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The study of droughts by water budget method over Andhra Pradesh

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ABSTRACT. The study of droughts based on water budget method seems to provide a more realistic approach than on rainfall alone. The frequency and pattern of variation of the drought situations for a group of 9 stations in Andhra Pradesh during the last 70 years have been studied by computing aridity indices values from water balance considerations of Thornthwaite (1955). From this study it has been seen that a minimum of 3-4 effective drought years may be expected over each station in a decade and that liability to drought is maximum in Nellore. An examination of the year to year changes in climate shows that the disastrous drought years generally became arid in nature.

1. Introduction

According to water budget approach by Thornthwaite, drought is defined as a condition when the amount of water needed for transpiration and direct evaporation exceeds the amount in soil. The water deficiency thus results when expressed as the ratio of water need becomes a very useful parameter called aridity index. Subrahmanyam and Subramanyam (1964) reported that for the analytical study of drought this index serves as a useful parameter. This approach has been followed for the quantitative assessment of the severity and extent of drought as well as frequency of their occurrence in Andhra Pradesh during the last 70 years. The results are reported here.

2. Potential evapotranspiration, water balance approach and drought indexing

The monthly or annual potential evapotranspiration of a place gives an estimate of monthly or annual water need. The estimation of monthly potential evapotranspiration (PE) values for the individual years is done by the formula (Thornthwaite 1948)

$$e = 1{\cdot}6\,(10\,t/I)^{a}$$

where I is a complex heat index and derived on the basis of monthly values, a the constant is a cubic function of I and t is montly mean temperature. The total evapotranspiration of the month has then to be adjusted for the length of the day and the length of the month. Substracting the potential evapotranspiration (PE) from the precipitation (P) results in a series of positive and negative differences which represents potential additions and losses to soil moisture storage. When precipitation is greater than the potential evapotraspiration, the actual evapotranspiration (AE) is equal to potential evapotranspiration. The precipitation (P) less than the potential evapotranspiration means potential loss of moisture from the soil. The actual loss of moisture from the soil will be at potential rate or at a lesser rate depending on the amount of moisture remaining in the soil. Actual evapotranspiration in this case is equal to precipitation *plus* moisture actually lost from the soil. Moisture deficit and surplus follow from the simple book keeping calculations, the former being the difference between potential and actual evapotranspiration of the months concerned while the latter is the excess of precipitation values over PE when the soils are at field capacity. If the soils are not at field capacity the excess water by precipitation over the potential evapotranspiration is termed as soil moisture recharge. This moisture is stored in the root zone of soil for subsequent use in dry season. This water is actually utilised by the vegetation before the water deficit occurs. During periods when there is water surplus, climate is moist and when there is water deficit, climate is dry. Water surplus and deficit assessed on a yearly basis expressed as percentage of annual water need are called humidity index (I_h) and aridity index (I_a) respectively. The moisture index used for classification of climate is given by (I_h—I_a). A place is classified as arid if its moisture index is between —100 to —66·7, semi-arid if the same is between —66·7 to —33·3 and dry subhumid when it is between—33·3 to 0. The study of water balance gives an insight to the magnitude

TABLE 1

Normal climatic water balance parameters
(Based on 70-yr data)

Station	Mean annual Rainfall (cm)	P.E. (cm)	Water deficiency (cm)	Mean aridity index	Climatic type
Nellore	106·0	179·8	101·9	56·6	S.A.
Kakinada	109·8	168·7	74·9	44·4	D.S.H.
Nizamabad	101·2	157·1	74·3	47·3	Do.
Visakhaapatnam	95·0	168·0	82·3	49·2	S.A.
Kurnool	63·9	171·5	109·5	63·7	Do.
Cuddapah	76·2	181·7	108·1	59·5	Do.
Hyderabad	78·5	152·5	81·1	53·2	Do.
Hanamkonda	94·4	166·2	81·6	49·1	Do.
Masulipatnam	108·6	169·6	76·3	45·0	Do.

S.A.=Semi-arid D.S.H=Dry sub-humid

of the aridity in the different regions and may be useful for planning operations for reclamation of land etc.

3. Data used and methods for drought classification

Mean monthly meteorological elements published in *Monthly Weather Reviews* (India met. Dep.) have been used. 9 stations of Andhra Pradesh have been chosen and 70 years data (1901—1970) were utilised. For each station following the book-keeping procedure of Thornthwaite (1955), the yearly water balances for the period mentioned were worked out and the aridity indices for each year were calculated. A maximum of soil storage capacity of 15 cm have been assumed consistent with the soil types of these regions for the water balance computations. The normal picture of water balance components have also been worked out and the same are given in Table 1.

The departure of the aridity index from its normal value was determined to study the severity of droughts. For this purpose the statistical procedure as suggested by Subrahmanyam (1964) has been adopted. Individual years of each station were then categorised. The grades of defining drought is given in Table 2.

Table 3 shows the decade-wise frequency of occurrence of drought (as per Table 2) and the total number of drought experienced at each station during the period of 70 years. The frequency of

TABLE 2

Classification of drought

Departure of aridity index from normal	Drought intensity
<0	No drought
$0-\frac{1}{2}d$	Moderate
$\frac{1}{2}d-d$	Large
$d-2d$	Severe
$> 2d$	Disastrous

occurrence of effective drought years (departure of aridity index exceeding $1/2\ d$), namely, large, severe and disastrous is given in Table 4.

4. Climatic classification and frequency of climatic changes

The normal water balance parameters are given in Table 1. The annual potential evapotranspiration which is an estimate of annual water need is the highest in the areas around Cuddapah and Nellore with values near about 180 cm. The annual values of water deficiency is higher at Kurnool, Cuddapah and Nellore. The climatic classification of the stations has been made as per Thornthwaite (1955) criteria and is given in the last column of Table 1. All stations considered in the study are found to be either semi-arid or dry sub-humid.

Seven stations have been found to be of semi-arid climate. Therefore, climatically a large part of the state lies in the semi-arid zone.

In view of the fact that the problem of drought is closely related to the climatic changes, year to year changes in climate have been studied. It is seen that moisture index which is an index of climate is found to exhibit fluctuations of such a magnitude that the climate of certain stations is temporarily changed by one or more stages into the dry or moist type. It is such occurrences that are of great interest and a systematic analysis of these may provide clues to secular or periodic changes in climate (Subrahamanyam 1964). Table 5 shows the decade-wise frequency of such climatic changes for the period of 70 years.

Table 5 reveals that Kurnool which is a semi-arid station has experienced maximum frequency of the arid climate followied closely by Cuddapah. Masulipatnam which belongs to semi-arid climate has shown that on about 36 per cent of the year its climate became humid type. On the other hand Kakinada which is a dry sub-humid place has never experienced arid conditions but about 57

TABLE 3

Decad-wise frequency distribution of drought years of different categories

Station	Drought character	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	Total
Nellore	Moderate	1	1	4	1	1	2	—	10
	Large	1	3	1	2	2	1	1	11
	Severe	3	1	2	4	2	2	—	14
	Disastrous	—	—	—	—	—	—	—	0
Kakinada	Moderate	2	2	4	2	3	2	1	16
	Large	1	4	—	—	2	2	2	11
	Severe	3	1	2	1	—	—	2	9
	Disastrous	—	—	—	—	—	—	1	1
Nazamabad	Moderate	—	2	3	3	1	x	x	9
	Large	1	3	—	—	1	x	x	5
	Severe	1	1	3	—	2	x	x	7
	Disastrous	—	1	—	—	—	x	x	1
Visakhaptnam	Moderate	1	3	1	4	2	1	3	15
	Large	3	1	2	—	—	2	1	9
	Severe	—	2	1	—	3	1	1	8
	Disastrous	—	—	—	1	—	1	—	2
Kurnool	Moderate	—	1	2	3	3	4	1	14
	Large	2	2	2	2	—	—	—	8
	Severe	2	2	2	1	1	—	1	9
	Disastrous	—	1	1	—	1	—	—	3
Cuddapah	Moderate	1	2	4	1	2	2	1	13
	Large	1	2	2	2	2	2	1	12
	Severe	2	1	1	3	1	2	—	10
	Disastrous	1	—	—	—	—	—	—	1
Hyderabad	Moderate	2	—	3	4	1	1	1	12
	Large	2	3	—	—	2	—	3	10
	Severe	2	2	2	1	—	2	—	19
	Disastrons	—	—	—	—	1	1	—	2
Hanamkonda	Moderate	2	1	2	2	1	2	2	12
	Large	1	1	1	1	3	2	2	12
	Severe	3	3	—	—	1	—	—	7
	Disastrous	—	1	—	—	—	—	—	1
Masulipatnam	Moderate	1	1	3	2	4	3	2	16
	Large	1	1	4	1	2	—	2	11
	Severe	4	3	—	—	2	1	1	11
	Disastrous	—	—	—	—	—	—	—	0

TABLE 4

Number of effective drought years in 70 years

Station	Large	Severe	Disastrous	Total
Nellore	11	14	—	25
Kakinada	11	0	1	21
Nizamabad	5	7	1	13
Visakhapatnam	9	8	2	19
Kurnool	8	9	3	20
Cuddapah	12	10	1	23
Hyderabad	10	9	2	21
Hanamakonda	12	7	1	20
Masulipatnam	11	11	—	22

per cent of the period its climate became semi-arid type. Hyderabad, a semi-arid station shows persistency of its climate.

Table 6 shows the distribution of years of lowest rainfall, disastrous drought and climatically arid type. It can be seen that the years of lowest rainfall do not coincide with the years of disastrous drought in the case of Kakinada, Nizamabad but coincides in the case of Visakhapatnam, Kurnool, Cuddapah Hyderabad and Hanamkonda. It is also seen that the disastrous drought years of Kakinada and Nizamabad have not created arid conditions but in the case of Visakhapatnam, Kurnool, Cuddapah, Hyderabad and Hanamkonda the stations have become arid type.

TABLE 5

Decade-wise frequency distribution of different climatic types in 70 years

Station	Climatic character	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	Total
Nellore	Arid	–	–	–	–	1	–	–	1
	Semi-arid	7	4	8	8	5	8	6	46
	Dry Sub-humid	3	6	2	2	4	2	4	23
	Moist Sub-humid	–	–	–	–	–	–	–	–
Kakinada	Arid	–	–	–	–	–	–	–	–
	Semi-arid	7	6	5	5	6	3	8	40
	Dry Sub-humid	3	4	5	5	4	6	2	29
	Moist Sub-humid	–	–	–	–	–	1	–	1
Nizamabad*	Arid	–	–	–	–	–	–	–	–
	Semi-arid	2	8	8	3	6	–	–	27
	Dry Sub-humid	2	1	2	7	4	–	–	16
	Moist Sub-humid	–	1	–	–	–	–	–	1
Visakhapatnam	Arid	–	–	–	1	–	1	–	2
	Semi-arid	7	9	7	7	8	7	9	54
	Dry-Sub-humid	3	1	3	2	2	2	1	14
	Moist Sub-humid	–	–	–	–	–	–	–	–
Kurnool	Arid	4	5	5	5	2	1	1	23
	Semi-arid	6	5	5	5	8	9	9	47
	Dry Sub-humid	–	–	–	–	–	–	–	–
	Moist Sub-humid	–	–	–	–	–	–	–	–
Cuddapah	Arid	4	1	2	4	3	2	1	17
	Semi-arid	6	9	8	6	7	8	9	53
	Dry Sub-humid	–	–	–	–	–	–	–	–
	Moist Sub-humid	–	–	–	–	–	–	–	–
Hyderabad	Arid	–	1	–	–	1	2	–	4
	Semi-arid	9	5	10	9	9	7	8	57
	Dry Sub-humid	1	4	–	1	–	1	2	9
	Moist Sub-humid	–	–	–	–	–	–	–	–
Hanamkonda	Arid	–	1	–	–	–	–	–	1
	Semi-arid	8	6	9	7	9	7	7	53
	Dry Sub-humid	2	3	1	3	1	3	3	16
	Moist Sub-humid	–	–	–	–	–	–	–	–
Masulipatnam	Arid	–	–	–	–	–	–	–	–
	Semi-arid	8	5	6	6	9	6	5	45
	Dry Sub-humid	2	3	4	4	1	3	5	22
	Moist Sub-humid	–	2	–	–	–	1	–	3

*Based on 44 years

TABLE 6

Station	Lowest rainfall years	Disastrous drought years	Arid years
Nellore	1947	*Nil*	1945
Kakinada	1905	1968	*Nil*
Nizamabad	1909	1920	*Nil*
Visakhaparnam	1951	1935, 51	1935, 51
Kurnool	1920	1920, 22, 41	23 years
Cuddapah	1904	1904	17 years
Hyderabad	1941	1941, 51	1913, 41, 51, 52
Hanamkonda	1920	1920	1920
Masulipatnam	1907	*Nil*	*Nil*

5. Time and space variability of the intensity of drought situations

(*a*) *Hyderabad*—The normal annual rainfall of the station is 78·5 cm. During the 70 years the highest annual rainfall of 182 per cent of the normal occurred in 1915. The year 1941 experienced the lowest annual rainfall of 61 per cent of the normal. As seen from Table 5 the climate of the station had changed 4 times to the arid type (in the years 1913, 1941, 1951, 1952) and 9 times to the dry sub-humid type. Table 3 shows that the station was liable to 12 years of moderate, 10 of large, 9 of severe and 2 of disastrous droughts (in the years 1941, 1951). Table 4 shows that the

total number of effective drought years was 21 with an average of 3 in a deacade. The elements of the water budget (cm) for the 4 driest years with wet year and normal are given below :

Item	Normal	Dry years				Wet year
		1913	1941	1951	1952	1915
Rainfall	78·5	48·8	48·2	38·1	45·7	154·9
Water need	152·5	158·5	164·9	155·4	147·9	143·1
Water deficit	81·1	108·6	116·2	112·8	102·2	54·4

The largest water need and deficit was in the year 1941 and followed closely by the year 1951. The year 1951 received 10 cm less rainfall than the year 1941, inspite of the fact that the year 1941 was comparatively bad than the year 1951 as the dificiency registered was by 4 cm more.

(*b*) *Visakhapatnam*—The variation in annual rainfall from year to year is small. During the 70-year period the highest rainfall amounting to 152 per cent of the normal occurred in the year 1910 when its moisture index rose to —2·0. The lowest annual rainfall which was 29 per cent of the normal occurred in the year 1951 and the moisture index fell to —81·5. The station experienced arid climate in the year 1935 and 1951. As seen from the Tables 3 and 4 there were 34 drought years, 2 being disastrous (in the year 1935, 1951), 8 severe, 9 large and 15 of moderate intensity. A minimum of 3 effective drought years may be expected in a decade. The elements of the water budget (cm) for the deficit and surplus years with the normal are given below. :

Item	Normal	Dry years		Wet year
		1935	1951	1910
Rainfall	95·0	47·3	27·3	144·2
Water need	168·0	164·6	166·8	161·2
Water deficiency	82·7	115·1	135·9	51·5

The year 1951 received very poor rainfall and hence experienced the greatest water deficiency of 135·9 cm.

(*c*) *Kakinada*—The highest annual rainfall amounting to 161 per cent of the normal was experienced in the year 1936, and the moisture index rose to —1·9. The lowest annual rainfall of 36 per cent of the normal occurred in the year 1905 when the moisture index fell to—60·8. As seen from Table 3 Kakinada experienced a total of 37 drought years, 1 being disastrous in the year 1968 , 9 severe, 11 large and 16 moderate.

(*d*) *Nellore*—The normal annual rainfall of the station is 106 cm. The highest annual rainfall amounting to 171 per cent of the normal occurred in the year 1946 and in the very next year 1947 the station had the lowest annual rainfall amounting to 49 per cent of the normal. Its climate became arid in the year 1945 when its moisture index fell to —69·8. It is interesting to note that although the year 1947 was the year of the lowest rainfall, its climate was not affected adversely while the year 1945 with more rainfall than the year 1947 by 21 cm became arid type. Probably the soil moisture plays a dominant role in controlling the deficiency and hence the aridity. Table 3 shows a total of 36 drought years, 14 being severe, 12 large, 10 moderate and none of disastrous intensity. It is seen from Table 4 that Nellore had exprienced a maximum number of 25 effective drought years. The elements of the water budget(cm) of 3 consecutive years when the station received excess and deficit rainfall is given below :

Item	Normal	1945	1946	1947
Rainfall	106·0	53·9	181·3	51·8
Water need	179·8	179·4	180·6	181·4
Water deficit	101·9	125·3	96·0	114·5

(*e*) *Kurnool*—The highest rainfall amounting to 169 per cent of the normal was received in 1949 and the lowest with 44 per cent of the normal in the year 1920. Moisture indices in these years were —39·5 and —84·0 respectively. As seen from Table 5 there were 23 shifts to the arid type climate and none to the humid type. There were 34 drought years; 3 being disastrous (in the year 1920, 1922, 1941), 9 severe, 8 large and 14 moderate. Largest water deficit of 150·3 cm was noticed in the year 1920 which proved to be disastrous drought year. During the period a total of 20 effective drought years were recorded and thus on an average a minimum of 3 such drought years may be expected in a decade.

(*f*) *Cuddapah*—The highest rainfall amounting to 161 per cent of the normal was received in 1903 and in the very next year 1904 the station had the lowest annual rainfall amounting to 40 per cent of the normal. It is seen from Table 5 that its climate became arid type 17 times. It had experienced 36 drought years; 1 being disastrous (in the year 1904) , 10 severe, 12 large and 13 moderate. A minimum of 3-4 effective drought years may be expected in a decade.

(*g*) *Nizamabad*—The highest annual rainfall amounting to 156 per cent of the normal occurred in the year 1928 and the lowest annual rainfall of

59 per cent of the normal was received in the year 1909. It experienced a total of 22 drought years, 1 being disastrous (in 1920), 7 severe, 5 large, and 9 moderate. Although the year 1909 received the lowest rainfall, it was not a disastrous drought year. Probably the distribution of soil moisture had minimised the intensity of the drought. The station experienced 13 effective drought years.

(*h*) *Masulipatnam*—During the period under study the highest annual rainfall amounting to 163 per cent of the normal occurred in the year 1917 and the lowest annual rainfall was 57 per cent of the normal in the year 1907. It had experienced a total of 38 drought years, 11 being severe, 11 large and 16 moderate. Thus a minumum of 3-4 effective drought years may be expected in a decade. The lowest water deficit occurred in the year 1913. The elements of the water budget for the two consecutive dry years 1913 and 1914 are given below :

Item	Normal	1913	1914
Rainfall	108·6	80·0	75·3
Water need	169·6	172·0	171·3
Water deficit	76·3	102·5	92·1

It is interesting to note that on the basis of rainfall, 1914 was a year of drought more severe than 1913. But the largest water deficit occurred in the year 1913 which received more rainfall than 1914. This supports the contention that the water budget method is a rational approach for the assessment of drought intensities.

(*i*) *Hanamkonda*—The climate of the station became once arid in the year 1920 with a moisture index –77·7 and 16 times the climate became dry sub-humid type. The station experienced a total of 32 drought years, 1 being disastrous (in the year 1920), 7 severe, 12 large and 12 moderate. A minimum of 3 effective drought years may be expected in a decade.

6. Conclusions

(1) The pattern of variation of the drought situations and the associated parameters based on water budget method in Andhra Pradesh were studied for 9 stations in the semi-arid and dry subhumid areas for a period of 70 years (1901-1970). It was noticed that there was no significant spatial variation in the frequency distribution of total number of effective droughts in Andhra Pradesh. A minimum of 3·4 drought years may be expected over each station in a decade and that the liability to drought is maximum in Nellore.

(2) It is, however, seen the years of lowest rainfall may or may not coincide with the years of disastrous drought intensity. This might have resulted either because the years of lowest rainfall might have a good distribution of rainfall or the deficit might have been offset by the preceding year and thus the drought intensity is reduced. Therefore, a systematic study of droughts based on the soil moisture availability deserves specific attention.

(3) An examination of the year to year changes in climate shows that the disastrous drought year generally became arid type.

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REFERENCES

Jagannathan, P. 1968 Agro-climatic zoning of India and their specific problems. I.C.A.R. Symp. on Crop patterns in India, New Delhi.

Subramanyam, V. P. and Subramaniam, A. R. 1964 *Indian J. Met. Geophys.*, 15, 3, pp. 393-402.

Subramanyam, V. P. 1964 Climatic water balances of the Indian Arid Zones, Symp. on Problems of Indian Arid Zone, Jodhpur.

Thornthwaite, C. W. 1948 *Geogr. Rev.*, 28, 1.

Thornthwaite, C. W. and Mather, J. R. 1955 The water balance, Publication in Climatology, 8, 1.