RESEARCH PAPER:

Assessment of occurrence and frequency of drought using rainfall data in Coimbatore, India

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Asian Journal of Environmental Science **| December, 2011 | Vol. 6 Issue 2 : 136 -142**

Received:
May, 2011
Revised:
August, 2011
Accepted :
October, 2011

SUMMARY

Rainfall data of twenty seven years (1981-2007) have been analyzed on annual, seasonal, monthly and weekly basis to assess the drought conditions and the frequency analysis has been made for predicting the expected rainfall at different probability levels. The analysis indicated that the maximum frequency of drought was observed to be in 50th to 52nd week and 1st to 13th week, February month and southwest monsoon and summer season. The observed frequency of drought was minimum in 44th week, October and November months and northeast monsoon. The analysis revealed that 2005 was the wettest year and 1995 was the driest year during 27 years study period. The expected rainfall of annual, Southeast monsoon, northeast monsoon, summer season, October and November month at one year recurrence interval was 477.33 mm, 90.2 mm, 97.2 mm , 47 mm, 30 mm and 26.1 mm, respectively. During the study period, the intensity of drought was observed to be mild/moderate and no occurrence of severe or extreme drought events were observed. The surplus water available during northeast monsoon can be effectively harvested and efficiently utilized to meet out the water demand for domestic areas and supplementary irrigation for agricultural areas during water deficit periods.

Key Words :
Rainfall, Intensity of drought, Weibull, Frequency analysis, Return period

How to cite this paper: Manikandan, M. and Tamilmani, D. (2011). Assessment of occurrence and frequency of drought using rainfall data in Coimbatore, India. *Asian J. Environ. Sci.*, **6**(2): 136-142.

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Rainfall is the major source of water for agriculture and the spatial and temporal uneven distribution of rainfall leads to occurrence of flood and drought in different regions simultaneously. Drought incidences; regardless its severity, have become more common in recent years in parallel to global climate changes. Droughts have adverse socio-economic, agricultural, and environmental impacts that can be reduced by assessing and forecasting drought behaviour. Probability and frequency analysis of rainfall data enable us to determine the expected rainfall at various chances (Bhakar *et al.,* 2008). Such information can also be used to prevent floods and droughts, and applied to planning and designing of water resources related to engineering such as reservoir design, flood control work and soil and water conservation planning (Agarwal *et al.,* 1988; Dabral *et al.,* 2009). Various researchers have investigated the meteorological droughts at various places of India (Kumar and Kumar, 1989; Ray *et al.,* 1987; Shrivastava *et al.,* 2008). Meteorological droughts were studied for predicting the expected rainfall at different probability levels for planning a suitable cropping pattern (Kumar, 2009; Singh *et al.,* 2007). In this context, an attempt has been made at Tamil Nadu Agricultural University, Coimbatore (T.N.), to analysis the nature of distribution of rainfall and to assess the drought conditions, frequency and drought intensity for Coimbatore.

EXPERIMENTAL METHODOLOGY

Location of study area:

The TNAU is located at 11^0 N latitude and 77^0 E longitude with an elevation of 426.72 m above mean sea level covering an area of 323.88 ha. It is situated 3 km away from Coimbatore city in the west direction. The long term mean annual rainfall is 657 mm distributed in 47 rainy days. Heavy rains are likely to occur during North East Monsoon. The mean maximum and minimum temperature is 31.5^{0}C and 21.4^{0}C, respectively. The mean relative humidity ranges between 61 to 91 per cent during 07:22 hours and ranges between 41 to 68 per cent during 14:22 hours. Coimbatore has a sub-tropical, semi-arid climate with hot summer. Daily rainfall data for 27 Years (1981 to 2007) were collected from the meteorological observatory, Agro-climatic Research Centre of TNAU and were converted into annual, monthly, seasonal and weekly rainfall by arithmetical ways. A year is divided into three seasons *i.e.* Southwest monsoon (June to September), Northeast monsoon (October to January) and summer season (February to May). The mean rainfall and standard deviation were determined.

Categorization of rainfall:

The annual, seasonal, monthly and weekly rainfall values were determined to assess drought occurrences during each period. Based on the following criteria given by Sharma *et al.* (1987), annual, seasonal, monthly and weekly rainfall events were classified as drought, normal and wet.

– A year receiving rainfall less than or equal to average, annual rainfall minus standard deviation is called a drought year; a year receiving rainfall more than or equal to average annual rainfall plus standard deviation is called a wet year; and a year receiving rainfall between the limits of annual rainfall corresponding to drought and wet year is called a normal year.

– A season receiving rainfall less than or equal to average seasonal rainfall minus standard deviation is called a drought season; a season receiving rainfall more than or equal to average seasonal rainfall plus standard deviation is called a wet season; and a season receiving rainfall between the limits of seasonal rainfall corresponding to drought and wet seasons is called a normal season.

– A month receiving rainfall less than or equal to 50 per cent of average monthly rainfall is called a drought month; a month receiving rainfall more than or equal to 200 per cent of average monthly rainfall is called a wet month; and a month receiving rainfall between 50 per cent and 200 per cent of average monthly rainfall is called a normal month.

– A week receiving rainfall less than or equal to half of the average weekly rainfall is called a dry week; and a week receiving rainfall twice the average weekly rainfall is called a wet week and a week receiving rainfall between the limits of weekly rainfall corresponding to dry and wet week is called a normal week.

Intensity of drought:

The intensity of drought was determined using the criteria suggested by IMD (1971) which is based on the percentage of deviation of rainfall from its long term mean. If the percentage deviation of rainfall from annual mean is zero or above zero, it is termed as no drought; if the percentage deviation is between 0 to -25, it is called as mild drought; if the deviation varies from -25 to -50, it is called as moderate drought; if the departure ranges between -50 and -75 per cent, it is called severe drought and if the departure exceeds -75 per cent of normal value, it is termed as extreme drought.

Frequency analysis and return period:

Determination of the frequency of occurrence of extreme hydrologic events like floods, droughts and severe storms are important in water resource planning and management. Frequency analysis provides information on probability of occurrence to calculate maximum expected rainfall for a particular recurrence interval.

The probability of each event is calculated by Weibull's method (Chow, 1964):

$$\mathbf{p = [M/(N+1)]\,x100}$$

where,

P = the probability of each event in per cent

M = the order number of the each event when the data are arranged in decreasing order

N = the total number of events in the data series

The return periods (recurrence interval) were calculated by using the formula:

$$\mathbf{Return\,period, T = 1/p = (N+1)/M}$$

EXPERIMENTAL FINDINGS AND DISCUSSION

The results are summarized below according to objectives of the study:

Distribution of annual rainfall:

The analysis of monthly, seasonal and annual rainfall for assessing the dry, normal and wet periods and probability chances of expecting rainfall at different return periods is presented in Table 1. The 27 years (1981-2007) annual rainfall is presented in Fig. 1. The maximum annual rainfall was received during the year 2005 (973.5 mm) and the minimum rainfall was received during the year 1995 (477.3 mm). The mean value of annual rainfall was 708.08 mm and standard deviation was found to be 162.03mm. Therefore, any year receiving less or equal to 546.06 mm will be the drought year. Any year receiving rainfall equal to or more than 870.11 mm will be wet year

Table 1: Monthly, seasonal and annual rainfall analysis

Month / Season	Mean rainfall (mm)	Number of month/season/ year predicted as			Expected rainfall (mm) at the probability levels			
					25	50	75	96.43
					Return period (years)			
		Drought	Wet	Normal	4	2	1.33	1.04
January	11.51	17	6	4	10.0	0.0	0.0	0.0
February	7.56	19	6	2	11.5	0.0	0.0	0.0
March	25.97	17	4	6	41.9	2.0	0.0	0.0
April	55.36	10	4	13	92.1	43.8	19.9	2.2
May	55.32	7	2	18	81.4	52.5	25.0	6.5
June	37.84	6	1	20	51.8	34.5	21.9	2.0
July	43.874	7	2	18	59.4	36.8	20.0	6.5
August	38.98	7	3	17	49.7	25.4	15.7	0.8
September	66.08	10	3	14	96.9	52.8	24.3	0.0
October	181.37	5	0	22	261.1	197.6	100.0	30.0
November	145.94	5	4	18	235.1	109.8	80.6	26.1
December	38.322	15	5	7	59.0	17.1	1.8	0.0
SWM	186.77	5	4	18	227.9	179.5	125.5	90.2
NEM	377.14	4	3	20	460.2	413.7	293.3	97.2
Summer	144.17	5	5	17	176.6	140.6	83.6	47.0
Annual	708.08	5	6	16	867.9	666.2	568.4	477.3

and between 546.06 mm and 870.11 mm will be normal year. During the study period of 27 years, 5 years (1986, 1988, 1991, 1995 and 2002), 6 years (1984, 1994, 1998 and 2004-06) and 16 years were found to be drought, wet and normal years, respectively. Fig. 2 shows the rainfall distribution during different months of the drought years. The worst drought was experienced in 1995 with annual rainfall below 67.41 per cent of its mean value. The wettest year was observed during 2005 which was 35 per cent more than mean annual rainfall.

It can also be observed that at one year return period only 477.3 mm of rainfall can be expected to occur and this value remains below the drought definition level. A rainfall of 867.9 mm which is equal to wet definition level may be expected once in 4 years. There is no systematic interval between two successive droughts but, on an average, one drought year can be expected over a period of 3 years. The time interval between drought years has a variation of 1 to 6 years.

The yearly intensity of drought is determined using the approach recommended by IMD and it reveals that the total number of years having no drought, mild drought and moderate drought were found to be 12, 11 and 4 years respectively. There was no occurrence of severe or extreme drought (Table 2).

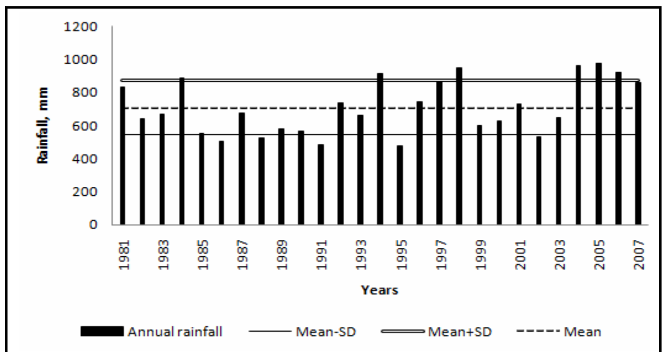

Fig. 1: Annual rainfall distribution over a period of 27 years

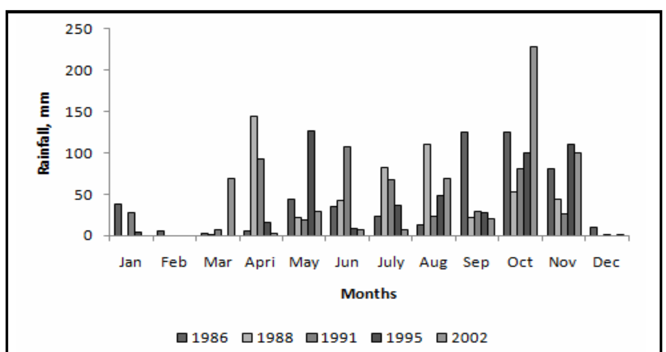

Fig. 2: Distribution of monthly rainfall during drought years

Table 2: Analysis of monthly / seasonal / annual intensity of droughts

Month / Season	No drought No.	No drought Years	Mild drought No.	Mild drought Years	Moderate drought No.	Moderate drought Years	Severe drought No.	Severe drought Years	Extreme drought No.	Extreme drought Years
January	6	1985-86, 1990-91, 1994, 2006	4	1984, 2004-05, 2007	0	0	1	1995	16	1981-83, 1987-89, 1992-93, 1996-2003
February	7	1984, 1987, 1993-94, 2000, 2003, 2007	0	0	1	1986	1	1999	18	1981-83, 1985, 1988-92, 1995-98, 2001-2002, 2004-2006
March	8	1984, 1989-90, 1993, 2002-03, 2005-06	1	1981	1	1982	2	1991, 1997	15	1983, 1985-88, 1992, 1994-96, 1998-2001, 2004, 2007
April	11	1982, 1988, 1991, 1994, 1996, 1998, 2001, 2003-05, 2007	3	1984-85, 1990	3	1997, 1999, 2006	5	1981, 1987, 1989, 1995, 2000	5	1983, 1986, 1992-93, 2002
May	10	1981, 1983, 1989-90, 1993, 1995, 2004-07	6	1982, 1984, 1986-87, 1997-98	4	1992, 1992, 1999, 2002	5	1985, 1988, 1991, 2000, 2003	2	1996, 2001
June	13	1981, 1983-85, 1988, 1991-92, 1996, 1998, 2001, 2004, 2006-07	3	1982, 1986, 2003	5	1987, 1993-94, 1999-2000	3	1989, 1997, 2005	3	1990, 1995, 2002
July	11	1988-89, 1991-92, 1994, 1996-98, 2003-04, 2007	4	1982, 1984, 1995, 2005	5	1981, 1983, 1986, 1993, 1999	3	1985, 2000-01	4	1987, 1990, 2002, 2006
August	9	1981-82, 1988, 1990, 1995, 2000, 2002, 2005, 2007	1	1996	10	1983, 1985, 1991, 1993, 1997-99, 2001, 2003-04	4	1986-87, 1989, 1992	3	1984, 1994, 2006
September	10	1981, 1984-86, 1992, 1998, 2000-01, 2004, 2006	4	1983, 1989-90, 1996	3	1982, 1987, 1994	7	1988, 1991, 1993, 1995, 1999, 2002, 2005	3	1997, 2003, 2007
October	15	1983-84, 1987, 1989, 1994, 1996-97, 1999, 2001-07	2	1990, 1993	5	1981-82, 1985-86, 1995	3	1988, 1991-92	2	1998, 2000
November	10	1981-82, 1992-94, 1997-98, 2004-06	4	1985, 1987, 1995, 2001	8	1983-84, 1986, 1990, 1999-2000, 2002-03	4	1988-89, 1996, 2007	1	1991
December	8	1981, 1983-84, 1987, 1996, 1998, 2005, 2007	2	1993, 1997	4	1986, 1994, 2000, 2003	3	1989, 1999, 2001	10	1982, 1985, 1988, 1990-92, 1995, 2002, 2004, 2006
Southwest monsoon	13	1981, 1985-86, 1988, 1991-92, 1994, 1996, 1998, 2000-01, 2004, 2007	6	1982-84, 1989, 1997, 2005	7	1990, 1993, 1995, 1999, 2002-03, 2006	1	1987	0	0
Northeast monsoon	15	1981, 1983-84, 1987, 1992-94, 1997-99, 2001, 2004-07	6	1982, 1985, 1989, 1996, 2002-03	3	1986, 1990, 1995	3	1988, 1991, 2000	0	0
Summer	12	1981, 1984, 1988, 1990, 1994, 1996, 1998, 2003-07	5	1982, 1989, 1991, 1993, 1995	5	1983, 1987, 1997, 2001-02	5	1985-86, 1992, 1999-2000	0	0
Annual	12	1981, 1984, 1992, 1994, 1996-98, 2001, 2004-07	11	1982-83, 1985, 1987, 1989-90, 1993, 1999-2000, 2002-03	4	1986, 1988, 1991, 1995	0	0	0	0

Distribution of seasonal rainfall:

The analysis of seasonal rainfall shows that the maximum rainfall for Northeast monsoon, Southwest monsoon and summer season were 598.8 mm, 417.1 mm and 282.7 mm during the year 2005, 2000 and 2004, respectively. The occurrence of rainfall amount was minimum in the Summer season (47 mm) during the year 1992 followed by Southwest monsoon (90.2) during the year 1987 and Northeast monsoon (97.2 mm) during the year 1988. The 27 years mean Southwest, Northeast and summer seasons were 186.77 mm, 377.14 mm and 144.17 mm and standard deviations were 76.05 mm, 133.85 mm and 68.82 mm, respectively. Northeast monsoon (53.26 per cent) receives the highest rainfall followed by Southwest monsoon (26.38 per cent) and summer season (20.36 per cent). This indicates that some planning is required for provision of supplementary irrigation to summer crops. On an average, the occurrence of drought, wet and normal seasons were 17.28, 14.81 and 67.9 per cent, respectively.

The expected rainfall of Northeast monsoon at 50 per cent chances is 413.7 mm. The expected rainfall of summer season at 50 per cent probability level (2 years return period) is 140.6 mm which is below the 27 years mean summer seasonal rainfall. This indicates that proper water conservation measures may be adopted for supplementary irrigation. A rainfall of 47 mm may be expected for summer season in one year return period. The surplus water available during Northeast monsoon can be effectively harvested and efficiently utilized to meet out the water demand and pumping requirement during summer season.

The seasonal intensity of droughts presented in Table 2 indicates that the station experienced 13 no droughts, 6 mild droughts, 7 moderate droughts and one severe drought during Southwest monsoon; 15 no droughts, 6 mild droughts, 3 moderate droughts and 3 severe drought during the northeast monsoon; 12 no droughts, 5 mild droughts, 5 moderate droughts and 5 severe drought during the summer season. It could be seen from Table 2 that extreme drought was not occurred for all the three seasons. During the study period, Northeast monsoon received highest number of no droughts, whereas summer season received highest number of severe drought.

Monthly rainfall:

The analysis of monthly rainfall data reveals that minimum average rainfall (7.56 mm) was received during February and maximum average rainfall (181.37 mm) was received during October. October month recorded the highest monthly rainfall of 333.1 mm during the year 2005 and November month recorded the second highest monthly rainfall (306.6 mm) during the year 1992. The drought was observed in 19 out of 27 years during February while in 5 out of 27 years in the month of October and November. October month received the highest number of normal rainfall (22 years) followed by June. It could be seen from the Table 1 that during 27 year study period, no wet month was observed in October even though it received the highest monthly rainfall. January and February months received the highest number of wet month followed by March and April. The occurrence of drought, wet and normal months was 38.58, 12.35 and 49.04, respectively. Therefore, occurrence of drought becomes more apparent when analyzing the monthly rainfall data as compared to long-term (seasonal or annual) data. Precautionary measures of moisture conservation should be adopted during northeast season experiencing the most drought events during summer seasons. The monthly intensity of drought revealed that the study area experienced 118 no drought months (36.42 %) while 34 months (10.49 %) affected by mild drought, 49 months (15.12 %) affected by moderate drought, 41 months (12.65 %) under severe drought, and 82 months (25.31 %) under extreme drought. From Table 1, it is observed that 261.1 mm of rainfall can be expected for October at 25 per cent chance which is above 27 years October mean (181.37 mm) monthly rainfall. A minimum rainfall of 30 mm and 26.1 mm may be expected to occur for October and November once in 1.04 year. The occurrence of expected rainfall during the drought month of February was 11.5 mm at 4 years recurrence interval.

Weekly rainfall:

The weekly rainfall pattern gave a better understanding of drought and steps to be taken for short term planning of cropping system. Weekly rainfall analysis for dry and wet periods and expected rainfall at different probability levels is given in Table 3. The analysis of the mean weekly rainfall (Table 3) shows that the maximum average weekly rainfall (56.71 mm) was received during 44th week followed by 45th week (54.36 mm), whereas 4th week received the minimum (0.38 mm). The number of drought weeks had a variation from 6 times (minimum) in the 45th week to 25 times (maximum) in the 4th and 5th week. The analysis further reveals that 62.61 per cent of the total weeks during 27 years period were found to drought weeks. It could be seen from the Table 3 that the number of droughts occurred were 11 or more (except 45th week) in every week with an average value of 16.9 over the period for which data were analysed. Although,

Table 3: Analysis of weekly rainfall for drought

Std. week	Mean rainfall (mm)	Number of weeks predicted as			Expected rainfall (mm) at the probability levels		
		Dry	Wet	Normal	25	50	75
1	4.41	24	3	0	0	0	0
2	1.50	23	2	2	0	0	0
3	4.49	24	3	0	0	0	0
4	0.38	25	1	1	0	0	0
5	0.74	25	2	0	0	0	0
6	1.10	24	3	0	0	0	0
7	2.43	24	3	0	0	0	0
8	1.86	23	3	1	0	0	0
9	6.75	21	5	1	1.8	0	0
10	9.93	21	4	2	2	0	0
11	6.31	20	5	2	5	0	0
12	2.82	23	2	2	0	0	0
13	2.42	22	3	2	0.5	0	0
14	10.30	18	6	3	17.6	1.5	0
15	17.30	17	4	6	12	4	0
16	14.96	12	4	11	23	8	0
17	11.09	14	6	7	18.4	3	0
18	20.83	13	5	9	28	14.5	1.5
19	10.01	17	4	6	14.56	3	0
20	10.33	16	7	4	21.4	3	0
21	11.63	14	4	9	20	5.8	0
22	8.79	13	4	10	14.3	4.7	0
23	5.74	14	6	7	10.5	2.5	0
24	9.19	14	4	9	11.5	3.4	1
25	9.73	15	6	6	15.4	3.7	0.5
26	9.71	16	7	4	20.6	2.5	0
27	9.00	15	5	7	12.8	3.4	0
28	16.24	16	5	6	23.4	6.2	1
29	7.57	14	7	6	16.4	3.2	1
30	8.82	16	5	6	15	2.8	0
31	7.81	11	5	11	12.8	5.5	0
32	7.30	15	4	8	13.8	3	0
33	7.56	17	3	7	10.5	2	0.2
34	11.97	15	4	8	10.6	4.4	0
35	9.09	15	6	6	14.9	4.1	0
36	6.08	17	4	6	11	1	0
37	14.22	11	4	12	18.5	8.2	0
38	14.41	16	4	7	16.3	4.1	0
39	27.59	15	7	5	55.5	10.1	1
40	30.79	12	4	11	44.91	17.5	3
41	33.79	13	5	9	52.5	19.4	6.1
42	46.95	13	4	10	75.6	27.2	3.4
43	49.51	11	4	12	79.2	33.6	17.8
44	56.71	13	4	10	106.4	36.4	10
45	54.36	6	3	18	69.2	50.2	30.5
46	27.59	13	3	11	44.1	17.2	1.2
47	19.90	17	7	3	40	1.6	0
48	11.53	17	7	3	30.2	1.2	0
49	10.05	16	6	5	17.1	1.5	0
50	11.61	22	3	2	5	0	0
51	7.40	19	2	6	10	0	0
52	5.44	22	3	2	0.5	0	0

44th week receiving highest mean weekly rainfall, but due its variation within 27 years, the drought spells were observed to be 13 times. The maximum number of wet weeks has occurred 7 times in 20th, 26th, 29th, 39th, 47th and 48th week while the minimum number of wet week was observed in 4th week (one time) during 27 years study period.

It was also observed that even at probability level of 50 per cent, there were no rainfall from 1st to 13th week and 50th to 52th weeks. It can be observed from the table that 30.5 mm rainfall can be expected to occur at 45th week at 75 per cent probability level. There is only 50 per cent probability of receiving more than 10 mm rainfall from 39th week to 46th week. A rainfall 106.4 mm may be expected for 44th week once at 25 per cent chances.

Conclusion:

Rainfall analysis based on 27 years (1981-2007) showed that 4th and 5th week has maximum frequency of drought while minimum was in case of 45th week, month-wise maximum frequency of drought was observed in February and minimum in October while season-wise, it was maximum in Southwest monsoon and summer season and minimum in Northeast monsoon. On an average the drought, wet and normal years were 18.52 per cent, 22.22 per cent and 59.26 per cent, respectively. During 27 years period, five years experienced drought and severity of drought was maximum during 1995. There are chances of occurrence of annual rainfall below average level once in every three years. The study area is mostly affected by mild droughts and no severe and extreme droughts were recorded during the study period. A rainfall of 30 mm, 26.1 mm, 90.2 mm, 97.2 mm 47 mm and 477.33 mm can be expected to occur at one year recurrence interval during October, November, Southeast monsoon, Northeast monsoon, summer season and annual, respectively. The surplus water available during Northeast monsoon can be effectively harvested and efficiently utilized to meet out the water demand for domestic areas and supplementary irrigation for agricultural areas during water deficit periods.

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