WATER RESOURCES MANAGEMENT UNDER DROUGHT CONDITIONS

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ABSTRACT *Drought is one of the most disastrous natural calamities that have affected human beings, agriculture and livestock throughout the history. Drought is characterized by deficit in water availability resulting either from sub-normal rainfall, erratic rainfall distribution, higher water requirements or a combination of all these factors. Under drought conditions, the management strategies need to be different than the normal times and there is a great need to evolve planning and operation tools for the same. Drought indices, deficit of rainfall, starting period, severity and termination are the important parameters to be analyzed, in order to evolve a more realistic planning for the mitigation of the drought. In this paper, the definition of drought, identification of droughts and their characterization have been elaborated with a case study of a drought affected district. Subsequently, the important strategies for the planning and management of water resources during drought situations are highlighted.*

Keywords: Drought characteristics, rainfall analysis, arid region, drought severity.

INTRODUCTION

Drought is a phenomenon, which has occurred in different parts of the world for centuries with unpredictable frequencies due to variability of rainfall, delay in onset of monsoon, long dry spells during the crop-growing season and early withdrawal of monsoon. It not only affects the socio-economic condition of million of people in drought affected areas, but also endangers the economy of a country. The escalating impacts of droughts have increasingly drawn the attention of scientists, planners and society. The vulnerability to drought in relation to the increasing needs of the growing population has become a point of great concern, especially on the food front. In spite of the technological developments in providing improved crop varieties and better management practices, in India, agriculture has been considered a gamble as the agricultural productivity is strongly influenced by the vagaries of the monsoon. While water scarcity and droughts are commonly used indistinctively, they are quite different phenomena affected by natural causes and water management practices. Water scarcity is defined as a situation where insufficient water resources are available to satisfy long-term average requirements. It refers to long-term water imbalances, combining low water availability with a level of water demand exceeding the natural recharge. Droughts, on the other hand, represent relevant temporary decrease of the average water availability, refer to important deviations from the average levels of natural water availability and are considered natural phenomena. The assessment carried out in the past thirty years reveals that drought events have regularly occurred. However, the duration of each event and the area and population affected have varied throughout this period. It is not possible to control the occurrence of droughts although the resulting impacts may be mitigated to a certain degree, namely through appropriate surveillance and management strategies.

Droughts are the resultant of acute water shortage due to shortage of rainfall over extended periods of time affecting various human activities and lead to problems like widespread crop failure, unreplenished ground water resources, depletion of water availability in reservoirs, shortage of drinking water and, reduced fodder availability etc. Often an area or region adopts itself to a certain level of water shortage based on the long-term climatic conditions experienced by it. Any negative departure from these levels creates conditions of drought, depending on the intensity and duration of this deficit. Thus drought conditions differ from region to region. Also the impact of drought over a region varies depending on which economic activity is impaired. Because drought affects many economic and social sectors, scores of definitions have been developed by a variety of disciplines and the approaches taken to define it also reflect regional and ideological variations. With increasing population and increasing demand for an additional water supply, be it for municipal use or for irrigated agriculture, the key to the successful operation of any water resources system lies in the management of the system under uncertain supply such as in droughts.

In order to manage such conditions, one needs to know the characteristics of droughts and an appropriate methodology that would identify such drought condition in an accurate way. Many kinds of drought definitions and indices have been developed and documented by variety of disciplines. Most of the drought indices developed in the past is adhoc and work in isolation. An operational definition of drought based on the availability of water would be needed for the assessment and the management of droughts.

This paper presents the general definition of drought, application of a well tested procedure, proposed by Mohan and Rangacharya (1991) for the identification of droughts, and highlights the important strategies for the planning and management of water resources during drought situations. The methodology has been validated by analyzing droughts based on monthly rainfall series of four sub-basins of a drought affected district of Tamilnadu and found to be efficient in identification and characterization of droughts. Based on the identified droughts, several strategies have been suggested for the management of droughts in the study area.

DEFINITION OF DROUGHT

In general, drought conceptualization differs with different people, based on the purpose for assessment, variable used for defining the drought, and the hydrological and meteorological aspects of a location. To a meteorologist it is the absence of rain while to the agriculturist it is the deficiency of soil moisture in the crop root zone to support crop growth and productivity. To the hydrologist it is the lowering of water levels in lakes, reservoirs, etc., while for the city management it may mean the shortage of drinking water availability Thus, it is unrealistic to expect a universal definition of drought for all fields of activity. Droughts differ from other natural hazards in several ways as detailed below:

(a) no universal definition;
(b) no single indicator or index can identify precisely the onset and severity of the event;
(c) slow-onset, creeping phenomenon that makes it difficult to determine the onset and end of the event;
(d) duration may range from months to years;
(e) impacts are generally non-structural and difficult to quantify;
(f) spatial extent is usually much greater than for other natural hazards, making assessment and response actions difficult, since impacts are spread over larger geographical areas;
(g) because of their potentially long duration, the core area or epicenter will change over time, reinforcing the need for continuous monitoring of climate and water supply indicators
(h) impacts are cumulative and the effects magnify when events continue from one season or year to the next;

Eventhough, the drought has no universally acceptable definition, it can be defined as a lack or shortage of water with respect to normal availability in a place for a continuously long period of time (ShakirAli, 2001). Drought is normally defined in terms of deviation from the normal rainfall. In this type of definition, drought occurs at a location, when the observed rainfall for any week, month, session or year is less than an arbitrarily chosen proportion of the normal rainfall. Droughts may be classified in three ways as follows:

Meteorological Drought: It may be defined as a situation when the rainfall during a year is substantially below normal rainfall.

Hydrological Drought: Hydrological drought shows the marked depletion of surface water and consequently drying up of reservoirs, lakes etc. It occurs in a prolonged meteorological drought condition and has wide consequences not only to agricultural crops, but also to other water based industries.

Agricultural Drought: It may be defined as a lack or shortage of soil moisture in root zone to support healthy crop growth during the crop growing season leading to water stress, wilted crop and damage and failure of crop. Agricultural droughts do not necessarily coincide with period of meteorological droughts and hydrological drought.

Drought has various classifications for better understanding of drought severity. The limit of various drought indices based on the rainfall deficiency, ratio of rainfall to potential evapotranspiration, aridity index and run off volume are discussed according National Commission on Agriculture (NCA 1976) the droughts have been classified on the basis of annual rainfall deficiency under three conditions:

Mild Drought: Annual rainfall deficiency from normal ranges between 0 - 20%
Moderate Drought: Annual rainfall deficiency from normal ranges between 20 - 50%
Severe Drought: Annual rainfall deficiency from normal is more than 50%

Consequently the areas were also classified into two groups as follows:

Moderate drought affected area: Areas where annual rainfall is 25% less than normal rainfall with 5 years return period or 20% probability.
Chronically severe drought affected area: Areas where annual rainfall is 25% less than normal rainfall with 2.5 years return period or 40% probability.

The drought prone areas in our country are classified based on annual rainfall departures fall either in arid, semi-arid and dry sub-humid regions where droughts occur frequently. The frequencies of occurrence of droughts in different meteorological sub-divisions are given in Table 1. The historical rainfall data of the country suggests that the monsoon rainfall recorded in the country during drought year 1918 was the lowest. The severe drought years that occurred over the 200 years (1801 to 2000) in the country are shown in Table 2.

Table 1 Frequency of occurrence of drought in different meteorological sub-divisions

Meteorological sub-division	Frequency of deficient rainfall
Assam	Very rare. Once in 15 years
West Bengal, Madhya Pradesh, Konkan, Bihar and Orissa	Once in 5 years
South Interior Karnataka, Eastern Uttar Pradesh and Vidarbha	Once in 4 years
Gujarat, east Rajasthan, western Uttar Pradesh	Once in 3 years
Tamil Nadu, Jammu & Kashmir and Telangana, West Rajasthan	Once in 2.5 years

(Source: Choudhury, 2007)

Bhamle and Mooby (1980) developed a drought index based on monthly monsoon (June-September) rainfall and classified the drought into four categories:

Mild drought -1
Moderate drought -2
Severe drought -3
Extreme drought -4

The drought index is defined as

$I_K = 0.5\ I_{K-1} + (M_K / 48.55)$ (1)

$M = [100 \times (R - Ravg) / \sigma_R]$ (2)

where, I_K, I_{k-1} is the drought intensities of the K^{th} and K_{-1}^{th} month, M is moisture index, R is monthly rainfall; Ravg is mean rainfall and σ_R is standard deviation of rainfall.

Table 2 Reported drought events in India over the past 200 years:

Period	Drought years	Period	Drought years
1801 - 1825	1801,4,6,12,19,25	1901 - 1925	1901,4,5,7,11,18,20
1826 - 1850	1832, 33,37	1926 - 1950	1939,41
1851 - 1875	1853,60,62,66,68,73	1951 - 1975	1951,65,66,71,72,74
1876 - 1900	1877,83,91,97,99	1975 - 2000	1977,78,79,82,83,85,8 7,88,92

(Source: Choudhury, 2007)

According to National Commission on Agriculture (NCA 1976), the agricultural drought is an occasion when the rainfall in a week is half of the normal rainfall or less, when the normal rainfall is 5 mm or more. If there are four such consecutive weeks in the rainy season (15th June to 15th October) the area may be classified as drought affected. Khambete & Biswas (1984) inferred from their drought study over dry farming tract of Maharastra that agricultural drought occurs when there is a rainfall deficiency of less than 18 mm per week during the month of June to October. They classified the drought into five categories based on drought proneness index (DI), and the Index of drought proneness is defined as

$DI = (P \times P_1) \times 100 / I - P_0$ (3)

where, P is initial probability of wet week, ($P = P_0 / [1 - (P_1 - P_0)]$; P_0 is the probability of wet week preceded by dry week, and P_1 is probability of wet week preceded by wet week.

Chronic Drought	$DI \leq 20$
Severe Drought	$20 < DI \leq 35$
Moderate Drought	$35 < DI \leq 50$
Mild Drought	$50 < DI \leq 70$
Occasional Drought	$70 < DI$

Sastri and Chakravarthy (1984) defined the drought considering crop growth stages during growth period and considering a day having less than 6 mm rainfall as a dry day. If a dry week of seven such sequential dry days occurs 4 times during vegetative, 2 times in tasseling, 4 times in grain filling and maturity phases of the maize crop or 10 times during the sowing to harvesting period of this crop then the drought is called an agricultural drought. Das et al. (1971) gave climate crop growth index by using ratio of annual rainfall to evapotranspiration ratio. Mishra (1983) gave the classification based on the ratio of monthly ratio of rainfall to potential evapotranspiration. Sastri and Chakravarthy (1984) have used Annual Index of Moisture Adequacy. Ramana Rao et al. (1982) suggested drought classes based on ratio of actual evaporation to potential evapotranspiration at crop growth stages. Lohani et al. (1990) classified the drought based on departure from runoff volume. Mohan and Rangacharya (1991) proposed a methodology which modifies the procedure for drought analysis given by Herbst et al. (1966). The review of literature reveals that a number of drought indices are available. It is necessary to test the suitable drought index and the appropriate one should be selected according to the agro-ecological condition of the region for which drought analysis is required.

IDENTIFICATION OF DROUGHT

Drought can be quantified using the three important parameters, namely, initiation and termination i.e. location in absolute time, duration, and the severity. Dracup et al. (1980) proposed that the following steps are required in drought analysis at a single site:

a) Determination of nature of water deficit: The first step is to determine the nature of the water deficit. Thus one has to select the basic phenomenon or phenomena for the definition of drought. In this study, rainfall is considered as the basic phenomena.

b) Identification of the variable: In this step, the variable (or variables) describing the phenomenon must be determined, such as whether to use monthly rainfall or a similar variable. The total depth of rainfall in the catchment is taken as the variable in this study.

c) Identification of the Integral period of time: The integral period of time is the time increment, i.e. hour, day, month, season, year etc., over which the hydrological data are averaged or totaled in the drought analysis. The month is taken as the integral period of time in this study.

d) Choice of truncation level: The fourth step is to establish the truncation level which is employed to distinguish droughts from other events in the historic record. In this study, the truncation level is defined for each month as the mean monthly rainfall of that month. It is to be noted that the truncation level may be a misnomer as a value less than this indicates a deficit which need not necessarily cause a drought, yet if sustained for a period of time, can result in a drought. The characteristics of droughts like onset, duration, and severity have been analyzed from an operational standpoint.

The procedure suggested by Mohan and Rengacharya (1991) has been adopted in the present study for the identification of droughts from the long term monthly rainfall data of a drought affected district of Tamilnadu. The main problem in analyzing droughts is separating their occurrence in the record, i.e. defining their occurrence. The procedure for determining the onset of a drought is given below.

If T(t) denotes the truncated rainfall (i.e. monthly mean rainfall) for time period t, Q(t) denotes the actual rainfall in time period t, E(t) denotes effective rainfall in time period t and D(t) denotes the difference (either positive or negative) in time period t, then:

$$E(t) = Q(t) + D(t-1) \times W(t) \quad (4)$$

$$D(t) = Q(t) - T(t) \quad (5)$$

where, W(t) = weighing factor for month t and is given by

$$W(t) = 0.1[1 + T(t) / \sum_{t=1}^{12} T(t) / 12] \quad (6)$$

Using equations (4), (5) and (6), the effective rainfall for each month of record was calculated by allowing for the carry-over effect of surplus or deficit of rainfall in the preceding month; for the first month of record the carry-over was taken as zero so that effective rainfall was equal to the actual rainfall. This process was continued to obtain the effective monthly rainfall for the full period of record. Mohan and Rengacharya (1991) suggested a new formula for computing truncated rainfall which takes into account of the monthly variability. The new formula is given by:

$$T(t) = \overline{Q}(t) - [\sigma_t^2 / \overline{Q}(t)] \quad (7)$$

where, $\overline{Q}$ (t) = mean monthly rainfall for the month (t) and σ_t = standard deviation of rainfall for the month (t).

There are a few parameters like mean monthly deficit (MMD), mean annual deficit (MAD), and maximum of the mean monthly rainfall (MMMI), that are required for testing the onset and termination of drought. Finally, an index for drought severity is estimated by calculating the average monthly drought intensity (DI), that is, the total deficits beyond the monthly mean deficits for the period of drought (PD) divided by the sum of the mean monthly deficits for the same period, the product (DI * PD) being the drought severity.

This modified method was applied by them to monthly rainfall data in the catchment of the Bhadra Reservoir in the State of Karnataka, India, which falls in the semi arid region and they had reported that the results on drought initiation, drought duration and other drought characteristics were found to be quite similar to the historical droughts. Thus, it is aimed in this paper to apply the same method to the arid region, namely Sivaganga District, which the drought affected district in the

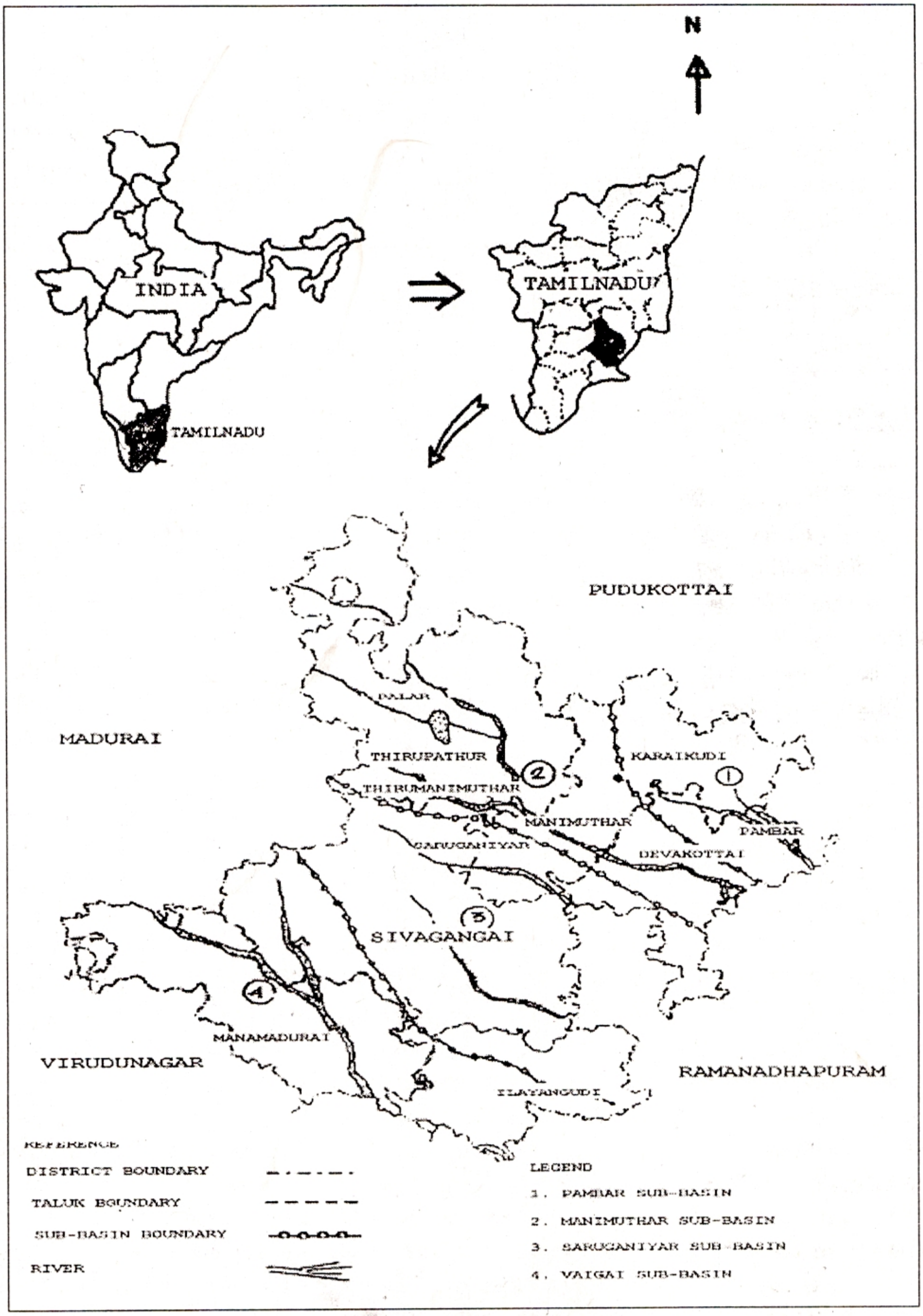

Fig.1 Location map of Sub-basins of Sivagangai District

Tamil Nadu state. Sivaganga District is located between longitude of $78^0.5$' and 79^0 and consists of the four sub-basins, namely Pambar sub-basin, Manimuthar sub-basin, Saruganiyar sub-basin, and Vaigai sub-basin. The location map of these sub-basins is shown in Fig.1. Brief details about all the four sub-basins are given below.

The Pambar sub-basin covers 69,165 ha. and this basin is mostly covered by hydrological soil group 'C' with slow infiltration and moderate run off potential and group 'D' with very slow infiltration and high run off potential. Agricultural land is found to cover about 34,049 ha. where as the pasture land is of 9683 ha. while the forest and waste land is 20,408 ha and the Urban area is 5025 ha. In this sub-basin, the average annual rainfall over the 10 years is 900.58 mm. The Manimuthar sub-basin covers 1,16,240 ha. in the district. There are 7 anicuts and 15 open offtakes are available across Manimuthar River benefiting 93 tanks. The soil type is similar to the Pambar sub-basin, namely group C and group D. Agricultural land is found to occupy about 62,069 ha, pasture land is of 20,670 ha., whereas, the forest and waste land accounts for 25,119 ha., and urban areas is about 8,382 ha. In this sub-basin, the average annual rainfall over the 10 years is 756.54 mm. The Saruganiyar sub-basin covers 1, 25,161 ha. in the district, and the average annual rainfall of the sub-basin over 10 years is 607.50 mm. This basin is also covered by soil groups C and D with very slow infiltration and high run off potential. Agricultural land is found to cover about 64,921 ha., pasture land is of 20,202 ha., whereas the forest and waste land accounts for 27,975 ha., and 12,063 ha. is of urban areas.

The Vaigai sub-basin covers 60,294 ha. in the district, and the average annual rainfall of the sub-basin over the 10 years is 738.11 mm. The soil group in the sub-basin is 'D' with very slow infiltration and high run off potential. The agricultural land is found to cover about 34,304 ha., whereas the pasture land is of 8761 ha., the forest and wasteland is of 14,278 ha., and urban areas of 2951 ha.

The drought identification methodology was systematically applied to the above four sub-basins separately and the results are discussed subsequently. The present study was carried out with ten years of monthly rainfall data from 1995-2004 for all the sub-basins. Table 3 lists the monthly rainfall statistics for all the sub-basins. The month-wise truncated rainfall, mean monthly deficits, and the sliding scale that are to be compared for determination of the onset of a drought for each month, and the same procedure is adopted for all sub-basins, and these parameters for all the four sub-basins are listed in Table 4. Using these values, the droughts have been identified in terms of onset, termination, and severity for all the sub-basins and the identified droughts are shown in Table 5, Table 6, Table 7, and Table 8 indicate the details of onset, termination and severity of the droughts for the Pambar, Manimuthar, Saruganiyar, and Vaigai sub-basins respectively. The difference between the monthly effective rainfall and the mean monthly rainfall over the different years are plotted and are shown in Fig. 2, Fig. 3, Fig. 4, and Fig. 5, for Pambar, Manimuthar, Saruganiyar, and Vaigai sub-basins respectively. From these plots, the drought characteristics namely, drought onset, and the duration of the drought could be identified and from these values the severity of the drought could be evaluated.

Table 3 Statistics of monthly rainfall series for Different sub-basins

Month	Pambar Sub-Basin			Manimuthar Sub-Basin			Saruganiyar Sub-Basin			Vaigai Sub-Basin		
	Mean	Std. Devn	CV (%)	Mean	Std. Devn	CV (%)	Mean	Std. Devn	CV (%)	Mean	Std. Devn	CV (%)
Jan	12.07	20.43	29	8.44	12.6	149	11.19	11.76	105.00	8.74	11.46	131.00
Feb	32.60	65.50	201	30.68	61.42	200	19.93	32.95	165.00	17.42	28.41	163.00
Mar	2.65	5.686	214	2.72	4.98	183	3.95	9.05	229.00	4.38	8.86	202.00
Apr	34.18	29.872	87	39.92	32.27	80	38.94	31.97	82.00	49.94	36.28	73.00
May	69.84	52.80	75.6	82.81	69.70	84	78.87	52.27	66.00	76.39	57.12	75.00
June	59.25	23.57	39	59.96	21.36	36	43.11	37.70	87.00	41.73	34.21	82.00
July	91.61	56.5	61.6	83.22	47.72	57	68.68	55.69	81.00	52.51	33.34	64.00
Aug	76.18	33.67	44	76.49	34.38	45	67.52	34.66	51.00	66.24	43.14	65.00
Sep	121.34	57.43	47.3	122.24	66.45	54	91.25	53.50	57.00	89.85	58.39	65.00
Oct	180.54	87.09	48.22	180.77	90.82	50	154.89	72.21	46.00	168.54	79.16	47.00
Nov	141.84	69.93	49	135.02	63.03	46	101.25	70.46	69.00	117.20	72.17	62.00
Dec	70.93	58.46	82.4	64.16	50.52	78	49.51	57.42	116.00	47.16	53.56	113.00

Table 4 Parameters used for drought identification in different sub-basins

Month	Pambar Sub-Basin			Manimuthar Sub-Basin			Saruganiyar Sub-Basin			Vaigai Sub-Basin		
	Truncated rainfall (mm)	MMD (mm)	Sliding scale	Truncated rainfall (mm)	Monthly mean deficit (mm)	Sliding scale	Truncated rainfall (mm)	Monthly mean deficit (mm)	Sliding scale	Truncated rainfall (mm)	Monthly mean deficit (mm)	Sliding scale
Jan	-22.51	0	138.52	-10.57	-5.18	135.09	-1.16	0.00	121.22	-6.28	0.00	131.36
Feb	-99	0	132.13	-92.28	-36.91	132.99	-34.50	0.00	114.23	-28.94	0.00	123.87
Mar	-9.55	0	125.74	-6.39	-4.47	130.89	-16.78	0.00	107.24	-13.54	0.00	116.38
Apr	8.08	-2.07	119.35	13.83	-2.44	128.79	12.69	-2.54	100.25	23.58	-5.15	108.89
May	29.91	0	112.96	24.14	0	126.69	44.23	-4.93	93.26	33.67	-1.50	101.40
June	50.16	-3.88	106.57	52.37	-3.095	124.59	10.14	-0.89	86.27	13.68	-2.35	93.91
July	56.75	-5.67	100.18	55.85	-5.71	122.59	23.52	-0.73	79.28	31.34	-2.60	86.42
Aug	61..29	-5.05	93.79	61.03	-6.98	120.39	49.73	-7.66	72.29	38.14	-4.70	78.93
Sep	94.16	-12.82	87.4	86.12	-11.91	118.29	59.88	-4.20	65.30	51.90	-3.55	71.44
Oct	138.52	-20.78	81.01	135.09	-16.66	116.19	121.22	-15.74	58.31	131.36	-15.37	63.95
Nov	107.36	-14.38	74.62	105.09	-14.18	114.19	51.79	-7.54	51.32	73.09	-13.77	56.46
Dec	22.74	-3.52	68.23	24.38	-4.14	111.99	-17.08	0.00	44.33	-13.60	0.00	48.97

Table 5 lists the details of onset, termination and severity of the droughts for the Pambar sub-basin. From this table, it can be inferred that the longest period of 5 months drought occurred during Oct. 1997 to Feb. 1998. On the other hand, the Oct. 1996 – Jan. 1997 drought, even though it had duration of 4 months, it had a severity of only about half when compared to the Oct. 1997 – Feb. 1998 drought. Table 6 gives the details of onset, Termination and severity for Manimuthar sub-basin. It indicates that the longest period of 7 months drought occurred during Oct. 1996 to Apr. 1997 and also during Oct. 1997 to Apr. 1997. The 5 months drought from Jul 2002 to Nov 2002 had a severity only about one third when compared to Oct. 1996 to Apr. 1997 drought. The highest severity occurred in Oct. 1996 to Apr. 1997 drought due to the fact that during this entire period all the monthly rainfall was less than their corresponding truncated rainfall values.

Table 5 Characteristics of Identified Drought for Pambar River Basin

Sl.No	Onset	Termination	Duration (months)	Severity
1	01 – Oct 96	31 – Jan 97	4	620
2	01 – Oct 97	28 – Feb 98	5	1020
3	01 – July 2000	31 – Aug 2000	2	590
4	01 – June 2001	30 – Sep 2001	4	440

Table 6 Characteristics of Identified Drought for Manimuthar River Basin

Sl.No	Onset	Termination	Duration (months)	Severity
1	01 – Oct 1996	30 – Apr 1997	7	1280
2	01 – Oct 1997	30 – Apr 1998	7	1010
3	01 – July 2002	30 – Nov	5	420

Table 7 Characteristics of Identified Drought for Saruganiyar Sub-basin

Sl.No	Onset	Termination	Duration (months)	Severity
1	01 – Oct 1996	31 – Jan 1997	4	45
2	01 – Apr 1998	30 – Jun 1998	3	721

Table 8 Characteristics of Identified Drought for Vaigai Sub-basin

Sl.No	Onset	Termination	Duration (months)	Severity
1	01 – Oct 1996	30 – Nov	2	373
2	01 – Apr 1998	30 – Jun 1998	3	1000
3	01 – Jul 2000	30 – Nov	5	714

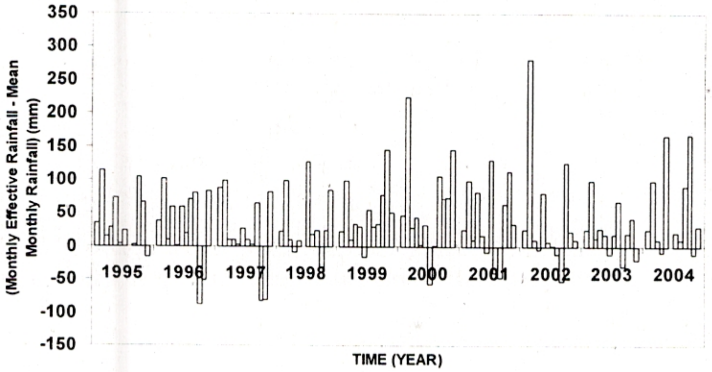

Fig. 2 Monthly variation of rainfall deficits / excess for the Pambar sub-basin

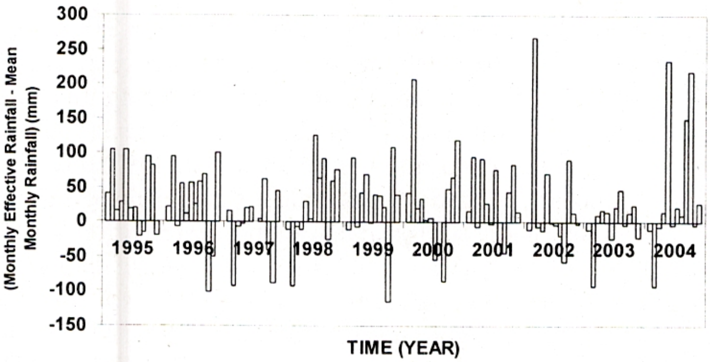

Fig. 3 Monthly variation of rainfall deficits / excess for the Manimuthar sub-basin

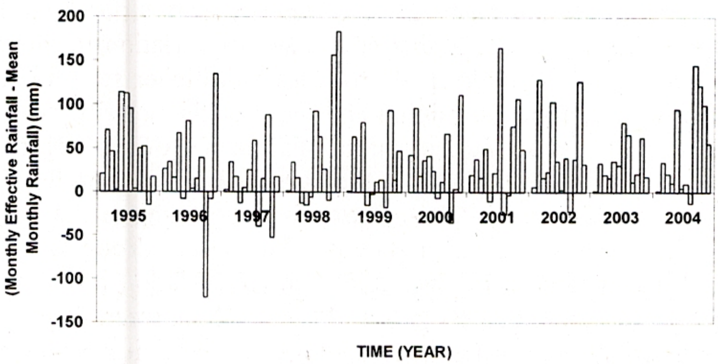

Fig. 4 Monthly variation of rainfall deficits / excess for the Saruganiyar sub-basin

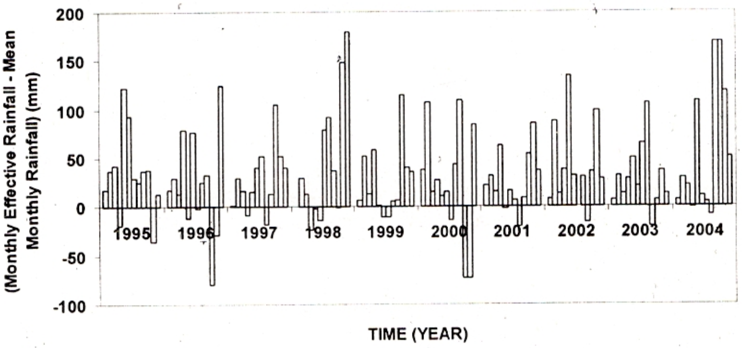

Fig. 5 Monthly variation of rainfall deficits / excess for the Vaigai sub-basin

The details of drought onset, termination and severity for Saruganiyar sub-basin are shown in Table 7. It may be noted that the highest severity occurred during Apr 1998 to Jun 1998 drought and it was due to the fact that during this entire period all the monthly rainfall was less than their corresponding truncated rainfall values in this sub-basin. On the other hand, the Oct 1996 to Jan 1997 drought had only 2 months excess rainfall than their truncated value, thus resulting in a less severity. Table 8 lists the details of onset, Termination and severity for Vaigai sub-basin. These results indicate that the Apr 1998- Jun 1998 drought had a duration of 3 months and high severity of 1000, whereas the July 2000 to Nov 2000 drought has a longer duration of 5 months with severity of about 75% of the other drought namely, Apr 1998 to Jun 1998 drought. Also the monthly rainfall in this period of July 2000 to Nov 2000 was less than their corresponding truncated rainfall and had 2 months excess rainfall that resulted in a less severity.

It is also found that the sub-basin which has lesser mean and lesser coefficient of variation (Saruganiyar sub-basin) resulted in less number of droughts and also with less duration and less severity. On the other hand, it is observed that the sub-basin that has higher mean and higher coefficient of variation in rainfall (Pambar sub-basin) resulted in more number of droughts with higher severity. The tradeoff curve between the mean annual rainfall and the drought severity has been plotted with the data pertaining to all the four sub-basins and is shown in Fig. 6. The best fit polynomial curve that could be fitted to the data is also shown in the figure. It can be seen that the coefficient of determination is quite high for the fit proving the suitability of the curve for future prediction. The severe droughts in all the sub-basins were also compared with the actual rainfall deviation based assessment of droughts, and it was found that there is a close match between them. Therefore, it can be concluded that the modified methodology of identifying droughts is verified and suitable for any type of rainfall data to identify the droughts.

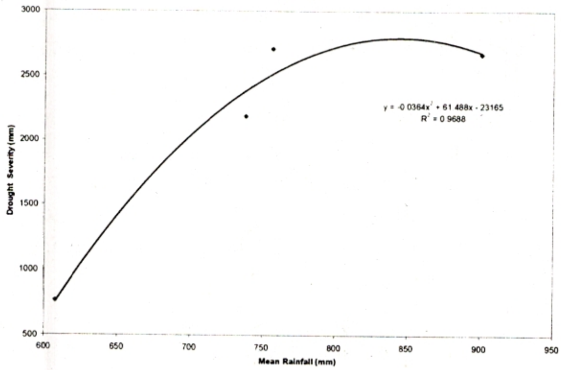

Fig. 6 Tradeoff curve between the Mean Annual Rainfall and the Drought Severity

WATER RESOURCES MANAGEMENT DURING DROUGHTS

Drought management is an essential element of water resources policy and strategies, especially in drought prone areas. Drought Management Plans (DMP) should be prepared in advance before they are needed, based on relevant country specific legislation and after careful studies are carried out concerning the characterization of the drought in the basin, its effect and the mitigation measures. The scale for preparing the DMP should be the river basin or a sub-basin that makes a management system.

The main objective of drought management plans is to minimize the adverse impacts on the economy, social life and environment when drought appears. It also aims at extending WFD criteria and objectives to realize drought management. This general objective can be developed through a series of specific objectives that might include:

- Guarantee water availability in sufficient quantities to meet essential human needs to ensure population's health and life.
- Avoid or minimize negative drought impacts on the status of water bodies, especially on ecological flows and quantitative status for groundwater and in particular, in case of prolonged drought.
- Minimize negative effects on economic activities, according to the priority given to established uses in the River Basin Management Plans, in the linked plans and strategies (e.g. land use planning).

A multilevel approach is suggested for water resources management during drought situations. Drought planning should be developed at different levels and linked to the River Basin Management Plan (RBMP):

At national level focus should be put in policy, legal and institutional aspects, as well as in funding aspects to mitigate extreme drought effects. National level measures should determine drought on-set conditions through a network of global indices and indicators at the national or regional level global basin indices/indicators network, which for instance can activate drought decrees for emergency measures with legal constraints or specific budget application.

Drought Management Plans (DMP) at river basin level are contingency management plans supplementary to River Basin Management Plans. DMPs are mainly targeted to identify and schedule on-set activation tactical measures to delay and mitigate the impacts of drought. River Basin Management Plans have to include a summary of the programmes of measures in order to achieve the environmental objectives and may be supplemented by the production of more detailed programmes and management plans (e.g. DMPs) for issues dealing with particular aspects of water management.

At local level, tactical and response measures to meet and guarantee essential public water supply as well as awareness measures are the main issues.

In order to achieve the specific DMP objectives, 3 basic elements should support a DMP: 1) a drought early warning system, 2) drought indicators correlation with thresholds for different stages of drought as it intensifies and recedes and 3) measures to achieve specific objectives in each drought phase. In the development of the DMP it is necessary to ensure transparency and public participation. A brief discussion on how these three objectives could be achieved are given below.

Early Warning Indicators System

One of the main objectives of the DMP is establishing a reliable early warning system based on hydrological indicators, easy to obtain and representative of the spatial and temporal situation of drought that allows drought on-set identification, control and assess their severity. It is convenient that the indicators system is hydrological, so it can characterize hydrological droughts, because DMP deals with the decision making process regarding the river basin water resources management under drought conditions. Some of the indicators that can be used are combinations of:

- Stored surface reservoir volumes
- Aquifer water levels
- Stream flows
- Reservoir outflows
- Rainfall (in representative control points)
- Indicators from quality and environmental networks

Apparently, this information does not necessarily reflect a situation of drought but could also express a situation of water scarcity, but as indicators can be correlated with basin simulation model results, no deficit situations must be consistent with normality status of the indicators.

To obtain an indicator's system and determine representative indicators, it is necessary to select, aggregate and weight basic indicators based on the associated resources and demands. Finally, the calibration of indicators through historical series, allows adjusting the weights given to each indicator, and obtaining an aggregated group of indicators, suitable for and representative of the basin. Summary global basin indicators can also serve to establish national indicator systems, since they are representative of the each basin situation.

Mitigation Measures

Measures to be taken during hydrological droughts can be grouped as follows:

Preventing or strategic measures are developed and used under the normal status. They belong to the hydrological planning domain and their main objective is reinforcing the structural system to increase its response capacity (to meet supply guarantees and environmental requirements) towards droughts.

Operational measures are those that are typically applied when droughts occur (during pre-alert and alert status). These are mainly control and information measures in pre-alert and conservation resources measures. If the drought is prolonged excessively, the status of water resources can deteriorate to a point in which emergency operational measures might be needed, consisting essentially of applying water restrictions. Severe Water conservation measures and restrictions, to be adopted if drought worsens to extreme status, should be ranked according to parameters such as: priorities among different uses, environmental requirements, status of drought etc.

Organizational measures establish competent agents and an appropriate organization to develop and follow-up the DMP; create coordination protocols among administrations and public and private entities directly linked to the problem, in particular to those entities in charge of public supply. Follow-up measures serve in the process of watching out for the compliance and application of the DMP and its effects. Finally, *restoration drought measures* include the deactivation of adopted measures and the activation of restoration ones over the water resources effects and the aquatic ecosystem.

The approach to drought in the past has been generally reactive and response oriented, i.e. through crisis management. Critical issues that could be addressed as integral parts for reducing the impact of drought should include:

1. Improved understanding of the drought climatology (frequency, intensity, and spatial extent) of drought patterns
2. Understanding the principal causes of drought at local regional scale
3. Supporting and strengthening of collection and processing of meteorological and hydrological observations, and the promotion of Early Warning Systems
4. Developing an inventory of drought indicators and indices, as applicable to different regions of the country
5. Development and dissemination of Drought vulnerability/risk assessment tools and should form the base for assessment of Drought severity in order to determine the compensation package
6. Dissemination of drought planning methodologies that could be adopted by drought-prone states/districts in the preparation of plans
7. Development of decision support models for the dissemination of drought-related information to end users and appropriate methods for considering the

climate change effects and water supply requirements assessment under different conditions
8. Development of national and regional drought and disaster management policies
9. Development of comprehensive drought reduction strategies that emphasize monitoring and early warning, risk assessment, mitigation, and response as an essential part of drought preparedness
10. Assessment of the availability of skilled human resources to be involved in drought preparedness planning
11. Education and awareness of policy makers and the public regarding the importance of improved drought preparedness as a part of integrated water resources management
12. Integration of local or indigenous coping mechanisms and enhancement of regional/state level governmental, NGO and public collaboration and participation.

CONCLUSIONS

In this paper, the definition, identification and management approaches for mitigating the droughts are discussed in detail. The modified methodology suggested by Mohan and Rangacharya (1991) was applied to rainfall series data of four sub-basins in a drought affected district to assess the characteristics of droughts. Based on the identification and characterization of droughts in all the four sub-basins, it is inferred that the sub-basin which has lesser mean and lesser coefficient of variation resulted in less number of droughts and also with less duration and less severity, whereas the sub-basin that has higher mean and higher coefficient of variation in rainfall resulted in more number of droughts with higher severity. In addition, for the effective drought management, a shift from crisis management to drought risk management through early warning systems, advance planning for emergency response and better preparedness is necessary and being started in the recent years. This paradigm shift in management strategy has since made some impact, yet the sustainability in rainfed areas is yet to be achieved.

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