

Intensification and persistence of kharif agricultural drought during 1987

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(Received 28 March 1988)

सार — भारत के 33 उपमंडलों में, 1987 की दक्षिणपश्चिम मानसून ऋतु (जून से सितम्बर) के दौरान, कृषीय सूखा के तीव्रकरण और अनुलम्बना के अध्ययन हेतु, लेखकों द्वारा सुझाए गए एक सरल संलग्न का प्रयोग करके, थोर्नथ्वाइट की जल संतुलन तकनीक पर आधारित साप्ताहिक शुष्कता असंगति सूचकांक (ए. ए. आई.) का प्रयोग किया गया है। अधिकतम तीव्रकरण और अनुलम्बना की अवधियों तथा क्षेत्रों की पहचान की गई है।

विश्लेषण से ज्ञात हुआ कि मुख्यतः देश के उत्तर व पश्चिम क्षेत्रों में केवल 7 उपमंडलों में सूखा तीव्रकरण घटित हुआ है। तीव्रकरण की प्रत्येक घटना के साथ अनुलम्बना आवश्यक रूप से संबन्धित रही, जब कि विपरीत परिस्थिति दृष्टिगोचर नहीं हुई। अधिकतम समाकलित सूखा अनुलम्बना राजस्थान एवं गुजरात में हुआ। मौसमविज्ञानी सूखा से तुलना करने पर पता चला कि कृषीय सूखा का तीव्रकरण अथवा अनुलम्बना उन उपमंडलों में अवश्य हुआ जो कि शीत ऋतु से प्रभावित हुए।

ABSTRACT. Weekly Aridity Index (AI) based on Thornthwaite's water balance technique has been employed to study the intensification and persistence of kharif agricultural drought during the southwest monsoon season of 1987, in 33 meteorological sub-divisions of India, by adopting a simple criterion. The periods and areas of maximum intensification and persistence have been identified.

The analysis revealed that intensification occurred in only seven sub-divisions confined mostly to the northern and western regions of the country. Persistence was invariably associated with intensification whereas reverse observation was not perceptible. Mixed mode drought persistence was maximum in Rajasthan and Gujarat region. A comparison with meteorological drought, however, revealed that either intensification or persistence of agricultural drought did occur in those sub-divisions that were affected by severe meteorological drought.

1. Introduction

Kharif agricultural production in India is mainly dependent on rainfall during the southwest monsoon season (June to September). Agricultural practices and operations are planned according to the frequency and quantum of rainfall in a region. The delayed, sluggish or weak activity of monsoon in any year leads to large scale drought conditions disrupting badly the agricultural and hydrological operations. Although there is no unique explanation of drought, yet a vivid account of definitions of drought has been compiled from various sources (WMO 1975).

Agricultural drought is marked by the prolonged water deficit in the soil when the plants are damaged due to insufficient water supply. The magnitude of the damage caused to the crops is higher when the drought conditions persist over a period of time, particularly in critical phases of crop growth when water requirement of the crop is important. The crop damage is of more

serious concern with prolonged persistence of drought of severe intensity. Moreover, knowledge of drought persistence over fairly long period of time can provide vital information regarding the tendency of drought to persist over a particular region and may, therefore, serve as a useful means for drought monitoring. In addition to this, information on the intensification of drought during consecutive intervals of time constitutes an important component of drought analysis. The aim of the present study is to analyse the spread, intensification and persistence of kharif agricultural drought over India during 1987. Comparison has also been made with the meteorological drought conditions prevailing over various parts of the country.

Various workers in the world have used different kinds of indices to identify and study drought. In India, too, many workers have studied meteorological and agricultural drought (Appa Rao *et al.* 1983, Bhalme *et al.* 1980, Chowdhury *et al.* 1984, George *et al.* 1969, Moolley

et al. 1983 and Prasad 1986). Prasad (1987) suggested and adopted a simple criterion to study the intensification and recession of droughts in a dry farming region of India by using the percentiles of monthly rainfall during southwest monsoon period. In the present paper, weekly Aridity Index (AI), based on Thornthwaite's (1957) water balance technique, has been used to analyse the spread, intensification and persistence of kharif agricultural drought during 1987. Percentage deficiency of seasonal rainfall (June to September) from the normal has been employed to identify meteorological drought. Intensification and persistence of kharif agricultural drought has been identified on the basis of simple criteria suggested by the authors. Synoptic weather features associated with the activity of monsoon during 1987 have also been discussed.

2. Data and method

For studying meteorological drought, percentage deficiencies of seasonal rainfall from the normal, in respect of 33 meteorological sub-divisions of India, were extracted from *Weekly Weather Report (WWR)* for the week ending on 30 September 1987. The details of synoptic weather features were also obtained from the WWRs published by India Meteorological Department (IMD), Pune.

Agricultural drought analysis was carried out by using weekly Aridity Index (AI). Potential Evapotranspiration (PE) values computed by Rao *et al.* (1971) using Penman's method and Actual Evapotranspiration (AE) values computed by Thornthwaite's (1957) water balance technique were employed to determine AI for each week of monsoon season during 1987. Weekly rainfall of 169 stations, uniformly spread over the map of India, was utilised to compute AE.

According to Thornthwaite's concept of aridity, it describes the water deficiency experienced by plants due to shortage of available moisture. Rainfall is first used by plants to meet their evapotranspirative demands. Any excess amount of rainfall percolates and recharges the soil till it attains field capacity. The surplus water passes as surface runoff or deep drainage. When the rainfall is less than the evapotranspirative demands, the plant sucks moisture from the soil, ultimately making the soil devoid of its moisture.

The basic input data required for computing AE comprises of weekly rainfall (P), normal PE estimated by using Penman's formula and water holding field capacity of the soil (F_c) used from the Soil Map of India published by the National Atlas Organisation of India. The AE values depend on the fact whether rainfall exceeds or falls short of potential evapotranspiration.

Case 1 — When rainfall (P) exceeds PE, addition to soil moisture storage takes place and evapotranspiration proceeds unhindered. In such a case,

$$AE = PE \quad (1)$$

Case 2 — When PE exceeds rainfall (P), there is potential loss of moisture from the soil. Under such circumstances,

$$AE = P - (S_i - S_{i-1}) \quad (2)$$

where,

S_i = Water storage for i^{th} week,
 $-(S_i - S_{i-1})$ = Moisture actually lost from the soil.

Water storage (S_i) is computed by using the following formula :

$$S_i = F_c \times \exp \left[\frac{\text{Acc}(P - PE)_i}{F_c} \right] \quad (3)$$

where, $\text{Acc}(P - PE)_i$ = Accumulated negative values of $(P - PE)_i$. $\text{Acc}(P - PE)_i$ is given by :

$$\text{Case 1 : } P < PE \text{ and } S_i < F_c \\ \text{Acc}(P - PE)_i = \text{Acc}(P - PE)_{i-1} - (P - PE)_i \quad (4)$$

$$\text{Case 2(a) : } P > PE \text{ and } S_i < F_c \\ \text{Acc}(P - PE)_i = S_{i-1} + (P - PE)_i \quad (5)$$

and the expression on the right hand side can reach a maximum value of field capacity (F_c) in our computation scheme.

$$\text{Case 2(b) : } P > PE \text{ and } S_i = F_c \\ \text{Acc}(P - PE)_i = 0$$

which is also consistent with Egn. (3) above as can be verified by putting : $\text{Acc}(P - PE)_i = 0$ in Eqn. (3).

Aridity Index (AI) is then computed as follows:

$$AI = [(PE - AE)/PE] \times 100$$

where PE signifies water need of the plants and $(PE - AE)$ denotes the water deficit. An anomaly of AI from a normal value would thus signify the water shortage from a long term climatic value. The positive values of anomalies represent agricultural drought conditions of varying degree. Following classification is used to identify the intensity of agricultural drought :

Weekly anomaly of AI (%)	Agricultural drought intensity
1-25	Mild
26-50	Moderate
>50	Severe

The data relating to mild, moderate and severe agricultural drought, in 33 meteorological sub-divisions of India, for 18 weeks of southwest monsoon season during 1987 and the account of meteorological drought during 1875 to 1987, was obtained from the Drought Research Unit of IMD at Pune.

Meteorological droughts in IMD are identified when the deficiency of seasonal rainfall (June to September) from the normal exceeds 25 per cent (IMD 1971). The intensity of meteorological drought is

identified by using the following classification :

Seasonal rainfall deficiency (%)	Meteorological drought intensity
26-50	Moderate
>50	Severe

In addition, a drought year is identified when more than 20 per cent area of the country is affected by drought (IMD 1971).

In order to identify the intensification and persistence of kharif agricultural drought, following criteria have been proposed and adopted by the authors :

- Intensification of drought takes place when the intensity of drought enhances from mild to moderate and then severe during at least three consecutive weeks.
- Unimode drought persistence of a particular intensity (mild, moderate or severe) is marked when drought of that intensity continues during at least three consecutive weeks.
- Mixed mode drought persistence occurs when drought of any intensity, from among the mild moderate or severe categorisation, persists during at least three consecutive weeks.

Mild drought in 3 successive weeks is "unimode persistence". Severe drought in 2 successive weeks and moderate drought in the immediately following week constitutes "mixed mode drought persistence". The latter drought persistence has a much stronger adverse impact on crops than the former. In view of this situation, it may be necessary to mention that there is no comparability between the two modes of drought persistence in respect of their adverse impact on crops.

3. Results and discussion

3.1. Monsoon activity

For analysing agricultural drought the monsoon period (June-September) was divided into three distinct phases on the basis of progress, advance and retreat of southwest monsoon during 1987:

Phase I : *Progress phase* — From onset (2 June) to complete progress (27 July)

Phase II : *Active phase* — From complete progress to start of withdrawal (12 September)

Phase III : *Retreat phase* — From start of withdrawal to the end of monsoon season (30 September).

The southwest monsoon during 1987 advanced timely over Kerala on 2 June and covered the whole country by 27 July. The complete progress was delayed by more than 12 days from the normal (15 July). The withdrawal of monsoon commenced on 12 September, late by 11 days from the normal (1 September).

In general, synoptic weather systems that contribute to rainfall during monsoon season, include monsoon trough, monsoon depressions originating from Head Bay, remnants of Pacific typhoons that reintensify into cyclonic storms in the Bay of Bengal, low and upper level cyclonic circulations and western disturbances. During 1987, the prominent synoptic features included 2 depressions and one severe cyclonic storm that recurved and travelled away across Bangla Desh contributing very little to the rainfall over India.

3.2. Agricultural drought

3.2.1. Spread of drought

Progress phase — In the beginning of progress phase, mild to severe drought appeared over the country. The intensification of depression further into a severe cyclonic storm over north Bay in the evening of 4 June provided very little relief to diminish drought conditions due to its rapid weakening as low and its movement across Bangla Desh in a northeasterly direction. By the week ending on 29 July, severe drought spread over Punjab, Haryana, east and west Rajasthan, Saurashtra & Kutch, Gujarat region, west Madhya Pradesh and some Peninsular areas. During this phase, the ratio of sub-divisions affected by moderate and severe drought ranged from 1 : 2 to 1 : 9.

Active phase — In the middle of active phase, drought conditions diminished progressively northwards from southern Peninsula and central parts of India due to the rainfall in association with a depression and some low and upper level cyclonic circulations by the week ending on 26 August. During next two weeks, severe drought further retreated covering only Saurashtra & Kutch and some parts of west Rajasthan and Punjab. However, mild to moderate drought conditions prevailed over India, west of 80° E, till the end of active phase. Formation of a depression over Bihar plateau and neighbourhood on the evening of 11 September, too, provided insignificant relief at the end of this phase. The highest ratio of sub-divisions affected by moderate and severe drought emerged as 1 : 15 in the week ending on 5 August and reversed to 4 : 1 in the weeks ending on 2 and 9 September.

Retreat phase — In the retreat phase severe drought over most of the central parts of India weakened to moderate conditions except some northern parts and east coastal regions and some areas of Saurashtra & Kutch and Gujarat region. In the middle of this phase, the number of sub-divisions affected by severe drought was 13 times more than that covered by moderate drought. At the end of monsoon season, ratio of number of sub-divisions affected by moderate and severe drought emerged as 1 : 13 in the week ending on 23 September and reversed to 2 : 1 in the weeks ending on 15 July and 30 September.

Northeastern parts of the country, however, remained practically free from drought conditions throughout the monsoon period where floods caused havoc to life and property.

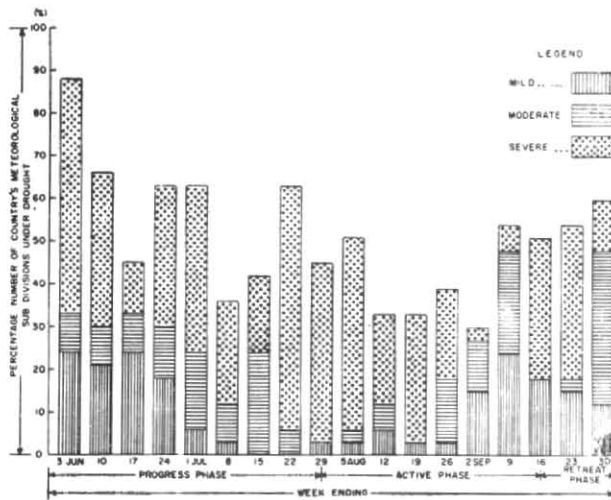


Fig. 1. Percentage number of sub-divisions affected by agricultural drought during southwest monsoon of 1987

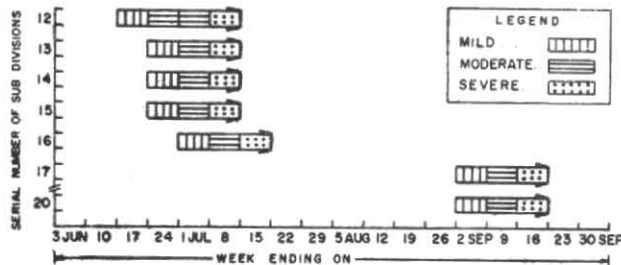
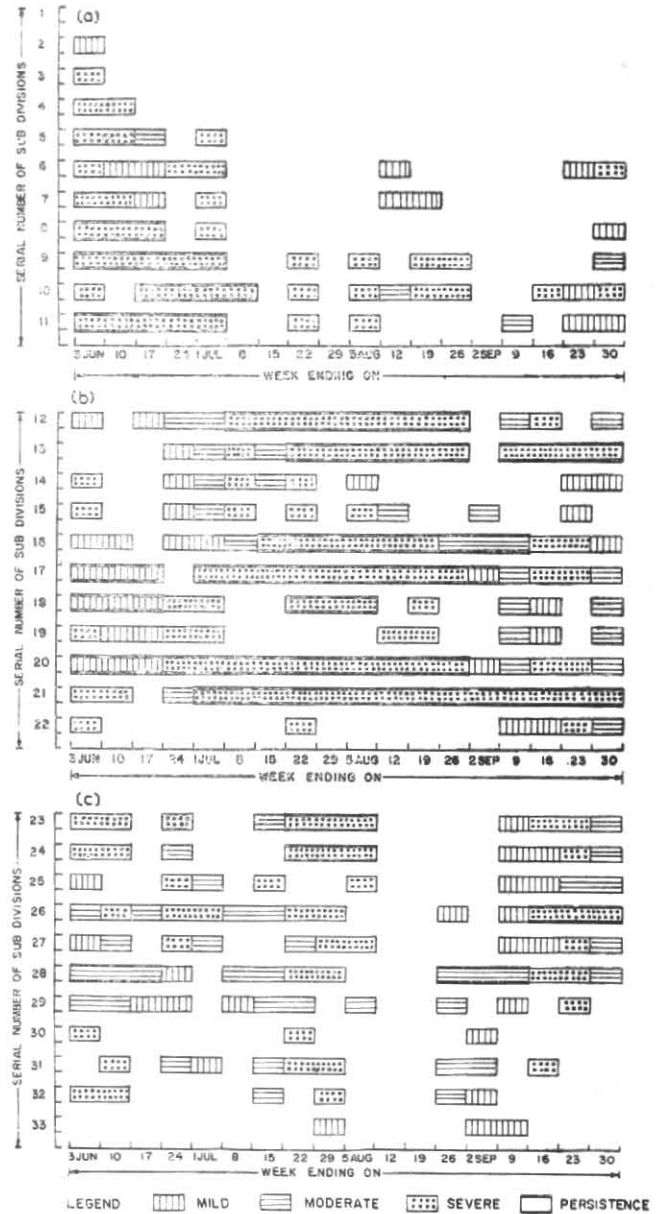


Fig. 2. Intensification of agricultural drought during southwest monsoon of 1987



Figs. 3 (a-c). Spread and persistence of agricultural drought during southwest monsoon of 1987

Fig. 1 depicts the percentage number of meteorological sub-divisions affected by mild, moderate and severe agricultural drought. Less than 30% and 40% sub-divisions were covered by mild and moderate droughts respectively. The number almost doubled to 70% under severe drought indicating a general increase in the frequency of sub-divisions with the enhancement of drought intensity. Higher number of sub-divisions was affected by mild drought during June and September than in July and August. Maximum frequency of sub-divisions covered by moderate drought appeared in the last week of September. An appreciable increase in the frequency of sub-divisions affected by severe drought may be observed generally in all the phases of monsoon season. It suggests a general increase in the spatial

extent of drought with the enhancement of intensity from mild and moderate to severe.

It may be mentioned that few occasions of severe droughts occurred in the extreme northeast and south Peninsular areas. Fluctuations in drought intensity were also irregular in those areas as well as in coastal Andhra Pradesh and Telangana. Mild and moderate droughts were more frequent in Rayalaseema and Tamilnadu.

3.2.2. Intensification and persistence

Intensification of agricultural drought during 1987 is shown in Fig. 2. Spread and persistence of agricultural drought is shown in Figs. 3 (a-c). Sub-divisions

serial numbers in Figs. 2 and 3 correspond to those indicated below :

(1) Arunachal Pradesh, (2) Assam & Meghalaya, (3) Nagaland, Manipur, Mizoram & Tripura, (4) Sub-Himalayan West Bengal, (5) Gangetic West Bengal, (6) Orissa, (7) Bihar Plateau, (8) Bihar Plains, (9) East Uttar Pradesh, (10) Plains of West Uttar Pradesh, (11) Hills of West Uttar Pradesh, (12) Haryana, (13) Punjab, (14) Himachal Pradesh, (15) Jammu & Kashmir, (16) West Rajasthan, (17) East Rajasthan, (18) West Madhya Pradesh, (19) East Madhya Pradesh, (20) Gujarat Region, (21) Saurashtra & Kutch, (22) Konkan & Goa, (23) Madhya Maharashtra, (24) Marathwada, (25) Vidarbha, (26) Coastal Andhra Pradesh, (27) Telangana, (28) Rayalaseema, (29) Tamil Nadu, (30) Coastal Karnataka, (31) North Interior Karnataka, (32) South Interior Karnataka and (33) Kerala.

Intensification was confined to certain sub-divisions clustered together in northern and western parts of India. Intensification commenced first in Haryana and then simultaneously in Punjab, Himachal Pradesh and Jammu & Kashmir followed by west Rajasthan during progress phase. Intensification ended abruptly in Jammu & Kashmir and thereafter drought appeared on isolated occasions. In Himachal Pradesh intensification was followed by moderate and severe droughts and thereafter only mild drought appeared on three different occasions. Intensification was followed by a continuous spell of either moderate or severe drought in Haryana, Punjab and west Rajasthan during the critical phase of crop growth. Drought conditions were, however, relaxed in these sub-divisions in the initial crop growth stages.

Only east Rajasthan and Gujarat region in western India displayed intensification of agricultural drought during the retreat phase followed by severe and moderate droughts during next two weeks. No intensification occurred during active phase of monsoon due, apparently, to the establishment of monsoon current over the country.

Persistence of severe agricultural drought of varying degrees prevailed over large parts of India except extreme northeast and south Peninsular areas. Unimode persistence of severe drought appeared in the beginning of monsoon over Bihar plains and sub-divisions of Uttar Pradesh delaying sowing operations of kharif crops. It emerged swiftly over western parts of India and extended throughout the active stages of growth. Persistence of 6 weeks or more occurred over Haryana, Punjab, east and west Rajasthan, Gujarat region and Saurashtra & Kutch mostly during active phase of monsoon. Maximum unimode persistence of severe drought of 14 weeks duration occurred in Saurashtra & Kutch. Severe drought persisted for only three weeks during active phase in west Madhya Pradesh, Madhya Maharashtra and Marathwada and in coastal Andhra Pradesh in retreat phase. In these sub-divisions, short duration persistence does not appear to suggest adverse impact on crop production.

Unimode persistence of moderate drought occurred in Rayalaseema in the beginning of progress phase and at the end of active phase of monsoon when west Rajasthan also displayed persistence. Mild drought

persisted for three weeks in east Rajasthan, west Madhya Pradesh and Gujarat region commencing with the beginning of progress phase.

Unimode persistence of severe drought was followed by intensification in Haryana, Punjab and west Rajasthan while reverse activity was perceptible in east Rajasthan and Gujarat region.

Drought intensification and persistence for a longer duration of six weeks or more was confined to some northern and western parts of the country. These regions remained unaffected by the rainfall associated with the severe cyclonic storm and the two depressions that formed during the progress and active phases of southwest monsoon during 1987. Also, regions located in the east and extreme northeast of the country displayed no intensification or recession of drought. In those regions, on the contrary, floods caused colossal damage to life and property.

The maximum mixed mode drought persistence occurred in east and west Rajasthan and Gujarat region covering almost the entire monsoon season. Extreme northwestern and some of southern Peninsular areas, however, remained free from such a persistence.

3.3. Meteorological drought

Analysis of meteorological drought revealed 1987 as the 26th drought year during a period of 113 years from 1875 to 1987. Uniquely, it also emerged as the third consecutive drought year during that period. A couple of rare events of two consecutive drought years had, however, occurred during 1904-05 and 1965-66.

About 47 per cent area of the country was affected by meteorological drought during 1987 and it ranked 4th in order of spatial extent during past 113 years. However, 1918 was the worst drought year of the past century when 70 per cent area of the country fell in the grip of drought.

During 1987, in all, 50 per cent sub-divisions were affected by drought of either moderate or severe intensity. The sub-divisions affected by meteorological drought are shown below :

Moderate — Nagaland, Manipur, Mizoram & Tripura, Orissa, East Uttar Pradesh, Hills of West Uttar Pradesh, Jammu & Kashmir, East Rajasthan, Gujarat Region, Vidarbha, Coastal Andhra Pradesh, Kerala.

Severe — Plains of West Uttar Pradesh, Haryana, Punjab, Himachal Pradesh, West Rajasthan, Saurashtra & Kutch.

It will be seen that the meteorological drought of severe order occurred in plains of west Uttar Pradesh, Haryana, Punjab, Himachal Pradesh, west Rajasthan and Saurashtra & Kutch. In these areas either persistence and/or intensification of agricultural drought had invariably taken place. A few sub-divisions, namely Nagaland, Gangetic West Bengal, Vidarbha and Kerala which were covered by moderate drought, did not suffer from either persistence or intensification. This suggests that the areas under severe drought conditions are more likely to be associated with either intensification and/or persistence of agricultural drought during the southwest monsoon season.

4. Conclusions

(a) Aridity Index (AI) based on Thornthwaite's water balance technique has been employed to analyse the week to week march of agricultural drought during the southwest monsoon season of 1987. The severe drought spread over most of India during the progress phase and diminished progressively northwards thereafter in the active phase. Some relief from drought conditions was perceptible for a brief period due to rainfall in association with a couple of depressions, lower and upper level cyclonic circulations and western disturbances. During retreat phase, severe drought weakened to moderate intensity and covered most of the country. The northeastern parts of India, however, remained practically free from drought.

(b) Intensification of drought from mild to moderate and severe occurred in only seven sub-divisions mostly located in northern and western India during progress and retreat phases of monsoon.

(c) Unimode persistence of severe drought of 6 or more weeks' duration was more frequent. Longest persistence of 14 weeks occurred in Saurashtra & Kutch.

(d) Both intensification and persistence of severe drought was observed in Haryana, Punjab, Himachal-Pradesh, east and west Rajasthan and Gujarat region. These areas remained devoid of the rainfall associated with the two depressions and suffered from severe meteorological drought.

(e) Mixed mode drought persistence was maximum in east and west Rajasthan and Gujarat region extending almost throughout the monsoon season.

(f) Percentage deficiency of seasonal rainfall (June to September) revealed meteorological drought during 1987. It appeared as the 26th drought year of India and fourth in order of spatial extent during a period of 113 years from 1875 to 1987. Fifty per cent of the sub-divisions were affected by drought of either moderate or severe intensity. Intensification and/or persistence of agricultural drought invariably took place in all sub-divisions where severe meteorological drought had occurred.

Acknowledgements

The authors wish to express their sincere gratitude to the Director General of Meteorology for encouragement to carry out this research work. They are also very grateful to Shri Nootan Das, Deputy Director General of Meteorology (Weather Forecasting), looking after the current duties of Additional Director General of Meteorology (Research), Pune for going through the manuscript and making helpful suggestions.

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