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Study of drought indices in relation to rice crop production over some States of India

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सार — भारत के कुछ राज्यों के लिए वर्ष 1989 और 1990 की खरीफ के मौसम के दौरान फसल के आकलन के लिए भारत मौसम विज्ञान विभाग और राष्ट्रीय सुदूर संवेदन अभिकरण द्वारा प्रयुक्त सूखा मानीटरन इनडाइसिस की चर्चा की गई है। यह पाया गया है कि भारत मौसम विज्ञान विभाग द्वारा प्रयुक्त सूचकांक निश्चित अवधियों के दौरान निश्चित क्षेत्रों में सामान्य से भीषण सूखा दर्शाते हैं जबकि राष्ट्रीय सुदूर संवेदन अभिकरण ने सूखा-विहीन स्थितियों की सूचना दी है। दूसरी तरफ, 1989 के दौरान, प्रत्येक राज्य द्वारा, पिछले आठ वर्षों के आंकड़ों पर आधारित माध्यमानों के सन्दर्भ सहित प्रारम्भिक आकलित चावल की फसल चार राज्यों में उच्च तथा एक राज्य में कम मान बताती है। राष्ट्रीय सुदूर संवेदन अभिकरण और भारत मौसम विज्ञान विभाग के मध्य उच्च दर्जे का सहसंबंध पाया गया था जो कि 1989 के दौरान फसल आकलन के लिए अंशतः अनुकूल होता है।

ABSTRACT. Drought monitoring indices used by India Meteorological Department (IMD) and National Remote Sensing Agency (NRSA) have been discussed in relation to crop estimates during kharif seasons of 1989 and 1990 for some States over India. It was found that index used by IMD showed moderate to severe drought over certain areas during certain periods, while NRSA reported non-drought conditions. On the other hand, the preliminary estimated rice crop by the respective States during 1989 suggested higher values in four States and lower in one State, with reference to the mean values based on the previous eight years data. A high degree of correlation between NRSA and IMD drought indices was found, which agree partially with the yield estimates during 1989.

Key words — Drought, Aridity index, Potential evapotranspiration, Leaf area index, Rainfall.

1. Introduction

Drought is one of the natural disasters which has a direct impact on socio-economic aspects due to marked decrease of food production of the country. A number of studies have been reported to understand the Indian drought and their impact on foodgrain production of the country and prediction; namely, Parthasarathy *et al.* (1987, 1988, 1990) and Choudhury *et al.* (1989).

Definition of drought directly or indirectly considers the water deficiency due to temporal and spatial distribution of rainfall. Three types of droughts are generally important namely, meteorological, hydrological and agricultural.

Attempts are being made during recent past to detect and monitor droughts during kharif and rabi seasons of India by two organisations, namely, India Meteorological Department (IMD) and National Remote Sensing Agency (NRSA) of Department of Space (DOS). The former utilises rainfall & it's derivatives and the latter, the satellite pictures. NRSA is monitoring drought during the last two years and IMD during the last one decade. An attempt has been made in this paper to compare the indices of IMD and NRSA, in relation to kharif crops of 1989 and 1990.

2. Data

Analysis was carried out using weekly, monthly and seasonal rainfall data of district, meteorological sub-division and State levels, for six and ten States of India respectively in 1989 and 1990 as shown in Fig. 1. IMD uses weekly aridity anomalies computed for 194 stations over India and NRSA uses National Agricultural Drought Assessment and Monitoring System (NAD AMS) bulletins of once in two weeks, for drought assessment.

3. Methodology

3.1. *Drought monitoring by IMD*

IMD uses an index to assess the drought situation based on the Thornthwaite's concept of water deficiency experienced by the growing plants/crops. It is termed as aridity index and given as (PE—AE)/PE. The potential water need of the plant is represented by PE (Potential Evapotranspiration) and the actual evapotranspiration by AE and the difference between these two parameters indicate the water stress.

TABLE 1 (a)

Calendar periods for fortnightly observation

S. No.	Standard week No.	Calendar period
1	23, 24	4 Jun–17 Jun
2	25, 26	18 Jun–1 Jul
3	27, 28	2 Jul–15 Jul
4	29, 30	16 Jul–29 Jul
5	31, 32	30 Jul–12 Aug
6	33, 34	13 Aug–26 Aug
7	35, 36	27 Aug–9 Sep
8	37, 38	10 Sep–23 Sep
9	39, 40	24 Sep–7 Oct

TABLE 1 (b)

Drought severity level adopted by NRSA based on satellite pictures (in per cent)

Delay in vegetation growth	NDVI anomaly compared to normal year (in per cent)	Drought severity level
Up to 1 fortnight	Up to 10	Normal [N]
1–2 fortnights	Above 10 but below 25	Mild [L]
2–4 fortnights	Above 25 but below 50	Moderate [M]
More than 4 fortnights	Above 50	Severe [S]

TABLE 1 (c)

Drought severity level adopted by IMD based on aridity anomalies (in per cent)

Non arid (NA)	0 or less
Mild (M)	1 to 25
Moderate (MO)	26 to 50
Severe (S)	More than 50

The climatic water balance (Thcnthwaite and Mather 1957) provides actual evapotranspiration, water deficiency, water surplus and run-off of a place. These are of great importance in assessing the irrigation requirements, hydrological and agricultural potential of a place (Rao *et al.* 1976). The technique takes into account the precipitation (P) against PE. Positive (P—PE) indicates addition of moisture to already existing soil moisture storage. A negative value can lead to loss of moisture from the soil. In the former case, the actual evapotranspiration, AE=PE and evapotranspiration can proceed unhindered with a healthy growth of crop. In the latter case, AE will be either potential or lesser rate. AE in this case is precipitation *plus* moisture actually lost from the soil. The PE—AE indicates the water deficit of the place, whereas P—AE is water surplus which is available for run-off. Stationwise AE values were computed as per the procedure given by Rao *et al.* (1976) for the standard weeks during the kharif seasons of 1989 and 1990.

Actual PE values for the years 1989 and 1990 are not calculated, however, they are based on Penman's formula and taken from the normal monthly PE values published by Rao *et al.* (1971). The water deficiency or drought over a station was estimated as the difference between actual and normal value, and is called as anomaly.

The anomalies were categorised into three types namely, Mild: 1-25 : Moderate :26 -50 and Severe : More than 50 [Table 1 (c)]. They were plotted and analysed for identification of the deficit/excess areas on weekly basis during monsoon season June to September. The areas of different drought intensities were compared with the previous weeks, for recession or intensification of the drought. This technique was used to study the past Indian droughts by George and Ramasastry (1975), Appa Rao and Vijayaraghavan (1983) and Rajendra Prasad and Datar (1988).

3.2. *Drought monitoring by NRSA*

Prolonged and severe meteorological drought culminates into agricultural drought. Vegetation is a useful and important parameter to detect agricultural drought over a region. This can be effectively monitored by satellite sensors. Choudhary (1988) discussed the role of satellites in drought assessment and monitoring over Sahel. In photosynthesis process, the atmospheric carbondioxide and the leaf water are combined to produce sugar with the help of incident solar energy in the visible (VIS) band. Part of this incident radiation is reflected and the rest is absorbed by the leaf. However, the solar radiation in the near infrared (NIR) band scatter very much within the leaf, due to difference in the refractive indices between the hydrated cells and the inter-cellular air space. Due to this scattering, a large amount of incident solar radiation is reflected back into the atmosphere. The contrasting behaviour of green leaves in the above two spectral bands permits to monitor the status of vegetation with the help of Advanced Very High Resolution Radiometer (AVHRR) of the satellite. The spectral reflectance in visible (VIS) and near infrared regions (NIR) suggest that the normalised difference (NDVI) could reflect the green leaf area index of the crop as :

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{VIS}}{\mathrm{NIR} + \mathrm{VIS}}$$

The polar orbiting NOAA satellite provide AVHRR data for computation of NDVI based on daily global observations. The NDVI is used to represent the vegetation status and thereby the moisture stress faced by the crops which reflects the drought. To minimise the effects like atmospheric clouds, aerosols, water vapour and to make NDVI to be an effective indicator of vegetation, temporal composition was done. NRSA used NOAA-9 satellite observations for generation and preparation of fortnightly composited NDVI maps.

TABLE 2(a)

Fortnightly progressive drought conditions during the year 1989 based on aridity anomaly values of IMD
[For severity level refer Table 1(c)]

	17 Jun	1 Jul	15 Jul	29 Jul	12 Aug	26 Aug	9 Sep	23 Sep	7 Oct
(1) Andhra Pradesh									
(1) Coastal A.P.	NA	M	NA	NA	NA	M	NA	NA	M
(2) Rayalaseema	M/MO	M	NA	NA	M	S	S	NA	M
(3) Telangana	NA/MO	M	NA	NA	NA	NA	M	S	NA
(2) Gujarat									
(1) Gujarat Region	NA	M	NA	NA	M	NA	M	M	MO
(2) Saurashtra & Kutch	M/S	M/S	M/S	NA	M/S	S	S	MO	MO
(3) Karnataka									
(1) Coastal Karnataka	NA	NA	NA	NA	NA	NA	M	NA	NA
(2) South Interior Karnataka	NA/M	MO	NA	NA	M	S	NA	NA	NA
(3) North Interior Karnataka	M	NA	NA	NA	M	S	NA	NA	M
(4) Maharashtra									
(1) Konkan & Goa	NA	NA	NA	NA	M	NA	NA	NA	NA
(2) Madhya Maharashtra	NA/MO	NA	NA	NA	M	NA	M	NA	M
(3) Marathwada	M/MO	NA	NA	NA	M	NA	M	M	MO
(4) Vidarbha	NA/M	NA	M	NA	M	NA	M	M	MO
(5) Orissa									
(1) Orissa	NA/S	S	NA	S	NA	NA	NA	NA	M
(6) Tamil Nadu & Pondicherry									
(1) Tamil Nadu & Pondicherry	NA	M	NA	NA	M	S	NA	NA	M

Note — For symbols please see Table 1 (c).

NRSA (Anonymus 1989, 1990) monitors drought once in two weeks during kharif season [Table 1(a)]. In the bulletin, the drought conditions based on comparative analysis of current picture with those of the previous years, the level of drought over the State and the vegetation trend development are indicated. The severity level is based on delay in vegetation growth, anomaly values and is monitored in three levels, namely, "mild, moderate and severe" [Table 1(b)].

4. Monsoons of 1989 and 1990

India had three consecutively good monsoon rainfall years, *i.e.*, 1988; (16%), 1989 (1%) and 1990 (6%). During 1989, the country as a whole received 1% above normal rainfall with 77% area of the country under excess/normal monsoon rains. This was a year with no major floods except on one occasion over the State of Maharashtra. The seasonal rainfall was in excess in six, normal in twenty three and deficient in two meteorological sub-divisions of the country (Gupta *et al.* 1990). The year 1990 monsoon was the third consecutive good year, with drought prone areas, namely, Gujarat and Rajasthan States receiving atleast normal rainfall. No major floods were reported over the country as a whole. The seasonal rainfall was in excess in seven, normal in twenty-five and deficient in three meteorological sub-divisions. The total rainfall of the country was 6% above normal (Gupta *et al.* 1991).

5. Results and discussion

5.1. *Analysis of rainfall*

In this study, the meteorological sub-divisions considered are part of northwest and peninsular regions of India. The summer monsoon rainfall of these regions are highly variable in time and space. Parathasarathy *et al.* (1987, 1988) studied the droughts and floods over the region by standard deviate of the rainfall for the classification. However, IMD uses percentage departure from mean as the criteria for classification of rainfall, as excess (+ 20% or more), normal (+19 to —19%), deficient (—20 to —59%) and scanty (—60% or less). In the present analysis, the authors have adopted the IMD's classification for comparison of rainfall with drought indices of NRSA.

The weekly, monthly and seasonal rainfall deficiencies over districts and meteorological sub-divisions

TABLE 2 (b)

Fortnightly progressive drought conditions during 1991 based on aridity anomaly values of IMD

[For severity level refer Table 1 (c)]

	17 Jun	1 Jul	15 Jul	29 Jul	12 Aug	26 Aug	9 Sep	23 Sep	7 Oct
(1) Andhra Pradesh									
(1) Coastal A.P.	NA	MO	NA	M/MO	NA	M	NA	MO	NA
(2) Rayalaseema	NA	NA	NA	MO	NA	M/S	NA	NA/S	NA
(3) Telangana	NA	M/MO	NA	M	NA	NA/M	NA	M	NA
(2) Gujarat									
(1) Gujarat Region	M	NA	MO/S	NA/S	NA	NA	NA	M	NA/M
(2) Saurashtra & Kutch	M	NA	S	S	MO/S	NA	NA	M	M
(3) Haryana									
(1) Haryana, Delhi & Chandigarh	M	NA	NA	NA	NA	M	NA	NA	NA
(4) Karnataka									
(1) Coastal Karnataka	NA	NA	NA	NA	NA	NA	NA	M	NA/M
(2) North Interior Karnataka	NA	NA	NA	MO	NA	M	NA/MO	S	MO/S
(3) South Interior Karnataka	NA	NA	NA	MO	NA	NA/S	NA	S	S
(5) Madhya Pradesh									
(1) West Madhya Pradesh	NA	NA	M	NA	NA	NA/M	NA	NA/M	NA/M
(2) East Madhya Pradesh	NA	NA	NA	NA	NA	NA/M	NA	M	NA/M
(6) Maharashtra									
(1) Konkan & Goa	NA	NA	NA	NA	NA	NA	NA	NA/M	M
(2) Madhya Maharashtra	NA	NA	S	NA	NA	NA	MO	S	NA/S
(3) Marathwada	NA	NA	MO/S	NA	NA	NA	NA	M	NA
(4) Vidarbha	NA	NA	NA	NA	NA	NA	N	M	NA
(7) Orissa									
(1) Orissa	NA	MO	NA	NA	NA	NA	NA	NA/M	NA
(8) Rajasthan									
(1) West Rajasthan	M	NA	M/MO	S	NA	M	NA	M	M
(2) East Rajasthan	M	NA	M	S	NA	NA	NA	NA	NA
(9) Tamil Nadu									
(1) Tamil Nadu & Pondicherry	M	NA	NA	M	NA/M	M/S	NA	MO	S
(10) Uttar Pradesh									
(1) East Uttar Pradesh	MO	NA	NA	NA	NA	M	NA	M	M
(2) Plains of West Uttar Pradesh	M	NA	NA	NA	NA	NA/M	NA	NA/M	M
(3) Hills of West Uttar Pradesh	M	NA	NA	NA	NA	NA	NA	NA	M

Note—For symbols please see Table 1(c).

of the country were analysed for spatial and temporal variations. The results are discussed below for meteorological sub-divisions of India covering the States under consideration.

5.1.1. *Seasonal rainfall*

The seasonal rainfall deficiencies indicated that during the years 1989 and 1990, major areas of the country received excess to normal rainfall. During 1989, the seasonal rainfall was normal to excess over the whole country, whereas in 1990 three meteorological sub-divisions received deficient rainfall (Gupta *et al.* 1990, 1991).

5.1.2. *Monthly rainfall*

During the year 1989, June rainfall was normal to excess. In the other months, three to five (out of fourteen) meteorological sub-divisions were affected by deficient to scanty values. The year 1990 showed occurrence of deficient rainfall over many sub-divisions and the maximum areas were affected in the month of July.

It was seen that in the year 1990, more areas were affected by deficient to scanty rainfall, when compared to the year 1989, though the total Indian rainfall in both the years was above normal.

5.1.3. *Weekly rainfall*

The analysis on weekly basis, showed a number of continuous dry spells of two weeks or more, with scanty rainfall. Orissa, Rayalaseema and North Interior Karnataka, showed sometimes continuously dry spells of 5 weeks. Shorter dry spells were seen in all the States more or less during August and to a certain extent in July 1989. August month generally showed major spells of dry weather.

During 1990, some States, like, Gujarat showed dry spells of more than 10 weeks and 5 or more weeks over Coastal Andhra Pradesh and Uttar Pradesh. In general the year 1990 had more dry spells than 1989.

5.1.4. *Analysis of fortnightly district rainfall*

In order to obtain more details on spatial scale, cumulative district rainfall on fortnightly basis was studied. The station network of districts varied from year to year and maximum available data was used in the analysis. It was seen that during June 1989 Tamil Nadu was the worst affected State with more than 50% of the districts under deficient to scanty rainfall.

During 1990, deficient to scanty rainfall occurred over large number of districts covering Haryana, Tamil Nadu, Rajasthan and Uttar Pradesh.

5. 2. *Analysis of drought conditions*

The rainfall analysis of IMD was based on stationwise data and the results were reported on meteorological sub-division scale, whereas the bulletins of NRSA were on districtwise basis. In case, a particular area was affected by two types of drought, say mild to moderate, then it will be indicated as a combined one.

5.2.1. *Drought bulletins of IMD*

The weekly aridity anomaly values, are given in Tables 2(a) and 2(b) for the years 1989 and 1990 respectively. It was seen that there were spells of continuous droughts (moderate to severe) of more than two fortnights. Saurashtra & Kutch even indicated spells of five consecutive fortnights of drought during 1989. During 1990, Saurashtra & Kutch, North Interior Karnataka and Madhya Maharashtra were worst affected. The results suggest that though the overall performance of the monsoon for the country as a whole was very good, certain areas were nevertheless affected by moderate to severe drought conditions.

5.2.2. *Drought bulletins of NRSA*

It is seen from NRSA bulletins that during the year 1989, limited number of districts were affected by drought mainly in the fortnight ending on 17 June. The rest of the monsoon period was generally devoid of any major drought. Some States like Andhra Pradesh, Karnataka and Tamil Nadu showed spells of mild to moderate droughts, during August and September. The picture during the year 1990 was slightly different. In Andhra Pradesh, Gujarat, Tamil Nadu, Karnataka and Rajasthan a number of districts were affected by drought conditions. Tamil Nadu and Karnataka indicated that droughts continued over many districts during the whole season whereas Andhra Pradesh, Gujarat and Rajasthan showed them to be prevalent during the later part of the monsoon season.

5.2.3. *Movements of drought*

The temporal distribution of different drought intensities as monitored by NRSA during the years, 1989 and 1990 indicated less spatial and temporal droughts, whereas IMD analysis suggested that more parts were affected by droughts. Gujarat appeared to be badly affected during both the years.

5.2.4. *Relation between the drought bulletins issued by IMD and NRSA*

Relationship between indices used by these two organisations for two years data was examined by rank correlation method. The correlation indicated that they were highly significant (99% level), suggesting a high degree of association between these two drought estimates.

6. Qualitative assessment of rice crop production during 1989

An attempt was made to compare the rice crop production of the six States during the year 1989 with the data of previous years. For this purposes the short time average of 1981-1988 was compared with the provisional values of 1989 for five States out of six. It was observed that the only, State Tamil Nadu showed a decrease in rice crop production in 1989 and other States showed an increase in their value.

In case of Tamil Nadu, except for the first two fortnights, NRSA index indicated non-drought whereas IMD suggested mild to severe drought. However, Gujarat indicated non-drought conditions by NRSA throughout the season, whereas IMD suggested mild to severe conditions on many occasions. The drought conditions were mostly confirmed to Saurashtra & Kutch areas, this State produces less rice as compared to other districts of the State. This could possibly be a reason for higher average production of Gujarat inspite of wider drought affected areas.

An interesting observation noted during August 1990 was that while IMD/NRSA indices showed the normal conditions, whereas heavy floods occurred over Gujarat causing heavy loss of the standing crops. An insight into the above analysis would suggest that IMD index based on meteorological inputs needs to be integrated with agricultural drought, keeping in view the impact of latest advancements in technological trend (Appa Rao and Srivastava 1990). The extent to which this can be incorporated in NRSA index, which is based on retrieval of data through satellite, requires further detailed study.

7. Conclusions and suggestions

The above study has brought out the following results :

(*i*) During monsoon seasons of the years 1989 and 1990, India received normal to excess rainfall. However, weekly,'fortnightly and monthly rainfalls of the districts and meteorological sub-divisions indicated deficient to scanty values over certain areas during some periods.

(*ii*) The IMD analysis revealed the drought conditions during certain periods, whereas non-drought conditions were mainly notice over major parts of the country by NRSA. However, high correlation between these indices (IMD/NRSA) has been found.

(*iii*) Preliminary crop estimates of 1989 indicated higher yields in four States and lower value in one State, with reference to the mean value based on previous eight years data.

An integrated approach is needed to cover both meteorological as well as agricultural drought, particularly to damages suffered by floods, for better results.

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