RESEARCH PAPER | International Journal of Agricultural Engineering | Volume 10 | Issue 2 | October, 2017 | 260-267
e ISSN–0976–7223 ■ Visit us : *www.researchjournal.co.in* ■ **DOI: 10.15740/HAS/IJAE/10.2/260-267**

Assessment of meteorological drought for Parbhani district of Maharashtra, India

■ **TARATE SURYAKANT BAJIRAO, VIJAY KUMAR SINGH AND DANIEL PRAKASH KUSHWAHA**

Received : 01.03.2017; **Revised :** 07.07.2017; **Accepted :** 21.07.2017

See end of the Paper for authors' affiliation

Correspondence to :

TARATE SURYAKANT BAJIRAO
Department of Soil and Water Conservation Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. NAGAR (UTTARAKHAND) INDIA
Email : taratesuryakant01 @gmail. com

■ **ABSTRACT :** A study was carried out to estimate the drought occurrences for rainfed area of Parbhani district of Maharashtra, India. Rainfall plays an important role during crop growth in rainfed agriculture system. Rainfall data of 32 years (1983 - 2014) have been analyzed on annual, seasonal, monthly and weekly basis to find out drought occurrences at Parbhani. The drought analysis indicated that during the study duration the drought, normal and wet years were found to be 9.37, 68.75 and 21.87 per cent, respectively. The occurrences of drought, normal and wet seasons were 7.29, 73.95 and 18.75 per cent, respectively. The percentage of drought, normal and wet months were observed to be 48.43, 38.80 and 12.76 per cent, respectively while drought, normal and wet weeks were observed with a frequency of 70.07, 16.28 and 13.64 per cent, respectively. The research revealed that 9 years showed moderate drought intensity, 9 years showed mild drought intensity while the remaining 14 years observed with no drought condition. No severe or extreme drought was observed during this study duration. The mean value, standard deviation and co-efficient of variation of annual rainfall were found to be 947.5 mm, 312.3 mm and 32.96 %, respectively. The analysis also indicated the need of assured irrigation during late winter and summer season.

■ **KEY WORDS :** Rainfall analysis, Meteorological drought, Drought year

■ **HOW TO CITE THIS PAPER :** Bajirao, Tarate Suryakant, Singh, Vijay Kumar and Kushwaha, Daniel Prakash (2017). Assessment of meteorological drought for Parbhani district of Maharashtra, India. *Internat. J. Agric. Engg.*, **10**(2) : 260-267, **DOI: 10.15740/HAS/IJAE/10.2/260-267.**

Agriculture is one of the most important sector of India. More than 70 per cent of population of our country is engaged in agriculture sector for employment. India holds about 17.5 per cent population of the world, receives second highest position after china but it contributes only 2.7 per cent area of world. So, in such situation it is very important to increase food productivity against such rapid increasing population. In India, natural disaster like drought occurs more frequently. It hampers agricultural activities, ultimately reduces crop yield and disturbs economic, social balance of human being.

In India, near about 80 per cent rainfall occurs because of monsoon rain but it shows erratic nature. At some region it falls more than need or above annual average and creates situation like flood, waterlogging. Similarly, in some cases it falls with very less magnitude or below the average annual precipitation results to drought like condition. Deficiency of rainfall is the basic cause of drought (Ray *et al.*, 2012). Hence, the rainfall is most dominating factor while designing any agricultural activities (Sonakar *et al.*, 2016). A different rainfall event

at the same area shows temporal and spatial variation with time. The distribution of rainfall, its magnitude and frequency at any particular area are very helpful in crop planning and management. (Singh and Sharma, 2003). Hence, it indicates the importance of analysis of actual changing trend of annual rainfall against natural disaster like drought and flood. Adverse effects of droughts like socioeconomic, agricultural and environmental impacts that can be reduced by assessment as well as forecasting of drought behavior (Manikandan and Tamilmani, 2011). In the past, for Indian continent various researches on investigation of meteorological droughts conducted by various researchers (Kumar and Kumar, 1989; Ray *et al.*, 1987; Shrivastava *et al.*, 2008; Ray *et al.*, 2014; Tiwari *et al.*, 2007; Dabral, 1996; Ramdas and Malik, 1948; Marathe *et al.*, 2001 and Dhar *et al.*, 1979). Drought is a serious hazard against food security causes human migration and mortality. No specific or systematic method have yet been formulated for fully prediction and understanding of drought (Salas, 1986). Depending on the climatic conditions, the occurrence of drought and drought severity varies from place to place (Ray *et al.*, 2014). In India, 18 per cent of geographical area is vulnerable to drought. Long term rainfall and drought analysis is vital for proper planning and management of cropping pattern (Singh *et al.*, 2014). For proper planning and management of agricultural activities weekly data are more useful as compared to monthly, seasonal and annual rainfall data (Bhelawe *et al.*, 2015). In this context, an attempt has been made to assess the meteorological drought occurrence at Parbhani

METHODOLOGY

Location of study area:

The study area is located at 19^0 16' N latitude and 76^0 47' E longitude and situated at an altitude of 409 m above mean sea level. The climate of the study area is characterized as semi-arid and tropical. It comes under moderate to moderately high rainfall zone with an average annual rainfall of 947.5 mm. The soil of the command area is medium deep black clay. The mean maximum and minimum temperature of the study area is 44.6^0C and 21.8^0C, respectively. The mean relative humidity ranges from 30 to 98 per cent. The daily rainfall data of 32 years (1983-2014) was collected from IMD recognized observatory located in Vasantrao Naik Marathwada Agricultural University, Parbhani. The daily rainfall data series were divided in to annual, seasonal, monthly and weekly rainfall data series for determination of drought severity. The whole year is divided into three different seasons of four month each namely summer (from February to May), monsoon (from June to September) and winter (from October to January). For weekly analysis, the annual rainfall data were converted into 52 standard meteorological weeks of 7 days duration. The last day of every year is counted in the 52^{nd} meteorological week while in case of leap year 29^{th} day of February is counted in the 9^{th} meteorological month. The data were analyzed for drought investigation on weekly, monthly, seasonal and annual basis. The average rainfall, standard deviation and co-efficient of variation were also determined.

Categorization of rainfall:

The annual, seasonal, monthly and weekly rainfall values were determined to assess drought occurrences during each period. The annual, seasonal, monthly and weekly rainfall events were classified as drought, normal and wet on the basis of criteria suggested by Sharma *et al.* (1979).

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

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

A month which receives rainfall less than or equal to 50 per cent of average monthly rainfall is called a drought month while 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 which receives rainfall less than or equal to half of the average weekly rainfall is called a dry week

while a week which receives rainfall twice the average weekly rainfall is called a wet week and a week which receives rainfall between the limits of weekly rainfall corresponding to dry and wet week is called a normal week.

Intensity of drought:

The yearly intensity of drought was determined by using the criteria suggested by IMD (1971) which is based on the percentage deviation of rainfall from its long term average and it is given by (Eq.1).

$$Di = \frac{(Pi - \mu)}{\mu} \times 100 \quad (1)$$

where,

Di is the percentage deviation from the long-term average,

Pi is the annual rainfall, mm and

μ is the long term average of the annual rainfall, mm

Drought codification based on percentage deviation of rainfall from normal is presented in Table 1. The percentage of deviation (Di) is used to categorize the drought.

Table A : Codification of drought based on percentage deviation of rainfall from normal value (IMD, 1971)

Percentage deviation of rainfall from normal	Intensity of drought	Code
0.0 or above	No drought	M_o
0.0 to - 25.0	Mild drought	M_1
-25.0 to - 50.0	Moderate drought	M_2
-50.0 to - 75.0	Severe drought	M_3
-75.0 or less	Extreme drought	M_4

RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Rainfall analysis :

The results based on objectives of study are described below:

Distribution of annual rainfall:

The 32 years (1983-2014) average annual rainfall is presented in Table 2. The whole rainfall data indicate that the maximum annual rainfall was received during the year 1990 (1711 mm) while the minimum rainfall was received during the year 2014 (569.7 mm). The mean value, standard deviation and co-efficient of variation of annual rainfall were found to be 947.5 mm, 312.3 mm and 32.96%, respectively. Therefore, the year which receives rainfall less or equal to average annual rainfall plus standard deviation having magnitude equal to 1260 mm will be considered as wet years and the year which receives rainfall equal to or less than average annual rainfall minus standard deviation having magnitude equal to 635.2 mm considered as wet year and in between the range of 635.2 mm and 1260 mm will be normal year which is shown in Table 1. In the drought analysis of 32 years, 3 years namely 1986, 2004 and 2014 were found to be drought years and 7 years namely 1983, 1988, 1989, 1990, 1998, 2005 and 2010 were found to be wet years while the remaining 22 years were found to be normal years. Hence, it reveals that during the period of 1988 to 1990, wet years observed continuously indicating the need flood protection structures. From this study, the worst drought was observed in the year 2014 with an annual rainfall deviation of 39.83 per cent below its mean value while the wettest year was observed as 1990 which showed rainfall magnitude of 80.58 per cent above the mean annual rainfall. After analysis of 32 year data, the drought, normal and wet years were found to be 9.37, 68.75 and 21.87 per cent, respectively.

The yearly drought intensity is determined by using the recommendation given by IMD. Out of 32 year of study duration, 9 years showed moderate intensity, 9 years showed mild drought while the remaining 14 years showed no drought intensity. No severe or extreme drought was found during 32 years study duration as shown in Table 2.

Distribution of seasonal rainfall:

The average rainfall values, number of drought, normal and wet seasons and corresponding rainfall values

Table 1 : Analysis of annual rainfall for drought at Parbhani of Maharashtra

Average rainfall (mm)	Rainfall value (mm)			Total number of years		
	Drought (less than)	Normal (in between)	Wet (more than)	Drought	Normal	Wet
947.46	635.2	635.2 - 1260	1260	03	22	07

Table 2 : Yearly drought intensity of Parbhani, Maharashtra

Year	Annual rainfall, (mm)	Mean rainfall, (mm)	% deviation from mean	Category	Intensity of drought
1983	1451.7	947.4625	53.21978	M_0	No drought
1984	660.4	947.4625	-30.298	M_2	Moderate drought
1985	684.7	947.4625	-27.7333	M_2	Moderate drought
1986	641.8	947.4625	-32.2612	M_2	Moderate drought
1987	819	947.4625	-13.5586	M_1	Mild drought
1988	1564.9	947.4625	65.16749	M_0	No drought
1989	1344.4	947.4625	41.8948	M_0	No drought
1990	1711	947.4625	80.58762	M_0	No drought
1991	742.6	947.4625	-21.6222	M_1	Mild drought
1992	822.7	947.4625	-13.1681	M_1	Mild drought
1993	792.7	947.4625	-16.3344	M_1	Mild drought
1994	790.3	947.4625	-16.5877	M_1	Mild drought
1995	848.7	947.4625	-10.4239	M_1	Mild drought
1996	995.9	947.4625	5.11234	M_0	No drought
1997	970.3	947.4625	2.410386	M_0	No drought
1998	1463	947.4625	54.41244	M_0	No drought
1999	952.8	947.4625	0.563347	M_0	No drought
2000	954.4	947.4625	0.732219	M_0	No drought
2001	1121.7	947.4625	18.38991	M_0	No drought
2002	864.6	947.4625	-8.74573	M_1	Mild drought
2003	767.4	947.4625	-19.0047	M_1	Mild drought
2004	575.2	947.4625	-39.2905	M_2	Moderate drought
2005	1408.3	947.4625	48.63913	M_0	No drought
2006	994.6	947.4625	4.975131	M_0	No drought
2007	853.8	947.4625	-9.88562	M_1	Mild drought
2008	648.1	947.4625	-31.5962	M_2	Moderate drought
2009	672.9	947.4625	-28.9787	M_2	Moderate drought
2010	1295.2	947.4625	36.70198	M_0	No drought
2011	677.5	947.4625	-28.4932	M_2	Moderate drought
2012	688.2	947.4625	-27.3639	M_2	Moderate drought
2013	970.3	947.4625	2.410386	M_0	No drought
2014	569.7	947.4625	-39.871	M_2	Moderate drought

of different seasons are shown in Table 3. The analysis indicated that during the summer, monsoon and winter season the average seasonal rainfall observed to be 41.21, 777.08 and 129.18 mm, respectively. For the summer season, out of 32 seasons, 6 seasons, 1 season and 25 seasons were found to be wet, drought and normal. The drought summer season was observed in year 1983. This information shows need of surplus irrigation during summer season for crop growing. During the analysis of monsoon season 3, 7 and 22 seasons were found to be drought, wet and normal, respectively. The excess water of monsoon season can be stored and utilized in successive winter season. Sometimes the drainage facilities are needful to prevent water logging. The analysis showed that during winter season, there were 3, 5 and 24 drought, wet and normal seasons, respectively. Hence, the analysis reveals the strongest need of supplemental irrigation as well as drainage and flood protection work

Distribution of monthly rainfall:

The average values of monthly rainfall and corresponding values of drought, normal and wet month rainfall are presented in Table 4. Analysis of monthly

rainfall data indicated that minimum average rainfall of 5.56 mm was observed during February month and maximum average rainfall of 232.33 mm was observed during August month. The analysis showed that July month received the highest monthly rainfall of 844.90 mm during the year 2005 while many months of especially summer season were found with no rainfall. As presented in Table 4, the December month has highest drought frequency, receives 24 drought months out of 32 months followed by March, February, January and May. The minimum numbers of drought months were observed during the month of June, receiving 5 drought months out of 32 months. June month received the highest number of normal rainfall of 24 times out of 32 followed by July, September. During the study period of 32 years, the January received highest number of wet months, 7 out 32 followed by February, March, October and November while September received minimum number of wet years, 2 out of 32. During the study duration, the frequency of drought, normal and wet months were found to be 48.43, 38.80 and 12.76 %, respectively. The study revealed that occurrence of drought becomes more apparent when analyzing the monthly rainfall data as compared to long-term seasonal or annual rainfall data. Also the research indicated that soil moisture conservation, rainwater harvesting practices should be adopted to conserve excess water of monsoon season and utilize it for winter and summer seasonal crops.

Distribution of weekly rainfall:

The average values of weekly rainfall and corresponding values of drought, normal and wet weekly rainfall ranges are presented in Table 5. The weekly rainfall distribution shows a better understanding about severity of drought and practices to be followed for short term planning and management of cropping pattern. The total numbers of dry, normal and wet weeks corresponding to different meteorological weeks considering 32 years data are presented in Table 5. The analysis of average weekly rainfall indicated that the maximum average weekly rainfall was observed during 32nd week having magnitude of 60.08 mm followed by 34th, 35th,31st meteorological week while the lowest rainfall was received in 51st meteorological week with average weekly value of 0.04 mm. The weekly analysis indicated that 51st standard meteorological week showed

Table 3 : Analysis of seasonal rainfall for drought at Parbhani of Maharashtra

Season	Average rainfall (mm)	Rainfall value (mm)			Total number of seasons		
		Drought (less than)	Normal (in between)	Wet (more than)	Drought	Normal	wet
Summer	41.21	4.37	4.37-78.05	78.05	01	25	06
Monsoon	777.08	486.06	486.06-1068	1068.0	03	22	07
Winter	129.18	17.9	17.9-240.5	240.5	03	24	05

Table 4 : Analysis of monthly rainfall for drought at Parbhani of Maharashtra

Month	Average rainfall (mm)	Values of rainfall (mm)			Total numbers of month		
		Drought month (less than)	Normal month (in between)	Wet month (more than)	Drought month	Normal month	Wet month
January	8.16	4.08	4.08-16.32	16.32	20	05	07
February	5.56	2.78	2.78-11.12	11.12	22	05	05
March	11.10	5.55	5.55-22.2	22.2	23	04	05
April	6.77	3.38	3.38-13.54	13.54	17	11	04
May	17.78	8.89	8.89-35.56	35.56	20	09	03
June	152.26	76.13	76.13-304.5	304.5	05	24	03
July	223.93	111.97	111.9-447.8	447.86	06	23	03
August	232.33	116.17	116.17-464.7	464.7	10	19	03
September	168.57	84.28	84.28-337.14	337.14	07	23	02
October	86.07	43.03	43.03-172.14	172.14	14	13	05
November	25.55	12.77	12.77-51.10	51.10	18	09	05
December	9.41	4.70	4.70-18.82	18.82	24	04	04
				Total	186	149	49

Table 5 : Analysis of weakly rainfall for drought at Parbhani of Maharashtra

Meteorological week	Average rainfall (mm)	Rainfall value (mm)			Total number of weeks		
		Drought (less than)	Normal (in between)	Wet (more than)	Drought	Normal	Wet
1	1.48	0.74	0.74-2.97	2.97	28	01	03
2	4.17	2.09	2.09-8.34	8.34	28	00	04
3	1.16	0.58	0.58-2.33	2.33	28	01	03
4	1.06	0.53	0.53-2.13	2.13	30	00	02
5	0.55	0.27	0.27-1.09	1.09	30	00	02
6	2.45	1.23	1.23-4.91	4.91	26	01	05
7	1.16	0.58	0.58-2.31	2.31	30	01	01
8	0.95	0.48	0.48-1.90	1.90	28	00	04
9	1.34	0.67	0.67-2.68	2.68	28	02	02
10	6.09	3.04	3.04-12.18	12.18	26	02	04
11	2.53	1.27	1.27-5.06	5.06	30	00	02
12	0.73	0.36	0.36-1.46	1.46	26	01	05
13	1.44	0.72	0.72-2.88	2.88	27	00	05
14	1.19	0.60	0.60-2.68	2.68	25	04	03
15	2.5	1.25	1.25-5.01	5.01	26	02	04
16	1.05	0.53	0.53-2.11	2.11	25	01	06
17	0.98	0.49	0.49-1.96	1.96	22	02	08
18	2.11	1.06	1.06-4.22	4.22	24	02	06
19	1.11	0.55	0.55-2.22	2.22	23	04	05
20	4.9	2.45	2.45-9.81	9.81	24	03	05
21	6.66	3.33	3.33-13.32	13.32	22	05	05
22	8.53	4.27	4.27-17.07	17.07	22	07	03
23	28.65	14.33	14.33-57.30	57.30	18	10	04
24	41.98	20.99	20.99-83.95	83.95	11	16	05
25	43.03	21.52	21.52-86.06	86.06	12	17	03
26	40.31	20.15	20.15 - 80.60	80.60	17	11	04
27	37.83	18.91	18.91-75.66	75.66	15	14	03
28	21.07	21.07	21.07-84.29	84.29	15	13	04
29	43.45	21.73	21.73-86.91	86.91	15	11	06
30	37.64	37.64	37.64-150.54	150.54	16	13	03
31	50.0	25.01	25.01-100.04	100.04	16	11	05
32	60.08	30.04	30.04-120.16	120.16	21	03	08
33	43.58	21.79	21.79-87.17	87.17	15	11	06
34	59.76	29.88	29.88-119.51	119.51	13	15	04
35	56.07	28.03	28.03-112.13	112.13	13	13	06
36	46.84	23.42	23.42-93.68	93.68	14	10	08
37	31.04	15.52	15.52-62.08	62.08	17	09	06
38	41.68	20.84	20.84-83.37	83.37	13	14	05
39	30.58	15.29	15.29-61.15	61.15	18	09	05
40	33.60	16.80	16.80-67.19	67.19	20	06	06
41	22.17	11.08	11.08-44.33	44.33	21	05	06
42	17.17	8.58	8.58-34.33	34.33	22	06	04
43	11.29	5.65	5.65-22.58	22.58	25	02	05
44	3.91	1.95	1.95-7.82	7.82	25	03	04
45	5.28	2.64	2.64-10.56	10.56	24	03	05
46	4.27	2.13	2.13-8.54	8.54	24	02	06
47	7.68	3.84	3.84-15.37	15.37	24	02	06
48	7.03	3.51	3.51-14.05	14.05	29	01	02
49	4.07	2.04	2.04-8.14	8.14	29	00	03
50	2.05	1.02	1.02-4.09	4.09	28	01	03
51	0.04	0.02	0.02-0.08	0.08	31	00	01
52	2.48	1.24	1.24-4.96	4.96	27	01	04
		Total			1166	271	227

Table 6 : Statistical characteristics of monthly, seasonal and annual rainfall distribution for Parbhani of Maharashtra

Month/Season/ Year	Mean (mm)	Standard deviation(mm)	Co-efficient of variation (%)
January	8.16	13.35	164
February	5.56	11.42	205.4
March	11.10	21.23	191.3
April	6.77	8.17	120.7
May	17.78	30.70	172.7
June	152.26	94.56	62.10
July	222.93	162.74	73.00
August	232.33	146	62.84
September	168.6	108.2	64.17
October	86.07	79.73	92.63
November	25.55	40.62	159
December	9.41	21.51	228.6
Season			
Summer	41.21	36.84	89.39
Monsoon	777.08	291.02	37.45
Winter	129.2	111.3	86.14
Annual	947.5	312.3	32.96

maximum number of drought weeks with frequency of 31 out of 32 followed by 4th, 5th,7th and 11th standard meteorological weeks. The minimum number of drought weeks were observed during 24th standard meteorological weeks receives 11 drought weeks out of 32 meteorological weeks. The analysis reveals that the frequency of drought, normal and wet week was found to be 70.07, 16.28 and 13.64 per cent, respectively. The analysis indicated that the maximum frequency of drought weeks was observed in winter and summer season as compared to monsoon season. Hence it indicates the need of supplemental irrigation during this water deficit periods.

Statistical analysis :

After analysing 32 years rainfall data, the monthly, seasonal, annual values of standard deviation and co-efficient of variation are presented in Table 6. The annual standard deviation and co-efficient of variation were found to be 312.3 mm and 32.96 per cent, respectively. Monthly standard deviation varies from 8.17 mm to 162.74 mm. Co-efficient of variation was found to be above 100 per cent for November, December and January months of winter season and and all months of summer season. Maximum value of standard deviation was observed during monsoon season indicating weather instability. The minimum standard deviation of 36.84 mm was observed during April month indicates better weather stability.

Conclusion :

The drought analysis on annual basis indicated that the drought, normal and wet years were found to be 9.37, 68.75 and 21.87 per cent, respectively. Analysis of seasonal rainfall indicated that the occurrence of drought, normal and wet seasons were 7.29, 73.95 and 18.75 per cent, respectively. The percentage of drought, normal and wet months were observed to be 48.43, 38.80 and 12.76 per cent, respectively. Drought analysis on weekly basis showed the occurrence of drought, normal and wet weeks with a frequency of 70.07, 16.28 and 13.64 per cent, respectively. Hence, the analysis indicates that short term weekly or monthly rainfall analysis shows more appearance of drought. After analyzing 32 years rainfall data, the research indicate the need of assured irrigation during winter and summer season as the number of drought weeks are more. Soil water conservation practices, rainwater harvesting practices must be adopted in order to store monsoon seasonal water and utilize it for winter and summer season during deficit period. The analysis indicated that out of 32 years of study duration, 9 years showed moderate drought intensity, 9 years showed mild drought intensity while the remaining 14 years showed no drought intensity. No severe or extreme drought was observed during this study duration.

Authors' affiliations:
VIJAY KUMAR SINGH AND DANIEL PRAKASH KUSHWAHA, Department of Soil and Water Conservation Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. NAGAR (UTTARAKHAND) INDIA

REFERENCES

Bhelawe, Sanjay, Chaudhary, J.L., Manikandan, N. and Deshmukh, Rupesh (2015). Meteorological drought assessment in Raipur district of Chhattisgarh state, India. *Plant Arch.,* **15** (1) : 465-469.

Dabral, P.P. (1996). Meteorology drought analysis based on rainfall data. *Indian J. Soil Cons.,* **24**(1): 37-40.

Dhar, O.N., Rakhecha, P.R. and Kolkarni, A.K. (1979). Rainfall study of severe drought year of India. *Internat. Symposium Hydrological Aspect of drought,* **1** : 28-36.

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.

Kumar, D. and Kumar, S. (1989). Drought analysis based on rainfall data. *Indian J. Soil Cons.*, **17** (1): 55-59.

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) : 136-146.

Marathe, R.A., Mohanty, S. and Singh, S. (2001). Meteorological drought analysis based on rainfall data of Nagpur. *J. Soil & Water Cons.*, **45** : 1-5.

Ramdas, L.A. and Malik, A.K. (1948). *Agricultural situation in India*, Technical Bulletin, ICAR, New Delhi.

Ray, C.R., Senpati, P.C. and Lal, R. (1987). Investigation of drought from rainfall data at Gopalpur, Orissa. *Indian J. Soil Cons.*, **15** (1): 15-19.

Ray, Lala I.P., Bora, P.K., Ram, V., Singh, A.K., Singh, R., and Feroze, S.M. (2012). Meteorological drought assessment in Barapani, Meghalaya. *J. Indian Water Resour. Soc.*, **32** (1-2) : 56-61.

Ray, Lala I.P., Bora, P.K., Singh, A.K., Singh, Ram, Singh, N.J. and Feroze, S.M. (2014). Impact and assessment of meteorological drought on rice based farming system in east Garo Hills District of Meghalaya, India. *J. Agri. Search*, **1**(4): 227-232.

Salas, J.D. (1986). State of the art of statistical technique for describing drought characteristic WARRDCC, International Seminar on Drought Analysis. Italy.

Sharma, H.C., Chauhan, B.S. and Ram, S. (1979a). Probability analysis of rainfall for crop planning. *J. Agril. Engg.*, **16** (3):22-28.

Shrivastava, K. Salil, Raveendra, K. Raj and Pandey, Ashish (2008). Assessment of meteorological droughts in North Lakhimpur district of Assam. *J. Indian Water Resour. Soc.*, **28**(2): 26-31.

Singh, Bhim, Arya, C.K., Singh, Jitendra and Mourya, K.K. (2014). Analysis of rainfall data for storage and irrigation planning in humid south-eastern plain of Rajasthan in India. *J. Appl. & Natural Sci.*, **6** (1): 214-219.

Singh, B. and Sharma, M.K. (2003). A study of pattern of rainfall of crop research station-Masodha(U.P.). *Mausam*, **54** (2) : 552-556.

Sonakar, S.V., Kumar, Vinod and Tomar, A.S. (2016). Drought analysis for Udham Singh Nagar district of Uttarakhand (India). *Internat. J. Res. Engg. & Appl. Sci.*, **6** (4) : 29-37.

Tiwari, K.N., Paul, D.K. and Gontia N.K. (2007). Characterization of meteorological drought. *Hydrology*, **30** (1-2): 15-27.