Hydrological Drought Analysis – Krishna Basin

KV Rao
Senior Scientist(SWCE)
CRIDA, Hyderabad-500 059

Drought is not a rare or random event, but a normal recurrent feature of climate. Persisting over months and years, drought can affect large areas and cause tremendous social hardship, environmental damage and economic loss. Since drought affects many social and economic sectors, a multitude of definitions have been developed by a range of disciplines. Drought occurs with differing frequencies throughout the world and affects all types of economies, developed and developing alike. Approaches to define drought reflect regional and ideological differences. These factors make any universal attempt at definition unrealistic (Wilhite 1993). For practical purposes, however, drought can be classed as meteorological, agricultural, groundwater or surface (van Lanen and Peters 2000).

Based on a disciplinary perspective can be found in Dracup et al.(1980), where droughts are related to precipitation (meteorological), streamflow (hydrological), soil moisture (agricultural) or any combination of the three. A similar classification can be found in Wilhite & Glantz (1985), where four categories are identified:

- Meteorological drought: Usually expressions of precipitation's departure from normal over some period of time. Reflects one of the primary causes of a drought.
- Hydrological drought: Usually expressions of deficiencies in surface and subsurface water supplies. Reflects effects and impacts of droughts.
- Agricultural drought: Usually expressed in terms of needed soil moisture of a particular crop at a particular time.
- Socio-economic drought: Definitions associating droughts with supply of and demand for an economic good.

A drought event is caused by a certain meteorological situation, for instance a persisting anticyclone/high pressure system. Associated with the prevailing dry and warm weather, a meteorological drought with a rainfall deficit develops. The rainfall deficit and the high evapotranspiration reduce the soil water content, which might cause an agricultural drought if occurring during the growing season. Due to the precipitation deficit in the catchments, stream flow decreases until it is only fed by groundwater and finally the groundwater reservoirs will also deplete. Consequently, hydrological droughts lag the occurrence of atmospheric droughts and depending on the season and the crop also the occurrence of agricultural drought. Water in hydrological storage systems such as surface and groundwater reservoirs is often used for multiple and competing purposes, e.g. flood control, irrigation, recreation, hydropower, navigation or wildlife habitat, further complicating the sequence and quantification of impacts (Wilhite, 2000). When the demand exceeds the supply, a socio-economic drought occurs. It is the rising demand on surface water resources (compare Chapter 1), which calls for a better prediction of the natural water supply and thus a better understanding and prediction of the characteristics of hydrological drought.

Hydrological drought can be defined in many different ways. Tate and Gustard (2000) reviewed climatological, agro-meteorological, streamflow, groundwater, and operational drought definitions from a hydrological perspective. Water balance indices constructed from different hydrometeorological variables govern the climatological and agro-meteorological definitions while extreme values and runs below a threshold usually define drought in streamflow time series

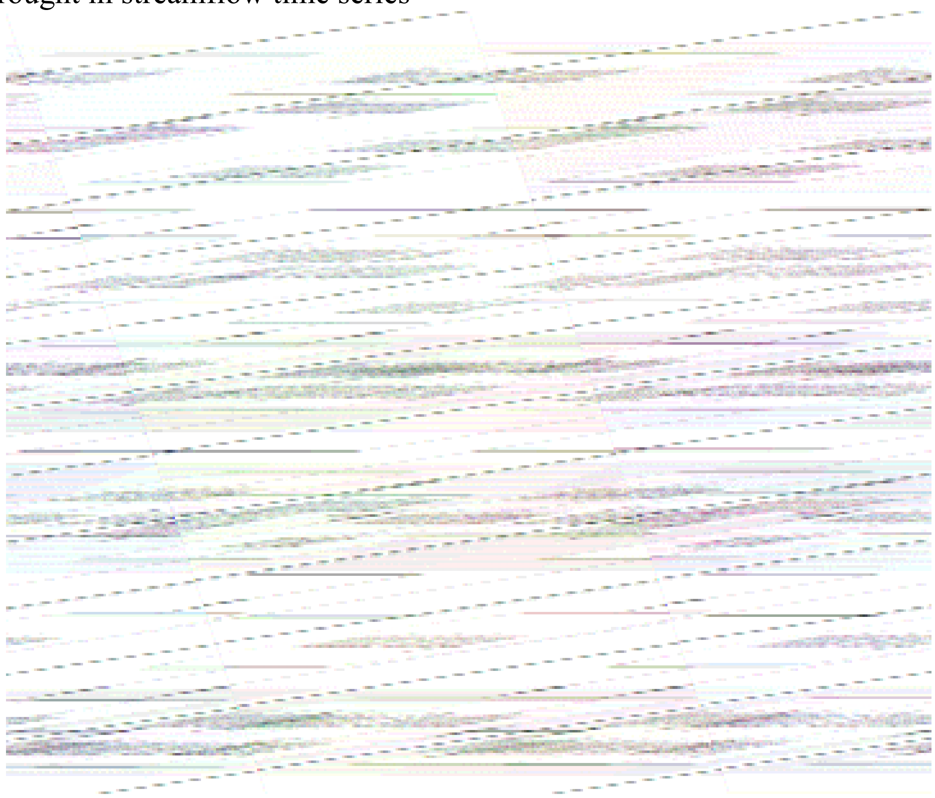


Fig.1 Propagation of drought through the hydrological cycle (modified after NDMC, 2001)

Event definition

The threshold level method

Hydrological drought events derived from streamflow time series are most frequently defined by the threshold level concept: a drought event starts, when the flow falls below the threshold and ends either when the threshold is exceeded or when the water deficit volume below the threshold has been replenished.

The most important decision for drought definition is the choice of the threshold level. Basically, a threshold can be constant or varying over the year, depending on how one wants to define the 'abnormal' situation. If particular seasons are treated separately, a different constant value can be chosen for instance to study summer and winter droughts

(Figure 3.2a). If the 'normal' situation is considered to be a typical annual regime, the threshold should be varying at a monthly or daily resolution (Figure 3.2b/c). Such a varying threshold determines relative streamflow deficits during both, the high and low flow seasons. However, flow which is less then usual during a particular season but not absolutely low is commonly not considered a drought. Hence, events defined with the varying threshold level should be called streamflow deficiency or streamflow anomaly rather than streamflow drought.

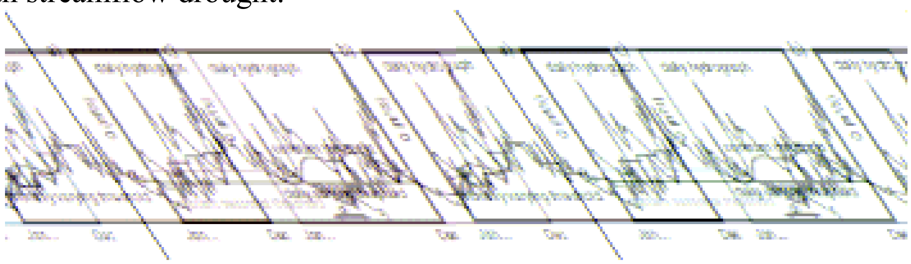


Fig 2.The threshold level method a) constant and seasonally constant threshold with indicated drought parameters di and si b) monthly varying threshold c) daily varying threshold

A general decision to make is how to derive the actual threshold level value. This value can be a certain streamflow, e.g. necessary to fill a reservoir or to guarantee an ecological habitat in the river, or a certain water level required for navigation.

The varying threshold level method determines periods below an annual threshold cycle, which consists of a specified exceedance probability, p, of daily flow duration curves. Since daily discharge values are used in the study, the varying threshold should also have a daily resolution. Normally, fdcs are based on calendar units (year, month, day) (Figure 3.5a). For a short time period like Period 1 (1962-90), a daily fdc would be constructed of 29 values only. To increase the sample size, a daily flow duration curve was obtained from a moving window sample also including the streamflow values of the preceding and following days (Figure 3.5b). This procedure allows the construction of a smooth fdc for each day of the year.

Under Indian conditions, a commonly used index for drought analysis is to compare the runoff depth or volume for given duration i.e month or a year with along term mean or standard period normal value for the given duration. It is considered that if during any year the runoff is found to be less than 75% of the normal runoff , the year would be considered as drought year and if it occurs in 25% or more than 25% of years, the area would be considered to be drought prone. (CWC,1982).

Based on this definition, available stream flow data on yearly basis was considered for various stations and analysis was performed. The following table summarises the information of selected gauging stations on sub basin name, data available period, no . of drought years and classification of station for hydrological drought based on the above definition.

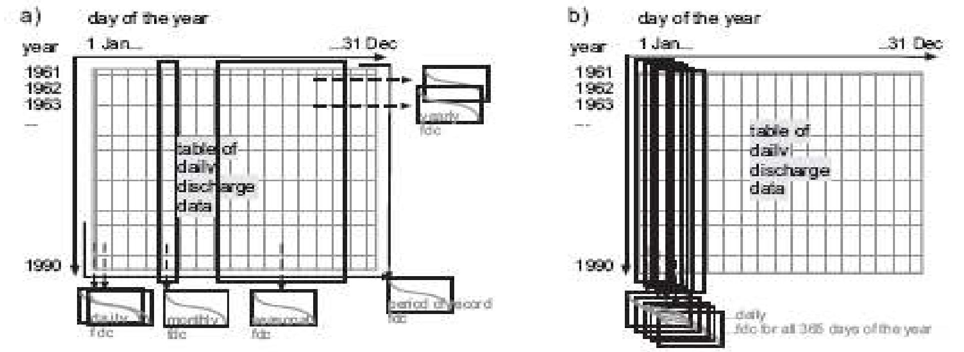


Fig. 3.5 Flow duration curves a) based on calender units b) for each day of the year based on a moving time window

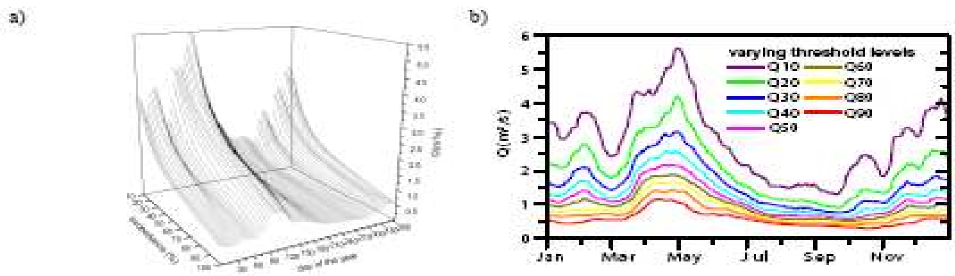


Fig 3. Flow Duration curve for every day .The varying threshold level approach applied to the a) daily flow duration curves from a 21-day moving window b) the resulting annual exceedance cycles

Comparison of annual flows with average and 75% of average flows for Vijayawada is shown in Fig 4 .

Low flow analysis:

Another parameter for consideration of hydrological drought analysis is to low flow index. Low flow data are normally specified in terms of the magnitude of low flow for a given time interval with in a year or season. The flow duration curves are used to define low flow index (LFI) as the 10 days average flow which is exceeded by 95% of the time of duration of the series. Flow duration curves for various periods for chosen sites using the available data were constructed.

Daily flow frequency distribution of moving average (7 day basis) values observed at Arjunwad station (Sub Basin K1) is shown the following Fig.5

Similarly , the information was generated for moving day on 10 day, 15 day, 30 days basis for stations which have got more 20 years of data. Further , frequency distribution curves were generated utilizing on daily discharges and on moving day average basis for 7 day, 10 day, 15 day, 30 days also. This info is useful for understanding the low flows that were experienced during the past years.

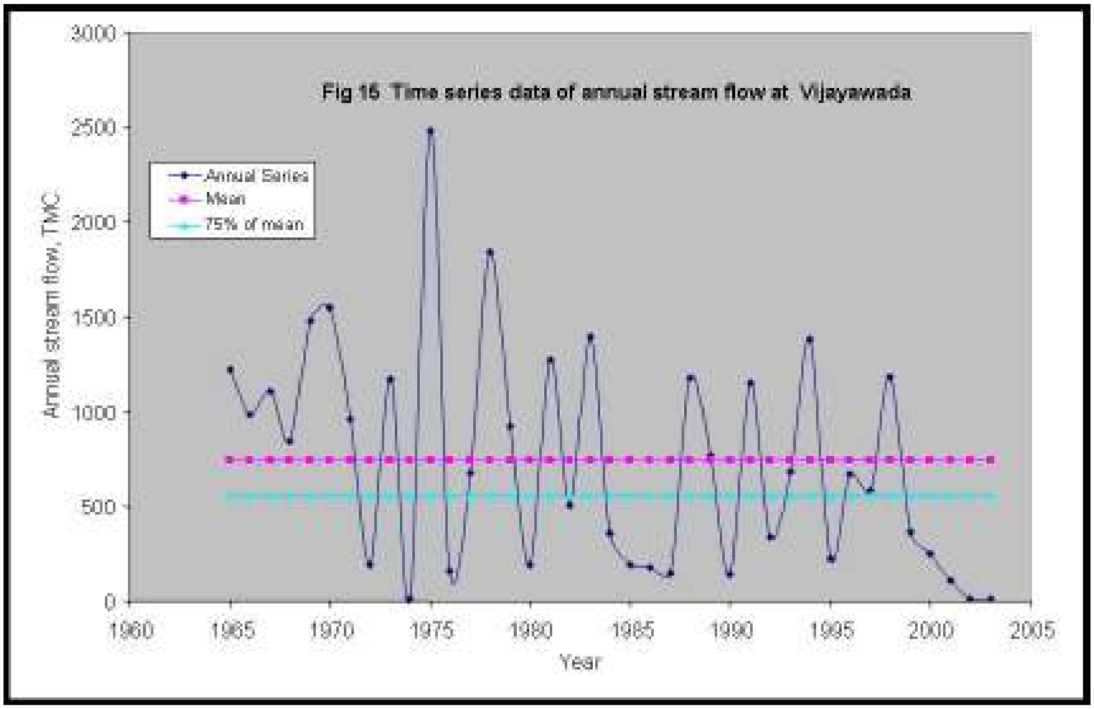
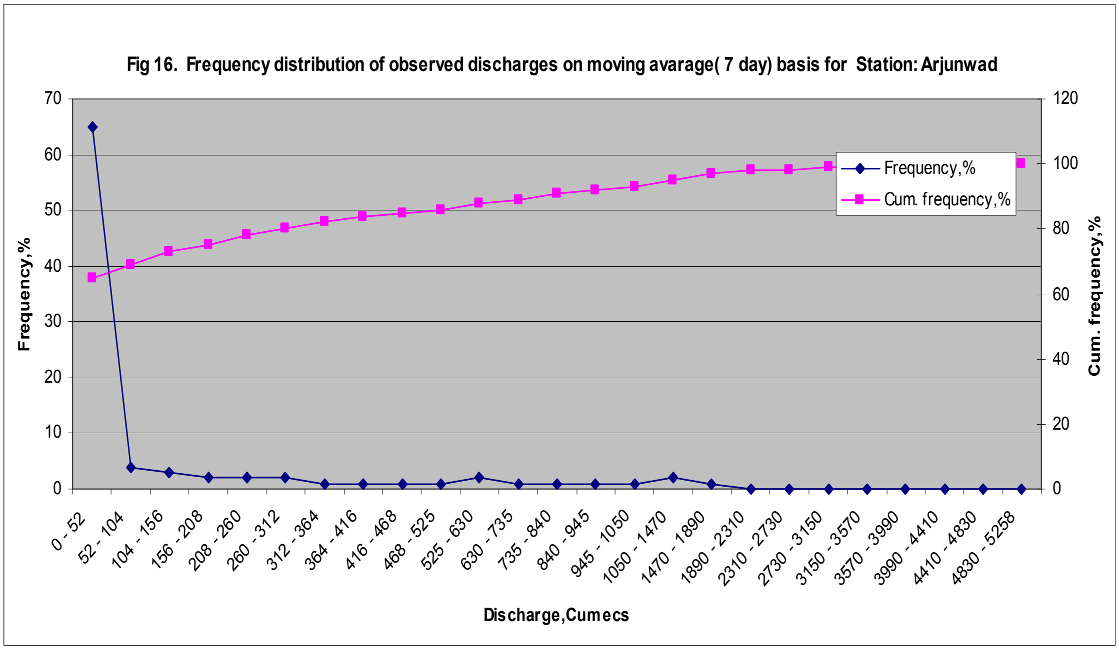


Table.1 Categorisation of selected gauge stations for hydrological drought analysis based on CWC criteria

Sub basin name	Station name	Drought /Non drought	No. of drought years	No. of years of data availability	Start and end of data available years
K1	Koyananagar	Drought	10	32	1972 2003:
K5	Narsingpur	Drought	15	39	1965 2003:
K5	Sarathi	Drought	13	39	1965 2003:
K5	Wadakbal	Drought	18	39	1965 2003:
K7	Vijayawada	Drought	17	39	1965 2003:
K7	Wadepally	Drought	15	39	1965 2003:
K8	Bavapuram	Drought	14	39	1965 2003:
K9	T_ramapuram	Drought	10	39	1965 2003:
K10	Damarcherla	Drought	16	36	1968 2003:
K12	Keesara	Drought	18	38	1965 2002:

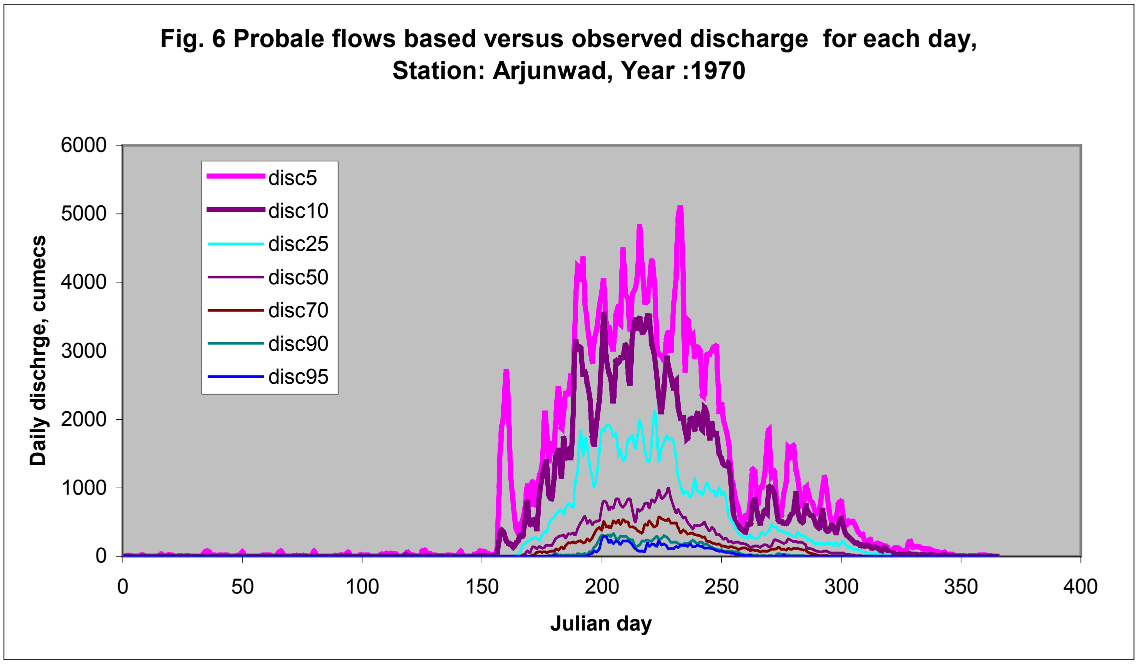


Hydrological drought analysis (Deficit , duration and intensity analysis)

In order to understand the hydrological drought in terms of duration, deficiency of flow and intensity, one needs to assess the observed flow against the flows at different probability levels. Considering that the monsoon is limited to South West monsoon to a larger extent, deficiency or duration of deficit flow with reference to average flow value of a season annual basis for a particular season may lead to erroneous conclusions. In order to over come this difficulty, flow duration curves for each day of year were constructed considering flows on a particular day for each station. Stations with more than 20 years of data were only considered for this analysis.

A sample output of variable discharge for each day at different probabilities is given below (Fig 6) .

In order to estimate the drought duration and deficit volume , difference between observed discharge and probable flows was estimated on a daily basis. Maximum duration (continuous days) of negative flows i.e (negative difference between actual flow and probable flow at different probabilities) was cumulated and maximum duration and deficit volume was estimated in every year. Observed flow against probable flows for different probabilities is shown in the following Fig 7.



In order to estimate the drought duration and deficit volume, difference between observed discharge and flows at different probabilities was estimated on daily basis. Maximum duration (continuous days) of deficit flows i.e (negative difference between actual flow and probable flow at different probabilities) was accumulated thus estimating maximum duration and corresponding deficit volume for every year. Observed flow against probable flows for different probabilities is shown in the following Fig 7.

Estimated maximum duration of drought spell and it's deficit volume in every year at different probabilities shown in the following Table. Hydrological drought can be based on maximum duration or maximum deficit. In this exercise, drought intensity analysis was carried out based on (a) maximum duration and corresponding deficit volume and (b) maximum deficit volume and corresponding duration. Accordingly, drought intensity was estimates were compared for both maximum deficit and maximum duration basis on yearly basis for each of the stations. An example of drought intensity estimations is given in following Table 2 for drought intensity analysis based on discharge, Table 3 for drought intensity analysis based on duration and Table 4 for drought intensity comparison based on maximum duration and discharge for station Arjunwad.

Analysis of hydrological drought intensity for identified stations (Fig 8) based on stream flow indicate that the intensity is higher at Vijayawada, Wadepally, Bavapuram and Narsinghpur stations located in K-7, K-7, K-8 and K-5 sub basins respectively. In case of Vijayawada and Wadepally gauging stations, the hydrological drought intensity is consistently higher from 1990 onwards and is comparable with severity of intensities experienced during ,1985-86 and 1986-87.

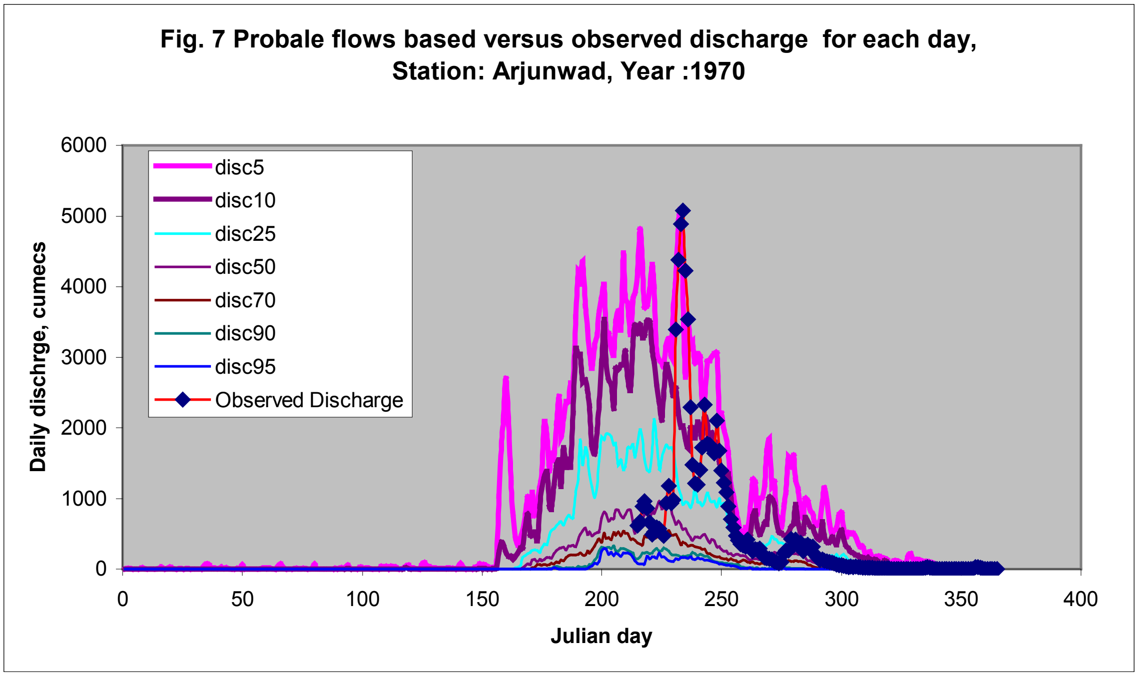


Table 2 Maximum duration of drought spell and its deficit volume in every year at different probabilities based on discharge at Arjunwad

Year	10%		50		75		90	
	Duration, days	Deficit volume, (cumecs)	Duration, days	Deficit volume, (cumecs)	Duration, days	Deficit volume, (cumecs)	Duration, days	Deficit volume, (cumecs)
1969	49	56875.8	35	5701.2	15	859.7	1	18.9
1970	62	91734.2	7	2068.1	2	116.1	0	0
1971	63	112067	25	5087.7	3	223.8	0	0
1972	146	141717	56	19770.9	16	4424.5	12	969.3
1973	52	85854.7	16	6090.5	11	1341.7	0	0
1974	76	109181	20	5742.8	8	352.7	0	0
1975	28	58377.4	17	5719.2	11	2119	3	153.5
1976	127	70687.7	9	3030.4	6	393.3	0	0
1977	58	94508.4	14	5640.2	12	2232.3	6	66.9
1978	62	91189	7	1886.1	6	182.4	0	0
1979	39	67102.3	13	6238.7	11	2891.7	9	1006.1
1980	128	65265.2	13	3507.1	4	402.6	0	0
1981	66	94557.1	8	2169.1	6	435.7	1	2.2
1982	163	153830	23	6958.6	20	3002.8	15	265.7
1983	42	71778.4	12	3227.8	4	522.9	1	43.2
1984	71	114686	12	2769.3	4	272.3	0	0
1985	191	159623	36	5156.2	19	1299.8	5	38.8

1986	39	82207.6	34	6860.4	25	3308.9	22	1470
1987	193	183180	29	18102.6	28	9373.58	23	3069.58
1988	43	62839.3	24	6395	17	1886.29	0	0
1989	137	101866	18	7239.74	15	3294.44	7	912.45
1990	21	47206.9	16	4809.9	12	1215.43	9	193
1991	108	41057.4	29	1347.29	3	54.8	0	0
1992	72	110013	32	8527.88	24	3715.53	4	321.6
1993	87	94243.1	9	2697.2	6	347.6	0	0
1994	31	52021.1	13	4304.4	9	577.1	0	0
1995	92	147198	27	14078.1	25	7414.71	19	3047.81
1996	64	84075.4	28	9654.5	23	4450	19	971.4
1997	59	57587.3	11	4924.7	10	2111.2	6	610.5
1998	122	159999	24	7050.72	9	1568.6	3	94.3
1999	67	84042.4	46	10349.1	43	3596.73	7	303.7
2000	193	183808	39	20467.3	35	10036	18	2704.5
2001	126	168531	35	13266.4	20	3407.9	14	324.6
2002	199	191051	41	14455.8	13	3125.5	9	673
2003	179	188796	100	17656.3	21	3810	5	401.2
2004	4	26	0	0	0	0	0	0

Table 3 Maximum duration of drought spell and its deficit volume in every year at different probabilities based on duration at Arjunwad

Year	10%		50		75		90	
	Duration, days	Deficit volume, (cumecs)	Duration, days	Deficit volume, (cumecs)	Duration, days	Deficit volume, (cumecs)	Duration, days	Deficit volume, (cumecs)
1969	59	22266	35	5701	15	860	1	19
1970	86	19838	7	2068	3	58	0	0
1971	101	24720	25	5088	4	131	0	0
1972	146	141717	56	19771	27	1682	13	364
1973	52	85855	16	6091	11	1342	0	0
1974	76	109181	20	5743	8	345	0	0
1975	28	58377	17	5719	11	2119	3	154
1976	127	70688	28	1504	9	102	0	0
1977	71	22691	22	369	12	2232	6	67
1978	65	25452	18	1251	6	182	0	0
1979	46	11950	22	5248	11	2892	9	1006
1980	128	65265	30	2218	15	345	0	0
1981	80	16140	14	444	7	351	1	2
1982	163	153830	27	3660	23	1418	15	266
1983	69	15986	31	1835	6	187	1	43
1984	71	114686	18	1450	6	188	0	0
1985	191	159623	36	5156	19	1300	5	39

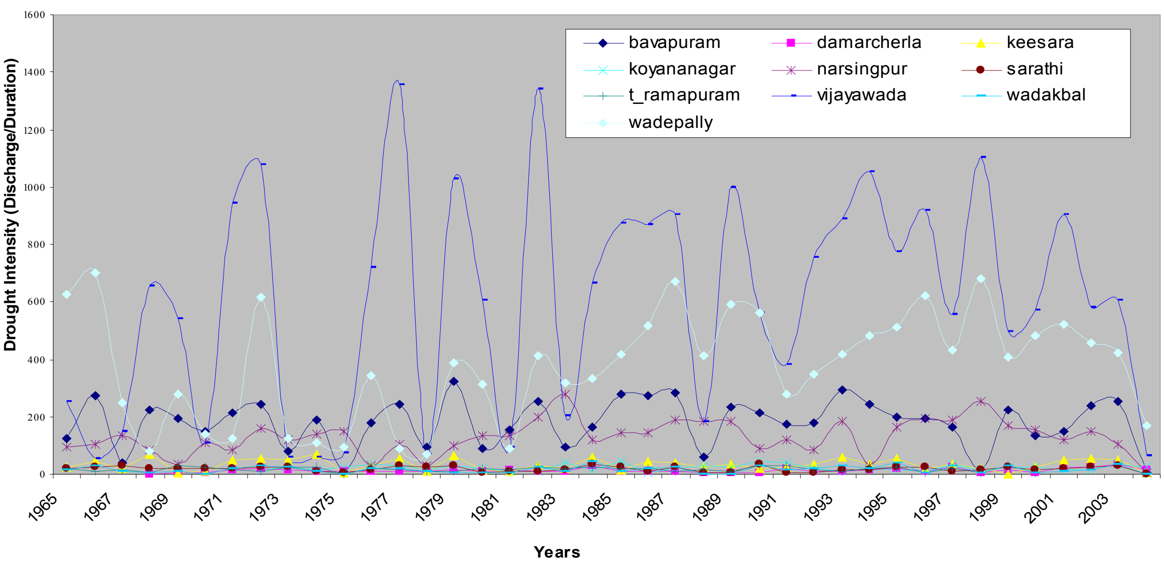
1986	121	71801	38	3961	25	3309	22	1470
1987	193	183180	43	4977	28	9374	23	3070
1988	71	13287	27	6039	17	1886	0	0
1989	137	101866	22	3284	16	1148	10	175
1990	52	42816	20	3133	12	1215	9	193
1991	108	41057	29	1347	5	44	0	0
1992	96	25494	32	8528	24	3716	10	177
1993	87	94243	11	1471	6	348	0	0
1994	87	19451	13	4304	9	577	0	0
1995	92	147198	33	8402	28	3711	19	3048
1996	64	84075	48	8477	30	1585	19	971
1997	66	38847	49	4830	26	1438	6	611
1998	122	159999	24	7051	10	514	3	94
1999	67	84042	46	10349	43	3597	7	304
2000	193	183808	39	20467	35	10036	18	2705
2001	126	168531	35	13266	26	1650	14	325
2002	199	191051	56	6624	40	2972	13	103
2003	179	188796	100	17656	21	3810	5	401
2004	4	26	0	0	0	0	0	0

Table 4 Comparative analysis of hydrological drought intensity based on maximum duration and discharge at different probabilities at Arjunwad

Year	10%		50%		70%		90%	
	Duration	Discharge	Duration	Discharge	Duration	Discharge	Duration	Discharge
1969	377	1161	163	163	57	57	19	19
1970	231	1480	295	295	19	58	0	0
1971	245	1779	204	204	33	75	0	0
1972	971	971	353	353	62	277	28	81
1973	1651	1651	381	381	122	122	0	0
1974	1437	1437	287	287	43	44	0	0
1975	2085	2085	336	336	193	193	51	51
1976	557	557	54	337	11	66	0	0
1977	320	1629	17	403	186	186	11	11
1978	392	1471	70	269	30	30	0	0
1979	260	1721	239	480	263	263	112	112
1980	510	510	74	270	23	101	0	0
1981	202	1433	32	271	50	73	2	2
1982	944	944	136	303	62	150	18	18
1983	232	1709	59	269	31	131	43	43
1984	1615	1615	81	231	31	68	0	0
1985	836	836	143	143	68	68	8	8
1986	593	2108	104	202	132	132	67	67
1987	949	949	116	624	335	335	133	133

1988	187	1461	224	266	111	111	0	0
1989	744	744	149	402	72	220	17	130
1990	823	2248	157	301	101	101	21	21
1991	380	380	46	46	9	18	0	0
1992	266	1528	267	267	155	155	18	80
1993	1083	1083	134	300	58	58	0	0
1994	224	1678	331	331	64	64	0	0
1995	1600	1600	255	521	133	297	160	160
1996	1314	1314	177	345	53	193	51	51
1997	589	976	99	448	55	211	102	102
1998	1311	1311	294	294	51	174	31	31
1999	1254	1254	225	225	84	84	43	43
2000	952	952	525	525	287	287	150	150
2001	1338	1338	379	379	63	170	23	23
2002	960	960	118	353	74	240	8	75
2003	1055	1055	177	177	181	181	80	80
2004	7	7	0	0	0	0	0	0

Fig 19 Hydrological drought Intensity analysis -Time series data



Summary

A procedure for estimation of hydrological drought at sub basin level is presented. An application of the same for selected sub basins in Krishna basin were discussed. .