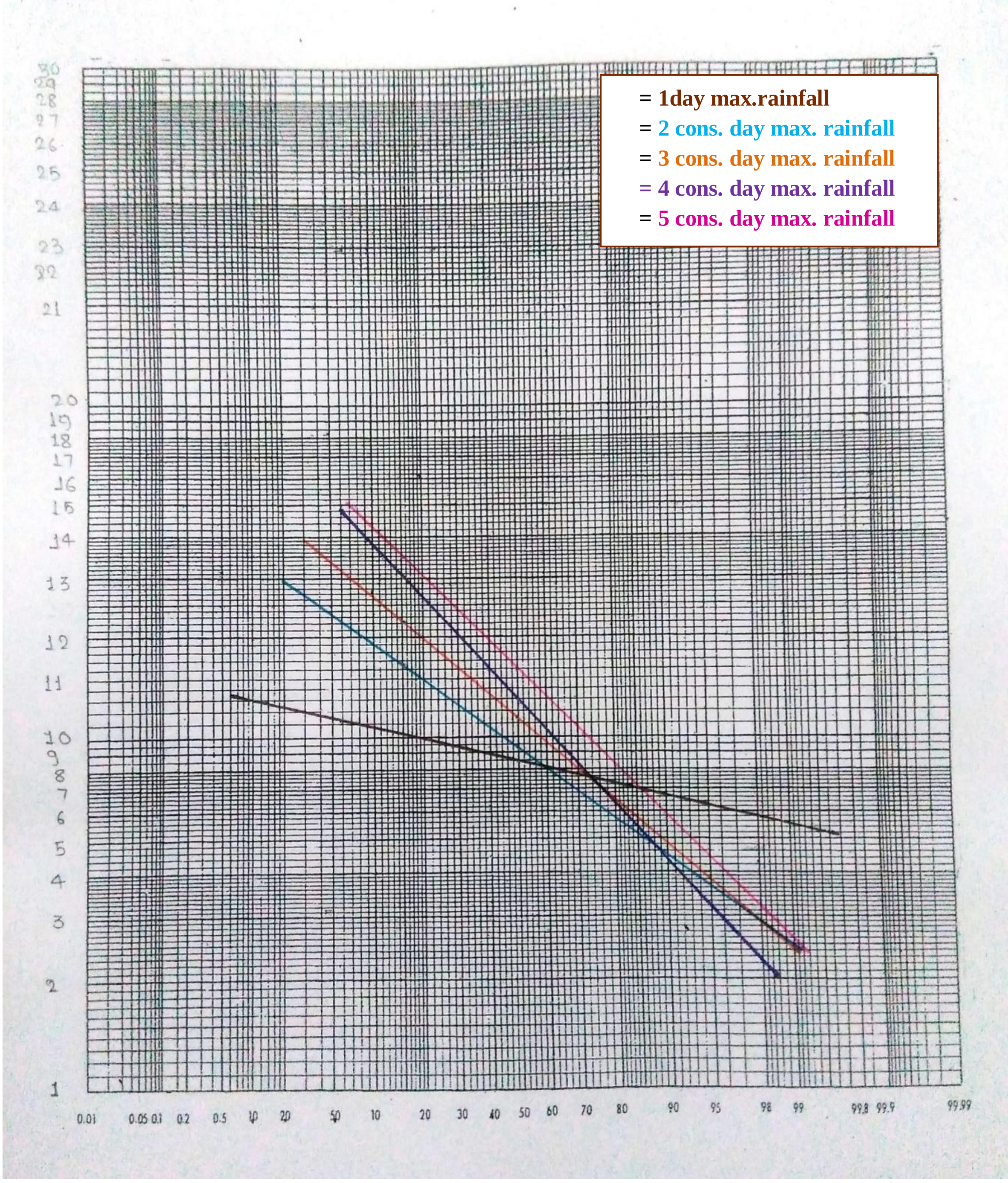
In order to know the magnitude of annual maximum 1 to 5 consecutive day's maximum rainfall for different return periods, probability analysis was carried out by Weibull's method. Using Weibull's equation the probability of occurrence of 1 to 5 consecutive day's maximum rainfall was derived and presented in Table 4.43. The calculated probability values as presented in Table 4.43 were plotted on X-axis whereas the corresponding values of maximum rainfall (mm) was plotted on Y-axis. The frequency line was drawn after computing the plotted points using 'computed method' suggested by Ogrosky and Mockus (1957).

Table 4.44 Computed values of consecutive day's maximum rainfall for different per cent chance of probability

Sr. No.	Per cent chance of probability (%)	Computed values of Mean, Mean+ S.D and Mean-S.D. for 1 and 2 to 5 consecutive day's maximum rainfall				
		1 day	2 day	3 day	4 day	5 day
1	15.9(mean+ SD)	10	11.37	12.26	13.01	13.5
2	50 (mean)	8.31	9.41	10.12	10.60	11.06
3	84.1(mean-SD)	6.62	7.45	7.98	8.19	8.62

In the computed In the computed method three points were plotted at 15.9, 50 and 84.1 per cent chance of probability by calculating the values of mean, mean + standard deviation and mean – standard deviation of rainfall. The data is represented in Table 4.44. The three probability levels of 15.9, 50, 84.1 per cent and the corresponding values of mean, mean + standard deviation, mean-standard deviation of rainfall were plotted. These three points were joined as a straight line on the graph as shown in Fig 4.7. Using straight line, the observed rainfall values were determined at different selected probability levels of 50, 20, 10, 5, 2 and 1 per cent from Fig. 4.7. These rainfall values are the observed values of rainfall which are presented in Table 4.45. These were then used for chi square test to test the hypothesis.

Rainfall, √x, mm



Probability (%)

Fig. 4.7 Frequency analysis of 1 to 5 consecutive day's maximum rainfall for Umarga station

Table 4.45 Observed values of consecutive day's maximum rainfall at different probabilities for Umarga

Sr. no.	Probability (P)	Observed values				
		1 day	2 day	3 day	4 day	5 day
1	50	68.89	108.16	116.64	129.96	139.24
2	20	90.25	127.69	151.29	163.84	182.25
3	10	102.01	144.00	166.41	187.69	213.16
4	5	106.09	151.29	182.25	213.16	256.00
5	2	110.25	163.84	213.16	256.00	324.00
6	1	114.49	171.61	231.04	289.00	400.00

4.8.3 Prediction of consecutive day's maximum rainfall using probability distributions

The expected maximum rainfall values for 1 to 5 consecutive day's were estimated by four probability distributions viz., Gumbel, Lognormal, Log Pearson type-III and Normal. The computed expected values for these probability distribution are presented in Table 4.46. Among these four probability distributions the best fit probability distribution was decided by Chi-square test for their goodness of fit. The observed maximum rainfall values presented in Table 4.45 and computed maximum rainfall presented in Table 4.46 were used for Chi square test to find the goodness of fit.

4.46 Annual maximum consecutive day's rainfall under different frequency distribution for Umarga

Sr. No.	Probability (P)	Consecutive day's maximum rainfall (mm) Gumbel Distribution				
		1 day	2 day	3 day	4day	5 day
1	50	71.94	86.04	99.30	**108.88**	**118.67**
	20	93.62	120.61	140.29	**158.57**	**170.61**
	10	111.22	143.48	167.42	**191.47**	**204.97**
	5	128.10	165.42	193.44	223.01	237.93
	2	149.92	193.80	227.11	263.83	280.59
	1	166.35	215.11	252.39	294.48	312.60
		Log Normal Distribution				
2	50	64.74	85.47	99.36	109.87	120.21
	20	92.71	121.52	141.74	160.77	174.04
	10	111.89	144.53	168.49	192.40	206.64
	5	131.29	167.99	195.42	223.81	238.78
	2	152.88	193.32	223.74	256.73	272.14
	1	170.20	212.90	245.81	284.30	297.80
		Log Pearson Type III Distribution				
3	50	67.71	86.28	100.91	109.64	120.79
	20	93.41	121.01	140.20	156.81	167.04
	10	109.30	142.47	163.98	182.38	192.65
	5	124.85	170.17	186.75	202.92	215.29
	2	141.53	189.34	210.84	230.12	237.66
	1	154.20	208.86	228.69	247.08	253.01
		Normal Distribution				
4	50	**71.95**	**92.45**	**106.89**	118.08	128.30
	20	**97.27**	**125.35**	**145.91**	165.39	177.73
	10	**110.52**	**142.57**	**166.34**	190.15	203.60
	5	121.45	157.13	183.61	210.58	224.95
	2	133.76	172.77	202.16	233.58	248.98
	1	141.97	183.44	214.82	248.93	265.02

4.8.4 Goodness of fit of probability distributions

Using observed and estimated annual maximum consecutive day's rainfall Chi square values were estimated under each probability distribution and presented in Table 4.47. The lowest value of Chi square among various probability distribution was considered for their goodness of fit.

4.47 Calculated Chi square values under different probability distribution for Umarga

Probability distribution	χ^2 calculated value				
	1 day	2 day	3 day	4 day	5 day
Gumbel	38.21	19.81	297.91	**77.96**	**62.05**
Log normal	44.09	21.39	294.07	93.81	81.45
Log Pearson type-III	132.98	25.53	296.21	182.83	182.27
Normal	**17.36**	**59.21**	**297.28**	171.91	146.68

Data presented in Table 4.47 clearly indicates that Normal probability distribution was the best fit probability distribution for one, two and three consecutive day's maximum rainfall. However Gumbel distribution was the best fit probability distribution for four and five consecutive day's maximum rainfall for Umarga station.

4.8.5 Estimation of consecutive day's maximum rainfall

The expected values of 1 to 5 consecutive day's maximum rainfall for recurrence intervals of 2, 5 and 10 years were estimated with best fitted probability distribution and presented in Table 4.48. It is reveals that for 2 years recurrence interval (50% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 71.95 mm to 118.67 mm, for 5 years recurrence interval (20% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 97.27 to 170.67 mm and for 10 years recurrence interval (10 % probability) these values varied from 110.52 to 204.97 mm.

Table 4.48 Consecutive day maximum rainfall for different recurrence intervals for Umarga Station

Sr. No.	Recurrence interval (years)	Rainfall for consecutive day's (mm)				
		1 day	2 day	3 day	4 day	5 day
1	2	71.95	92.45	106.89	108.88	118.67
2	5	97.27	125.35	145.91	158.57	170.61
3	10	110.52	142.57	166.34	191.47	204.97

4.8.6 Drainage Coefficient for Umarga Station

The drainage coefficient estimated for Umarga taluka station is presented in Table 4.49. The data reveals that drainage coefficient for one day maximum rainfall and 2, 5 and 10 years recurrence interval varied from 23.96 to 47.96 mm, 1.27 to 73.27 mm and 14.52 to 86.52 mm respectively. However in case of two consecutive day's maximum rainfall and 5 and 10 years recurrence interval is 12.29 mm and 23.74 mm respectively.

Table 4.49 Estimated Drainage Coefficients (mm/day) for Umarga

Basic infiltration rate (mm/hr)	D. C. for 1 day for R. I. (yrs.)			D. C. for 2 day for R. I. (yrs.)			D. C. for 3 day for R. I. (yrs.)		
	2	5	10	2	5	10	2	5	10
1	47.96	73.27	86.52	-	12.29	23.74	-	-	-
2	23.96	49.27	62.52	-	-	-	-	-	-
3	-	25.27	38.52	-	-	-	-	-	-
4	-	1.27	14.52	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-

4.9 Estimation of Drainage Coefficient for Washi

4.9.1 Arrangement consecutive day's maximum rainfall

Daily rainfall data (2000-2016) for Washi station was analysed to obtain 1 to 5 consecutive day's maximum rainfall. The data so obtained was arranged in descending order and the ranks were assigned for each year which is presented in Table 4.50

Table 4.50 Year-wise one to five consecutive day's maximum rainfall for Washi

Sr. no.	One day (mm)	Two day (mm)	Three day (mm)	Four day (mm)	Five day (mm)	Probability (%)	Recurrence interval (years)
1	92	118	155.7	205	225.7	3.12	32.00
2	88.3	116	143	161	188	6.25	16.00
3	84	109	131.7	148	159	9.38	10.66
4	83.3	107	128	143.7	148	12.5	8.00
5	83	102	120	138	143.7	15.62	6.40
6	82	100.3	110.6	132	142	18.76	5.33
7	70	95	109	117.3	139	21.88	4.57
8	68.7	92.6	106	112.6	138	25	4
9	68	86	106	111	120	28.16	3.55
10	60.7	84	105	110	119.6	31.25	3.2
11	60	68.7	99	106	113.3	34.48	2.90
12	54	67	76	82.6	98	37.59	2.66
13	52	59	74	82	82.7	40.65	2.46
14	46	57	60	63.3	82.6	43.85	2.28
15	42	56.3	59	63	74	46.94	2.13
16	36	49	57	61.7	68	50	2

4.9.2 Plotting positions of consecutive day maximum rainfall data by Weibull's method

In order to know the magnitude of annual maximum 1 to 5 consecutive day's maximum rainfall for different return periods, probability analysis was carried out by Weibull's method. Using Weibull's equation the probability of occurrence of 1 to 5 consecutive day's maximum rainfall was derived and presented in Table 4.50. The calculated probability values as presented in Table 4.50 were plotted on X-axis whereas the corresponding values of maximum

rainfall (mm) was plotted on Y-axis. The frequency line was drawn after computing the plotted points using 'computed method' suggested by Ogrosky and Mockus (1957).

Table 4.51 Computed values of consecutive day's maximum rainfall for different percent chance of probability

Sr No.	Per cent chance of probability (%)	Computed values of Mean, Mean+ S.D and Mean- S.D. for 1 and 2 to 5 consecutive day's maximum rainfall				
		1 day	2 day	3 day	4 day	5 day
1	15.9(mean+ SD)	9.21	10.43	11.54	12.4	13.01
2	50 (mean)	8.10	9.15	10.01	10.56	11.15
3	84.1(mean-SD)	6.99	7.87	8.48	8.72	9.29

In the computed method three points were plotted at 15.9, 50 and 84.1 per cent chance of probability by calculating the values of mean, mean + standard deviation and mean – standard deviation of rainfall. The data is represented in Table 4.51. The three probability levels of 15.9, 50, 84.1 per cent and the corresponding values of mean, mean+standard deviation, mean-standard deviation of rainfall were plotted. These three points were joined as a straight line on the graph as shown in Fig 4.8.Using straight line, the observed rainfall values were determined at different selected probability levels of 50, 20, 10, 5, 2 and 1 per cent from Fig. 4.8. These rainfall values are the observed values of rainfall which are presented in Table 4.52. These were used for chi square test to test the hypothesis.

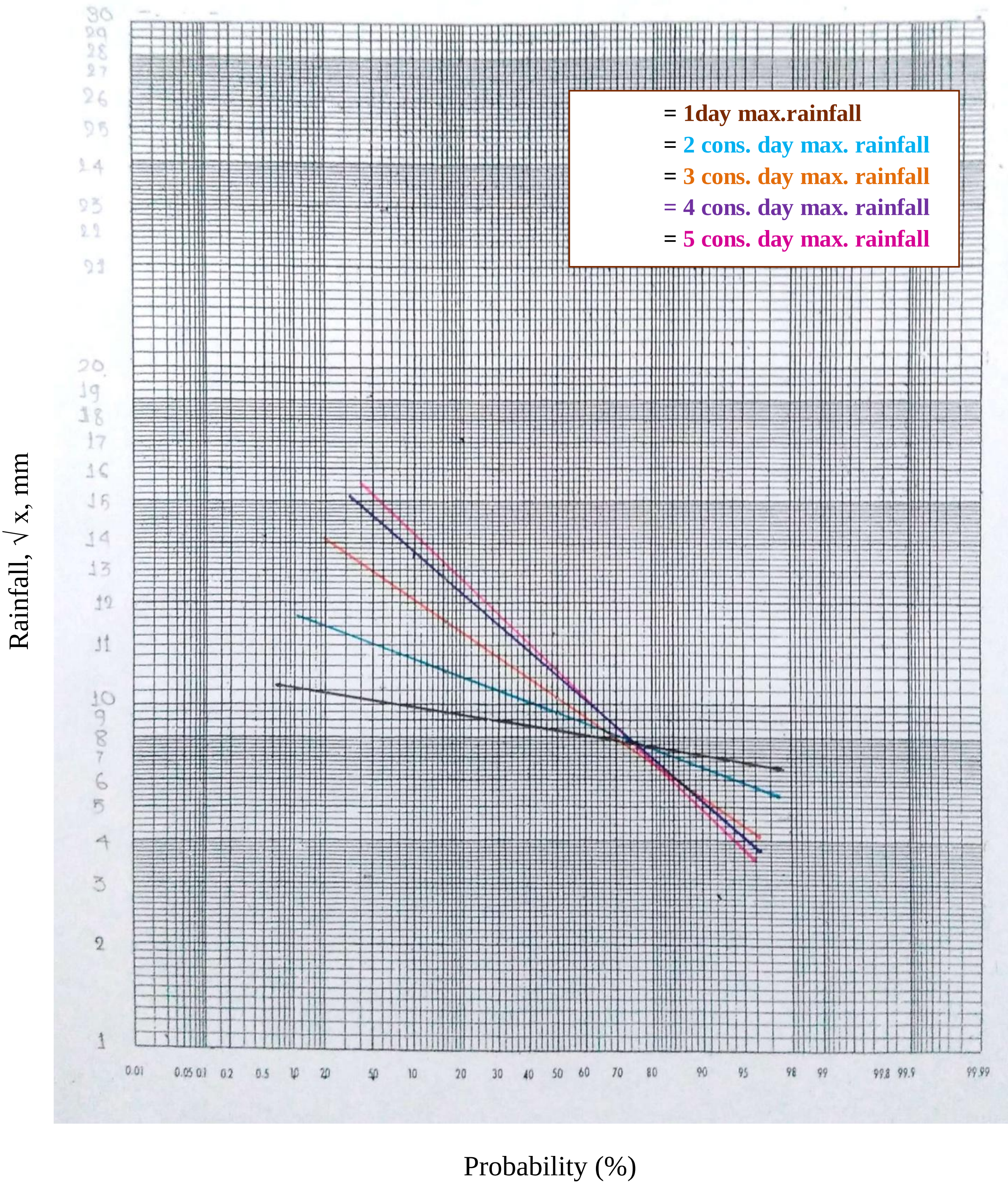


Fig. 4.8 Frequency analysis of 1 to 5 consecutive day’s maximum rainfall for Washi station

Table 4.52 Observed values of consecutive day's maximum rainfall at different probabilities for Washi

Sr. No.	Probability (P)	Observed values				
		1 day	2 day	3 day	4 day	5 day
1	50	72.25	90.25	101.60	112.36	132.25
2	20	81.90	101.60	132.25	140.42	165.12
3	10	100	110.25	144	156.25	191.82
4	5	101.60	121	156.25	170.30	220.52
5	2	110.25	121.22	170.04	196.56	256
6	1	111.30	122.10	182.25	225	289

4.9.3 Prediction of consecutive day's maximum rainfall using probability distribution

The expected maximum rainfall values for 1 to 5 consecutive day's were estimated by four probability distributions viz., Gumbel, Lognormal, Log Pearson type-III and Normal. The computed expected values for these probability distribution are presented in Table 4.53. Among these four probability distributions the best fit probability distribution was decided by Chi-square test for their goodness of fit. The observed maximum rainfall values presented in Table 4.52 and computed maximum rainfall values presented in Table 4.53 were used for Chi square test to find the goodness of fit.

4.53 Annual maximum consecutive rainfall day's under different frequency distribution for Washi

Sr. no.	Probability (P)	Consecutive day's maximum rainfall (mm) Gumbel Distribution				
		1 day	2 day	3 day	4day	5 day
1	50	63.98	81.65	97.54	108.33	**120.63**
	20	79.52	102.01	124.26	143.27	**158.17**
	10	89.81	115.48	141.97	166.39	**183.01**
	5	99.67	128.40	158.90	188.56	206.83
	2	111.65	145.12	180.85	217.25	237.65
	1	122.01	157.67	197.33	238.79	260.79
		Log Normal Distribution				
2	50	**62.61**	81.28	**97.55**	**108.97**	121.70
	20	**78.95**	102.55	**125.34**	**145.19**	160.64
	10	**90.17**	116.24	**142.88**	**167.70**	184.19
	5	102.10	130.12	160.50	190.05	207.41
	2	114.92	144.83	179.10	213.48	231.51
	1	125.21	156.33	193.56	241.92	250.07
		Log Pearson Type III Distribution				
3	50	65.33	83.00	100.02	112.26	125.87
	20	82.01	104.71	128.52	146.88	161.48
	10	91.65	117.82	144.83	165.88	180.18
	5	100.46	133.39	159.93	182.74	196.24
	2	110.01	143.71	175.42	199.06	211.73
	1	116.89	153.81	186.63	211.11	222.16
		Normal Distribution				
4	50	66.86	**85.42**	102.4	114.81	127.50
	20	81.66	**104.80**	127.93	148.06	163.32
	10	89.40	**114.94**	141.24	165.46	182.01
	5	95.78	123.31	152.22	179.83	197.44
	2	102.97	132.73	164.59	195.99	214.81
	1	107.77	139.02	172.84	206.78	226.40

4.9.4 Goodness of fit of probability distributions

Using observed and estimated annual maximum consecutive day's rainfall Chi square values were estimated under each probability distribution and presented in Table 4.54. The lowest value of Chi square among various probability distributions was considered for their goodness of fit.

Table 4.54 Calculated Chi square values under different probability distribution for Washi

Probability distribution	χ^2 calculated value				
	1 day	2 day	3 day	4 day	5 day
Gumbel	3.30	13.54	2.63	5.37	**7.23**
Log normal	4.19	13.29	1.86	5.62	10.83
Log Pearson type-III	**1.77**	12.42	**0.52**	**2.63**	33.52
Normal	2.67	**3.66**	1.05	3.07	28.64

Data presented in Table 4.54 clearly indicates that Log Pearson Type III probability distribution was the best fit probability distribution for one, three and four consecutive day's maximum rainfall. However Gumbel probability distribution was the best fit probability distribution for five consecutive day's maximum rainfall and Normal distribution was the best fit for two consecutive day's maximum rainfall for Washi station.

4.9.5 Estimation of consecutive day's maximum rainfall for Recurrence Interval

The expected values of 1 to 5 consecutive day's maximum rainfall for recurrence intervals of 2, 5 and 10 years were estimated with the best fitted probability distribution and presented in Table 4.55. It is reveals that for 2 years recurrence interval (50% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 62.61 to 120.63 mm, for 5 years recurrence interval (20% probability) the values of 1, 2, 3, 4 and 5 consecutive day's maximum rainfall varied from 78.95 to 158.17 mm and for 10 years recurrence interval (10% probability) these values varied from 90.17 to 183.01 mm.

Table 4.55 Consecutive day maximum rainfall for different recurrence intervals for Washi Station

Sr. No.	Recurrence interval (years)	Rainfall for consecutive day's (mm)				
		1 day	2 day	3 day	4 day	5 day
1	2	62.61	85.42	97.55	108.97	120.63
2	5	78.95	104.80	125.34	145.19	158.17
3	10	90.17	114.94	142.88	167.70	183.01

4.9.6 Determination of Drainage Coefficient

The drainage coefficient estimated for Washi taluka station is presented in Table 4.56. The data reveals that drainage coefficient for one day maximum rainfall and 2, 5 and 10 years recurrence interval varied from 17.33 to 41.33 mm, 10.01 to 58.01 mm and 19.65 to 67.65 mm respectively. However in case of two consecutive day's maximum rainfall and 5 and 10 years recurrence interval it is 4.40 mm and 9.47 mm, respectively.

Table 4.56 Estimated Drainage Coefficient (mm/day) for Washi

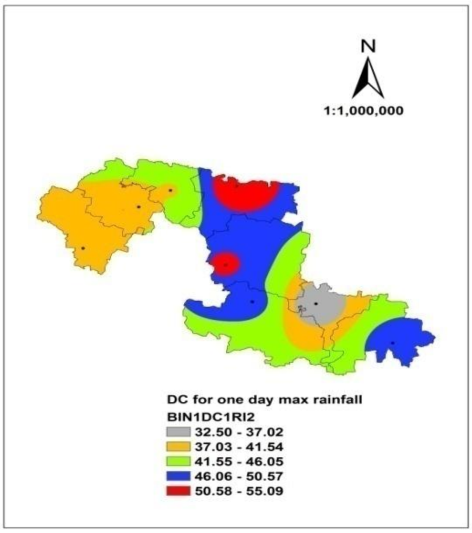
Basic infiltration rate (mm/hr)	D. C. for 1 day for R. I. (yrs.)			D. C. for 2 day for R. I. (yrs.)			D. C. for 3 day for R. I. (yrs.)		
	2	5	10	2	5	10	2	5	10
1	41.33	58.01	67.65	-	4.40	9.47	-	-	-
2	17.33	34.01	43.65	-	-	-	-	-	-
3	-	10.01	19.65	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-

The present study indicates that drainage coefficient estimated for 1 to 3 consecutive day's maximum rainfall are more significant because crop tolerance period of major crops in Osmanabad district is maximum 3 days. Similarly, the analysis of rainfall of Osmanabad district indicated that there are rare chances of 4and 5 consecutive day's maximum rainfall that occur. Most of the talukas of Osmanabad showed chances of occurrence of 1 to 2 days consecutive days rainfall, except Bhoom where there can be chances of 3 consecutive days rainfall. Among various talukas of the district Kallam, Tuljaputr, Osmanabad, Umarga and Bhoom showed higher values of drainage coefficient whereas Lohara, Paranda and Washi have lesser chances of water stagnation.

From the above discussion, it is concluded that soils of Osmanabad district with predominantly clayey to medium texture and having basic infiltration rate between 1 to 5 mm/hr may necessarily have to be provided with drainage system for its major crops grown in the district.

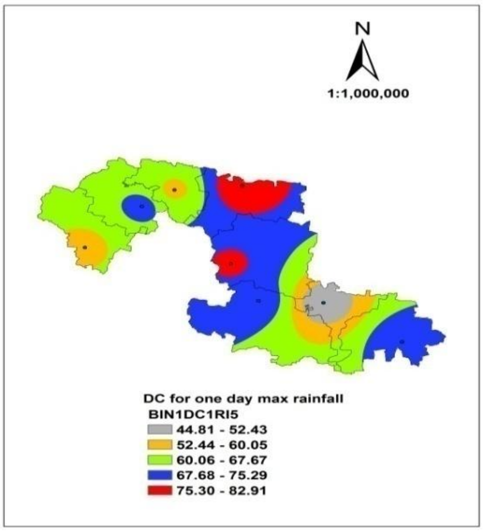
4.10 Development of drainage coefficient maps for Osmanabad district

The estimated Talukawise drainage coefficients under different infiltration rate, consecutive day's maximum rainfall and recurrence interval were used to prepare respective drainage coefficient maps for Osmanabad district. For this spatial analyst tool in Arc GIS with Inverse Distance Weighing (IDW) interpolation Technique of GIS was used. The maps so developed are presented in Fig. 4.9 through Fig. 4.16.



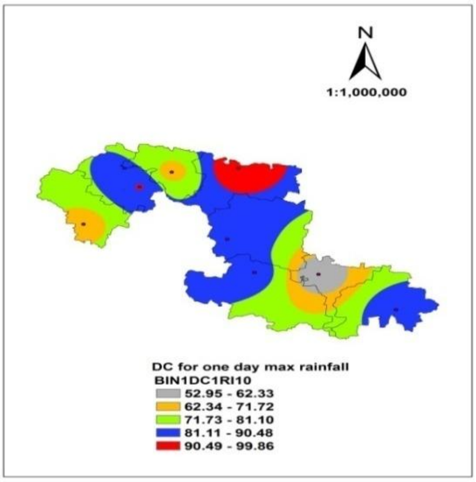
(1mm/hr BIN, 1DMR, 2RI)

Fig 4.9 (a)



(1mm/hr BIN, 1DMR, 5RI)

Fig 4.9 (b)

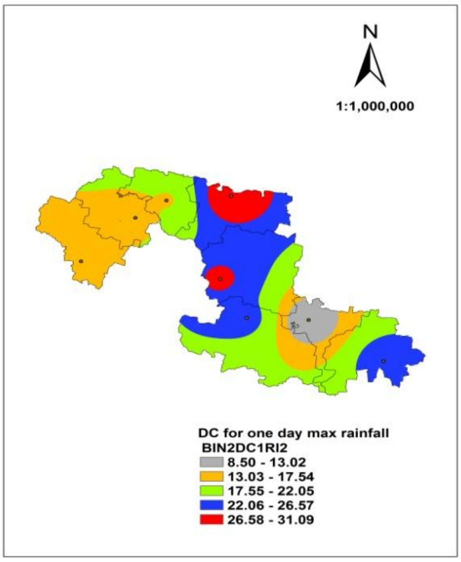


(1mm/hr BIN, 1DMR, 10RI)

Fig 4.9 (c)

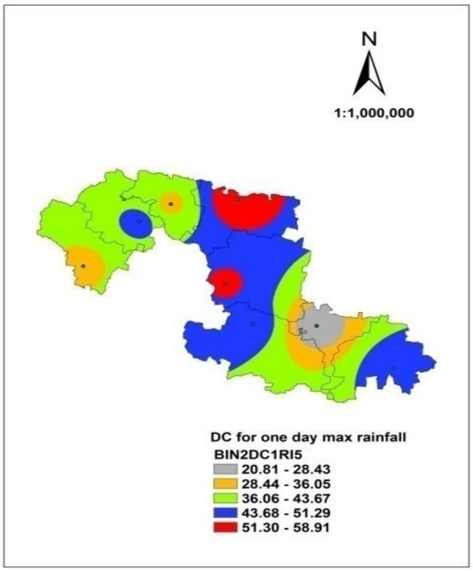
BIN- Basic Infiltration Rate; DMR- Day's maximum rainfall; RI- Recurrence Interval

Fig. 4.9 Drainage Coefficient for one day maximum rainfall of Osmanabad district (Basic infiltration rate 1 mm/hr)



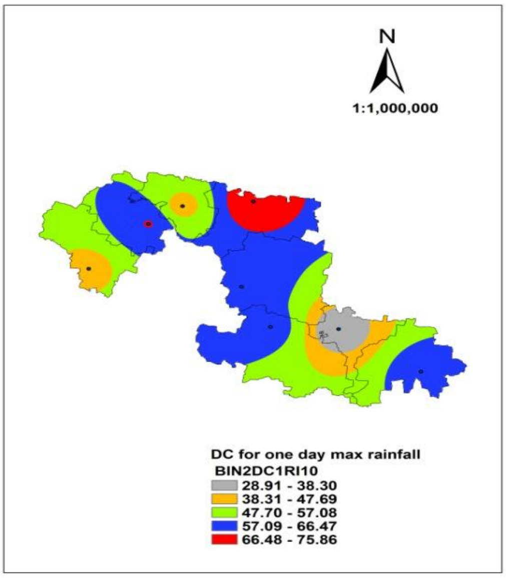
(2mm/hr BIN, 1DMR, 2RI)

Fig 4.10 (a)



(2mm/hr BIN, 1DMR, 2RI)

Fig. 4.10 (b)

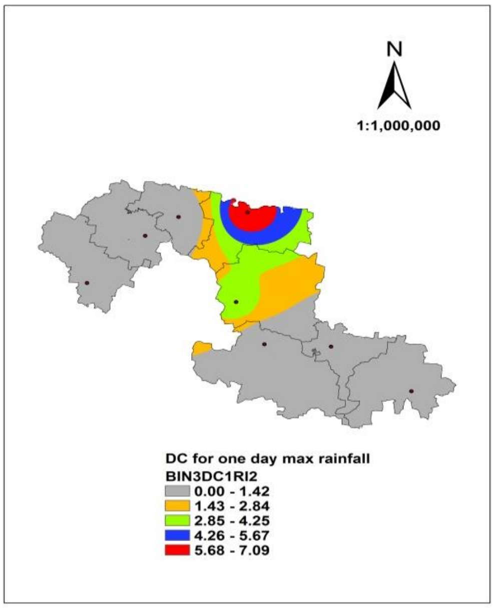


(2mm/hr BIN, 1DMR, 10RI)

Fig 4.10 (c)

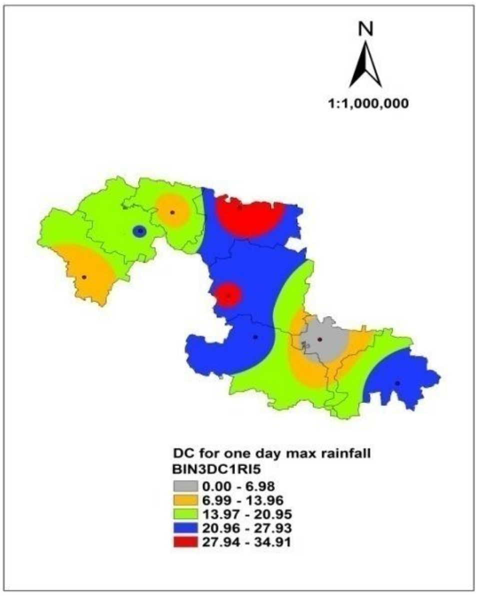
Fig. 4.10 Drainage coefficient for one day maximum rainfall of Osmanabad district

(Basic infiltration rate, 2 mm/hr)



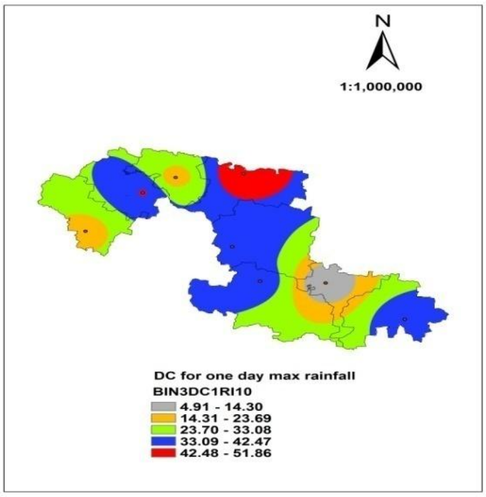
(3mm/hr BIN, 1DMR, 2RI)

Fig. 4.11 (a)



(3mm/hr BIN, 1DMR, 5RI)

Fig. 4.11 (b)

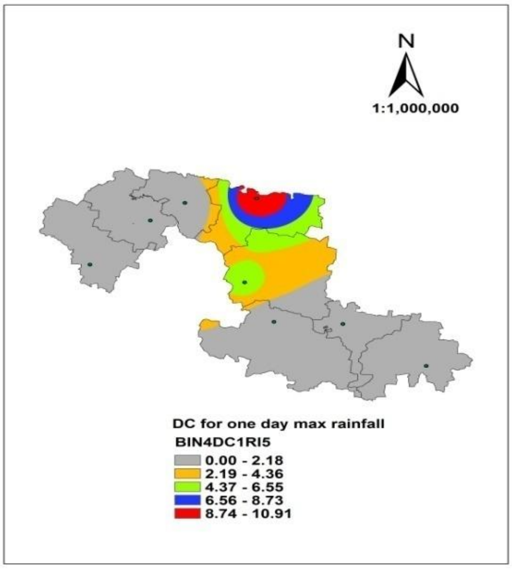


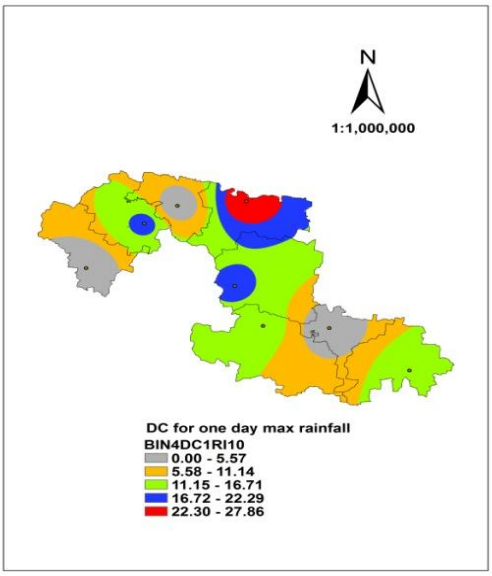
(3mm/hr BIN, 1DMR, 10 RI)

Fig. 4.11 (c)

Fig. 4.11 Drainage Coefficient for one day maximum rainfall for Osmanabad district

(Basic infiltration rate 3 mm/hr)





(4mm/hr BIN, 1DMR, 5RI)

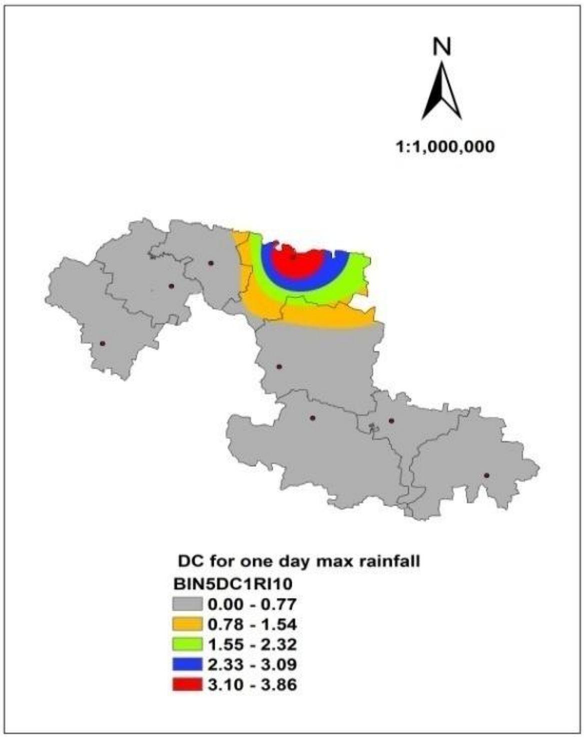
Fig 4.12 (a)

(4mm/hr BIN, 1DMR, 10RI)

Fig 4.12 (b)

Fig. 4.12 Drainage coefficient for one day maximum rainfall for Osmanabad district

(Basic infiltration rate 4 mm/hr)

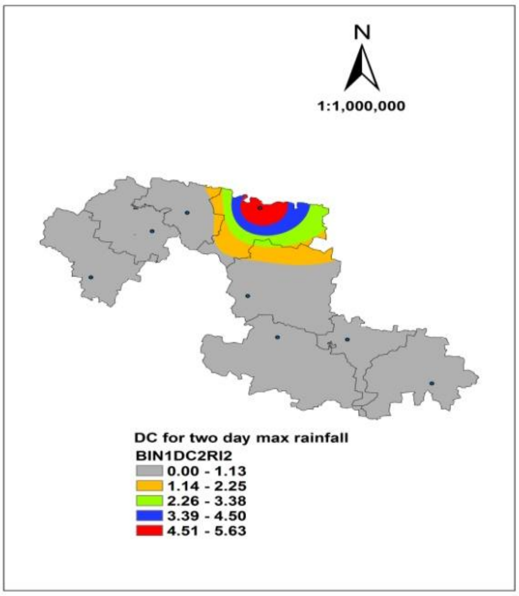


(5mm/hr BIN, 1DMR, 10RI)

Fig 4.13 (a)

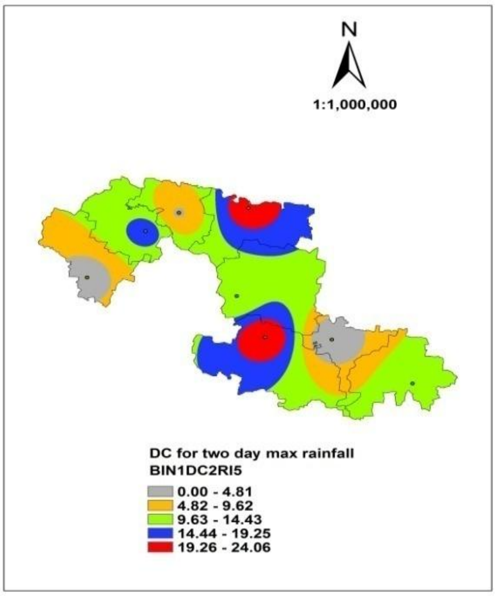
Fig. 4.13 Drainage coefficient for one day maximum rainfall for Osmanabad district

(Basic infiltration rate 5 mm/hr)



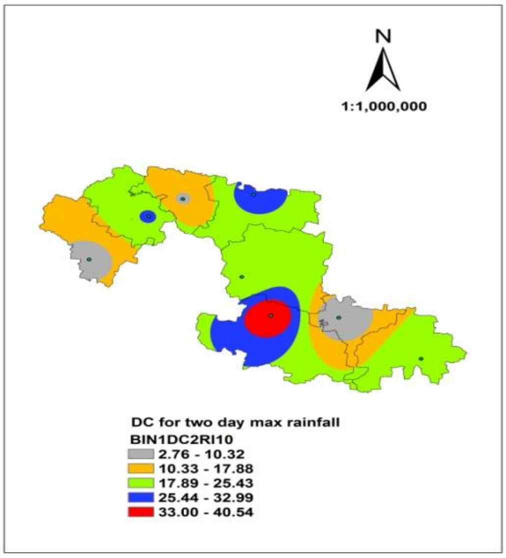
(1mm/hr BIN, 2DMR, 2RI)

Fig 4.14 (a)



(1mm/hr BIN, 2DMR, 5RI)

Fig. 4.14(b)



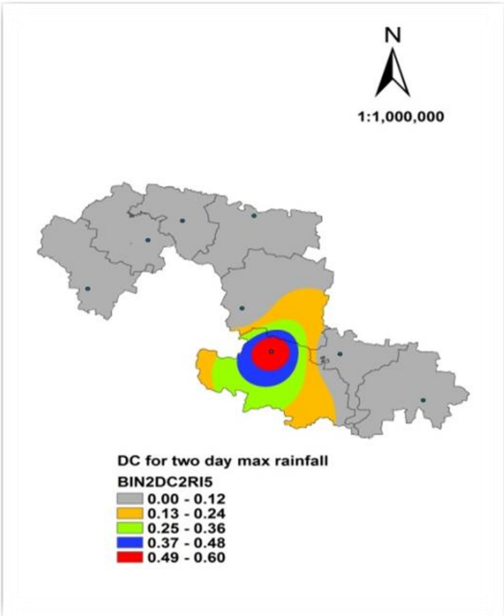
(1mm/hr BIN, 2DMR,10RI)

Fig. 4.14 (c)

BIN- Basic Infiltration Rate; DMR- Day’s maximum rainfall; RI- Recurrence Interval

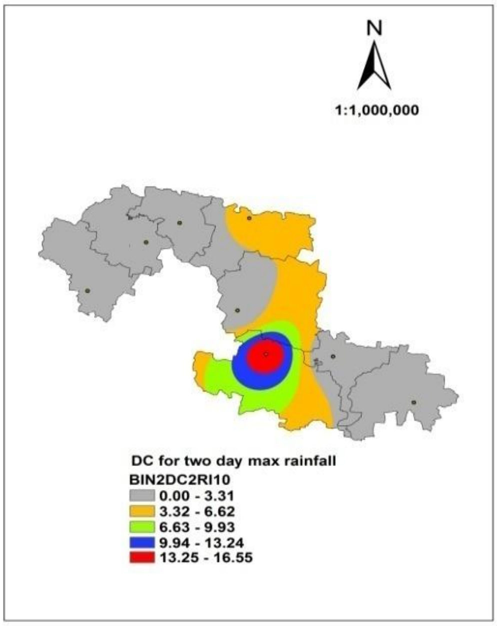
Fig. 4.14 Drainage coefficient for two day maximum rainfall of Osmanabad district

(Basic infiltration rate 1 mm/hr)



(2mm/hr BIN, 2DMR, 5RI)

Fig. 4.15 (a)

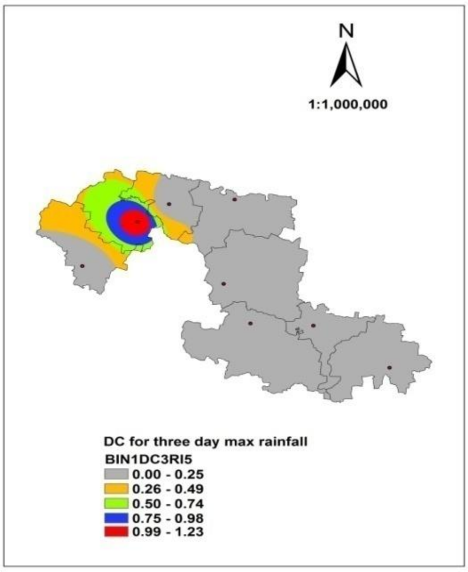


(2mm/hr BIN, 2DMR, 10RI)

Fig. 4.15 (b)

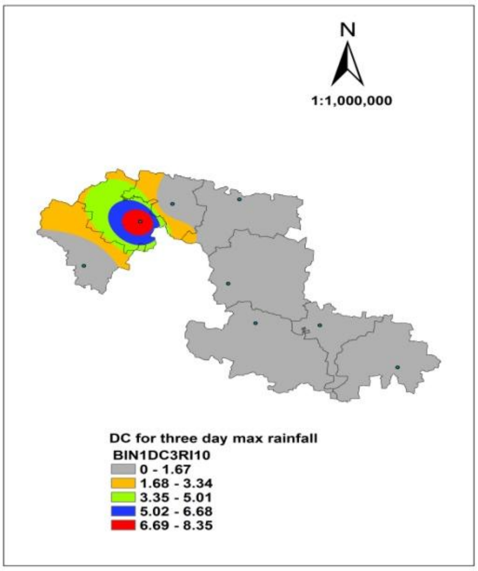
Fig. 4.15 Drainage coefficient for two day maximum rainfall of Osmanabad district

(Basic infiltration rate 2 mm/hr)



(1mm/hr BIN, 3DMR, 5RI)

Fig. 4.16 (a)



(1mm/hr BIN, 3DMR, 10RI)

Fig. 4.16 (b)

BIN- Basic Infiltration Rate; DMR- Day's maximum rainfall; RI- Recurrence Interval

Fig. 4.16 Drainage coefficient for three day maximum rainfall of Osmanabad district

(Basic infiltration rate 1 mm/hr)

The drainage coefficients maps shown in Fig. 4.9 to Fig. 4.16 for various basic infiltration rates, consecutive day's maximum rainfall and recurrence intervals give the location wise situation for planning of drainage system in the district.

These maps can be used for planning and designing of drainage systems in Osmanabad district. On the basis of the rainfall pattern and infiltration rate. It is observed that Kallam and Bhoom taluka of Osmanabad will necessarily have to be provided with surface drainage systems.

SUMMARY AND CONCLUSIONS

CHAPTER-V

SUMMARY AND CONCLUSIONS

The surface stagnation of water in croplands of heavy rainfall areas or areas with improperly designed irrigation systems is now assuming a more serious dimension because of the unplanned development, restricted drainage, rising water tables in irrigation commands, inadequate drainage system capacity and improper upkeep and maintenance of the drainage system. Because of intensive irrigation in many areas, low-lying lands have become unproductive due to water logging and salt accumulation. Similarly, under intensive and heavy rainfall, these lands cannot remove excess water and become water logged. These areas have to be provided with drainage for removal of excess water from the agricultural land. A careful planning of drainage system for agricultural land requires the information on amount of excess water that has to be removed.

For this, the indirect method of estimation of drainage coefficient based on probability analysis of historical rainfall data of various stations in the district can be useful. However the rainfall changes with the geographical locations and the drainage coefficient for any region varies with the land use, size of area, rainfall intensity, frequency and duration. Osmanabad district falls in assured rainfall zone having medium to heavy soils with slow water removal rate. In addition, the area is commanded by major irrigation projects and farmers are also shifting to high water requiring cash crops. Therefore the present study on estimation of drainage coefficient based on rainfall analysis and development of spatial distribution maps of drainage coefficient for Osmanabad district was undertaken which has not been attempted so far.

The talukawise daily rainfall data of Osmanabad district for the period of 31 years (January 1986 to December 2016) was collected from Maharashtra Engineering Research Institute (MERI), Nashik. The data was arranged year wise in descending order. The observed values of maximum 1 to 5 consecutive day's maximum rainfall were computed by Weibull's method. The expected values of maximum 1 to 5 consecutive day's maximum rainfall were estimated using various probability distributions such as Gumbel, Lognormal, Log Pearson Type III and Normal. Using the standard equations and adopting the prescribed procedure, 1 to 5 consecutive day's maximum rainfall values were estimated. The observed and expected values of 1 to 5 consecutive day's maximum rainfall were compared using Chi-square test and the best fit probability distribution was determined.

The basic infiltration rates for the soils of Osmanabad region were referred from earlier studies conducted using infiltrometer tests. The values of crop tolerance period for the major crops were referred from the standard publication (IS 8835-1978). The drainage coefficient was estimated based on the various years return period by subtracting the basic infiltration rate from estimated maximum consecutive day's rainfall.

In order to avoid tedious calculations and time the VNMKV_DCS software developed by VNMKV Parbhani was used for determination of drainage coefficient. Similarly spatial distribution maps of drainage coefficient for Osmanabad were developed based on the consecutive day's maximum rainfall, basic infiltration rate of soil, recurrence period using Inverse Distance Weighing Technique of GIS.

The highlights of important findings of the present study are summarized in the form of following conclusions:

1. The analysis of rainfall of Osmanabad indicated that there are rare chances of 4 and 5 consecutive day's maximum rainfall that could occur. Most of the talukas of Osmanabad district showed chances of occurrence of 1 to 2 consecutive day's rainfall, except Bhoom where there can be chances of 3 consecutive day's rainfall.
2. The soils of Kallamb, Bhoom, Omerga, Osmanabad and Tuljapur talukas having basic infiltration rate between 1 to 4 mm h^{-1} necessarily have to be provided with agricultural land drainage system based on tolerance of different crops to water logging.
3. Among various talukas of the district Kallamb, Tuljapur, Osmanabad, Omerga and Bhoom showed higher values of drainage coefficient whereas Lohara, Paranda and Washi have lesser chances of water stagnation.
4. The spatial distribution maps of drainage coefficient for Osmanabad district indicate that the maximum drainage coefficient is for Kallamb taluka at basic infiltration rate of 1 to 5 mm/hr with recurrence interval of 2, 5, 10 years and minimum drainage coefficient is for Lohara taluka for basic infiltration rate 1 to 3 mm/hr with recurrence interval of 2 and 5 years.
5. The developed drainage coefficient maps can be used by the farmers group or development agencies for planning and designing surface drainage systems for

Osmanabad district based on the prevailing cropping pattern. Similarly based on the recurrence interval the design of drainage systems and other structures can be decided.

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