International Journal of Agriculture Sciences
ISSN: 0975-3710 & E-ISSN: 0975-9107, Volume 12, Issue 18, 2020, pp.-10214-10222.
Available online at https://www.bioinfopublication.org/jouarchive.php?opt=&jouid=BPJ0000217

Research Article

RAINFALL ESTIMATION FOR DROUGHT ANALYSIS USING GUMBEL'S DISTRIBUTION METHOD FOR LUCKNOW DISTRICT

KHAN S.[1], ALI Q.S.W.[2]* AND WESLEY C.J.[3]
[1]Department of Soil Water Land Engineering & Management, Vaugh Institute of Agricultural Engineering and Technology, Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj, 211007, India
[2]National Water Mission, Ministry of Jal Shakti, New Delhi, India
[3]Department of Centre for Geospatial Technologies, Vaugh Institute of Agricultural Engineering and Technology, Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj, 211007, India
*Corresponding Author: Email - wamiqali.786@gmail.com

Received: September 03, 2020; Revised: September 24, 2020; Accepted: September 25, 2020; Published: September 30, 2020

Abstract: Droughts occur when there is not enough rain for a long period of time. During the study rainfall data of fifteen years from 2001 to 2015 based on standard weeks was analyzed for Lucknow district of India. The monthly maximum rainfall at different probability levels was calculated by using Gumbel's Probability method. The daily rainfall data series is divided into annual, seasonal, monthly, and weekly average data series. During weekly average rainfall analysis, it was observed that maximum 15 times drought occurs in 49th week while minimum of 4th times is in case of 29th week. The maximum number of surplus weeks during the fifteen years' time was 4 and the minimum numbers of drought weeks *i.e.* zero were found in the 32nd and 49th standard week of the year during fifteen years' time. The maximum number of normal weeks during the 15 years period was 9 during in the 29th week, and the minimum numbers of drought weeks *i.e.* zero were found in the 2nd, 12th, 15th, 21st, 41th, 44th, 45th, 46th, 47th, 48th and 49th standard week. The percentage of normal, surplus and drought months are respectively 42.22%, 10.56%, and 47.22% out of total number of months for fifteen years duration. The percentage of drought, surplus and normal years are 6.37%, 20% and 73.34% respectively according to Standard Deviation (sd). The analysis has revealed erratic distribution of precipitation during *Rabi* season thereby preventing the farmers to go for *Rabi* crops. Therefore, the irrigation must be assured for sowing *Rabi* crops. The monthly maximum rainfall at different probability level was calculated by Gumbel's Distribution method. From the drought analysis, it was observed that study area is drought prone at two stages; firstly, at the beginning of the season which can cause delay in transplantation and secondly, at the beginning of the grain ripening stage, which can drastically reduce the crop yield. The annual daily maximum rainfall received at any time ranged between 1539.60 mm (maximum) to 628.11 mm (minimum) indicating a very large range of fluctuation during the period of study.

Keywords: *Drought, Gumbel's distribution, Standard deviation, Time series, Transplantation*

Citation: Khan S., *et al*., (2020) Rainfall Estimation for Drought Analysis using Gumbel's Distribution Method for Lucknow District. International Journal of Agriculture Sciences, ISSN: 0975-3710 & E-ISSN: 0975-9107, Volume 12, Issue 18, pp.- 10214-10222.

Academic Editor / Reviewer: Dr H. V. Pandya, P. T. Patel

Introduction

Drought is an extended period where water availability falls below the statistical requirements for a region. It is not purely physical phenomenon, but rather interplays between natural water availability and human demands for water supply. There are two main kinds of drought definitions: conceptual and operational. Conceptually, it can be defined as "a protracted period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield" [8]. The defining of drought is difficult; it depends on differences in regions, needs, and disciplinary perspectives. Kumar and Kumar (1989) [1] analyzed weekly, monthly, seasonal, and yearly rainfall data for drought situation at Pant Nagar and Ranchi station respectively. Tiwari, *et al*., (2007) [2] characterized the meteorological drought indices using the daily rainfall data of Hazaribagh station. Similar meteorological drought analysis was done by various researchers [3-5] for various stations in India. Sudhishri, *et al*., (2004) [6] analyzed to study the weekly, monthly, and yearly drought and comparing the different models for finding a suitable method for drought investigation by studying the water balance. The IMD method was adjudged more suitable for drought identification than the revised IMD method. Frequency analysis was done to predict weekly, Bhaskar, *et al*., (2006) [7] examined normal, abnormal and drought months for the period of 1981-2005 of Udaipur region. Total 12 drought months were found during the rainy season in the duration of 1981-2005. Probability of occurrence of 6 drought months in a year was 96% and for 10 months was 4%. Drought analysis needs continuous long time-series of monthly rainfall. Standardized Precipitation Index (SPI) and Standardized Runoff Index (SRI) which determine meteorological and hydrological drought index respectively are computed with the input data [8-11]. Drought occurring years during 1801-2015 are given below in [Table-1].

Data and Methodology

Study area

The study carried out for Lucknow district, UP. The Latitude and Longitude of Lucknow is 26.85 and 80.95 respectively. [Fig-1] shows the area of study. Lucknow district is bounded on the east by the Barabanki, on the west by Unnao, on the south by Raebareli and in the north by Sitapur and Hardoi; Lucknow sits on the north western shore of the Gomti River.

Data Collection

The daily rainfall data for a period of 15 years (2001-2015) was collected from Indian Meteorological Department, Lucknow Centre, C.C.S., Amausi, Lucknow.

Methodology

Classification of annual, seasonal, monthly, and weekly rainfall data

The daily rainfall data series is divided into annual, seasonal, monthly and weekly data series. A year is divided into three seasons *i.e.* monsoon (June to September), winter (October to January), and summer (February to May). The last day of every year (365th day) and last 2 days of a leap year are accounted in the 52nd week.

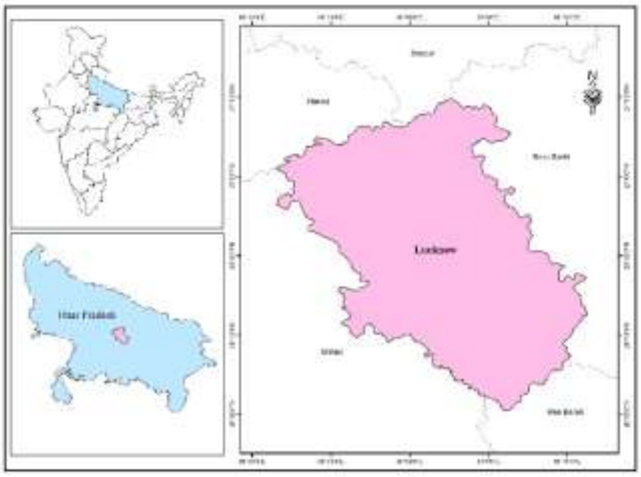

Fig-1 Study area map

Table-1 *All India drought occurring years (1801-2015)*

Period	Drought Years	Number of Drought
1801-1830	1801,1804,1806,1812,1819,1825	6
1831-1860	1832,1833,1837,1853,1860	5
1861-1890	1862,1866,1868,1873,1877,1883	6
1891-1920	1891,1897,1899,1901,1904,1905,1907,1911,1918,1920	10
1921-1950	1939,1941	2
1951-1980	1951,1965,1966,1971,1972,1974,1979	7
1981-2010	1982,1987,2002,2009	4
2011-2015	2015	1

Source: India Meteorological Department

Drought Analysis

There are various definitions of drought used in different countries according to the purpose and area of interest of investigators. In the present study the following definition of term drought has been used for the analysis.

Drought Week: The week was classified as drought week in which rainfall received less than 50 percent of average rainfall [10].

Surplus Week: The week was classified as surplus week in which rainfall received more than twice of average weekly rainfall.

Normal Week: The week was classified as normal week in which rainfall received in between 50 percent and 200 percent of average weekly rainfall.

Drought Year: The year was classified as drought year in which precipitation received was less than or equal to $\bar{x}-\sigma$, where, $\bar{x}$ is mean annual precipitation and σ is standard deviation.

Surplus Year: The year was classified as surplus year in which precipitation received was more than or equal to $\bar{x}+\sigma$.

Normal Year: The year was classified as normal year in which precipitation received was $\bar{x}\pm\sigma$, *i.e.* in between $\bar{x}-\sigma$ and $\bar{x}+\sigma$.

Analysis of Rainfall Data

The rainfall data (2001-2015) were converted into weekly, monthly and annually were used for computation of drought pattern. Normal, Surplus and Drought months/years with expected monthly, seasonal and mean annual rainfall at different probability level based on the method suggested by Sharma, *et al.*, (1979) was used to get the rainfall magnitude for the estimation of probability of occurrence. Probability of occurrence is actually reciprocal of recurrence interval. The recurrence interval of an event was obtained by the probability method. The probability method is as follows:

The available rainfall data of 15 years (2001-2015) was month wise arranged in descending order of magnitude *i.e.* rainfall in January during 15 years is arranged separately, for February separately and so on.

The rank (m) of each rainfall is determined. It is equal to its position in the series. In other words, the highest rainfall will have m=1, the second highest m=2, and so on.

Now the recurrence interval (return period) of any rainfall of rank m is calculated by the Weibull formula.

$$T = N+1 / m \qquad (1)$$

Where,

T - Recurrence interval

N - Total number of years for which the data were recorded

m - Rank number

Once the recurrence interval for a particular period of rainfall has been calculated, the probability of occurrence can be determined (in percentage) as follows:

$$\text{Probability of occurrence} = 1 / T \times 100 \qquad (2)$$

The computed value of the probability of occurrence and rainfall were used to study the frequency distribution of rainfall.

Gumbel's Distribution Method

This extreme value distribution was introduced by Gumbel (1941) and is commonly known as Gumbel's distribution. Gumbel is one of the most widely used probability distribution function for extreme value in hydrologic studies for prediction of maximum rainfall [12].

The following steps were used to analyze the rainfall data for probability distribution.

Firstly, the mean of rainfall was calculated.

$$\bar{x}= \Sigma x / n \qquad (3)$$

Where,

$\bar{x}$ = Mean of rainfall

Σx= Sum of rainfall value of particular month

Now standard deviation was calculated with the help of formula

$$\sigma x= \sqrt{\Sigma x(x-2)^2} / n \qquad (4)$$

Where,

σ_x= Standard deviation

n= Total number of years.

The recurrence interval (return Period T) was calculated at different probability level as 90, 70, 50, 30 and 10.

T=1/P

The expected rainfall was calculated by formula:

$$x_T= \bar{x} + K\sigma_x \qquad (5)$$

Where,

x_T= Expected rainfall in mm

$\bar{x}$= Mean of rainfall value

σ_x = Standard deviation

$K=Y_T-Y_n / S_n$

Where, K= General equation of hydrologic frequency analysis

Y_n= -ln (ln T/ T-1)

Y_n=0.5128

S_n=1.0206

Result and discussion

The present study was conducted for the planning and management of Lucknow district in Uttar Pradesh. The rainfall was categorized on the basis of weekly, monthly and annual rainfall data for drought, normal and surplus conditions. The irrigation requirement of different crops was determined using on various climatologically and effective rainfall data of the command area. Estimation of weekly rainfall probabilities plays significant role for crop planning. The inadequate and uneven distribution of rainfall in the Lucknow district results frequent crop failure. Features of local rainfall, such as quantity and duration of onset of monsoon, length of dry and wet periods are important in determining the dates of planting and supplemental irrigation [13-18].

Table-2 *Number of Drought, Normal and Surplus weeks (2001-2015)*

Standard Weeks	Average rainfall (mm)	Value of rainfall (mm)			Total number of weeks		
		Drought Week (less than)	Surplus week (more than)	Normal week (in between)	Drought	Surplus	Normal
1	8.807	4.40	17.61	4.40-17.61	10	4	1
2	0.727	0.36	1.45	0.36-1.45	13	2	0
3	3.393	1.69	6.786	1.697-6.786	11	1	3
4	2.913	1.46	5.82	1.46-5.82	11	1	3
5	3.333	1.67	6.67	1.67-6.67	11	3	1
6	7.786	3.89	15.57	3.89-15.57	12	2	1
7	8.94	4.47	17.88	4.47-17.88	8	3	4
8	4.227	2.11	8.45	2.11-8.45	10	3	2
9	4.613	2.31	9.23	2.31-9.23	11	2	2
10	1.573	0.786	3.15	0.786-3.15	9	3	3
11	4.46	2.23	8.92	2.23-8.92	10	3	2
12	0.84	0.42	1.68	0.42-1.68	13	2	0
13	0.293	0.15	0.59	0.15-0.59	13	1	1
14	0.873	0.44	1.75	0.44-1.75	11	2	2
15	4.267	2.13	8.53	2.13-8.53	12	3	0
16	2.667	1.33	5.33	1.33-5.33	11	2	2
17	2.813	1.41	5.63	1.41-5.63	11	3	1
18	4.393	2.19	8.786	2.19-8.786	13	1	1
19	5.213	2.61	10.43	2.61-10.43	9	2	4
20	6.66	3.33	13.32	3.33-13.32	12	2	1
21	5.317	2.66	10.63	2.66-10.63	13	2	0
22	9.793	4.89	19.59	4.89-19.59	9	3	3
23	14.98	7.49	29.96	7.49-29.96	9	3	3
24	11.233	5.62	22.45	5.62-22.45	11	3	1
25	35.093	17.55	70.19	17.55-70.19	10	4	1
26	36.247	18.12	72.49	18.12-72.49	5	2	8
27	52.013	26.01	104.03	26.01-104.03	7	1	7
28	56.153	28.08	112.31	28.08-112.31	7	1	7
29	73.007	36.50	146.01	36.50-146.01	4	2	9
30	67.493	33.75	134.99	33.75-134.99	6	3	6
31	47.687	23.84	95.37	23.84-95.37	6	1	8
32	28.253	14.13	56.51	14.13-56.51	7	0	8
33	63.013	31.51	126.03	31.51-126.03	6	1	8
34	74.547	37.27	149.09	37.27-149.09	6	3	6
35	30.607	15.30	61.21	15.30-61.21	6	2	7
36	42.873	21.44	85.75	21.44-85.75	8	3	4
37	46.5867	23.29	93.17	23.29-93.17	8	3	4
38	48.267	24.13	96.53	24.13-96.53	7	3	5
39	28.68	14.34	57.36	14.34-57.36	7	3	5
40	17.493	8.75	34.99	8.75-34.99	10	1	4
41	7.133	3.57	14.27	3.57-14.27	13	2	0
42	5.807	2.90	11.61	2.90-11.61	11	2	2
43	3.173	1.59	6.35	1.59-6.35	12	2	1
44	0.447	0.22	0.89	0.22-0.89	14	1	0
45	0.513	0.26	1.03	0.26-1.03	14	1	0
46	0.447	0.22	0.89	0.22-0.89	13	2	0
47	0.62	0.31	1.24	0.31-1.24	14	1	0
48	1.66	0.83	3.32	0.83-3.32	13	2	0
49	0	0	0	0-0	15	0	0
50	0.427	0.21	0.85	0.21-0.85	12	2	1
51	0.933	0.47	1.87	0.47-1.87	13	1	1
52	1.013	0.51	2.02	0.51-2.02	12	2	1

Rainfall analysis

The rainfall data of 15 years (2001-2015) were analyzed for weekly, seasonal and annual rainfalls.

Weekly rainfall

Probability analysis of rainfall for 15 years using Weibull's method was used for calculating the rainfall for drought, normal and surplus conditions. The weekly distribution of rainfall shown in the [Fig-2]. The maximum weekly rainfall during 15 years period was 74.54 mm in 34th week and minimum weekly rainfall was 0.293 mm in 13th week as shown in [Fig-2]. For 15 years data, numbers of weeks under drought, surplus and normal conditions are shown in [Table-2]. It may be observed from the [Table-2], the maximum number of drought weeks during the 15 years period was 15 during in the 49th week, and the minimum numbers of drought weeks *i.e.*, 5 were found in the 26th standard week of the year during 15 years period. The maximum number of Surplus weeks during the 15 years period was 4 during in the 1st and 25th week, and the minimum numbers of Surplus weeks *i.e.* zero were found in the 32nd, and 49th standard week of the year during 15 years period. The maximum number of Normal weeks during the 15 years period was 8 during in the 26th, 31st, 32nd, and 33th week, and the minimum numbers of drought weeks *i.e.* zero were found in the 2nd, 12th, 15th, 21st, 41st, 44th, 45th, 46th, 48th and 49th standard week.

Monthly rainfall

The average monthly rainfall of 15 years (2001-2015) is shown in [Fig-3]. From the [Fig-3], it has been observed that the average monthly rainfall of these periods was of erratic nature with the minimum total of 2.7 mm in November month and maximum total of 262.833 mm in July month. It has been found that erratic distribution of precipitation during *Rabi* season (October-January) thereby preventing the farmers to go for *Rabi* crops. Therefore, the irrigation must be assured for sowing *Rabi* crops. Estimation of weekly rainfall probabilities plays significant role for crop planning.

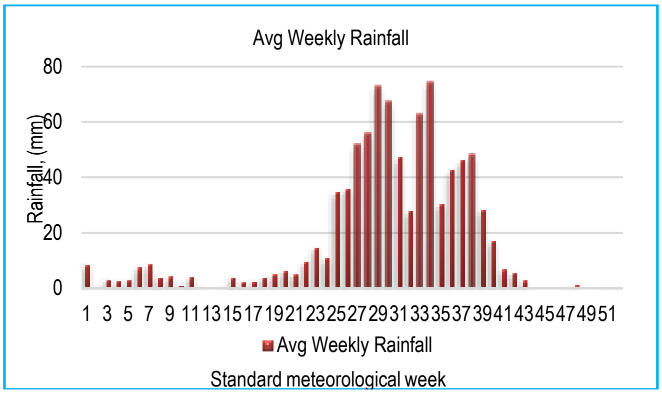

Fig-2 Graph shows Mean weekly rainfall distribution (2001-2015)

Table-3 *Mean Monthly rainfall during the years (2001-2015)*

Month	Monthly Rainfall (mm)
January	17.013
February	26.447
March	10.387
April	10.76
May	27.265
June	118.54
July	262.833
August	212.60
September	171.22
October	155.70
November	2.70
December	80.10

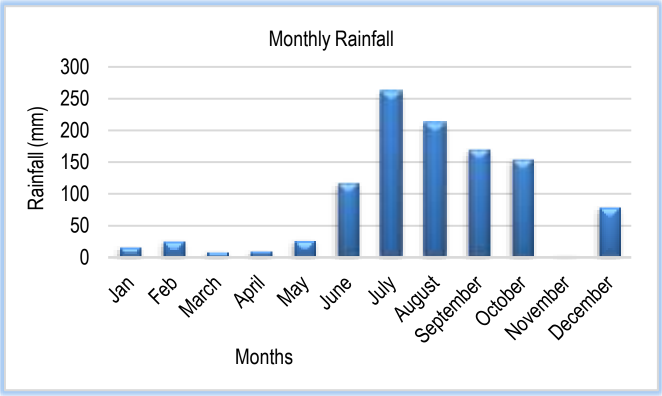

Fig-3 Graph shows Mean monthly rainfall distribution (2001-2015)

Annual and Seasonal rainfall

The annual and seasonal rainfall of 15 years (2001-2015) is shown in [Table-4,] and [Fig-4, 5]. From the [Table-4], it can be observed that the total annual rainfall of these periods was of erratic nature with the minimum total of 628.1 mm in 2015 and maximum total of 1539.6 mm in 2008. The average annual rainfall was found to be 893.88 mm. The maximum seasonal rainfall during monsoon season was 1448.4 mm in 2008 and minimum 423.30 mm in 2015.

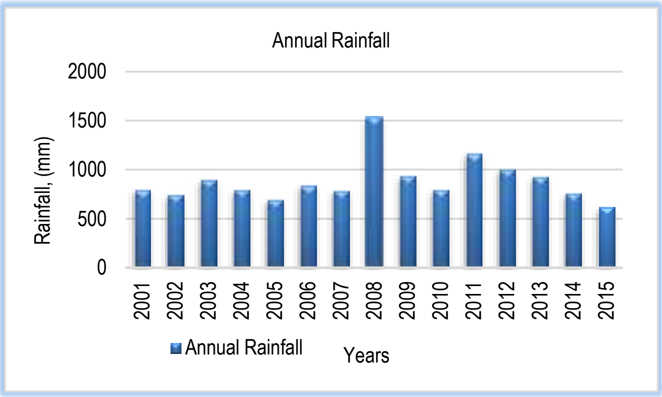

Fig-4 Graph shows Annual rainfall distribution (2001-2015)

The [Fig-4] is shows the peak values of annual rainfall were observed during the year 2008, followed by 2011, 2012, 2009, 2013 and 2003 whereas droughts were observed during the year 2015 followed by 2005, 2002, 2014, 2007, 2004, 2010, 2001 and 2006 for which the annual rainfall were less than mean annual rainfall (893.89 mm). The percentage of seasonal rainfall with respect to annual rainfall for 15 years period is also shown in the [Table-4]. From the table, it was found that the percentage of seasonal rainfall with respect to annual rainfall was maximum with 94.08 percent during the year 2008 and minimum with 67.39 percent during the year 2015.

Table-4 *Annual and seasonal rainfall distribution (2001-2015)*

Year	Annual rainfall (mm)	Seasonal rainfall (mm) (June to Sep)	Seasonal rainfall/ Annual rainfall (%)
2001	802.58	581.3	72.42
2002	750.3	705.5	94.02
2003	904.9	781.6	86.37
2004	799.2	717.4	89.76
2005	703.1	634.6	90.25
2006	844.9	707.5	83.74
2007	794.4	632.2	79.58
2008	1539.6	1448.4	94.07
2009	942.9	819.9	86.96
2010	800.9	702.3	87.69
2011	1174.3	1093.9	93.15
2012	1014.2	897.8	88.52
2013	939.2	741.2	78.92
2014	769.7	591.3	76.82
2015	628.1	423.3	67.39

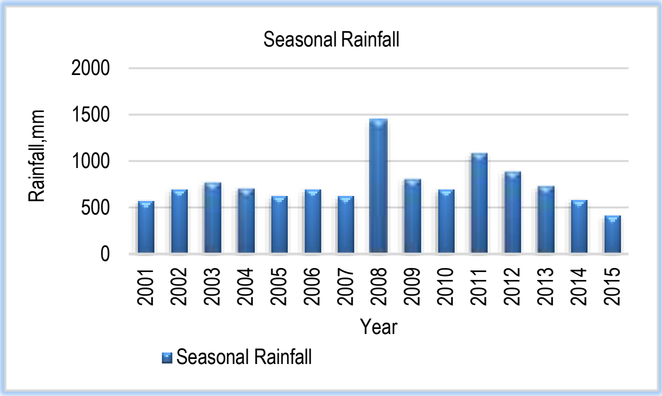

Fig-5 Graph shows Seasonal rainfall distribution (2001-2015)

Probability analysis for annual rainfall and seasonal rainfall

The knowledge of annual rainfall maximum daily rainfall will be of great importance in hydrologic design of structures and flood control. To forecast the maximum daily rainfall, the probability curves were prepared for hydrologic events. The observed maximum daily rainfall, annual rainfall and seasonal rainfall values with Weibull's probability distribution were plotted on the frequency curves, which are shown in the [Fig-8].

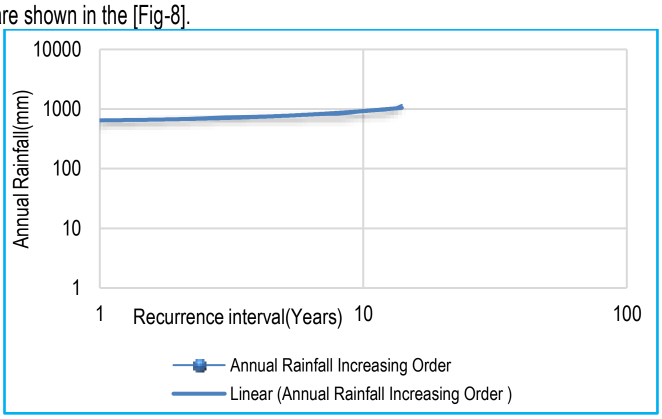

Fig-6 Graph shows recurrence interval of annual rainfall during (2001-2015)

Table-5 *Probability and recurrence interval of Annual rainfall (2001-2015)*

Year	Annual Rainfall (mm)	Rainfall in decreasing order	Rank (m)	P=m/(N+1)	T=1/P	P (%) = m/(N+1)*100
2001	802.58	1539.6	1	0.0625	16.0	6.25
2002	750.3	1174.3	2	0.125	8.00	12.50
2003	904.9	1014.2	3	0.1875	5.33	18.75
2004	799.2	942.9	4	0.25	4.00	25.00
2005	703.1	939.2	5	0.3125	3.20	31.25
2006	844.9	904.9	6	0.375	2.66	37.51
2007	794.4	844.9	7	0.4375	2.28	43.75
2008	1539.6	802.58	8	0.50	2.00	50.00
2009	942.9	800.9	9	0.5625	1.77	56.25
2010	800.9	799.2	10	0.625	1.62	62.51
2011	1174.3	794.4	11	0.6875	1.45	68.75
2012	1014.2	769.7	12	0.75	1.33	75.00
2013	939.2	750.3	13	0.8125	1.23	81.25
2014	769.7	703.1	14	0.875	1.14	87.51
2015	628.1	628.1	15	0.9375	1.06	93.75

Table-6 *Probability and recurrence interval of seasonal rainfall (2001-2015)*

Year	Seasonal rainfall (June to September)	Rainfall in decreasing order	Rank (m)	P=m/(N+1)	T=1/P	P (%) = m/(N+1)*100
2001	581.3	1448.4	1	0.0625	16	6.25
2002	705.5	1093.9	2	0.125	8.0	12.50
2003	781.6	897.8	3	0.1875	5.33	18.75
2004	717.4	819.9	4	0.25	4.00	25.00
2005	634.6	781.6	5	0.3125	3.20	31.25
2006	707.5	741.2	6	0.375	2.66	37.50
2007	632.2	717.4	7	0.4375	2.28	43.75
2008	1448.4	707.5	8	0.5	2.00	50.00
2009	819.9	705.5	9	0.5625	1.77	56.25
2010	702.3	702.3	10	0.625	1.60	62.50
2011	1093.9	634.6	11	0.6875	1.45	68.75
2012	897.8	632.2	12	0.75	1.33	75.00
2013	741.2	591.3	13	0.8125	1.23	81.25
2014	591.3	581.3	14	0.875	1.14	87.50
2015	423.3	423.3	15	0.9375	1.06	93.75

Table-7 *Month wise distribution of number of months to be drought, surplus and normal*

Months	Average rainfall (mm)	Values of rainfall (mm)			Drought month	Surplus month	Normal month
		Drought (less than)	Surplus (more than)	Normal (in between)			
January	17.01	8.51	34.03	8.51-34.03	9	3	3
February	26.45	13.22	52.89	13.22-52.89	7	6	2
March	10.39	5.19	20.77	5.19-20.77	7	6	2
April	10.76	5.38	21.52	5.38-21.52	8	5	2
May	27.27	13.63	54.53	13.63-54.53	7	6	2
June	118.54	59.27	237.08	59.27-237.08	4	9	2
July	262.83	131.42	525.67	131.42-525.67	0	14	1
August	212.6	106.3	425.2	106.3-425.2	1	13	1
September	171.22	85.61	342.44	85.61-342.44	5	9	1
October	155.7	77.85	311.4	77.85-311.4	13	2	0
November	2.7	1.35	5.4	1.35-5.4	9	3	3
December	80.1	40.05	160.2	40.05-160.2	15	0	0
Total	1095.57				85	76	19

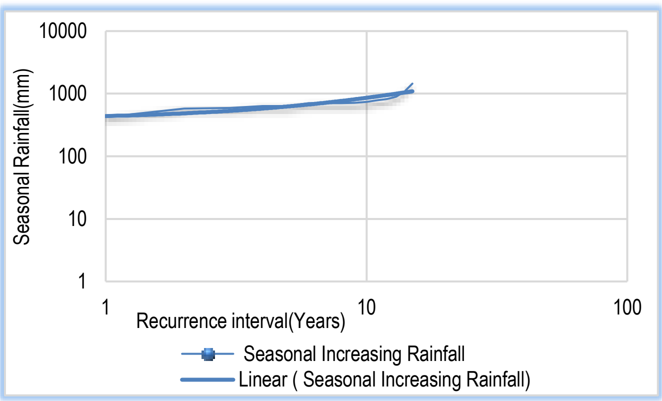

Fig-7 Graph shows recurrence interval of seasonal rainfall (2001-2015)

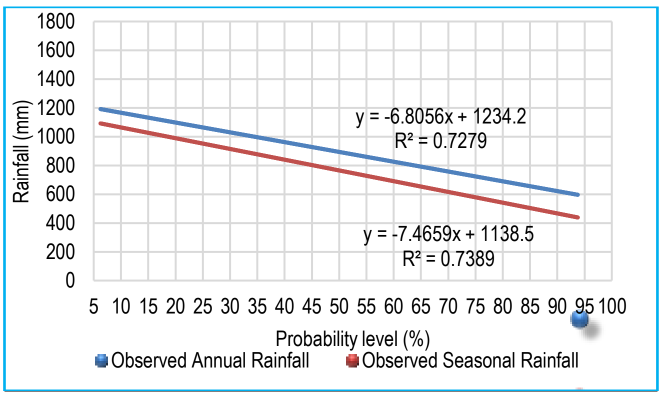

Fig-8 Graph shows observed annual and seasonal rainfall distribution for different probability levels

Table-8 *Year wise distribution of number of months to be drought, surplus and normal*

Year	Average Rainfall(mm)	Values of rainfall (mm)			Drought month	Surplus month	Normal month
		Drought (less than)	Surplus (more than)	Normal (in between)			
2001	66.25	33.12	132.49	33.12-132.49	7	4	1
2002	89.81	44.9	179.62	44.9-179.62	8	2	2
2003	75.41	37.7	150.82	37.7-150.82	7	3	2
2004	66.6	33.3	133.2	33.3-133.2	8	3	1
2005	58.61	29.3	117.22	29.3-117.22	7	2	3
2006	70.41	35.2	140.87	35.2-140.87	7	2	3
2007	66.2	33.1	132.4	33.1-132.4	6	2	4
2008	128.3	64.15	256.6	64.15-256.6	7	3	2
2009	78.58	39.29	157.15	39.29-157.15	8	3	1
2010	66.74	33.37	133.48	33.37-133.48	8	3	1
2011	97.86	48.93	195.72	48.93-195.72	7	2	3
2012	83.98	41.99	167.95	41.99-167.95	8	3	1
2013	78.27	39.13	156.53	39.13-156.53	6	3	3
2014	64.14	32.07	128.28	32.07-128.28	7	2	3
2015	52.34	26.17	104.68	26.17-104.68	6	2	4
Total					107	39	34

From the figures it is observed that rainfall values were decreasing with increasing in probability levels. The probabilities and recurrence interval of annual rainfalls are shown in [Table-5] and [Fig-5] and seasonal rainfalls for the period (2001-2015) are shown in [Table-6] and [Fig-6]. The excepted annual and seasonal rainfall at different percent probability levels are shown in [Fig-8].

Drought analysis

Drought, normal and surplus months

It was observed from [Table-7] that about 42.22 percent of the total numbers of months were normal months during the period of 15 years (2001-2015). It was also observed that the maximum numbers of drought months were 15 in the month of December and minimum numbers of drought months were 4 observed in July month during 15 years (2001-2015) period. Excess amount of rainfall was observed in the month of July were the total surplus months were 14 during the period of 15 years and the minimum number of surplus months were 0 observed in the month of December. The maximum numbers of normal months were 3 in the month of January & November and minimum numbers of normal months were 0 observed in October and December month during 15 years (2001-2015) period.

Drought, normal and surplus month in a year

The year wise distribution of number of months to be drought, surplus and normal are presented in [Table-8]. It can be observed from [Table-8] that about 18.89 percent of the total numbers of months in the year (2001-2015) were normal, about 21.67 percent were surplus and 59.44 percent were drought months. Maximum numbers of drought months were observed to be 8 in the year 2002, 2003, 2009, 2010, 2012 and minimum numbers of drought months were observed to be 6 in the year 2007, 2013 and 2015. Excess amount of rainfall was observed in the year 2001 with a total of 4 months during the period of 15 years and the minimum number of surplus months were observed in the year 2002, 2005, 2006, 2007, 2007, 2014 and 2015 with a total of 1 month. The maximum numbers of normal months were observed to be 4 in the year 2007 and 2015 and Minimum numbers of normal months were observed to be 1 in the year 2001, 2004, 2009, 2010 and 2012.

Analysis of Monthly Rainfall

The monthly rainfall at different probability level is given in [Table-9]. From the [Table-9], it was clearly observed that at 10% probability level, the maximum rainfall is observed 397.26 mm in July month and the minimum rainfall was observed 9.12 mm in November month. The maximum rainfall at 30% probability level in July month is 306.2 mm and the minimum rainfall observed to be 4.77 mm in November month. Similarly, the rainfall for 50% probability level is 248.53 mm in July month, and the minimum observed rainfall was 2.02 mm in November month. At 70% probability level maximum rainfall is 199.8 mm in July month and the minimum rainfall observed to be zero in March and November month. Also, at 90% probability level, the maximum rainfall observed in July month was 155.63 mm and minimum rainfall zero was in January, February, March, April, October, November and December month.

Table-9 *Expected monthly distribution of rainfall (mm) at different probability levels*

Month	10%	30%	50%	70%	90%
Jan	44.32	25.82	14.11	4.20	0
Feb	74.93	42.09	21.28	3.70	0
Mar	35.84	18.60	7.68	0	0
April	30.94	17.27	8.61	1.29	0
May	57.27	36.94	24.07	13.19	3.33
June	235.07	156.11	106.1	63.84	25.54
July	397.26	306.2	248.53	199.8	155.63
Aug	366.80	262.34	196.18	140.27	89.6
Sep	322.22	219.95	155.18	100.44	50.83
Oct	87.25	48.06	23.24	2.26	0
Nov	9.12	4.77	2.02	0	0
Dec	16.75	9.13	4.31	0.24	0
Total	1677.77	1147.28	811.31	529.23	324.93

Analysis of Weekly Rainfall

The weekly rainfall at different probability level is given in [Table-10]. From the table, it was clearly observed that at 10% probability level, the maximum rainfall is observed in 34th week 175.77 mm and the minimum rainfall was observed to be zero in 49th week. The maximum rainfall at 30% probability level in 34th week is 107.20 mm and the minimum rainfall observed to be zero in 49th week. Similarly, the rainfall for 50% probability level is 64.57 mm in 29th week; minimum observed rainfall was zero in 49th week. At 70% probability level maximum rainfall is 35.85 mm in 29th week and the minimum rainfall observed to be zero in 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th, 10th, 11th, 12th, 13th, 14th, 15th, 16th, 17th, 18th, 19th, 20th, 21st, 22nd, 24th, 40th, 41th, 42nd, 43rd, 44th, 45th, 46th, 47th, 48th, 49th, 50th, 51st and 52nd week. Also at 90% probability level, the maximum rainfall observed in 31st week was 15.26 mm and minimum rainfall zero was in 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th, 10th, 11th, 12th, 13th, 14th, 15th 16th, 17th, 18th, 19th, 20th, 21st, 22nd, 23rd, 24th, 25th, 27th, 34th, 36th, 37th, 38th, 39th, 40th, 41st, 42nd, 43rd, 44th, 45th, 46th, 47th, 48th, 49th, 50th, 51th and 52nd week.

Normal, Surplus and Drought months

Normal months

The analysis reveals that during 15 years, about 42.22% of the total number of months for 15 years of record was normal months. The probability distribution of normal months obtained in a year and the percentage of the total years having a given number of normal months and probability distribution of surplus months in a year are shown in [Table-9 and 10]. The California method (chow, 1964) was used for probability analysis. Similarly, month wise distribution of normality is shown in [Table-9]. About 40.82% normal months occur between October to May and rest during monsoon. During 15 years, maximum 14 months were normal.

Surplus months

About 10.56% of the total number of months are surplus and about 73.68% of them occur between October to May and rest during monsoon.

About 15.79%, which is the largest of the total surplus months coincide with December-January. Percent of total years having a given number of surplus months and probability distribution of surplus months in a year are shown in [Table-9 and 10], respectively. During 15 years maximum 3 months were surplus.

Table-10 *Expected weekly distribution of rainfall (mm) at different probability levels*

Weeks	Rainfall at per chance				
	10%	30%	50%	70%	90%
1	28.4981	15.1584	6.70998	0	0
2	3.77073	1.70856	0.40254	0	0
3	15.4739	7.29007	2.10702	0	0
4	13.0488	6.18266	1.83413	0	0
5	14.9412	7.07759	2.09736	0	0
6	31.0981	15.306	5.30453	0	0
7	29.6686	15.6263	6.73287	0	0
8	14.4167	7.51358	3.14166	0	0
9	17.4041	8.73916	3.2514	0	0
10	5.28554	2.77075	1.17807	0	0
11	16.7716	8.43124	3.1491	0	0
12	4.17258	1.91496	0.48515	0	0
13	1.57096	0.70545	0.1573	0	0
14	3.4075	1.69076	0.6035	0	0
15	17.1559	8.42423	2.89426	0	0
16	9.98912	5.02861	1.88699	0	0
17	10.4153	5.26543	2.0039	0	0
18	24.5776	10.904	2.24416	0	0
19	18.9935	9.65828	3.74606	0	0
20	27.705	13.4483	4.41919	0	0
21	26.5141	12.1528	3.05741	0	0
22	31.3797	16.7563	7.49487	0	0
23	43.8734	24.2999	11.9035	1.42703	0
24	39.2661	20.2756	8.24848	0	0
25	106.958	58.2743	27.4413	1.38367	0
26	72.8933	48.0675	32.3446	19.0569	7.01469
27	118.283	73.3895	44.9571	20.9281	0
28	124.083	78.065	48.9203	24.2895	1.96743
29	152.218	98.5573	64.5724	35.851	9.82184
30	138.278	90.3259	59.9563	34.2903	11.0302
31	88.336	60.7986	43.3584	28.6193	15.2618
32	63.5742	39.6465	24.4925	11.6854	0.07887
33	133.207	85.6553	55.5392	30.0875	7.0215
34	175.77	107.197	63.7687	27.0661	0
35	64.4791	41.5326	27	14.7182	3.58763
36	115.498	66.2993	35.1404	8.80736	0
37	131.221	73.8864	37.575	6.88745	0
38	126.299	73.437	39.958	11.664	0
39	79.2964	45.0069	23.2905	4.93744	0
40	69.346	34.219	11.9722	0	0
41	35.2582	16.2053	4.13867	0	0
42	26.1786	12.3779	3.63751	0	0
43	13.9345	6.64449	2.02751	0	0
44	2.69665	1.17242	0.20709	0	0
45	3.09913	1.34741	0.238	0	0
46	2.15868	0.9989	0.26438	0	0
47	3.74311	1.6274	0.28746	0	0
48	7.67944	3.60164	1.01907	0	0
49	0	0	0	0	0
50	2.04478	0.94861	0.25437	0	0
51	5.4234	2.38166	0.45524	0	0
52	4.29553	2.07204	0.66385	0	0

Drought months

About 47.22% of the total number of months is drought months. The percent of total years with a given number of drought months and the probability distribution of drought months in a year are shown in [Table-9 and 10], respectively. During 15 years maximum 13 were drought months. Of the total drought months, 11.78% occur between June and September and the percentage distribution of drought months during June, July, August and September are 4.71, 0, 1.18 and 5.89 respectively as shown in [Table-11].

Similarly, during *Rabi* season (November to March), 55.31% of the total months are drought months. This shows the likelihood of failure of *Rabi* crops under rain fed conditions in most of the years. The percentage distribution of drought months in *Rabi* season are 10.59, 17.65, 10.59, 8.24 and 8.24 during November, December, January, February and March and the percentage distribution of drought months in Zaid season are 9.41, 8.24 and 4.71 during April, May and June. Similarly, the percentage distribution of drought months in *Kharif* season are 0, 1.18, 5.89 and 15.29 during July, August, September and October respectively as shown in [Table-9]. The percentage distribution of Surplus months in *Rabi* season are 15.78, 0, 15.78, 10.53 and 10.53 during November, December, January, February and March and the percentage distribution of Surplus months in Zaid season are 10.53, 10.53 and 10.53 during April, May and June. The percentage distribution of normal months in *Rabi* season are 3.95, 0, 3.95, 7.89 and 7.89 during November, December, January, February and March and the percentage distribution of normal months in Zaid season are 6.57, 7.89 and 11.84 during April, May and June. Similarly, the percentage distributions of normal months in *Kharif* season are 18.42, 17.11, 11.84 and 2.63 during July, August, September and October respectively.

Table-11 *Distribution of Drought (D), Surplus (S) and Normal (N) months*

Month	Percentage of month falling in the given month as			Percentage of total years having the given month as		
	Drought (D)	Surplus (S)	Normal (N)	Drought (D)	Surplus (S)	Normal (N)
January	10.59	15.79	3.95	60	20	20
February	8.24	10.53	7.89	46.67	13.33	40
March	8.24	10.53	7.89	46.67	13.33	40
April	9.41	10.53	6.57	53.33	13.33	33.33
May	8.24	10.53	7.89	46.67	13.33	40
June	4.71	10.53	11.84	26.67	13.33	60
July	0	5.26	18.42	0	6.67	93.33
August	1.18	5.26	17.11	6.67	6.67	86.67
September	5.89	5.26	11.84	33.33	6.67	60
October	15.29	0	2.63	86.67	0	13.33
November	10.59	15.79	3.95	60	20	20
December	17.65	0	0	100	0	0

Normal, Surplus and Drought Year

The normal, surplus and drought year was computed as per definition described in material and methods and yearly distribution of the same is presented in [Table-12] and [Table-13].

Drought Year

The mean annual rainfall of Lucknow is 893.89 mm and the value of standard deviation is 215.40. Therefore, any year receiving the rainfall less than or equal to 715.11 mm would be the drought year. Thus, drought year is about 13.33% of total 15 years.

Surplus Year

The year receiving the annual rainfall amount equal or more than 1070.67 mm would be the surplus year. Thus, surplus year is about 13.33% of the total 15 years.

Normal Year

The year receiving the rainfall between 715.11 and 1070.67 mm would be the normal year, which revealed that there are 11 normal years, which comes about 73.34% of the total 15 years.

The Drought, Surplus and Normal year are classified by using Indian Metrological Department (I.M.D 1971) method. The Yearly distribution of Normal, Surplus and Drought year according to I.M.D. method is shown in [Table-12].

Drought year = Average rainfall - 20% of Average rainfall

= 893.89 - 20% of 893.89

= 715.11 mm

Surplus year = Average rainfall + 20% of Average rainfall

= 893.89 + 20% of 893.89

= 1070.67 mm

Normal year = Rainfall between

= 715.11 and 1070.67 mm

Percentage

% of Drought year = 13.33%

% of Surplus year = 13.33%

% of Normal year = 73.34%

Table-12 *Yearly distribution of Normal, Surplus and Drought year according to I.M.D. method.*

Year	Total Rainfall (mm)	Normal	Surplus	Drought
2001	802.58	N		
2002	750.3	N		
2003	904.9	N		
2004	799.2	N		
2005	703.1			D
2006	844.9	N		
2007	794.4	N		
2008	1539.6		S	
2009	942.9	N		
2010	800.9	N		
2011	1174.3		S	
2012	1014.2	N		
2013	939.2	N		
2014	769.7	N		
2015	628.1			D
Total = 15	Average = 893.89			

The Drought, Surplus and Normal year are classified by using Standard deviation method. The Yearly distribution of Normal, Surplus and Drought year according to Standard deviation method are shown in [Table-13].

Table-13 *Yearly distribution of Normal, Surplus and Drought year according to Standard deviation*

Year	Total Rainfall (mm)	Normal	Surplus	Drought
2001	802.58	N		
2002	750.3	N		
2003	904.9	N		
2004	799.2	N		
2005	703.1	N		
2006	844.9	N		
2007	794.4	N		
2008	1539.6		S	
2009	942.9	N		
2010	800.9	N		
2011	1174.3		S	
2012	1014.2		S	
2013	939.2	N		
2014	769.7	N		
2015	628.1			D
Total = 15	Average = 893.89			

Standard Deviation (S.D.) = 215.4 mm
Average Rainfall (X) = 893.89 mm
Drought Year = X-S.D. = 893.89 – 215.40 = 678.49 mm
Surplus Year = X+S.D. =893.89 + 215.40 = 1109.29 mm

Normal Year = Rainfall between 678.49 and 1109.29 mm

Percentage (%) of Drought Year = 6.66%
Percentage (%) of Surplus Year = 20%
Percentage (%) of Normal Year = 73.34%

Seasonal and Non- Seasonal rainfall

The Seasonal and Non- Seasonal rainfall occurring in June to September and October to May in a year. The yearly rainfall during Seasonal and Non- Seasonal rainfall as shown in [Table-14] and [Fig-9]. The maximum rainfall is 1448.40 mm observed in year 2008 and the minimum rainfall is 347.20 mm observed in year 2014 during seasonal rainfall. The maximum rainfall is 423.3 mm observed in year 2015 and the maximum rainfall is 221.28 mm observed in year 2001 the minimum rainfall is 68.5 mm observed in year 2005 during non- seasonal rainfall.

The percentage of non-seasonal rainfall with respect to seasonal rainfall for 15 years period is also shown in [Table-14]. From the table, it was noticed that the percentage of non-seasonal rainfall with respect to seasonal rainfall was maximum with 48.38 percent during the year 2015 and minimum with 6.30 percent during the year 2008.

Table-14 *Yearly rainfall distribution of Seasonal and Non- Seasonal rainfall (mm)*

Year	Seasonal (June-September)	Non- Seasonal (October-May)	% (Non- Seasonal/ Seasonal rainfall)
2001	581.3	221.28	38.07
2002	705.5	44.8	6.35
2003	781.6	123.3	15.78
2004	717.4	81.8	11.40
2005	634.6	68.5	10.79
2006	707.5	137.4	19.42
2007	632.2	162.2	25.66
2008	1448.4	91.2	6.30
2009	819.9	123	15.00
2010	702.3	98.6	14.04
2011	1093.9	80.4	7.35
2012	897.8	116.4	12.97
2013	741.2	198	26.71
2014	591.3	178.4	30.17
2015	423.3	204.8	48.38

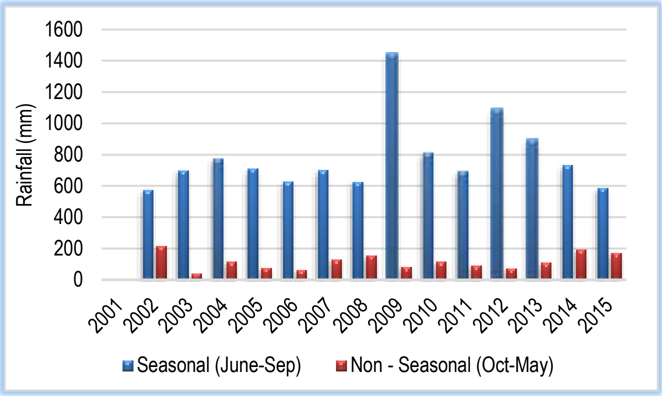

Fig-9 Graph shows Seasonal and Non- Seasonal rainfall (2001-2015)

Conclusion

The rainfall data for 15 years (2001-2015) of Lucknow district was analyzed. The rainfall data were used for computation of drought pattern, Normal, Surplus and Drought weeks, months, years, expected weeks, expected monthly, seasonal & non-seasonal and annual rainfall at different probability level. These computations were based on the method such as I.M.D and Standard Deviation (sd) suggested by Sharma, *et al*., (1979). Whereas the estimation of rainfall magnitude at different probability level was done using Gumbel's distribution method. The amount of rainfall at different probability level and return period was calculated by Weibull's method.

The following conclusions were drawn from study:

The rainfall amount and distribution are erratic and uneven.

During the weekly rainfall analysis for 15 years (2001-2015) time period, it was observed that maximum 15 times drought occurs in 49th week while minimum of 4th times is in case of 29th week. The maximum number of Surplus weeks during the 15 years period was 4 during in the 1st and 25th week, and the minimum numbers of drought weeks *i.e.* zero were found in the 32nd and 49th standard week of the year during 15 years period. The maximum number of Normal weeks during the 15 years period was 9 during in the 29th week, and the minimum numbers of drought weeks *i.e.* zero were found in the 2nd, 12th, 15th, 21st, 41nd, 44th, 45th, 46th, 47th, 48th and 49th standard week.

The analysis of weekly rainfall indicates that maximum rainfall 74.55 mm occurs in 34th week while minimum rainfall zero occurs in 49th week.

The analysis of average monthly rainfall pattern indicates that July month receives highest rainfall 262.83 mm and November month receives the least rainfall 2.7 mm.

The percentage of normal, surplus and drought months are respectively 42.22%, 10.56%, and 47.22% out of total number of months for 15 years.

The percentage of drought, surplus and normal years are 6.37%, 20% and 73.34% respectively according to Standard Deviation (sd).

It was also found that maximum number of severe droughts occurs in December, November, October and January month.

The analysis also revealed erratic distribution of precipitation during *Rabi* season thereby preventing the farmers to go for *Rabi* crops. Therefore, the irrigation must be assured for sowing *Rabi* crops. The monthly maximum rainfall at different probability level was calculated by Gumbel's Distribution method. From the drought analysis, it was observed that study area is drought prone at two stages; firstly, at the beginning of the season which can cause delay in transplantation and secondly, at the beginning of the grain ripening stage, which can drastically reduce the crop yield. The annual daily maximum rainfall received at any time ranged between 1539.60 mm (maximum) to 628.11 mm (minimum) indicating a very large range of fluctuation during the period of study.

Application of research: The Gumbel's Distribution Method is used for performing probability distribution function for prediction of extreme value in hydrologic studies for analysis of maximum rainfall occurred at various cropping stages in metrological drought prone areas.

Research Category: Hydro-Meteorological Analytical Research

Abbreviations: Mm - millimetre, - m - Rank number, N - Total number of years, P - Probability of rainfall, X - Mean of given data, T - Return period, IMD - Indian Meteorological Department, $\bar{x}$ -Mean of rainfall, Σx-Sum of rainfall value of a particular month, σ_x - Standard deviation of given data, x_T - Expected rainfall in mm, K - General equation of hydrologic frequency analysis, % - Percentage, Cm – Centimetre, M – Meter, M^2 - Meter square, °C - Degree Celsius.

Acknowledgement / Funding: Authors are thankful to Department of Soil Water Land Engineering & Management, Vaugh Institute of Agricultural Engineering and Technology, Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj, 211007, India. Authors are also thankful to Indian Meteorological Department, Lucknow Centre, C.C.S., Amausi, Lucknow

****Research Guide or Chairperson of research: Er. C. John Wesley**

University: Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj, 211007, India

Research project name or number: M Tech Thesis, Analysis of Rainfall Data for Drought Investigation of Lucknow district, UP

Author Contributions: All authors equally contributed.

Author statement: All authors read, reviewed, agreed and approved the final manuscript. Note-All authors agreed that- Written informed consent was obtained from all participants prior to publish / enrolment.

Study area / Sample Collection: Department of Meteorology, Lucknow Centre, C.C.S., Amausi, Lucknow.

Cultivar / Variety / Breed name: Nil

Conflict of Interest: None declared.

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

Ethical Committee Approval Number: Nil

References

[1] Kumar D. and Kumar S. (1989) *Ind. J. Soil Cons*., 17(1), 55-60.

[2] Tiwari K.N., Paul D.K. and Gontia N.K. (2007) *Journal of Hydrology*, 30(1-2), 15-27.

[3] Ramdas L.A. and Malick A.K. (1948) *Agricultural Situation in India, Technical Bulletin, ICAR, New Delhi.*

[4] Sharma H.C., Chauhan H.S. and Ram S. (1979) *Journal of Agricultural Engineering*, XVI (3), 87-94.

[5] Dhar O.N., Rakhecha P.R. and Kolkarni A.K. (1979) *International Symposium in Hydrological Aspect of drought,* (1), 28-36.

[6] Sudhishri S., Panda R.K. and Patnaik U.S. (2004) *Journal of Soil Water Conservation India*, 3(3&4), 157-168.

[7] Bhaskar S.R., Bansal A.K. and Singh R.V. (2006) *Journal of Agricultural Engineering*, 43, 3.

[8] Afrough E and Masoudi M. (2014) *International Journal of Scientific Research in Knowledge*, 2(9), 425-432.

[9] Afrough E., Masoudi M. and Hakimi S.S. (2012) *J. Ecol. Field Biol*., 35(4), 323-329.

[10] Hatmoko L.W., Seizarwati W. and Vernimmen R. (2016) *Procedia Environmental Sciences*, 33, 187-195.

[11] National Drought Mitigation Center, (2006) *National Drought Mitigation Center, USA.*

[12] Subramanya K. (2010) *Engineering Hydrology. Tata McGraw Hill Publication.*

[13] India Meteorological Department (IMD) (1971) *Climate Diagnostic Bulletin" of India-June, July, August* 1971; Rep. No 88, 89 and 90, National Climate Center, IMD, Pune.

[14] Aher P.D., Singh K.K. and Sharma H.C. (2012) *International Journal of Modern Engineering Research*, 2(4), 1883-1887.

[15] Shamsnia S.A. (2014) *Indian Journal of Fundamental and Applied Life Sciences*, 4(3), 39-44.

[16] Awchi T. and Jasim A.I. (2020) *J Geosci*., 13, 284.

[17] Talatahari S., Abdi A. and Hassanzadeh Y. (2017) *Theor Appl Climatol*., 129, 21-32.

[18] Zhang L., Wang, Y., Chen, Y., Bai, Y. and Zhang, Q. (2020) *Water*, 12, 421.