Assessment of Spatial and Temporal Drought Severity; A Study in Transition zone in Karnataka State in India

Abstract

Rainfall data from 1979-2019 was analysed across the agro climatic zones in transition region of Karnataka. Rainfall Anomaly Index and Mean deviation methods are used to identify drought years and wet years over both spatial and temporal on time scale. The North Eastern Transition Zone can be considered as most vulnerable zone as it recorded for about 24 dry years values which indicates existence of persistence drought in this zone. The Northern Transition Zone is not vulnerable when compared to Northern Eastern Transition Zone as most of the drought year values are nearer to wet year values (RAI -0.3 to -1.2) which implies that this zone has moderate drought condition. The Southern transition zone has normal drought condition (RAI +0.3 to -0.3) which implies neither wet nor neither dry condition. But if proper conservations were not taken, this zone may come in the hit list of most vulnerable zone in near future which will harm the farming community.

Keywords*:* Rainfall, Drought, Rainfall Anomaly index, Transition zone, Karnataka

Introduction

India, a sub-tropical country is highly sensitive to climate change. The main reason for its high sensitivity is due to the vagaries of rainfall. More than 68 percent of the net sown area in the country is drought prone, out of which 50 percent is severe in nature (Alley *et al*., 2007). India experienced at least one drought in every three years in the last five decades. However, the main concern is the increase in the frequency and spatial extent of prolonged droughts (Mishra and Singh, 2010). It is observed that from 1871 to 2009, India witnessed 24 major droughts among them five were severe. One of the major reasons reported for drought occurrence in India ha been due to the strong link with the EI Nino-Southern Oscillations (ENSO) pattern (Gadgil, 2003).

Rain-fed south central India is highly prone to droughts. The abnormally low rainfall in 1979 resulted in 20% reduction in food grain production, while the 1987 drought damaged 58.6 million hectares of cropped area and threatened 285 million people's livelihood. The 2002 drought resulted in the reduction of agricultural productivity from 2012 million tons to 174 million tons (Murthy and Sai , 2010). The arid (19.6%), semi-arid (37%) and sub-humid (21%), regions occupying 77.6 % of India's total land area of 329 million hectare are the most drought prone areas (CMP, 2010). There are less studies for assessment of drought at disaggregated micro level in semi arid zone.

Semi arid zone contributes about 42 percent of total food grain production, supporting 60 percent of livestock population and employing nearly 37 percent of marginal farmers through agricultural activities. It comprises states namely Andhra Pradesh, Karnataka, Tamil Nadu, Deccan plateau, parts of Gujarat and Maharashtra. Karnataka is ranks second after Rajasthan in terms of drought prone. The spatial and temporal feature of rainfall necessitates the need to examine its changing pattern in response to changing temperature because rainfall is one of the most important parameters that influence the agriculture of a region and food production. According to simulation studies, if proper mitigation measures are not taken, there can be agricultural productivity losses from 5 to 18% from 2030 to 2080 in semi arid tropic region of India (Singh and Bantilan, 2011).To understand the impact of climate change in case of drought the statistical analysis of variation of rainfall history of the region is important (Wilhite, 2016). Karnataka has Dry zone, Transition zone and Hilly zone which further divided into 10 agro climatic zones. The transition zone consists three agro climatic zones namely North eastern transition zone (NETZ), Northern Transition zone (NTZ) and Southern Transition zone (STZ). Transition zone was chosen for study as its many districts are ranking in top in category of vulnerability zones (KNDMS, 2018) and attempted to analyse extent of drought severity , mean deviation and deficit rainfall in the zone which will help to local specific adaptations and institutional development which ultimately favours farming community.

2. Study area and Methodology

Karnataka is located between 11° 40' N and 18° 27' N latitudes and between 74° 5' E and 78° 33' E longitudes, at the centre of the western Peninsular India (Figure 1) covering an area of 19.1 million hectares, accounting for 5.8 % of the country's total geographical area The southern transition zone has 1.66 Million ha which is large in area and also receives highest average rainfall of 820 to 910 mm among other two zones as shown in Table 1.

Table 1: Physiographic of Agro climatic zones in Transition Zone o in Karnataka

Agro Climatic Zones	Area (M ha)	Elevation above sea level (Metres)	Mean Rainfall (mm)	Districts	AgrometField Unit Location
NETZ	0.87	800 to 900	700 to 890	Bidar, Gulbarga	Bidar
NTZ	1.13	450 to 900	750 to 850	Dharwad, Belagavi, Haveri	Dharwad
STZ	1.66	800 to 900	820 to 910	Hassan, Shivamogga, Chikkamagaluru	Navile, Shivamogg

Source: Department of Mines and Geology, Government of Karnataka Annual Report 2013).

The lowest rainfall was received by NETZ with 700 to 890 mm. The northern transition has second higher either in terms of area or rainfall in transition region. Rainfall measure is used in drought index calculations as it is the most vital hydrological variable generally the only meteorological measurement made in semi arid areas (Tilahun,2006). Climatic variables like daily rainfall, temperature from 1979 to 2019 across Karnataka state was collected from AICRPAM CRIDA, Hyderabad.

i) Rainfall Anomaly Index (RAI)

In this study, RAI is modified to account for non normality like Standard precipitation Index (SPI) is used for the assessment of both temporal and spatial droughts as it is independent of time and space. Hence it is more useful in semi-arid regions particularly like India, as at many meteorological stations the recorded rainfall data available is less than 30 years, while most of the metrological drought assessment indices require more than 30 years of data (Rooy,1965). RAI is used to assess and identify droughts, drought severity and variability by comparing with some established arbitrary value. It is described as rainfall variability over a time and is estimated as below:

For positive anomalities

$$RAI= 3\left(\frac{RNF-RNF_m}{X-RNF_m}\right)\qquad\ldots\ldots\ldots\ldots(1)$$

For negative anomalities

$$RAI = -3\left(\frac{RNF-RNF_m}{Y-RNF_m}\right)\qquad\ldots\ldots\ldots\ldots(2)$$

Where, RNF = Actual rainfall for a given year (mm)

RNF_m =Mean rainfall of the total length of record (mm)

X= Mean of the ten highest values of rainfall (mm)

Y= Mean of the ten lowest values of rainfall (mm)

Table 2: Classification of Rainfall Anomaly Index

S. No	RAI Range	Drought Classification	Percent deficit from mean rainfall
1	>3	Extreme wet	
2	2.1 to 3	Severe wet	
3	1.2 to 2.1	Medium wet	
4	0.3 to 1.2	Weak wet	
5	+0.3 to -0.3	Normal	
6	-0.3 to -1.2	Weak drought	0 to 10
7	-1.2 to -2.1	Medium drought	10 to 15
8	-2.1 to -3	Severe drought	15 to 20
9	< -3	Extreme drought	>20

(Source: Keyantash and Dracup,2002)

A ranking of nine classes of rainfall abnormality ranging from extremely wet to extremely dry and range of each class is shown in Table 2 (Keyantash and Dracup, 2002); Roshan *et al.*, 2012). If the purpose of the study is to investigate dry periods the negative prefixed RAI is used, while positive RAI is used to study wet periods (Hansel and Matschullat, 2006).

ii) Percentage of Deficit rainfall (DR) or Rainfall Surplus (RS)

The percentage annual rainfall departure from the long term mean annual rainfall was used for drought assessment (Pai *et al.*, 2011) for all the stations. Percent of deviation for each year was further categorized into four percentage ranges namely 0 to 10, 10 to 15, 15 to 20 and greater than 20.

$$\text{Percentage of Deviation} = (P_{act} - P)/P * 100$$

P_{act} –Precipitation of the region

P-Mean precipitation of the region

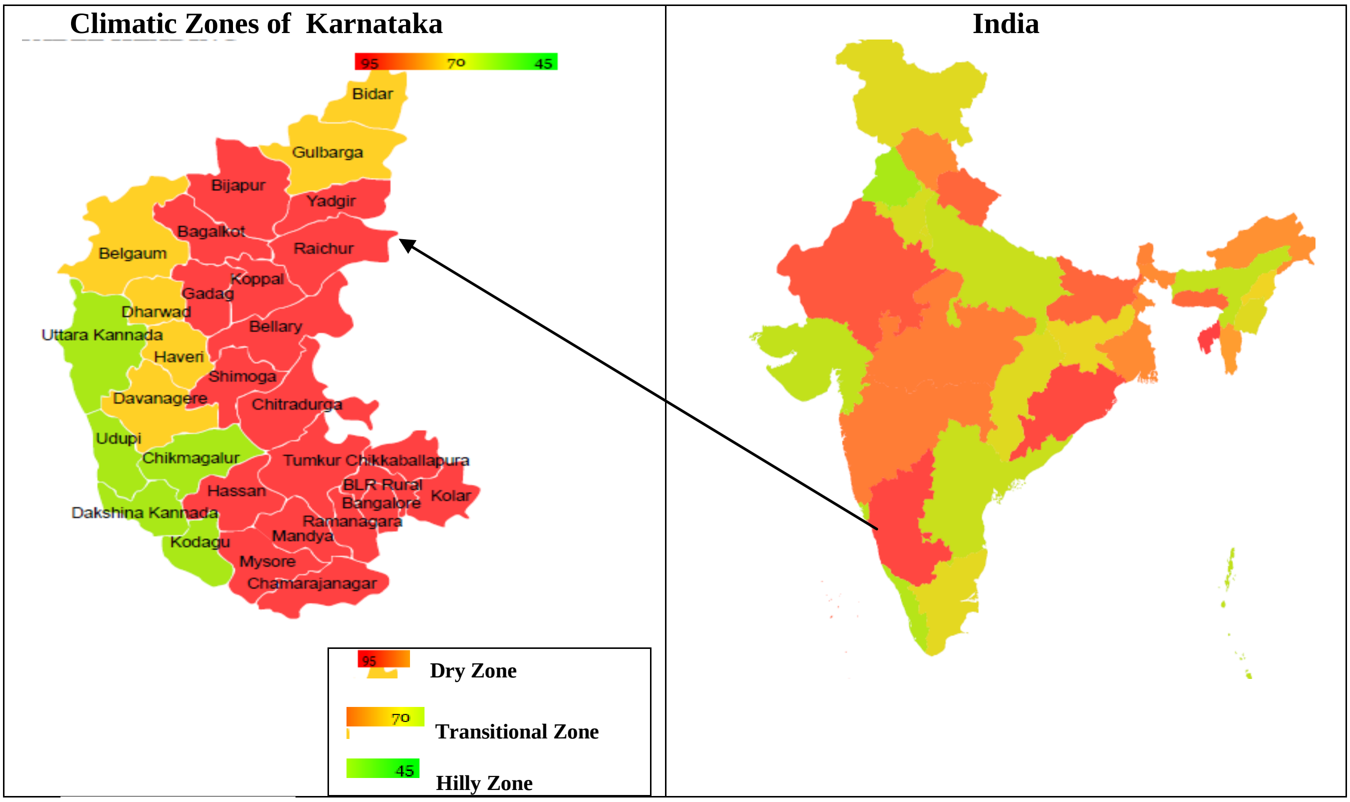

Figure 1 : Map Showing climatic zones of Karnataka state in India

3. Results and discussions

Dry and wet years of each transition zone have been presented. The study attempted to find out most drought affected zone based on occurrence and intensity of dry spells years over the forty years i.e. 1979 to 2019. If the RAI < -3, then it implies that, rainfall deficit will be certainly more than 20 % which can be considered as extreme drought.

Drought Severity in Northern Eastern Transition zone of Karnataka

The dry period RAI values in NETZ ranges from -3.85 to -0.20. During the year 1979 to 2019, the extreme drought (RAI < -3) noticed in four years i.e. 1991, 1992, 1993 & 1994 as shown in Table 3. It was also noticed that, about seven years are under severe drought condition (RAI -2.1 to -3) as shown in (Figure 2). Thirteen districts are under medium drought & weak drought (RAI -0.3 to -2.1). Out of 40 years about 24 years are under drought condition in NETZ. The wet period RAI ranges from 0.35 to 4.67. Out of 17 years of wet period, the occurrence of normal wet (+0.3 to -0.3) occurred in the year 2000. The extreme wet period accrued for seven years (>3 RAI) in 1983, 1988, 1990,1998, 2005, 2010 & 2016. The nine years have consequently falling in the category of medium wet to weak wet category with RAI ranges from 1.10 to 1.69 in different years. The North eastern transition zone can be considered as most vulnerable drought zone since it is more prone to drought occurrence for 24 years with less number of wet years during study period of 1979-2019. As a whole, North eastern transition zone has maximum mean deviation in the year 1994 with MD value -121.34 with -29.99 % DR. The minimum MD occurred in the year 2008 with value -6.21 which also recorded with -1.53 % DR .The maximum wet year is 1983 with positive deviation of 204.34 mm with 50.51% SR. The minimum wet year is 2000 with positive deviation of 15.27 mm with 3.77% SR.

Table 3: Drought Severity in North Eastern Transition Zone (NETZ)

S.No	Dry years of NETZ					S.No	Wet years of NETZ				
	Year	AR(mm)	MD(mm)	RAI	DR(%)		Year	AR(mm)	MD(mm)	RAI	SR(%)
1	1980	340.62	-63.98	-2.03	-15.81	1	1979	428.37	23.77	0.54	5.87
2	1982	333.93	-70.67	-2.24	-17.47	2	1981	469.04	64.44	1.47	15.93
3	1984	354.38	-50.22	-1.59	-12.41	3	**1983**	**608.94**	**204.34**	**4.67**	**50.51**
4	1985	342.97	-61.63	-1.95	-15.23	4	1987	456.49	51.89	1.19	12.82
5	1986	320.65	-83.95	-2.66	-20.75	5	1988	560.17	155.57	3.55	38.45
6	1991	290.84	-113.76	-3.61	-28.12	6	1989	452.86	48.26	1.10	11.93
7	1992	330.80	-73.80	-2.34	-18.24	7	1990	543.06	138.46	3.16	34.22
8	1993	346.77	-57.83	-1.83	-14.29	8	1995	475.67	71.07	1.62	17.57
9	**1994**	**283.26**	**-121.34**	**-3.85**	**-29.99**	9	1996	457.62	53.02	1.21	13.10
10	1997	343.75	-60.85	-1.93	-15.04	10	1998	546.44	141.84	3.24	35.06
11	1999	353.63	-50.97	-1.62	-12.60	11	**2000**	**419.87**	**15.27**	**0.35**	**3.77**
12	2001	383.17	-21.43	-0.68	-5.30	12	2005	595.61	191.01	4.36	47.21
13	2002	317.18	-87.42	-2.77	-21.61	13	2010	539.16	134.56	3.07	33.26
14	2003	320.88	-83.72	-2.65	-20.69	14	2013	478.73	74.13	1.69	18.32
15	2004	316.50	-88.10	-2.79	-21.77	15	2016	542.23	137.63	3.14	34.02
16	2006	325.15	-79.45	-2.52	-19.64	16	2017	444.84	40.24	0.92	9.95
17	2007	375.10	-29.50	-0.94	-7.29	17	2019	439.85	35.25	0.81	8.71
18	**2008**	**398.39**	**-6.21**	**-0.20**	**-1.53**						
19	2009	396.03	-8.57	-0.27	-2.12						
20	2011	318.33	-86.27	-2.73	-21.32						
21	2012	379.76	-24.84	-0.79	-6.14						
22	2014	350.71	-53.89	-1.71	-13.32						
23	2015	312.29	-92.31	-2.93	-22.82						
24	2018	294.59	-110.01	-3.49	-27.19						
Max dry value		**283.26**	**-121.34**	**-3.85**	**-29.99**	**Max wet value**		**608.94**	**204.34**	**4.67**	**50.51**
Min dry Value		**398.39**	**-6.21**	**-0.20**	**-1.53**	**Min wet value**		**419.87**	**15.27**	**0.35**	**3.77**
AR –Annual Rainfall; MD-Mean deviation ;RAI-Rainfall Anomaly Index; DR- Deficit Rainfall; SR-surplus Rainfall											
**Authors calculation based on data availability from AICRPAM, CRIDA, Hyderabad*											

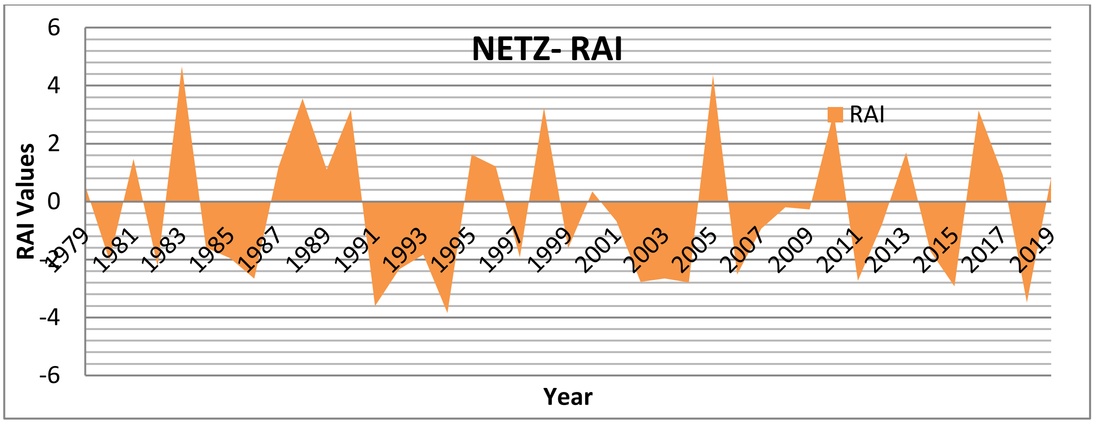

Figure 2; Dry and Wet years of North Eastern Transition Zone

Drought Severity in Northern Transition zone of Karnataka

In the northern transition zone, the dry years occurs for 22 years. The dry period (< -3 RAI) occurred in five years 2001, 2016, 2003, 1985,2002 with RAI values of -4.00 ,-3.96, -3.68, -3.64 & -3.00 respectively (Table 4) which imply that there is extreme drought. During forty years from 1979 to 2019, the weak and medium drought existed for about seventeen times with RAI values ranges from -0.3 to -2.1. About 10 years are under range of -0.73 to -0.01 which implies as normal condition of neither drought or nor wet years. With respective to percentage deviation of rainfall, about nine years i.e. 2001, 2016, 2003, 1985, 2002, 1995,1989, 2015 and 1990 are categorised in extreme drought condition (>20% deviation). The extreme wet years occurred with value (RAI >3) in the year 2014, 2009, 2019 with 3.02, 4.30 & 5.93 respectively (Figure 3).

About six years falls in the category of severe wet as the RAI values more than 2.07 to 2.81. The highest RAI of wet period accrued in 2019 with 5.93 (> 3 RAI) and lowest in 1980 with RAI value 0.25. It is observed that, the NTZ is not vulnerable when compared to NETZ as most of the drought year values are nearer to wet year values. As a whole, North transition zone has maximum mean deviation in the year 2001 with MD value -229.36mm with -33.58 % DR. The minimum MD occurred in the year 1987 with value -0.52 mm which also recorded with -0.08 % DR .The maximum wet year is 2019 with positive deviation of 329.31 mm with 48.21% SR. The minimum wet year is 1980 with positive deviation of 14.03 mm with 2.05% SR.

Table 4: Drought Severity in Northern Transition Zone (NTZ)

S. No	Dry years of NTZ					S. No	Wet years of NTZ				
	Year	AR(mm)	MD(mm)	RAI	DR(%)		Year	AR(mm)	MD(mm)	RAI	SR(%)
1	1981	671.64	-11.36	-0.20	-1.66	1	1979	798.08	115.08	2.07	16.85
2	1983	665.84	-17.16	-0.30	-2.51	2	**1980**	**697.03**	**14.03**	**0.25**	**2.05**
3	1984	620.42	-62.58	-1.09	-9.16	3	1982	800.04	117.04	2.11	17.14
4	1985	474.10	-208.90	-3.64	-30.59	4	1988	711.51	28.51	0.51	4.17
5	1986	614.75	-68.25	-1.19	-9.99	5	1991	754.03	71.03	1.28	10.40
6	**1987**	**682.48**	**-0.52**	**-0.01**	**-0.08**	6	1992	752.86	69.86	1.26	10.23
7	1989	523.83	-159.17	-2.77	-23.30	7	1993	726.06	43.06	0.78	6.30
8	1990	561.99	-121.02	-2.11	-17.72	8	1994	714.63	31.63	0.57	4.63
9	1995	514.63	-168.37	-2.94	-24.65	9	1997	760.52	77.52	1.40	11.35
10	1996	645.24	-37.76	-0.66	-5.53	10	2005	838.96	155.96	2.81	22.83
11	1998	641.22	-41.78	-0.73	-6.12	11	2006	791.00	108.00	1.94	15.81
12	1999	653.47	-29.54	-0.51	-4.32	12	2007	828.60	145.60	2.62	21.32
13	2000	643.26	-39.74	-0.69	-5.82	13	2008	735.41	52.41	0.94	7.67
14	**2001**	**453.64**	**-229.36**	**-4.00**	**-33.58**	14	2009	922.11	239.11	4.30	35.01
15	2002	511.05	-171.95	-3.00	-25.18	15	2010	818.03	135.03	2.43	19.77
16	2003	471.75	-211.25	-3.68	-30.93	16	2011	739.81	56.81	1.02	8.32
17	2004	655.34	-27.66	-0.48	-4.05	17	2012	836.64	153.64	2.77	22.49
18	2013	660.16	-22.84	-0.40	-3.34	18	2014	850.99	167.99	3.02	24.60
19	2015	527.37	-155.63	-2.71	-22.79	19	**2019**	**1012.31**	**329.31**	**5.93**	**48.21**
20	2016	456.00	-227.00	-3.96	-33.24						
21	2017	618.47	-64.53	-1.12	-9.45						
22	2018	647.88	-35.12	-0.61	-5.14						
Max dry value		**453.64**	**-222.36**	**-4.00**	**-33.58**	**Max wet value**		**1012.31**	**329.31**	**5.93**	**48.71**
Min dry value		**682.48**	**-0.52**	**-0.01**	**-0.08**	**Min wet value**		**697.03**	**14.03**	**0.25**	**2.05**

AR –Annual Rainfall; MD-Mean deviation ;RAI-Rainfall Anomaly Index; DR- Deficit Rainfall; SR-surplus Rainfall

**Authors calculation based on data availability from AICRPAM, CRIDA, Hyderabad*

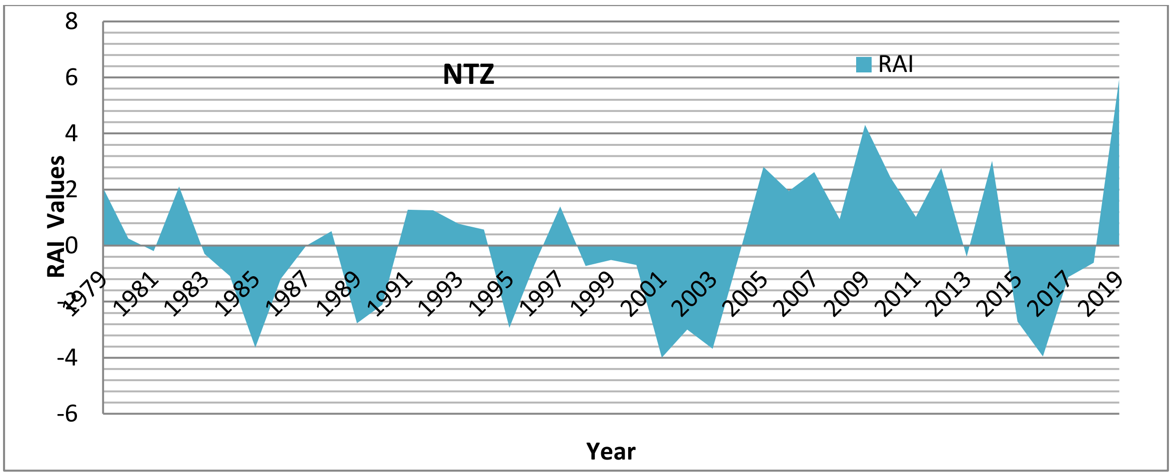

Figure 3; Dry and Wet years of North Transition Zone

Drought Severity in Southern Transition zone of Karnataka

In the Southern Transition Zone, the dry years occurred for 22 years as same as NTZ. The period from 1985 to 1989 recorded severe drought as the RAI values ranges -2.1 to -3. The extreme drought condition occurred in the year 2001, 2002, 2003 (< -3 RAI) as shown in Table 5. About four years recorded with RAI above -1.95 to -1.15 which imply as medium drought in the zone (Figure 4). Majority of the years falls in the weak and medium wet category. The STZ didn't registered any year with RAI > 3. This implies that this zone has normal condition of neither wet or neither dry condition. But if proper conservations were not taken, the zone may comes in the hit list of most vulnerable zone in near future. As a whole, Southern transition zone has maximum mean deviation in the year 2003 with MD value -317.98mm with -32.76 % DR. The minimum MD occurred in the year 2015 with value -5.46 mm which also recorded with -0.56 % DR .The maximum wet year is 2005 with positive deviation of 442.88 mm with 45.63 % SR. The minimum wet year is 1983 with positive deviation of 30.65mm with 3.16% SR.

Table 5: Drought Severity in Southern Transition Zone (STZ)

S.No	Dry years of STZ					S.No	Wet years of STZ				
	Year	**AR(mm)**	**MD(mm)**	**RAI**	**DR(%)**		**Year**	**AR(mm)**	**MD(mm)**	**RAI**	**SR(%)**
1	1979	917.41	-53.15	-0.73	-5.48	1	1980	1118.01	147.45	0.37	15.19
2	1982	962.10	-8.46	-0.12	-0.87	2	1981	1048.86	78.30	0.20	8.07
3	1984	945.86	-24.70	-0.34	-2.55	3	**1983**	**1001.21**	**30.65**	**0.08**	**3.16**
4	1985	759.21	-211.35	-2.90	-21.78	4	1991	1032.02	61.46	0.15	6.33
5	1986	886.88	-83.69	-1.15	-8.62	5	1992	1066.62	96.06	0.24	9.90
6	1987	828.22	-142.34	-1.95	-14.67	6	1994	1069.42	98.85	0.25	10.18
7	1988	791.06	-179.51	-2.46	-18.49	7	1997	1061.88	91.31	0.23	9.41
8	1989	774.59	-195.98	-2.68	-20.19	8	1999	1046.70	76.14	0.19	7.84
9	1990	803.13	-167.43	-2.29	-17.25	9	**2005**	**1413.45**	**442.88**	**1.11**	**45.63**
10	1993	907.47	-63.09	-0.86	-6.50	10	2007	1093.84	123.28	0.31	12.70
11	1995	752.88	-217.69	-2.98	-22.43	11	2009	1010.88	40.31	0.10	4.15
12	1996	811.72	-158.84	-2.18	-16.37	12	2010	1155.07	184.50	0.46	19.01
13	1998	883.04	-87.52	-1.20	-9.02	13	2011	1393.69	423.13	1.06	43.60
14	2000	961.05	-9.52	-0.13	-0.98	14	2012	1397.70	427.14	1.07	44.01
15	2001	720.25	-250.31	-3.43	-25.79	15	2013	1003.27	32.70	0.08	3.37
16	2002	661.29	-309.28	-4.24	-31.87	16	2014	1049.00	78.44	0.20	8.08
17	**2003**	**652.59**	**-317.98**	**-4.36**	**-32.76**	17	2017	1037.73	67.16	0.17	6.92
18	2004	935.86	-34.71	-0.48	-3.58	18	2018	1068.01	97.44	0.24	10.04
19	2006	883.66	-86.90	-1.19	-8.95	19	2019	1191.10	220.54	0.55	22.72
20	2008	942.41	-28.16	-0.39	-2.90						
21	**2015**	**965.10**	**-5.46**	**-0.07**	**-0.56**						
22	2016	789.02	-181.55	-2.49	-18.71						
Max dry value		**652.59**	**-317.98**	**-4.36**	**-32.76**	**Max wet value**		**1413.45**	**442.88**	**1.11**	**45.63**
Min dry value		**965.10**	**-5.46**	**-0.07**	**-0.56**	**Min wet value**		**1001.21**	**30.65**	**0.08**	**3.16**
AR –Annual Rainfall; MD-Mean deviation ;RAI-Rainfall Anomaly Index; DR- Deficit Rainfall; SR-surplus Rainfall											

**Authors calculation based on data availability from AICRPAM, CRIDA, Hyderabad*

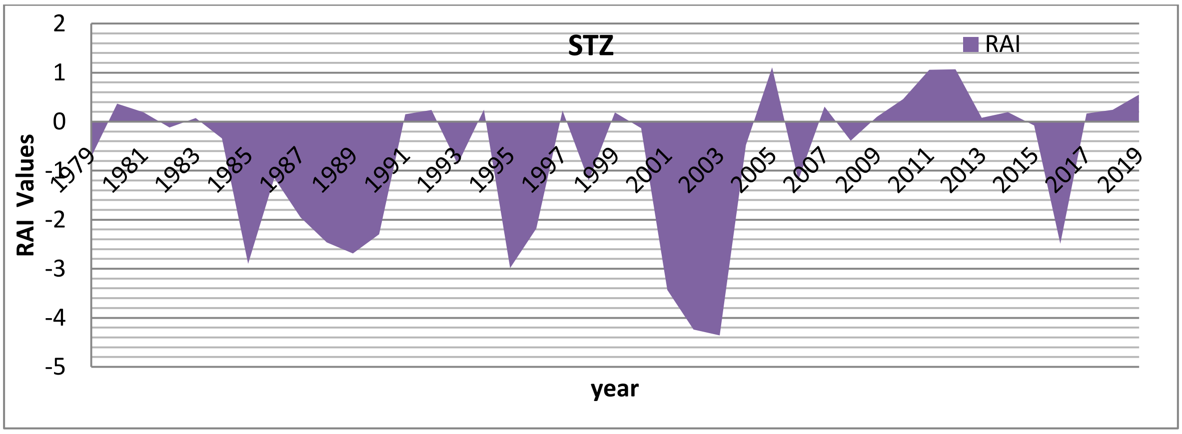

Figure 4; Dry and Wet years of Southern Transition Zone

The North Eastern Transition Zone can be considered as most vulnerable zone as it recorded for about 24 dry years values while Northern Transition Zone is not vulnerable when compared to Northern Eastern Transition Zone as most of the drought year values are nearer to wet year values and can be considered as moderate drought zone. The Southern transition zone has normal drought condition which implies neither wet nor neither dry condition.

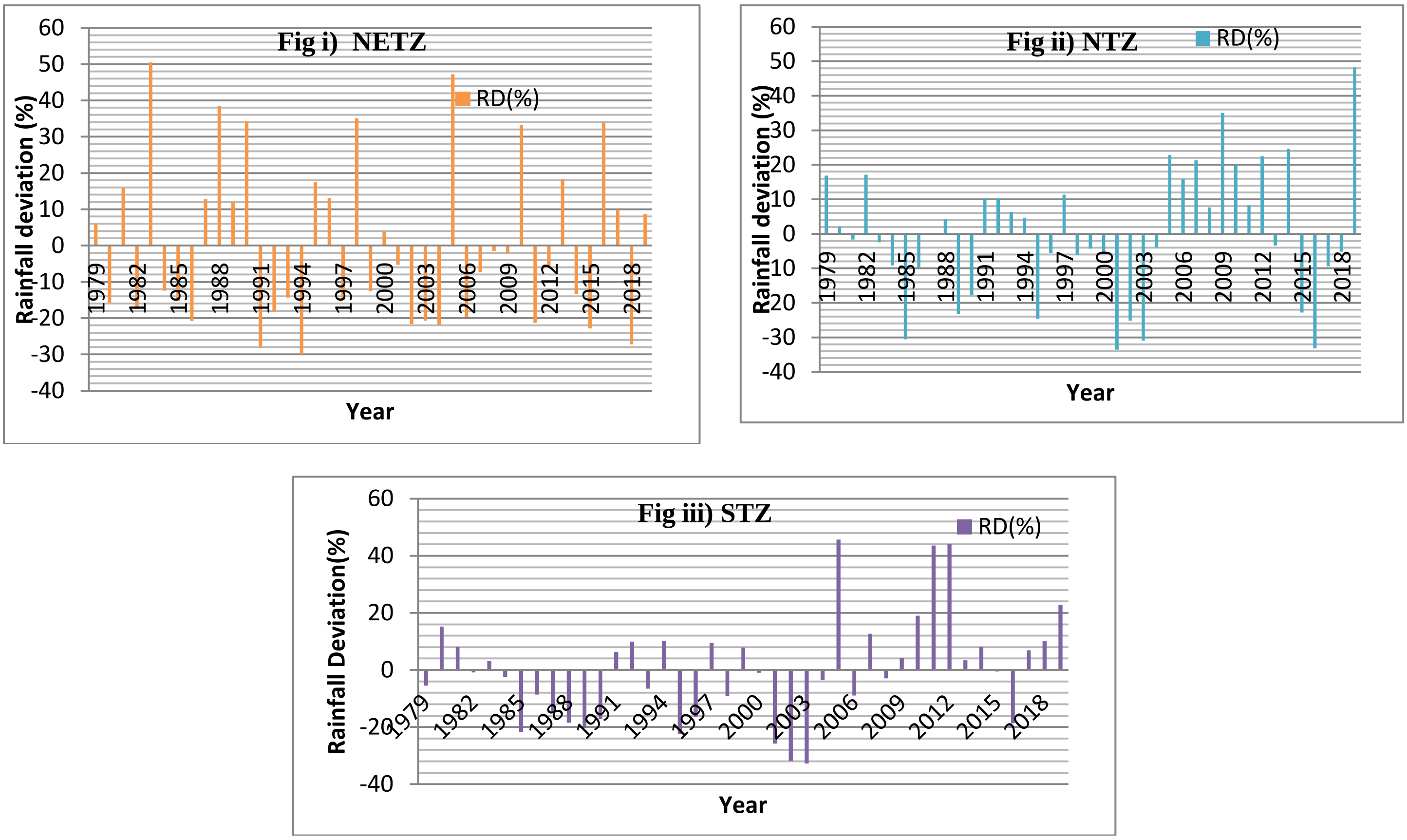

Figure 5 (i-iii): Rainfall Deviation across Agro climatic zones in Transition Zone

Conclusion and policy implication

The assessment of rainfall occurrence and dispersion is essential to estimate the irrigation supply to farm & nonfarm population for domestic and farm use respectively. The study revealed that, there is difference in drought occurrence and its intensity across the agro climatic zones in Transition region. The north eastern zone is already vulnerable with more dry years while southern transition is nearer to become as vulnerable zone. The state is surrounded by rivers Krishna in the north, Cauvery in the south, Tungabhadra in the central part Therefore, there is a great need and scope for development of irrigation sources in the drought districts. Investment should be made in creation micro irrigation methods, water harvesting structures like check dams, farm ponds which helps the farmers to increase crop production despite of existed drought condition in state.

Acknowledgments

This paper is a part of the Ph.D. research work of the author. The authors are thankful to ICAR-IARI for their financial assistance to carry out the research work and extend their gratitude to SAU-ANGRAU for granting study leave.

Competing Interests

Author has declared that no competing interests exis**ts.**

References :

Anonymous (2018). Karnataka Natural disaster management authority Government of Karnataka

Alley, R., Berntsen, T., Bindoff, N. L., Chen, Z., Chidthaisong, A., Friedlingstein, P., ... & Zwiers, F. (2007). Climate change 2007: The physical science basis. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers. IPCC Secretariat, Geneva, Switzerland. 21p*.

de Araújo, L. E., de Moraes Neto, J. M., & de Sousa, F. D. A. S. (2009). Classificação da precipitação anual e da quadra chuvosa da bacia do rio Paraíba utilizando índice de Anomalia de Chuva (IAC). *Ambiente & Água-An Interdisciplinary Journal of Applied Science*, *4*(3), 93-110.

Gadgil, S., Srinivasan, J., Nanjundiah, R. S., Kumar, K. K., Munot, A. A., & Kumar, K. R. (2002). On forecasting the Indian summer monsoon: the intriguing season of 2002. *Current Science*, *83*(4), 394-403.

Gadgil, S., & Joseph, P. V. (2003). On breaks of the Indian monsoon. *Journal of Earth System Science*, *112*(4), 529-558.

Keyantash, J., & Dracup, J. A. (2002). The quantification of drought: an evaluation of drought indices. *Bulletin of the American Meteorological Society*, *83*(8), 1167-1180.

Kumar, R., & Gautam, H. R. (2014). Climate change and its impact on agricultural productivity in India. *Journal of Climatology & Weather Forecasting*.

Modarres, R., & da Silva, V. D. P. R. (2007). Rainfall trends in arid and semi-arid regions of Iran. *Journal of arid environments*, *70*(2), 344-355.

Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of hydrology*, *391*(1-2), 202-216.

Pai, D. S., Sridhar, L., Guhathakurta, P., & Hatwar, H. R. (2011). District-wide drought climatology of the southwest monsoon season over India based on standardized precipitation index (SPI). *Natural hazards*, *59*(3), 1797-1813.

Rathod, I. M., & Aruchamy, S. (2010). Spatial analysis of rainfall variation in Coimbatore district Tamilnadu using GIS. *International journal of Geomatics and Geosciences*, *1*(2), 106-118.

Roshan, G., Ghanghermeh, A., & Grab, S. W. (2018). Testing a new application for TOPSIS: monitoring drought and wet periods in Iran. *Theoretical and applied climatology*, *131*(1), 557-571.

Singh, N. P., Bantilan, M. C. S., Kumar, A. A., Janila, P., & Hassan, A. W. R. (2011). Climate Change Impact in Agriculture: Vulnerability and adaptation concerns of semiarid tropics in Asia. *Crop adaptation to climate change*, 107-130.

Ujwala Rani, S., P Singh, N., Pramod, K., Nath Padaria, R., & Kumar Paul, R. (2021). Trend Analysis of Temperature and Rainfall across Agro Climatic Zones of Karnataka-A Semi Arid State in India.

Van Rooy, M. P. (1965). A RAINFALL ANOMALLY INDEX INDEPENDENT OF TIME AND SPACE, NOTOS.

Wanishsakpong, W., McNeil, N., & Notodiputro, K. A. (2016). Trend and pattern classification of surface air temperature change in the Arctic region. *Atmospheric Science Letters*, *17*(7), 378-383.

Wilhite, D. A. (2016). Managing drought risk in a changing climate. *Climate Research*, *70*(2-3), 99-102.

Ziernicka-Wojtaszek, A., & Kopcińska, J. (2020). Variation in atmospheric precipitation in Poland in the years 2001–2018. *Atmosphere*, *11*(8), 794.