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DROUGHT A WATER SCARCITY – CASE STUDY BY STATISTICAL APPROACH

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Abstract—In spite of the technological advancements made by India the drought still continues to be the major factor of uncertainty. The multiple effects of occurrence of drought in the arid and semi arid and semi arid regions have been reviewed. With this the drought is one of the worst natural calamities that have affected the humankind throughout the history. So that periodical assessment of the in a region must be necessary to take the management measures. The underlying concept of this paper is that the amount of precipitation required for the near normal operation of established economy of the area. For the recent years monsoon rainfall was meager and not able to cater the irrigation demand in most part of the Tamil Nadu. The objective of the study is to assess the water deficit in the form of drought severity in the study area of Cuddalore district by Modified Palmer Drought Severity Index and Cumulative effects of the rainfall as meteorological drought, the water deficit quantification of reservoirs and wells by Herbst drought assessment method were estimated and specified in the form of crop water requirements. After the examination of the drought intensity in the study area by the above said approaches were compared and concluded with their behavior to describe the water deficit.

Keywords—Meteorological Drought, Palmer Drought severity Index, Hydrological Drought, Cumulative Criteria Approach, Drought Intensity

I. INTRODUCTION

Drought has occurred in different parts of the Indian sub continent and other parts of the world for centuries with unpredictable frequencies due to variability of rainfall, delay in onset monsoon, long term dry spell during the cropping season that affects the vegetation. Drought condition is the result of drastic climatic variation resulting in prolonged fewer amounts of precipitation and extreme dry spell. National Commission on Agriculture - 1976 [9] defines “the meteorological drought is a situation when the actual rainfall is significantly lower than the climatologically expected rainfall over a wide area”. [2] Herbst et.al (1966) stated that the monthly precipitation, duration and intensity of droughts as well as the month of their onset and termination decides the long term hydrological droughts. Drought duration (D) is the period of time when there is a deficiency of precipitation/ stream/soil- moisture preceded and followed by periods when there is no deficiency. A drought event is a series of one or more consecutive drought months/seasons/ years. A drought can have duration of one or more months/seasons or even years. Drought intensity (I) refers to the magnitude to which actual precipitation/stream/soil- moisture are lesser than the mean or a given threshold value. (i.e. precipitation deficit/ stream flow deficit/ soil-moisture deficit). Drought intensity is nearly independent of the duration and this fact is very well discussed in many of the literature [3, 4, 5, 7 and 10]. Drought severity (S) refers to the accumulated deficits through out the drought duration (i e. I=S/D). In other words, if one can predict duration and intensity then the severity can be predicted using simple law of multiplication of duration and intensity. The drought severity is crucial for hydrological drought while the critical duration even with less severity is important for agricultural drought [6].

The degree of severity of meteorological drought in a region can be assessed by means of many methods. In India, percentage deviation of rainfall from the long- term mean rainfall calculated by India Meteorological Department (IMD) is adopted by several Government Departments to express the meteorological drought severity. In IMD method, the rainfall of an individual time period is considered for assessing the drought situation. It greatly neglects the effect of antecedent rainfall condition. Ravikumar and Karmagam [8] have made an attempt with cumulative criteria approach by including the antecedent condition and arrived at some meaningful results. Palmer's drought index [6] is considered to be an adequate measure for assessing the degree of drought severity over space and time. In this method, Palmer used the water budgeting concept for developing numerical drought severity index considering rainfall, evapotranspiration, soil moisture, and climate of the area and current and antecedent weather conditions. But however Palmer index does not reflect drought conditions in a tropical country like India [1]. Bhalme and Mooley [1] have modified Palmer index suitable to Indian conditions by modifying in the weighting factor equation to describe the moisture anomaly index.

Identification of Hydrological and Agricultural drought over the region is not common as like meteorological drought. Even though the availability of Herbst hydrological drought assessment method and a reasonable soil moisture drought estimation methods were to be used to prove to be useful in the crop yield investigation [6].

In this paper an attempt has been made to describe the drought severity in Cuddalore district of Tamil Nadu state using Modified Palmer indices were estimated for two rainfall stations. The data of these two rainfall seasons were also analysed by the cumulative criteria approach. In the ayacut of Willington reservoir long term monthly water levels of three observation wells were analysed to find out the dry spells using Herbst method.

II. STUDY AREA AND DATA BASE

The study area Cuddalore district of Tamil Nadu state lies between latitudes of 11˚05'N and 11˚55'N and longitudes of 78˚50'E and 79˚50'E with tropical climate prevailing over the region. The mean maximum temperature ranges from 30.16˚C to 40.34˚C and the mean minimum temperature ranges from 20˚C to 27˚C respectively. Thirty year monthly mean temperature data were collected for two stations, one at the coastal station of Annamalainagar and the other at an inland station of Lekkur at the Institute of Water Studies, Chennai. The average annual rainfall of this district is 1160 mm. There are 22 rain gauge stations spread over the district and are maintained by different organizations such as the Public Works Department and the Revenue and Forest Departments. Rainfall data analysis indicates that the precipitation varies from 941mm to 1389 mm. The historical rainfall data of 30 water year period for the 22 rain gauge stations were collected from Statistical Department, Cuddalore. Rainfall record shows that only 9 stations are having continuous rainfall data for the past 30 water years. The spatial distribution of soil types in this district and their percentage proportion collected from the soil testing laboratory of the, Agricultural Department, Cuddalore are Red soil (38.3%), black soil (40.4%), alluvial soil (5.2%), red loamy soil (1.4%), sandy soil (13.2%) and sandy loam soil (1.6%). The rain gauge locations selected for this study are depicted in Fig. 1.

The study area of Wellington Reservoir system is situated at a distance of 600 m from Kilacheruvai village in Tittagudi Taluk of Cuddalore District. It is situated at longitude of 79º 25' and latitude of 11º 54'. It can be easily assessable by Trichy – Chennai National Highway (NH – 45) by alighting at Tholudur. Fig.2 shows the location of Willington Reservoir system.

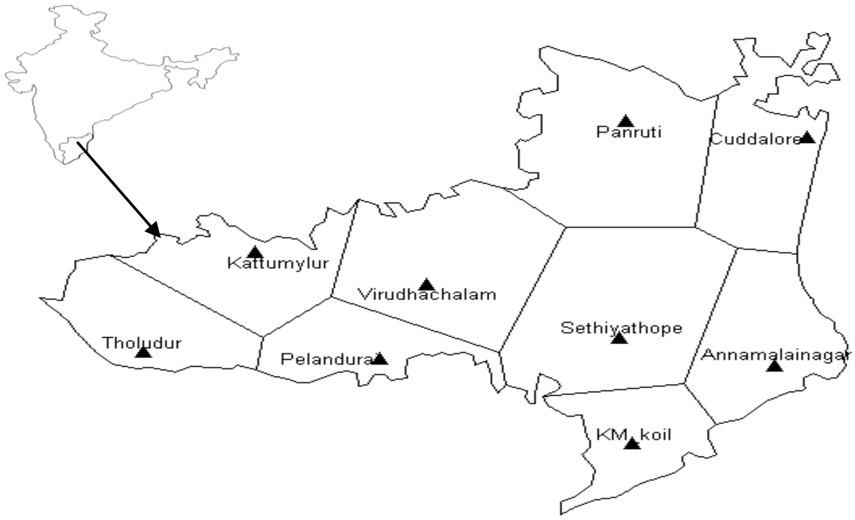

Figure 1 Rain Gauge Location and Thiessen Polygons of Cuddalore District

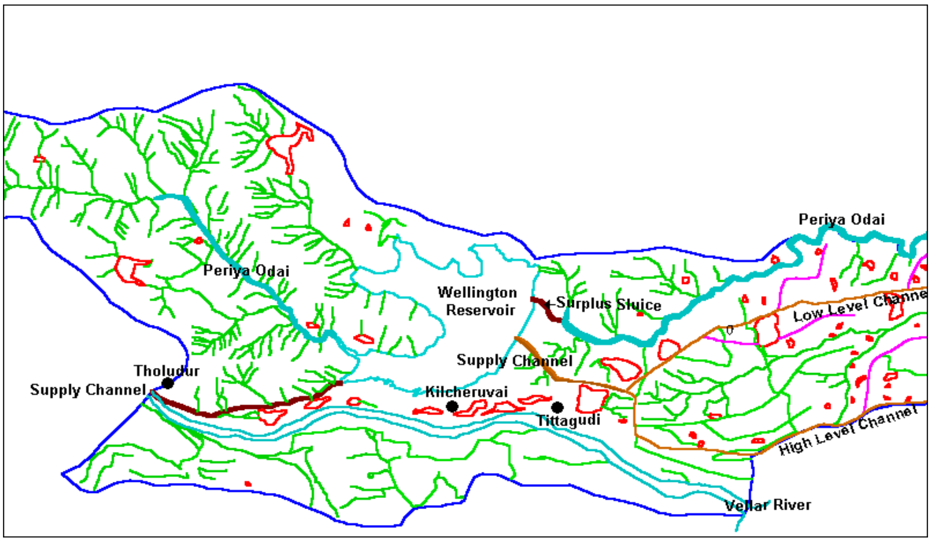

Figure 2 Willington Reservoir System and Well Locations

III. METHODOLOGY

3.1 Meteorological Drought Assessment

Meteorological drought is a situation when there is a significant decrease in precipitation from the normal over an area. Meteorological Drought assessments have carried out for 9 stations out of 22 stations in the district, due to the non-availability of continuous long – term historical data.

3.1.1. Modified Palmer's Drought Severity Index (MPDSI)

Palmer [6] gave a rational, systematic and objective approach for evolving the meteorological drought index as a single numerical value, which represents the drought severity. Palmer index model is an elaborate and comprehensive technique for computing the severity of droughts on the basis of current and antecedent rainfall, evapotranspiration and soil moisture. The PDSI is based on a supply and demand model of the soil moisture at a location. The supply is the sum of amount of moisture in the soil and the amount that is absorbed into the soil from rainfall. The demand however is not so as easy to see. Because the amount of water lost from the soil is depends on several factors such as temperature and the amount of moisture in the soil. It requires month-by-month water balance accounting for long record using two-layer soil model. The detailed modified PDSI estimation methodology given by H.N.Bhalme and D.A.Moole. Modified Palmer monthly drought severity indices were estimated 9 stations and results presented only for Cuddalore and Tholudur by using the long-term average of thirty water years data (1974-1975 to 2003-2004) and the short-term average of last five water years data (1999-2000 to 2003-2004),

$$X_i = X_{i-1} + (z_i/1.390) - 0.218 X_{i-1}$$
$$= 0.782 X_{i-1} + (z_i/1.390)$$

x – Drought severity, z – moisture anomaly index and i = current month

Drought category of each class is as given below;

4 or more	extremely wet	-0.50 to -0.99	incipient droughts
3.00 to 3.99	very wet	-1.00 to -1.99	mild drought
2.00 to 2.99	moderately wet	-2.00 to -2.99	moderate drought
1.00 to 1.99	slightly wet	-3.00 to -3.99	severe droughts
0.50 to 0.99	incipient wet	-4.00 or less	extreme drought
0.49 to -0.49	near normal		

3.1.2 Cumulative Criteria Approach

In this approach [8] the first time period's rainfall is compared with its average (long term mean rainfall). For the second time period the cumulative rainfall upto the second value is compared with the cumulative average rainfall, which will be twice the long-term mean rainfall. If the first time period's rainfall is deficit from the mean rainfall, the second time periods should cover this deficiency to reach cumulative mean rainfall up to the second value.

The excess or deficiency of rainfall of the preceding time periods will be influencing the adequacy of present time period's rainfall in meeting the requirement for the cumulative long-term mean rainfall. The percentage deviation is given by

$$\mathrm{CD_i} = \frac{\mathrm{PC}_i - \mathrm{PCM_i}}{\mathrm{P}_L} \mathrm{X100} \quad (2)$$

Where $\mathrm{PC_i}$ = Cumulative actual rainfall in the time period i; $\mathrm{PCM_i}$ = Cumulative mean rainfall in the time period i, and $\mathrm{P_L}$ = long – term mean rainfall for all the entire duration of data.

3.2 Hydrological Drought Assessment

Hydrological cycle, which act over the time scale to cause water deficiency. Where the space and time heterogeneity of the climatic situation has affected the drought situation resulting in lesser water being available in rivers, ground water recharge and soil moisture for crop production. Hydrological drought is an aspect of the total hydrological cycle and is affected by some degree of persistence because of the inertia of some processes within the cycle.

Attempts to quantity and test the persistence can be consider in two ways. Using annual rainfall (or) river flow data, the serial correlation can be tested to get the persistence. The other approach could be by studying the length of successive years of below average condition.

The real indicators of the drought would be the deficit in rainfall resulting in deficit of surface water, deficit in ground water and deficit in soil moisture. These would eventually affect in a drought situation, the water supply, and the availability for fooder and the crop production and can be said to be the characteristics of hydrological drought. One has to think of measures to avoid over exploitation of ground water, possibility of aquifer recharge augmentation, artificial enhancement of precipitation, reduction in evapotranspiration and management of land, logistical and social measures for mitigating drought impacts.

Herbst method is the best-suited for evaluation of hydrological drought. Herbst used in this method for the both surface water and ground water levels. Herbst (1966) developed a method to assess the meteorological drought severity using rainfall data, which was applied by Mohan et al., (1991) for stream flow data also.

$$Q_{ei} = Q_i + \left(D_{i-1} \times W_{i-1}\right)$$
$$D_{i-1} = \left(Q_{i-1} - Q_k\right)$$

Q_e = effective available water, Q = Actual available water, D = water deficit (or) deviation, W = Weighting factor, Q_K = long term mean available water for month i-1 and i = particular month

$$W_{i-1} = 0.1\left(1 + \frac{Q_{i-1} * 12}{Q_y}\right)$$

Q_y = mean annual available water

The drought periods are determined by comparing the deficiencies with a twelve sliding scale. The sliding scale is prepared as

SS(r) = MMMR + (r-1) MI

SS = sliding scale, MMMR – Maximum of Mean Monthly available water and r = order of the month from 1 to 12

MI = Monthly increment

$$MI = \frac{MAD - MMMR}{11}$$

MAD = Mean annual deficiency of available water.

Drought severity (I_m)

$$I_m = \frac{\sum_{i=m_1}^{m_2}\left(MD_i - MMD_i\right)}{\sum_{i=m_1}^{m_2}\left(MMD_i\right)}$$

$$I_h = I_m * T \qquad (3)$$

Where,
MD = Monthly Deficit of available water
MMD = Mean Monthly Deficiency of available water
I_m = Average monthly drought intensity
m_1 = month when the drought started

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m_2 = month when the drought terminated
T = duration of drought (m_2-m_1) and I_h = weighted index of drought

IV. RESULT AND DISCUSSION

4.1 Cumulative Criteria Approach

Results of this approach for the past four recent water years (2000-2001 to 2003-2004) are as illustrated in Tables 1 and 2. Table 1 describes the drought severity of the coastal station of Cuddalore, which was affected by severe drought in the southwest monsoon (June to Sep) period of 2000, 2001, 2002 and 2003 and also 2001 Jan to May. But IMD shows that 2000, 2001, 2002 and 2003 as the category of mild to moderate drought. As in the northeast monsoon (Oct to Dec) cumulative criteria shows all the four years have no drought but IMD method reflects as mild to severe drought. Winter and hot weather season of 2001, 2002 and 2003 (Jan to May) indicate there is no drought but the reflections of IMD are severe drought. Severe drought was obtained during the southwest monsoon of 2000 (Jun to Aug), 2002 –Aug, 2003 –Jun, July and winter, hot weather season of 2002 (Jan to May) for the inland station of Tholudur which is presented in table 2. But IMD method shows as the category of mild to severe drought in this monsoon season. No drought had occurred during the northeast, winter and hot weather seasons but IMD method predicts the drought category as moderate to severe. The variations of drought indication between cumulative criteria and IMD method are due to the carry over effect presented in figure 3 and figure 4.

Table 1 Cumulative Criteria based drought classification - Cuddalore (4 years)

Cuddalore	Rainfall(mm)	%Devi (IMD)	Drou.class	Cumm.Rain	Cumm.mean	%Devn	Drou.class
00- Jun	68.1	-10.7	M1	68.1	76.3	-10.7	M1
Jul	71.9	-5.8	M1	140.0	152.6	-16.5	M1
Aug	66.0	-13.5	M1	206.0	228.9	-30.0	M2
Sep	34.5	-54.8	M3	240.5	305.2	-84.8	M3
Oct	230.0	201.4	M0	470.5	381.5	116.6	M0
Nov	0.0	-100.0	M3	470.5	457.8	16.6	M0
Dec	147.6	93.4	M0	618.1	534.1	110.1	M0
Jan	0.2	-99.7	M3	618.3	610.4	10.4	M0
Feb	0.0	-100.0	M3	618.3	686.7	-89.6	M3
Mar	0.0	-100.0	M3	618.3	763.0	-189.6	M3
Apr	42.8	-43.9	M2	661.1	839.3	-233.6	M3
May	38.8	-49.1	M2	699.9	915.6	-282.7	M3
2001-Jun	46.7	-38.8	M2	746.6	991.9	-321.5	M3
Jul	123.8	62.3	M0	870.4	1068.2	-259.2	M3
Aug	90.7	18.9	M0	961.1	1144.5	-240.4	M3
Sep	118.7	55.6	M0	1079.8	1220.8	-184.8	M3
Oct	201.2	163.7	M0	1281.0	1297.1	-21.1	M1
Nov	138.9	82.0	M0	1419.9	1373.4	60.9	M0
Dec	111.8	46.5	M0	1531.7	1449.7	107.5	M0
Jan	55.6	-27.1	M2	1587.3	1526.0	80.3	M0
Feb	158.8	108.1	M0	1746.1	1602.3	188.5	M0

Mar	0.0	-100.0	M3	1746.1	1678.6	88.5	M0
Apr	0.2	-99.7	M3	1746.3	1754.9	-11.3	M1
May	14.1	-81.5	M3	1760.4	1831.2	-92.8	M3
2002-Jun	108.4	42.1	M0	1868.8	1907.5	-50.7	M3
Jul	25.9	-66.1	M3	1894.7	1983.8	-116.8	M3
Aug	25.7	-66.3	M3	1920.4	2060.1	-183.1	M3
Sep	119.3	56.4	M0	2039.7	2136.4	-126.7	M3
Oct	188.5	147.1	M0	2228.2	2212.7	20.3	M0
Nov	297.5	289.9	M0	2525.7	2289.0	310.2	M0
Dec	130.4	70.9	M0	2656.1	2365.3	381.1	M0
Jan	0.0	-100.0	M3	2656.1	2441.6	281.1	M0
Feb	0.0	-100.0	M3	2656.1	2517.9	181.1	M0
Mar	0.7	-99.1	M3	2656.8	2594.2	82.0	M0
Apr	1.5	-98.0	M3	2658.3	2670.5	-16.0	M1
May	76.1	-0.3	M1	2734.4	2746.8	-16.3	M1
2003-Jun	46.5	-39.1	M2	2780.9	2823.1	-55.3	M3
Jul	57.9	-24.1	M1	2838.8	2899.4	-79.4	M3
Aug	108.0	41.5	M0	2946.8	2975.7	-37.9	M3
Sep	75.6	-0.9	M1	3022.4	3052.0	-38.8	M3
Oct	203.6	166.8	M0	3226.0	3128.3	128.0	M0
Nov	404.6	430.3	M0	3630.6	3204.6	558.3	M0
Dec	11.0	-85.6	M3	3641.6	3280.9	472.7	M0
Jan	20.8	-72.7	M3	3662.4	3357.2	400.0	M0
Feb	0.0	-100.0	M3	3662.4	3433.5	300.0	M0
Mar	0.0	-100.0	M3	3662.4	3509.8	200.0	M0
Apr	0.0	-100.0	M3	3662.4	3586.1	100.0	M0
May	0.0	-100.0	M3	3662.4	3662.4	0.0	M0

Table 2 Cumulative Criteria based drought classification - Tholudur (4 years)

Tholudur	Rainfall(mm)	%Devi (IMD)	Drou.class	Cumm.Rain	Cumm.mean	%Devn	Drou.class
00- Jun	36.5	-64.0	M3	36.5	101.3	-64.0	M3
Jul	92.0	-9.2	M1	128.5	202.7	-73.2	M3
Aug	154.0	52.0	M0	282.5	304.0	-21.2	M1
Sep	245.8	142.6	M0	528.3	405.3	121.3	M0
Oct	192.5	90.0	M0	720.8	506.7	211.3	M0
Nov	540.0	432.9	M0	1260.8	608.0	644.2	M0
Dec	73.0	-28.0	M2	1333.8	709.3	616.3	M0
Jan	0.0	-100.0	M3	1333.8	810.7	516.3	M0
Feb	0.0	-100.0	M3	1333.8	912.0	416.3	M0
Mar	0.0	-100.0	M3	1333.8	1013.3	316.3	M0
Apr	31.0	-69.4	M3	1364.8	1114.7	246.8	M0
May	64.0	-36.8	M2	1428.8	1216.0	210.0	M0

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2001-Jun	24.0	-76.3	M3	1452.8	1317.3	133.7	M0
Jul	179.0	76.6	M0	1631.8	1418.7	210.3	M0
Aug	75.0	-26.0	M2	1706.8	1520.0	184.3	M0
Sep	152.0	50.0	M0	1858.8	1621.3	234.3	M0
Oct	296.0	192.1	M0	2154.8	1722.7	426.4	M0
Nov	108.5	7.1	M0	2263.3	1824.0	433.5	M0
Dec	140.0	38.2	M0	2403.3	1925.3	471.7	M0
Jan	6.5	-93.6	M3	2409.8	2026.7	378.1	M0
Feb	85.0	-16.1	M1	2494.8	2128.0	362.0	M0
Mar	0.0	-100.0	M3	2494.8	2229.3	262.0	M0
Apr	0.0	-100.0	M3	2494.8	2330.7	162.0	M0
May	75.0	-26.0	M2	2569.8	2432.0	136.0	M0
2002-Jun	44.0	-56.6	M3	2613.8	2533.3	79.4	M0
Jul	25.0	-75.3	M3	2638.8	2634.7	4.1	M0
Aug	38.0	-62.5	M3	2676.8	2736.0	-58.4	M3
Sep	184.0	81.6	M0	2860.8	2837.3	23.2	M0
Oct	265.0	161.5	M0	3125.8	2938.7	184.7	M0
Nov	92.0	-9.2	M1	3217.8	3040.0	175.5	M0
Dec	23.0	-77.3	M3	3240.8	3141.3	98.2	M0
Jan	0.0	-100.0	M3	3240.8	3242.7	-1.8	M1
Feb	0.0	-100.0	M3	3240.8	3344.0	-101.8	M3
Mar	8.0	-92.1	M3	3248.8	3445.3	-193.9	M3
Apr	57.0	-43.8	M2	3305.8	3546.7	-237.7	M3
May	125.0	23.4	M0	3430.8	3648.0	-214.3	M3
2003-Jun	139.2	37.4	M0	3570.0	3749.3	-177.0	M3
Jul	152.0	50.0	M0	3722.0	3850.7	-127.0	M3
Aug	428.0	322.4	M0	4150.0	3952.0	195.4	M0
Sep	206.0	103.3	M0	4356.0	4053.3	298.7	M0
Oct	252.0	148.7	M0	4608.0	4154.7	447.4	M0
Nov	215.0	112.2	M0	4823.0	4256.0	559.5	M0
Dec	41.0	-59.5	M3	4864.0	4357.3	500.0	M0
Jan	0.0	-100.0	M3	4864.0	4458.7	400.0	M0
Feb	0.0	-100.0	M3	4864.0	4560.0	300.0	M0
Mar	0.0	-100.0	M3	4864.0	4661.3	200.0	M0
Apr	0.0	-100.0	M3	4864.0	4762.7	100.0	M0
May	0.0	-100.0	M3	4864.0	4864.0	0.0	M0

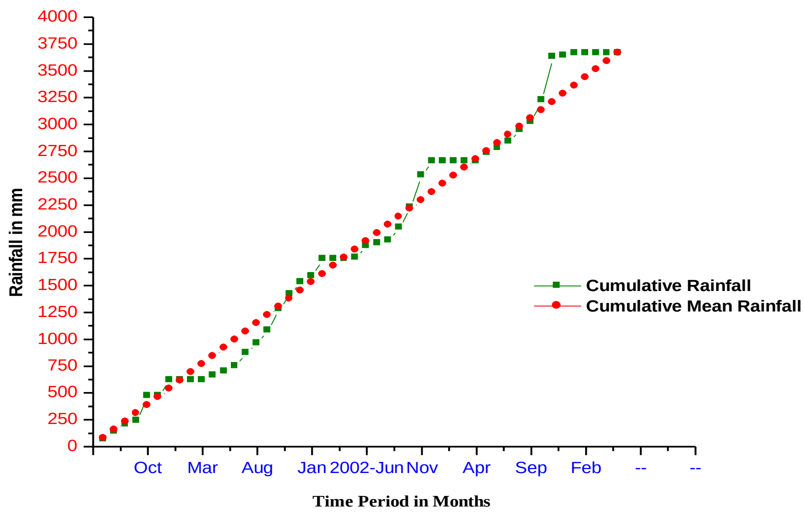

Figure 3 Illustration of Cumulative Criteria - Cuddalore (short term)

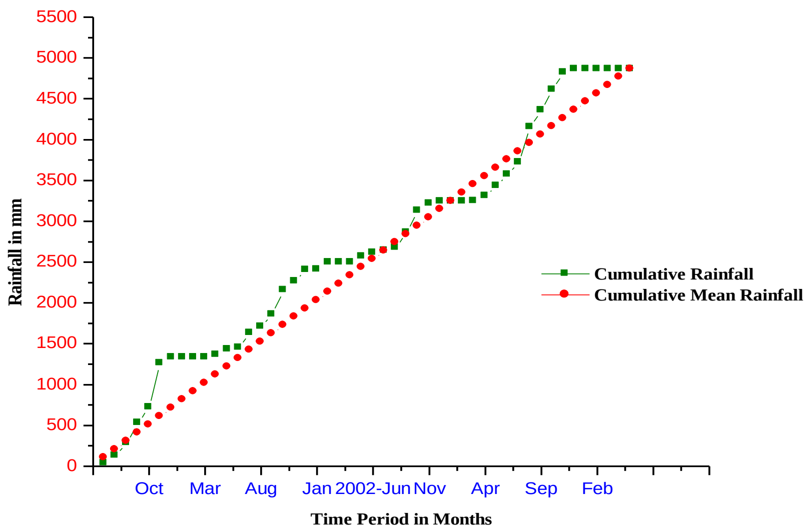

Figure 4 Illustration of Cumulative Criteria - Tholudur (short term)

4.2 MPDSI Estimation

MPDSI estimates based on long term 30 years average (1974-75 to 2003-2004) and short-term average of five years (1999-00 to 2003-2004) for Cuddalore and Tholudur stations were presented in Table 3, 4, 5 and 6 respectively. Long term 30 year average of MPDSI for coastal station of Cuddalore have classified the drought intensity slight to moderate wet condition during southwest monsoon period of 1999-00 & 2000-01 and incipient to slight wet for the same season during 2001-02, 2002-03 and 2003-04. Moderate to extreme wet condition had occurred in northeast and winter seasons. Mostly slight to moderate wet were occurred in the hot weather season of all the years (1999-00 to 2003-04). Whereas the short-term average intensity of drought during southwest monsoon had realized near normal to slightly wet. Incipient to moderately wet condition occurred in northeast, winter and hot weather seasons except in 1999-00 winters. In this season intensity shows that very to extremely wet conditions.

The long-term average MPDSI of inland station of Tholudur shows during the southwest and hot weather season intensity of drought as mostly moderately wet to extremely wet conditions.

Northeast monsoon and winter were experienced fully extremely wet conditions. Where as in the short-term average southwest monsoon realized incipient to moderate wet condition, northeast monsoon as moderately wet to extremely wet. Moderately wet to very wet in the winter season and mostly slight to moderately wet conditions in the hot weather season. Although most of the years are able to receive independent support for the drought conditions, still some years have not received support for drought conditions brought out by MPDSI. So we need some further critical examinations.

Over this district in winter and hot weather season the rainfall was worst, but the drought indices show that many years were moderately wet to extremely wet condition. From the results we examined the drought severity not only depends upon the weighting factor and also depends with soil properties and duration factors. Hence modification is not only needed in the weighting factor, but also in the duration factor estimation. The major improvement comes from the moisture anomaly index term in the equation for severity and also the main parameter to assess the drought severity as knowledge of AWC of soil and Duration factors.

Table 3 MPDSI – Cuddalore (30 Years Average)

Year	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1999-00	2.46	2.318	2.045	2.251	3.497	4.91	5.356	4.832	4.54	3.563	3.197	2.376
2000-01	2.192	2.017	1.911	1.702	2.627	2.25	2.574	2.298	2.044	1.612	1.446	1.092
2001-02	0.957	1.021	1.12	1.419	2.215	2.598	2.734	2.478	2.356	1.856	1.657	1.169
2002-03	1.266	1.087	0.908	1.232	1.978	3.205	3.357	3.00	2.674	2.104	1.88	1.565
2003-04	1.38	1.258	1.405	1.456	2.262	4.014	3.583	3.217	2.869	2.257	2.016	1.399

Table 4 MPDSI – Tholudur (30 Years Average)

Year	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1999-00	6.488	5.678	5.935	6.387	8.116	9.169	8.726	7.822	7.013	5.488	4.819	5.008
2000-01	4.219	3.989	4.583	5.829	7.045	8.961	8.197	7.341	6.561	5.135	4.553	3.392
2001-02	2.641	3.059	2.991	3.605	6.236	6.028	7.347	6.582	5.962	4.666	4.081	3.232
2002-03	2.703	2.255	1.914	2.911	5.259	5.067	4.074	3.643	3.244	2.541	2.269	2.766
2003-04	3.267	3.47	6.746	7.432	9.165	9.2	7.694	6.89	6.157	4.819	4.218	1.912

Table 5 MPDSI – Cuddalore (5 Years Average)

Year	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1999-00	0.558	0.526	0.359	0.453	1.734	3.422	4.126	3.743	4.337	3.681	3.275	2.2
2000-01	1.836	1.145	0.992	0.789	1.657	1.257	1.71	1.484	1.159	1.196	1.045	0.562
2001-02	0.28	0.634	0.592	0.661	1.386	1.814	2.027	1.857	2.273	2.067	1.795	1.038
2002-03	0.958	-0.168	-0.282	-0.122	0.615	2.036	2.321	2.031	1.65	1.576	1.355	0.971
2003-04	0.647	0.025	0.087	0.09	0.886	2.897	2.495	2.221	1.821	1.713	1.477	0.727

Table 6 MPDSI – Tholudur (5 Years Average)

Year	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1999-00	0.869	0.568	0.725	1.14	2.201	4.546	4.311	3.308	2.952	2.978	2.44	2.18
2000-01	1.611	1.451	1.582	2.292	2.921	6.259	5.783	4.429	3.94	3.75	3.202	1.734
2001-02	1.146	1.34	1.182	1.466	2.832	3.048	3.159	2.396	2.186	2.379	1.903	0.873
2002-03	0.477	0.199	0.018	0.582	1.843	2.041	1.808	1.321	1.152	1.489	1.233	1.053
2003-04	1.136	1.236	2.431	2.856	3.801	4.69	4.253	3.233	2.867	2.911	2.38	0.19

4.3 Hydrological Drought Assessment

In the ayacut of Willington reservoir ground water is the alternate source for agriculture. Over exploitation of ground water takes place during the drought period to meet the irrigation demand and other requirements. As a result, a steep decline in ground water levels was observed and leads to depletion of aquifer storage and ground water mining. So that the withdrawal of ground water should be restricted to average annual recharge in order to conserve the ground water from over exploitations during the drought periods. Long term analysis of water level fluctuation to arrive at the distinct dry spells in the ground water and their intensity will be helpful to manage these valuable resources.

Long-term monthly water levels of three observation wells of Willington reservoir system were analyzed to find out the dry spells using Herbst method. The deviation monthly ground water levels from the mean monthly values were quantified as drought intensity mentioned in Herbst method. Table 7, 8 and 9 were shown the dry spells, their duration and intensity for the three wells. Figure 5 shows the drought intensity for the well No.33068 located in Tholudur. In this dry spells intensity varied from 0.124 to 13.378 and two long spells were occurred for 45 and 84 months with and intensity 7.02 and 13.378 respectively in the year of 1980 to 1983 and 1997 to 2003. The water level of this well varied from 0.81 m to 5.48 m.

Water level data from 1971 to 2003 were analyzed and fluctuation was observed for the well Numbered as U / 33086. It is observed that the ground water level varied from 0.60 m to 5.86 m during the study period. Due to the continuous prevalence of drought during Jun 1991 to Dec 2003, the water level lowered to the minimum level of 5.86 m, which may be due to severe exploitations of ground water.

The temporal occurrences of dry spells for the well 33087 are depicted in table 6 and Figure 7. Eight no of Drought spells with drought intensity varied for .038 to 39.073 was identified. Water level fluctuations in this well were observed that 0.82 m to 10.32 m during the period of 1971 to 2003. Due to the severe exploitation during the periods 1982 to 2003 long dry spell had occurred with an intensity of 39.083 with duration of 264 months.

Table 7 Hydrological Drought Intensity on Well No.33068

Hydrological Drought - Ground Water Data - Well No.68					
Begin year	Begin month	End year	End month	Duration	Intensity
1971	Jan	1971	Feb	1	0
1971	Oct	1974	Dec	38	4.78
1978	Jan	1978	Oct	9	1.088
1978	Nov	1978	Dec	1	0.124
1979	Jan	1979	Dec	11	1.375

1980	Jan	1983	Oct	45	7.02
1984	Feb	1986	Mar	25	3.905
1986	May	1987	Sep	4	0.626
1987	Feb	1992	May	3	0.471
1992	Feb	1992	Mar	1	0.157
1992	Jun	1992	Dec	6	0.954
1993	Jan	1996	Mar	38	6.051
1996	Apr	1996	May	1	0.159
1996	Jul	1996	Dec	5	0.801
1997	Jan	2003	Dec	84	13.378

Table 8 Hydrological Drought Intensity on Well No.33086

Hydrological Drought - Ground Water Data - Well No.86					
Begin year	Begin month	End year	End month	Duration	Intensity
1971	Jan	1975	Nov	58	9.31
1977	Oct	1983	Jul	69	11.324
1984	Jan	1984	Dec	11	1.814
1985	Feb	1985	Mar	1	0.165
1985	Oct	1985	Nov	1	0.165
1986	Feb	1986	Dec	10	1.648
1987	Jan	1987	Aug	7	1.152
1988	Feb	1988	May	3	0.494
1990	Mar	1990	Apr	1	0.165
1991	Jun	2003	Dec	151	26.141

Table 9 Hydrological Drought Intensity on Well No.33087

Hydrological Drought - Ground Water Data - Well No.87					
Begin year	Begin month	End year	End month	Duration	Intensity
1972	Jan	1972	Oct	9	3.75
1973	Jan	1973	Feb	1	0.23
1977	Oct	1978	Jan	3	0.038
1978	Feb	1979	May	15	2.152
1980	Feb	1980	Dec	10	1.483
1981	Feb	1981	May	3	0.444
1981	Nov	1981	Dec	1	0.148
1982	Jan	2003	Dec	264	39.073

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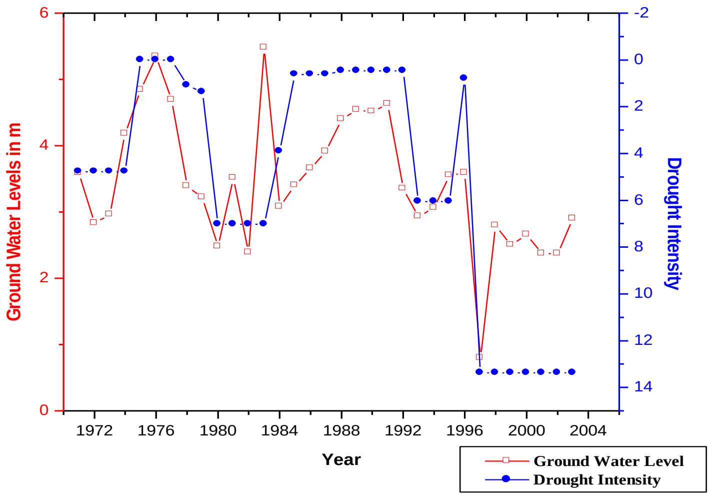

Figure 5 Hydrological Drought Intensity on Well No: 33068

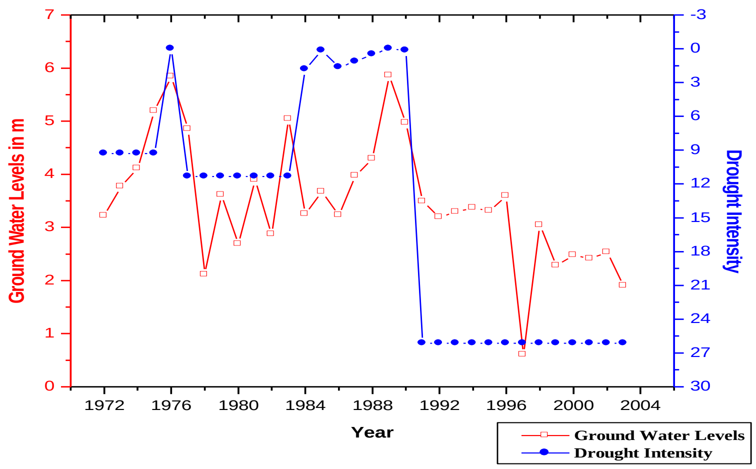

Figure 6 Hydrological Drought Intensity on Well No: 33086

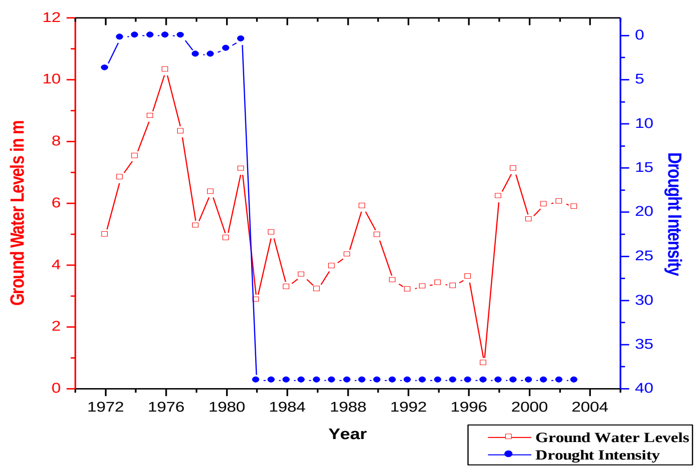

Figure 7 Hydrological Drought Intensity on Well No: 33087

V. CONCLUSION

Cumulative Criteria approach shows better results than IMD method to describe the drought condition in the study area. Because the inclusion of carry over effect with antecedent conditions. While considering the soil moisture from the knowledge of AWC in MPDSI estimation yields the better results to show the intensity of drought were occurred in the study area. However the sensitivity of duration factor used in MPDSI estimation, which depends on aerial distribution of rainfall and climatic variations in a region. Further improvement is needed to formulate the duration factor when applying the MPDSI estimation in different parts of India. Based on the results Hydrological drought assessment by Herbst method shows the severe dry spells in the Willington reservoir system due to the occurrence of low ground water levels in the recent years (1996 – 2003).

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